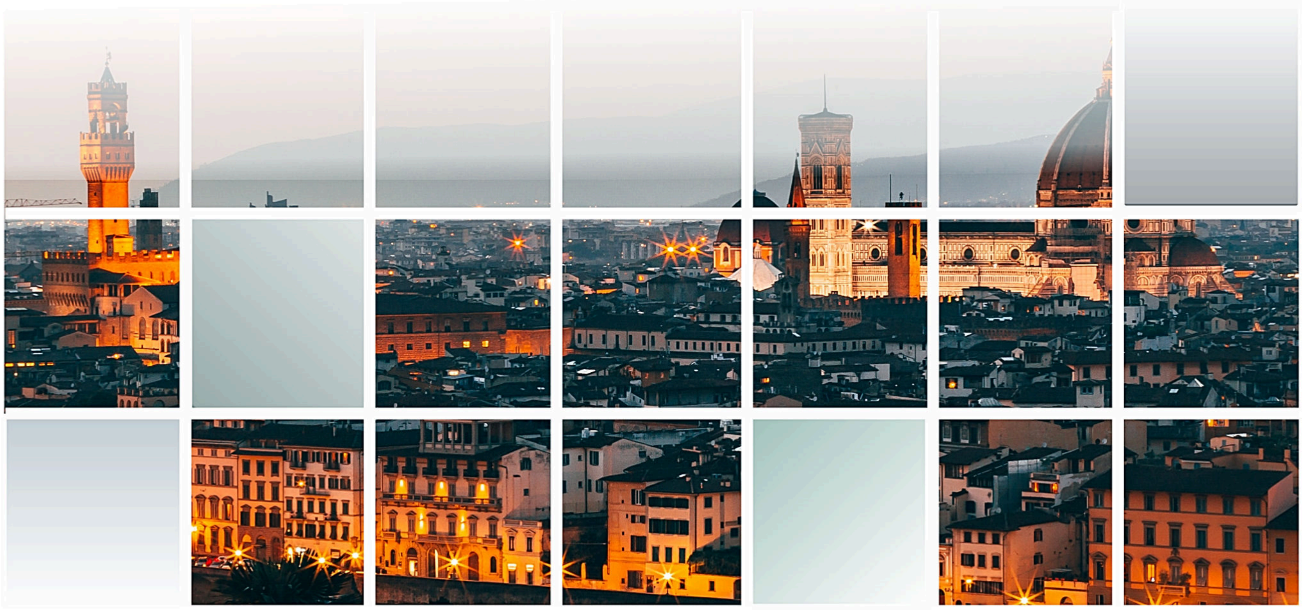
11th IWACP

"ENVIRONMENTAL CHALLENGES:
ACTION OR REACTION TO SAVE THE PLANET?
LOCAL AND GLOBAL STRATEGIES
FOR ECOLOGICAL AND SOCIETAL TRANSITION"

Advances in Cleaner Production

CONFERENCE PROCEEDINGS

Florence - Italy - July, 15th - 2022



www.advancesincleanerproduction.net

Conference Proceedings

General Chair and Founder

Biagio F. Giannetti – Paulista University (UNIP) - Brazil

Directive Committee

Ilaria Colivicchi - University of Florence, Italy – Chair

Ginevra Virginia Lombardi - University of Florence – Italy – Co-Chair

Consulting Committee

African Director of ACPN: Fernando J. Diaz Lopez - Innovation for Sustainable Development Network - France & Stellenbosch University - South Africa

Asian Director of ACPN: Gengyuan Liu – Beijing Normal University – China

European Center Director of ACPN: Ginevra Virginia Lombardi – University of Florence – Italy and Fernando J. Diaz Lopez - Innovation for Sustainable Development Network - France & SEEDS

Center America, South American and Caribbean Director of ACPN: Juan José Cabello-Eras – University of the Coast – Colombia and Luís Eduardo Velázquez Contreras – University of Sonora – Mexico

North American Center Director of ACPN: Weslynne Ashton – Illinois Institute of Technology – USA and Bruno Silvestre – University of Manitoba – Canada

Oceanian Director of ACPN - Linda Hancock and Linda Wollersheim - Deakin University - Australia

Special Volumes of the International Workshop: Advances in Cleaner Production Committee

Journal of Cleaner Production: Biagio F. Giannetti – Paulista University (UNIP) – Brazil

Advances in Cleaner Procution Network (ACPN) Committee

Feni Agostinho – Paulista University (UNIP) – Brazil

realization by

organized by

Advances in Cleaner Production Network

Boosting Knowledge Exchange Seeking Sustainability

in participation with

ACPN Global Center

ACPN African Center

ACPN Asian Center

ACPN European Center

ACPN North American Center

ACPN Center American, South American and Caribbean Center

ACPN Oceanian Center

Bibliographical reference

Advances in Cleaner Production, Proceedings of the 11th International Workshop, July 15th, 2022, Florence, Italy / Biagio F. Giannetti, Cecilia M.V.B. de Almeida, Feni Agostinho, edited by Paulista University and University of Florence.

Florence, Italy

269 p.

ISSN: 1984-8455

1. Cleaner Production
2. Proceedings
3. Sustainable Development

Scientific Committee of Advances in Cleaner Procution Network (ACPN) Committee

Feni Agostinho – Committee Coordinator – Paulista University (UNIP) – Brazil
Abdullah Engin Özçelik - Selçuk University – Turkey
Adela Tatiana Rodriguez Chaparro - Universidad Militar Nueva Granada - Colombia
Adilson C. Dalmora - University of São Paulo (USP) - Brazil
Adilson Rodrigues da Costa – Spectrum Engineering – Brazil
Adir Janete Godoy dos Santos – Adaplan Technical Drawings – Brazil
Adolf Acquaye – University of Kent – UK
Adriana de Paula Lacerda Santos - Federal University of Paraná (UFPR) - Brazil
Adriana Marotti de Mello – University of São Paulo (USP) - Brazil
Adriano Michael Bernardin - University of the Far South of Santa Catarina (UNESC) - Brazil
Adrielle Frimaio da Silva - Paulista University (UNIP) - Brazil
Agata Matarazzo - University of Catania - Italy
Ahsan Siraj - Zhengzhou University - China
Alaércio Nicoletti Junior - Methodist University of Piracicaba (UNIMEP) - Brazil
Alberto Reyes González - Higher Technological Institute of Puerto Vallarta - Mexico
Alcindo Neckel - IMED Business School - Brazil
Aldo Muro Junior - Federal Institute of Goiás (IFG) - Brazil
Aldo Roberto Ometto - University of São Paulo (USP) – Brazil
Alexandre Alonso Alves - Brazilian Agricultural Research Corporation (EMBRAPA) - Brazil
Alexandre Borges Fagundes - Santa Catarina State University (UDESC) - Brazil
Alexandre de Oliveira e Aguiar - Invento Consultoria Treinamento e Serviços - Brazil
Alexandre Nunes Cardoso - Brazilian Agricultural Research Corporation (EMBRAPA) - Brazil
Alexis Sagastume Gutierrez - University of the Coast (CUC) - Colombia
Ali Kaviani - University of Tehran - Iran
Amalia Zucaro - Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) - Italy
Amos Ncube - Parthenope University of Naples - Italy
Ana Soraya Nascimento – Secretariat of Green and Environment, São Paulo – Brazil
Anderson Luiz Szejka - Pontifical Catholic University of Paraná (PUC-PR) - Brazil
Andrea Genovese - University of Sheffield - UK
Andres Enrique Reyes Gonzalez – Higher Technological Institute of Puerto Vallarta – Mexico
Anthony M. Sarkis Jr. – Visionary Solution Consulting, LLC. - USA
Antonino Marvuglia - Luxembourg Institute of Science and Technology - Luxembourg
Antonio Carlos Dias Ângelo - São Paulo State University (UNESP)
Antonio Pasqualetto - Pontifical Catholic University of Goiás (PUC-GO) - Brazil
Antonio Sérgio Brejão - Paulista University (UNIP) - Brazil
Antonio Zuorro – Sapienza University of Rome - Italy
Armando Calabrese - University of Rome "Tor Vergata" - Italy
Armando Caldeira-Pires - University of Brasilia (UnB) - Brazil
Arno Pedro Clasen - Paulista University (UNIP) - Brazil
Arnoldo Jose de Hoyos Guevara - Pontifical Catholic University of São Paulo (PUC-SP) - Brazil
Asher Kiperstok - Federal University of Bahia (UFBA) / Federal University of Southern Bahia (UFSB) - Brazil
Atiq Zaman - Curtin University - Australia
Áurea Luiza Rapôso - Federal Institute of Alagoas (IFAL) – Brazil
Au Yong Hui Nee - Universiti Tunku Abdul Rahman - Malaysia
Barbara Bezerra - São Paulo State University (UNESP) - Brazil
Barbara Marchetti – eCampus University - Italy
Benedetto Rugani - Luxembourg Institute of Science and Technology – Luxembourg
Benjamin Karatzoglou - University of Macedonia - Greece
Berna Ulutas – Eskisehir Osmangazi University - Turkey
Beverley Thorpe - Clean Production Action – Canada
Biagio F. Giannetti – Paulista University (UNIP) - Brazil
Bianca Dutra de Lima – La Salle University – Brazil
Blessen Skariah Thomas – Indian Institute of Science – India

Brian D. Fath - Towson University- USA
Bruno Silvestre – University of Manitoba - Canada
Can B. Aktaş - TED University - Turkey
Carlos Alberto Mendes Moraes - University of the Sinos Valley (UNISINOS) - Brazil
Carlos Cézar da Silva – Federal Institute of Southern Minas Gerais (IFSULDEMINAS) – Brazil
Carlos Eduardo Durange de Carvalho Infante – Federal University of São João Del Rei – Brazil
Carlos Montalvo - Netherlands Organisation for Applied Scientific Research (TNO) - Netherlands
Carlos Rego de Oliveira – Lusíada University - Portugal
Cassia Maria Lie Ugaya - Federal Technological University of Parana State (UTFPR) - Brazil
Cecília Maria Villas Boas de Almeida – Paulista University (UNIP) - Brazil
Celia Martinez Alonso – La Madera Technological and Forestry Center (CETEMAS) – Spain
Changping Yang - Hunan University – China
Cherrafi Anass - Moulay Ismail University - Morrocco
Chongqing Wang – Central South University - China
Clandio Favarini Ruviaro – Federal University of Great Dourados (UFGD) - Brazil
Clara Rosalia Alvarez Chavez – University of Sonora (UNISON) - Mexico
Cláudia Aparecida de Mattos - Faculty of Industrial Engineering (FEI) - Brazil
Cláudia Freitas - Clavi Environmental Solutions - Brazil
Claudia Viviane Viegas – University of the Sinos Valley (UNISINOS) - Brazil
Claudio Becagli - University of Florence - Italy
Claudio Favi - Università Politecnica delle Marche - Italy
Claudio Palasciano – Polytechnic University of Milan – Italy
Cristiane F. da Silva – Federal Institute of Alagoas (IFAL) / Federal University of Bahia (UFBA) - Brazil
Cristiane Leis - University of São Paulo (USP) - Brazil
Cristiano Alves – Federal University of Rio Grande do Norte (UFRN) - Brazil
Cristina Braga – Federal University of Paraná (UFPR) – Brazil
Dabo Guan - University of East Anglia -UK
Dachamir Hotza - Federal University of Santa Catarina (UFSC) - Brazil
Dafne Oliveira Carlos de Moraes - Getúlio Vargas Foundation (FGV) - Brazil
Daiane Mülling Neutzling – University of Fortaleza – Brazil
Dalton Alexandre Kai – Pontifical Catholic University of Paraná (PUC-PR) - Brazil
Daniel Jugend - São Paulo State University (UNESP) – Brazil
Daniel Lupinacci – Federal Institute of Southern Minas Gerais (IFSULDEMINAS) – Brazil
Dario Assante - Università Telematica Internazionale Uninettuno - Italy
Dario Caro - University of California - USA
David Gabriel de Barros Franco - Pontifical Catholic University of Paraná (PUC-PR) - Brazil
David Jakubowicz Junior - Federal Fluminense University (UFF) - Brazil
David Slim Zepeda Quintana – University of Sonora (UNISON) – Mexico
Denise Alves Fungaro - Institute of Energy and Nuclear Research (IPEN) / National Commission for Nuclear Energy (CNEN) – Brazil
Denise Cardoso Pereira – Mackenzie Presbyterian University - Brazil
Denise Dumke de Medeiros - Federal University of Pernambuco (UFPE) - Brazil
Diogo A. Lopes Silva - Federal University of São Carlos (UFSCar) - Brazil
Donald Huisingh – Journal of Cleaner Production (JCP) - USA
Edenis César de Oliveira - GAMMON Teaching Foundation - Brazil
Eder Luz Xavier dos Santos - Federal University of Greater Dourados (UFGD) - Brazil
Edison Bittencourt - State University of Campinas (UNICAMP) – Brazil
Edivan Cherubini - Santa Catarina Federal University (UFSC) - Brazil
Edson Pinheiro de Lima – Pontifical Catholic University of Paraná (PUC-PR) - Brazil
Edson Talamini - Federal University of Rio Grande do Sul (UFRGS) - Brazil
Eduardo Romeiro Filho – Federal University of Minas Gerais (UFMG) - Brazil
Efthimios Zervas - Hellenic Open University - Greece
El Korchi Akram - National School of Applied Sciences of Agadir – Morocco
Elaine Aparecida da Silva - Federal University of Piauí (UFPI) - Brazil
Elza Bontempi - Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali - Italy
Enrico Benetto - Luxembourg Institute of Science and Technology - Luxembourg
Ernesto Giglio - Paulista University (UNIP) - Brazil
Everaldo Silvino dos Santos - Federal University of Rio Grande do Norte (UFRN) - Brazil
Fabio Papalardo - Paulista University (UNIP) - Brazil

Fábio Sevegnani – Paulista University (UNIP) - Brazil
Fabio Sporchia - University of Siena - Italy
Fadwa Bouhannana - École Nationale des Sciences Appliquées d'Agadir - Morrocco
Fagner José Coutinho de Melo – Federal University of Pernambuco (UFPE) - Brazil
Federica Cucchiella - University of L'Aquila – Italy
Federico Pulselli - Ecodynamics Group – University of Siena (UNISI) - Italy
Fernanda Frankenberger Silva – Independent Researcher – Brazil
Fernanda Hänsch Beuren - Santa Catarina State University (UDESC) - Brazil
Fernando Luiz Emerenciano Viana – University of Fortaleza – Brazil
Fernando Luiz Pellegrini Pessoa – Federal University of Rio de Janeiro (UFRJ) - Brazil
Flávio Horneaux Junior - University of São Paulo (USP) - Brazil
Flávio Leonel de Carvalho – Federal University of São Carlos (UFSCar) - Brazil
Francesco Corvaro - Università Politecnica delle Marche - Italy
Francesco Gonella – Ca'Foscari University of Venice – Italy
Francisco Bayardo Mayorquim Horta Barbosa - Federal University of Mato Grosso do Sul (UFMS) - Brazil
Francisco Chávez – Center American University José Simeón Cañas – El Salvador
Gabriel Bandeira - Pontifical Catholic University of Paraná (PUC-PR) - Brazil
Gang Liu - University of Southern Denmark - Denmark
Geandra Alves Queiroz - State University of Minas Gerais (UEMG) - Brazil
Gengyuan Liu - Beijing Normal University (BNU) - China
George Augusto Batista Câmara - Universidad Rey Juan Carlos - Spain
Geraldo Cardoso de Oliveira Neto - Nove de Julho University (UNINOVE) - Brazil
Giancarlo Pereira – University of the Sinos Valley (UNISINOS) - Brazil
Ginevra Virginia Lombardi – University of Florence – Italy
Gisele Chaves – Federal University of Santa Catarina (UFSC) - Brazil
Giulia Romano - University of Pisa - Italy
Gloria Ozuña – University of Sonora (UNISON) - Mexico
Gloria Rótolo - National Agricultural Technology Institute (INTA) - Argentina
Golam Kabir - University of Regina - Canada
Grace Andrea Montoya Rojas - Ingenieria Geogiencia y Sostenibilidad (INGEOS SAS) - Colombia
Guilherme M. Zanghelini - Santa Catarina Federal University (UFSC) - Brazil
Gülfem Bakan - Ondokuz Mayis University - Turkey
Gustavo Bustamante – Paulista University (UNIP) – Brazil
Hans Michel van Bellen – Federal University of Santa Catarina (UFSC) – Brazil
Hanz Schnitzer – Graz University of Technology - Austria
Hasan Aydogan - Selçuk Üniversity - Turkey
Helcio Raymundo - Paulista University (UNIP) – Brazil
Hilmi Yüksel - University of Dokyz Eylül - Turkey
Hirdan Costa – University of São Paulo (USP) - Brazil
Ieda Makiya – State University of Campinas (UNICAMP) – Brazil
Ilija Djekic - University of Belgrade - Serbia
Ismael Rocha - School of Higher Education in Advertising and Marketing (ESPM) – Brazil
Israel Herrera - Center for Energy, Environmental and Technological Research (CIEMAT) - Spain
Jae-Chun Lee – Korea Institute of Geology, Mining & Materials (KIGAM) - South Korea
James Greyson - BlindSpot Think Tank - UK
Janaina Macke – IMED Business School - Brazil
Jane Maria Faulstich de Paiva – Federal University of São Carlos (UFSCar) - Brazil
Javier Esquer Peralta – University of Sonora (Unison) - Mexico
Jeferson de Farias Sousa – Paulista University (UNIP) - Brazil
Jeremy Hall – Simon Fraser University - Canada
Jiayang Liu - Huanghuai University - China
Jimena Odetti – Higher Technological Institute of Puerto Vallarta – Mexico
João Bosco Lissandro Reis Botelho – Federal Institute of Amazonas (IFAM) – Brazil
João Ernesto Brazil Migliano – JEMCO & Associated - Brazil
Jordania Louse Silva Alves – Federal University of Amazonas (UFAM) - Brazil
Jorge Dutto - National University of Córdoba - Argentina
José Augusto de Oliveira - University of São Paulo (USP) – Brazil
José Daniel Nieto Columbié - Universidad de Oriente - Cuba
José Garcia Suarez - Center for Genetic Engineer and Biotechnology - Cuba

José Hugo de Oliveira – Federal Institute of Southern Minas Gerais (IFSULDEMINAS) – Brazil
Jose L. Casamayor - Nottingham Trent University - UK
José Luiz Prudente D'Oliveira – Pontifical Catholic University of Goiás (PUC-GO) - Brazil
José María Agudo Vallente - Universidad de Zaragoza - Spain
Jose Mighel Lehuede – APLE Sustainable Management – Chile
Josimar Pisonero Capote - Universidad de Oriente - Cuba
Juan Batista Cogollos Martinez – University of Cienfuegos - Cuba
Juán Cristóban Birbuet Rosazza - Center for Promotion of Sustainable Technologies - Bolívia
Juan Gabriel Rueda Bayona - Universidad del Valle - Colombia
Juan José Cabello Eras - University of the Coast (CUC) - Colombia
Juliana da Carvalho Isidoro - Institute of Energy and Nuclear Research (IPEN) / National Commission for Nuclear Energy (CNEN) – Brazil
Kannan Govindan - University of Southern Denmark - Denmark
Katia Regina Alves Nunes - Technische Universität Darmstadt - Germany
Ken Zarker - Northwest Green Chemistry - USA
Khalid Farooq - University of Malaysia Terengganu - Malaysia
Kleber Esposto - University of São Paulo (USP) - Brazil
Laurelena Crescêncio Palhano Afonso Siqueira – Federal University of Rio de Janeiro (UFRJ) - Brazil
Leandro Wiemes - Euvaldo Lodi Institute - Brazil
Leda Coltro - Food Technology Institute (ITAL/CETEA) - Brazil
Leo Tadeu Robles - Federal University of Maranhão (UFMA) - Brazil
Leonardo Borsacchi - University of Florence - Italy
Ligia França Cardoso – Federal University of Bahia (UFBA) – Brazil
Linda Hancock - Deakin University - Australia
Linyu Xu – Beijing Normal University - China
Lisa Mueller - FUTERA Power - Canada
Livia Maria Marini Silva – Federal University of Espírito Santo (UFES) – Brazil
Lixiao Zhang – Beijing Normal University – China
Lloyd Hipel – Enviro-Stewards Inc. – Canada
Loai Aljerf – Damascus University – Syria
Luc Hens – VITO – Netherlands
Luca Coscieme – Trinity College Dublin – Ireland
Luciana Faria – Federal Institute of Southern Minas Gerais (IFSULDEMINAS) – Brazil
Luciano Brito Rodriguez – Southwestern Bahia State University (UESB) - Brazil
Luis Antonio de Santa-Eulalia – University of Sherbrooke – Canada
Luís Eduardo Velázquez Contreras – University of Sonora (UNISON) – Mexico
Luisa Huaccho Huatuco – University of York - UK
Luísa Simon - University of the Sinos Valley (UNISINOS) - Brazil
Luiz Alexandre Kulay - University of São Paulo (USP) - Brazil
Luiz Carlos Jacob Perera – Mackenzie Presbyterian University – Brazil
Luiz César Ribas - São Paulo State University (UNESP) – Brazil
Luiz Claudio Gonçalves - São Paulo State Technological College (FATEC) - Brazil
Luiz Ghelmandi Netto – Paulista University (UNIP) – Brazil
Maddalena Ripa - Autonomous University of Barcelona - Spain
Mahamadou Biga - Diambeidou - UCLouvain - Belgium
Marcela Porto Costa – Espaço ECO Foundation – Brazil
Marcelo Nolasco – University of São Paulo (USP) - Brazil
Marcelo Real Prado – Federal Technological University of Parana State (UTFPR) - Brazil
Marcos Eduardo Melo dos Santos – University of São Paulo (USP) - Brazil
Marcos José Alves Pinto Jr. - State Center for Technological Education Paula Souza (CEETEPS)
Marcos José Barros – Federal Institute of Paraná (UFPR) – Brazil
Marcus Emanuel Mamana da Matta - Lisan Ecoadvisor Systems - Brazil
Marden V. Cardoso Dória – Federal Institute of Alagoas (IFAL) – Brazil
Maria Claudia Lucchetti - Roma Tre University - Italy
Maria Cléa Brito de Figueiredo - Brazilian Agricultural Research Corporation (EMBRAPA) - Brazil
Maria de Fátima de Freitas Bueno – Federal Institute of Southern Minas Gerais (IFSULDEMINAS) – Brazil
Maria Grazia Pazienza – University of Florence - Italy
Maria Laura - University of Siena - Italy

Maria Lúcia Pereira da Silva - University of São Paulo (USP) - Brazil
Maria Rosario Domingo Navas - National University of Distance Education - Spain
Mariana Sacramento - University of São Paulo (USP) - Brazil
Marina Bouzon – Federal University of Santa Catarina (UFSC) - Brazil
Mario Biggeri - University of Florence - Italy
Marisa Cristina Guimarães Rocha - State University of Rio de Janeiro (UERJ) - Brazil
Mark S. Rossi – Clean Production Action – USA
Mark T. Brown – University of Florida - USA
Marzena Smol – Polish Academy of Sciences – Poland
Massimo Gastaldi – University of L'Aquila – Italy
Matheus da Silva – La Salle University – Brazil
Matheus Vanzela – Federal Institute of Mato Grosso do Sul (IFMS) - Brazil
Mathis Wackernagel - Global Footprint Network - USA
Mauro Luiz Martens - Methodist University of Piracicaba (UNIMEP) - Brazil
Michael Simpson - LA Sanitation and Environment - USA
Miguel Afonso Sellito - University of the Sinos Valley (UNISINOS) - Brazil
Minelle E. Silva – University of Fortaleza – Brazil
Ming Xu - University of Michigan - USA
Mingzhou Jin - University of Tennessee - USA
Mirela Guedes Bosi - Federal University of Espírito Santo (UFES) – Brazil
Miriam Borchardt – University of the Sinos Valley (UNISINOS) - Brazil
Mohamad Ebrahim Tayeki Araghi - Islamic Azad University - Iran
Mohammad Atif Omar – Masdar Institute for Science and Technology – United Arab Emirates
Mohammed Aboughaly - University of Ontario Institute of Technology - Canada
Mohammed Osmani - Loughborough University - UK
Mohsen Brahmi - University of Sfax - Tunisia
Monica Cavalcante de Sá Abreu - Federal University of Ceará (UFCE)
Mustafa Acaroglu - Selçuk Üniversity - Turkey
Nancy Grijalva – University of Sonora (UNISON) – Mexico
Naor Silveira Fialho – São Paulo State University UNESP - Brazil
Nasrin Khalili – GEMS Consulting – USA
Natália de Assis Brasil Weber – University of São Paulo (USP) – Brazil
Noé Vargas Betancourt - University of Sonora (UNISON) – Mexico
Noor Faezah Juhari - University of Malaysia Terengganu - Malaysia
Nora Elba Múnguia Vega - University of Sonora (UNISON) – Mexico
Norma Aurea Rangel Vazquez - Technological Insttute of Aguascalientes - Mexico
Nurul Liyana Mohd Kamil - Universiti Malaya - Malaysia
Olawole Olanre Fawehinmi - Universiti Malaysia Terengganu - Malaysia
Olga Kordas - KTH Royal Institute of Technology - Sweden
Olívia Toshie Oiko – State University of Maringá (UEM) - Brazil
Olivier Le Corre - Mines Telecom Atlantique Institute - France
Olivier Sénéchal - Université de Valenciennes et du Hainaut Cambrésis - France
Omar Ouro Salim – University of Brasília (UnB) - Brazil
Orlando Jorquera – Federal University of Southern Bahia (UFSB) - Brazil
Oscar Osegueda - Center American University José Simeón Cañas – El Salvador
Osiris Canciglieri Junior - Pontifical Catholic University of Paraná (PUC-PR) - Brazil
Oswaldo Sanchez Junior - Institute of Technological Research (IPT) - Brazil
Otávio José de Oliveira - São Paulo State University (UNESP)
Pablo Lucas Carpejani Farias de Lima – Pontifical Catholic University of Paraná (PUC-PR) – Brazil
Paola Fantini – Polytechnic Institute of Milan – Italy
Pasquale Marcello Falcone - Parthenope University of Naples - Italy
Patrícia Soares Lins – Federal institute of Alagoas (IFAL) - Brazil
Patrizia Ghisellini - Parthenope University of Naples - Italy
Paul Adolfo Taboada González - Universidad Autónoma de Baja California - Mexico
Paulo Eduardo Antunes Grijó - Marbras et Mundi Project – Brazil
Paulo Ricardo da Rocha Araújo – Individual Consulting – Brazil
Pedro Henrique Bolanho Simões – Lisan Ecoadvisor Systems - Brazil
Pedro Medellín Milán – UASLP Environmental Agenda – Mexico
Pier Paolo Franzese - Parthenope University of Naples - Italy

Piyush Singhal - GLA University - India
Qichun Wu - University Malaya - Malaysia
Quetzalli Aguilar Virgen - Universidad Autónoma de Baja California - Mexico
R. M. Chandima Ratnayake – University of Stavanger – Norway
Rachel Faverzani Magnago - University of Southern Santa Catarina (UNISUL) - Brazil
Rafael Pflucker – Fundación Solidaridad Latinoamericana – Colombia
Rafaela da Rosa Cardoso Risemberg - Pontifical Catholic University of Paraná (PUC-PR) - Brazil
Rafat Siddique – Thapar University – India
Raffalla Taddeo - University "G. d'Annunzio" of Chieti, Pescara - Italy
Ramani Bai - Linton University College - Malaysia
Remo Santagata - Parthenope University of Naples - Italy
Renata Melo e Silva Oliveira – Pará State University (UEPA) - Brazil
Renato C. Ferreira de Souza – Federal University of Minas Gerais (UFMG) - Brazil
Ricardo Kalid – Federal University of Southern Bahia (UFSB) - Brazil
Ricardo Luis Barcelos - National Service of Commercial Learning (SENAC) - Brazil
Roberta Costa - University of Rome "Tor Vergata" - Italy
Roberth Andres Villazon Montalvan - University of Rome "Tor Vergata" - Italy
Roberto Antonio Martins - Federal University of São Carlos (UFScar) - Brazil
Roberto Merli - Roma Tre University - Italy
Roberto Rivas Hermann – Nord University Business School - Norway
Rodrigo Alvarenga – Santa Catarina State University (UDESC) - Brazil
Rodrigo Salvador – Technological Institute of Denmark - Denmark
Roque Brinckmann - Santa Catarina Federal University (UFSC) – Brazil
Rosa Anna Nastro - Parthenope University of Naples - Italy
Rose Reis de Souza - Paulista University (UNIP) - Brazil
Rossana Borges Teixeira - São Paulo State University (UNESP)
Rubens M. Kautzmann – La Salle University – Brazil
Rufis Fregue Tagne Tiegam - University of Yaounde I - Cameroon
Rui Zhao - Southwest Jiaotong University - China
Sail Liang – Beijing Normal University - China
Sampath Prasanna Dayaratn - Ace Property and Business Consultants (Pvt.) Ltd - Sri Lanka
Samuel Luis Ribeiro Silva - Federal University of ABC (UFABC) – Brazil
Sandra Souza - Federal Institute of Alagoas (IFAL) / Federal University of Bahia (UFBA) - Brazil
Sdenilson Caldas - Federal Institute of Alagoas (IFAL)
Sergio Almeida Pacca - University of São Paulo (USP) - Brazil
Sergio Ulgiati – Parthenope University of Naples – Italy
Shilpa Taneja - Chaudhary Devi Lal University - India
Shiva Gorjian - Tarbiat Modares University - Iran
Shohel Amin - Coventry University - UK
Silvio Viglia – University of Florida - USA
Sivanappan S. Kumar - Asian Institute of Technology - Thailand
Solimar Garcia – Paulista University (UNIP) - Brazil
Soraya Giovanetti El-Deir - Federal Rural University of Pernambuco (UFRPE) - Brazil
Stenford Mushiri - Zimbabwe National Developmente Centre - Zimbabwe
Stephen DeVito - Environmental Protection Agency – USA
Taís Larissa Silva - Federal Technological University of Parana State (UTFPR) - Brazil
Tamara Fonseca – São Paulo State University (UNESP) - Brazil
Tatiana Tucunduva P. Cortese - Nove de Julho University (UNINOVE) - Brazil
Tawanda Collins Muzamwese - Toxiconsol Consultancy - Zimbabwe
Thais Silva de Lima - Federal University of Bahia (UFBA) - Brazil
Thalita dos Santos Dalbelo - State University of Campinas (UNICAMP) – Brazil
Thomas Parker - European Spallation Source ESS AB - Sweden
Tiago Barreto Rocha - ACV Brasil - Brasil
Tian Xu – China Environmental Science Academy (CRAES) – China
Tíbor Rabóczkay – University of São Paulo (USP) – Brazil
Ubiratã Tortato - Pontifical Catholic University of Paraná (PUC-PR) – Brazil
Valdenildo Pedro da Silva - Federal Institute of Rio Grande do Norte (IFRN) - Brazil
Valérie Laforest - Ecole des Mines de Saint-Etienne - France
Vania Rodrigues Lopes – Hospital Augusto de Oliveira Camargo (HAOC) – Brazil

Varinder Kumar Mittal – Amity University – India
Victor Javier Gutierrez Martinez – Morelia Technological institute – Mexico
Vitor William Batista Martins – State University of Pará (UEPA) - Brazil
Vivian A. Atud - Sunburst Africa - South Africa
Wagner Cezar Lucato - Nove de Julho University (UNINOVE) - Brazil
Walter A. Pengue - Universidad Nacional de General Sarmiento - Argentina
Walter Cardoso Sátyro – Nove de Julho University (UNINOVE) – Brasil
Wei - Hsin Chen - National Cheng Kung University - Taiwan
Wesley W. Ingwersen- National Risk Management Research Laboratory - USA
Weslynne Ashton – Illinois Institute of Technology – USA
Yan Zhang – Beijing Normal University - China
Yiming Wei – Beijing Institute of Technology – China
Yong Jing Yi - Taylor's University - Malaysia
Yusliza Mohd Yusoff - Universiti Malaysia Terengganu - Malaysia
Yusuf, R. O. - University of Ilorin – Nigeria
Yutao Wang – Fudan University - China
Zengwei Tuan – Nanjing University – China
Zhang Jun – Hunan University – China
Zhifeng Yang - Beijing Normal University - China

Organization

Realized by

University of Florence

PPGEP-UNIP – Post-Graduate Program in Production Engineering of the Paulista University

Organized by

ACPN - Advances in Cleaner Production Network

In Participation with

Associated Institutions of ACPN

Aarhus University
Academy of Engineering Sciences of Serbia
Ace Property and Business Consultants (Pvt.) Ltd
ACV Brazil
Adadplan Desenhos Técnicos e Sustentabilidade
Agenda Ambiental UASLP
Al-Azhar University
Al-Mustaqbal University College
Amity University
APLE Gestión Sustentable
Aristotle University of Thessaloniki
Asian Institute of Technology
Bangladesh Agricultural Research Institute
Beijing Normal University
BlindSpot Think Tank
Ca' Foscari University of Venice
Católica Porto Business School
Center for Genetic Engineer and Biotechnology
Central South University
Centro de Promoción de Tecnologias Sostenibles
Centro Regional de Produccion mas Limpia Eje Cafetero
CETEMAS
Chaudhary Devi Lal University
Chinese Academy of Sciences, Institute of Applied Ecology
CIEMAT
Clavi Soluções Ambientais
Clean Production Action
Cocamar Cooperativa Agroindustrial
Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali
Coventry University
CT Quality
Curtin University
Damascus University
Danmarks Tekniske Universitet
Deakin University
Development Horizons Foundation
Ecodynamics Group - UNISI
Ecole des Mines de Saint-Etienne
École Nationale des Sciences Appliquées d'Agadir
EGADE Business School TEC de Monterrey
Ege University
EMBRAPA
ENEA
Enviro-Stewards Inc.
EPA
Eskisehir Osmangazi University
ESPM
European Spallation Source ESS AB
Facultad Regional Mendoza
FATEC
Fatec da Baixada Santista Rubens Lara
FATEC Zona Sul
Federal University of Sao Carlos
Federal University of São João del Rei
FEI
FGV
FIPERJ
Fundação Espaço ECO
Fundação GAMMON de Ensino
Fundacion Solidaridad latinoamericana
FUTERA Power
Galaxy Tech Solutions
GEMS Consulting
GLA University
Government College University Faisalabad
Grupo GEA
Hellenic Open University
Helps
HOSPITAL AUGUSTO DE OLIVEIRA CAMARGO - HAOC
Huanghuai University
Hunan University
IEL - Instituto Euvaldo Lodi
IFAL
IFAM

IFG
IFMS
IFPR
IFRN
IFSP
IFSULDEMINAS
IIT Madras
Illinois Institute of Technology (IIT)
IMED Business School
Indian Institute of Science
INGENIERIA GEOCIENCIA Y SOSTENIBILIDAD - INGEOS SAS
Institut Mines Telecom Atlantique
Instituto Politécnico de Leiria
Instituto Tecnologico Superior de Puerto Vallarta
INTA
Invento Consultoria Treinamento e Serviços
IPEN - CNEN/SP
Islamic Azad university
ITAL/CETEA
JEMCO & Associados
Jeonbuk National University
Journal of Cleaner Production
Kaunas University of Technology
KIGAM
King Abdulaziz University
Kothuis Consulting
KU LEUVEN
LA Sanitation and Environment
Leibniz-Institut für Agrartechnik und Bioökonomie e.V. (ATB)
Lisam Ecoadvisor Systems
Loughborough University
Lund University
Luxembourg Institute of Science and Technology
Mackenzie Presbyterian University
Masdar Institute for Science and Technology
Medlife Telemedicina
Morelia Technological Institute
Moulay Ismail University
Nanjing Normal University
Nanjing University
Napeia Consultoria e Projetos
National Cheng Kung University
National Institute of Industrial Engineering
National University of Colombia
Nord University Business School
Northwest Green Chemistry
Northwestern Polytechnical University
Nottingham Trent University
Nueva Granada Military University
Ondokuz Mayis University
Oregon State University
Parthenope University of Naples
Polish Academy of Sciences
Polytechnic University of Milan
Polytechnique-Montreal
Prefeitura Municipal de São Paulo
Projeto Marbras et Mundi
PROSPEKTIKER
PUC Campinas
PUC-GO
PUC-PR
PUC-RS
Research Institute of Innovative Technologies for Earth (RITE)
Roma Tre University
Sapienza University of Rome
Scientific Industrial Research and Development Centre
Secretaria de Agricultura e Abastecimento do Estado de São Paulo
SECRETARIAT OF GREEN AND ENVIRONMENT - São Paulo
Selçuk Üniversity
SENAC
Simon Fraser University
Southern University of Denmark
Southwest Jiaotong University
Spectrum Engenheiros Consultores Reunidos Ltda
StadtLABOR
STENUM
Sunburst Africa
Tarbiat Modares University
Taylor's University
Technical University of Crete
Technische Universität Darmstadt
TECHNOLOGICAL INSTTUTE OF AGUASCALIENTES
TED University
Tezpur University
Thapar University
The Green Institute
TNO
Toxiconsol Consultancy
Trinity College Dublin
UCLouvain
UCSI University
UDESC
UEM
UEMG
UEPA
UERJ
UESB
UFABC
UFAL
UFAM
UFBA
UFBA
UFC
UFES
UFF
UFGD

UFMA
UFMG
UFMS
UFPA
UFPE
UFPI
UFPR
UFRGS
UFRJ
UFRN
UFS
UFSB
UFSC
UFSCar
UnB
UNESC
UNESP
UNICAMP
UNIDAVI
UNIMEP
UNINOVE
UNIP
UNISC
UNISINOS
UNISON
Universidad Autónoma de Baja California
Universidad Autónoma de San Luis Potosí
Universidad Centroamericana José Simeón Cañas
Universidad de La Costa
Universidad de Oriente
Universidad de Zaragoza
Universidad del Valle
Universidad Militar Nueva Granada
Universidad Nacional de Colombia
Universidad Nacional de Córdoba
Universidad Nacional de Educación a Distancia (UNED)
Universidad Rey Juan Carlos
Universidade de Aveiro
Universidade de la Costa
Universidade de Lisboa
Universidade de Passo Fundo
Universidade do Rio Verde
Universidade do Sul de Santa Catarina
Universidade Estadual de Maringá
Universidade Federal de Itajubá
Universidade Federal de Ouro Preto
Universidade Federal do Ceará
Universidade Federal do Espírito Santo
Universidade Federal Rural de Pernambuco
Universidade La Salle
Universidade Lusíada
Università degli Studi di Parma
Università degli Studi eCampus
Università Politecnica delle Marche
Università Telematica Internazionale Uninettuno
Universitat Autònoma de Barcelona
Université de Valenciennes et du Hainaut Cambrésis
Universiti Malaysia Terengganu
Universiti Tunku Abdul Rahman
Universiti Utara Malaysia
University "G. d'Annunzio" of Chieti-Pescara
University Malaya
University of Belgrade
University of Brescia
University of Catania
University of Cienfuegos
University of Coimbra
University of Dokyz Eylül
University of Engineering and Technology, Peshawar
University of Florence
University of Florida
University of Fortaleza
University of Ilorin
University of Kent
University of L'Aquila
University of Lincoln
University of Macedonia
University of Malaysia Terengganu
University of New South Wales
University of Ontario Institute of Technology
University of Pamplona
University of Regina
University of Rome "Tor Vergata"
University of Sfax
University of Sheffield
University of Sherbrooke
University of Siena
University of Sri Jayewardenepura
University of Stavanger
University of Tehran
University of Tennessee
University of Winnipeg
University of Yaounde I
University of York
Universty of Pisa
UNIVESP
UnP
USP
UTFPR
Visionary Solutions Consulting, LLC.
VITO
Zhengzhou University
Zimbabwe National Development Centre

Acknowledgments

The Organizing Committee is extremely grateful to the invited speakers and their kind participation.

Sergio Ulgiati
Parthenope University of Naples – Italy

Feni Agostinho
Paulista University-UNIP - Brazil

Francesco Degli Innocenti
Italian Network of Bioplastics Producers - Italy

Sara Falsini
University of Florence - Italy

Cecília M. V. B. Almeida
Paulista University-UNIP - Brazil

Bernardo Piccioli Fioroni
National Network of Public Water, Environment and Energy Enterprises – Italy

Soraya El-Deir
Federal Rural University of Pernambuco – Brazil

Gabriella Maselli
University of Salerno - Italy

Annalisa Mauro
International Land Coalition - Italy

Rosaria Chifari
Fundació ENT - Spain

Imke de Koch
Stellenbosch University – South Africa

Maddalena Ripa
Autonomous University of Barcelona - Spain

Federico Pulselli
University of Siena – Italy

Thank you, the authors, and to all the participants who have made this event possible. Special thanks are addressed to the Universidade Paulista and University of Florence support committees.

Thank you to all the staff of the University of Florence who has contributed to the preparation of the event, especially **Ilaria Colivicchi and Ginevra Virginia Lombardi** who, from the beginning, as co-organizers, fully supported this project. Special thanks are addressed to the Head of the School of Economics and Management, **Prof. Andrea Paci**, and the Head of the Department of Economics and Business Sciences, **Prof. Maria Elvira Mancino**, for hosting and unconditionally supporting the workshop.

Special thanks are addressed to **Prof. Dr. João Carlos Di Genio *(in memorian)*** and **Sandra Rejane Gomes Miessa**, the Rector and Rector in Exercise of Universidade Paulista, **Prof. Dr. Marília Ancona-Lopez**, the Vice-Rector of Universidade Paulista, and to **Prof. Dr. Marina Soligo**, Vice-Rector of Post Graduation and Research of Universidade Paulista, for their unconditional support.

Special Welcome Message

On behalf of the Organizing Committee, I am honored to welcome all participants and express our deepest gratitude to the researchers for the important work presented in this edition of the International Workshop on Advances in Cleaner Production.

It is worth remembering that the IWACPs from 2007 to 2019 were face-to-face. During this period, eight events took place in Brazil, Colombia, and China. In 2020 and 2021, the problematic global health conditions imposed by the COVID19 pandemic have placed our academic community in a new challenge. Faced with this challenge, in 2020 and 2021, the events took place in a virtual format (mixed between synchronous and non-synchronous) and were based in Australia and Italy. As we know, the trend is that this year, 2022 will be marked as the year in which the pandemic will end. In this historic lineup of ACPN conferences, the 11th IWACP, International Workshop on Advances in Cleaner Production, in Florence is an important milestone. We can see this event as a mark of a resumption. Therefore, nothing is more appropriate than to hold this event in a city that symbolizes the Renaissance, Florence. In the city where it blooms.

This event is a testament to the resilience and power of the research community to overcome the extraordinary world situation we have been experiencing since 2020.

The community that works with sustainability and development issues shows competence. Congratulations!

The exciting program and the quality of the conferences and contributions allow this event to be considered an academic success.

This results from colleagues who have worked for several years in different academic, business, and government institutions.

You who actively participate in this event are responsible for the quality of the International Workshop on Advances in Cleaner Production.

My thanks to the Head of the School of Economics and Management, Prof. Andrea Paci, and the Head of the Department of Economics and Business Sciences, Prof Maria Elvira Mancino. A special thanks to Professor Ilaria Colivicchi and Professor Ginevra Virginia Lombardi and the Staff. Without these professors and staff's exceptional and competent support, this event would not have occurred.

I also hope that you will continue to contribute to the advancement of cleaner production and sustainable development.

Welcome!

General Chair and Founder
Biagio F. Giannetti – Paulista University (UNIP) - Brazil

Presentation

The **"International Workshop on Advances in Cleaner Production"** is a multi/interdisciplinary forum for the exchange of information and research results on technologies, concepts and policies based on Cleaner Production and conceived to assist the desired transition to a sustainable society.

Cleaner Production is a concept that goes far beyond the simple pollution control. It includes research and development of new processes, materials and products directed to promote the efficient use of resources and energy. Prevention must be the first approach of governments and corporations concerning sustainable development, and for this, environmental friendly strategies allied to economical robustness of products and services must be assured.

The adoption of Cleaner Production by governments, companies, and universities is getting speed with technical assistance and training programs, but it is worthy of attention that all these initiatives, even if implemented by all governments and corporations, do not guarantee the achievement of sustainable development. There is still a lack of a science, and consequently of a consolidated engineering devoted to the sustainable development.

Objectives

The **"11th International Workshop on Advances in Cleaner Production"** is an international forum to be held in July 15th, 2022 in Florence, Italy. The "11th International Workshop: Advances in Cleaner Production" aims to promote:

1. The exchange of academic information;

2. The presentation of recent achievements;

3. The discussion of common problems and their possible solutions;

4. The contact among academic knowledge and corporative experiences;

5. The discussion of the event's theme **"Environmental Challenges: Action or Reaction to Save the Planet? Local and Global Strategies for Ecological and Societal Transition".**

Researchers interested on Cleaner Production and Sustainable Development are invited to submit papers. Authors devoted to correlated themes are also welcome

This page is intentionally blank

Program

Time	July 15th, 2022
09:00 to 09:30	Reception
09:30 to 10:30	**Opening Ceremony** **Maria Elvira Mancino** Head of Department of Economics and Business Sciences University of Firenze **Andrea Paci** Head of the School of Economy and Management University of Firenze **Giorgia Giovannetti** Vice Rector for Internationalization University of Firenze **Biagio F. Giannetti** Paulista University and Founder of Advances in Cleaner Production Network
10:30 to 12:30	**Roundtable** Plastics and Bio-plastics. Benefits, Impacts, Perspectives **Coordinator** **Sergio Ulgiati** *Department of Science and Technology, Parthenope University of Napoli, Italy* *School of Environment, Beijing Normal University, Beijing, China.* **Feni Agostinho** *Universidade Paulista (UNIP), Programa de Pós-graduação Em Engenharia de Produção* *Laboratório de Produção e Meio Ambiente, São Paulo, Brazil.* **Speakers** **Francesco Degli Innocenti** *Technical Committee of Assobioplastiche, Italian Network of Bioplastics Producers* Title: Biodegradable plastics: The point of view of producers **Sara Falsini** *University of Florence, Department of Biology, Firenze, Italy* Title: Plastic waste: Instruction for a sustainable future **Cecilia Maria Villas Boas de Almeida** *Universidade Paulista (UNIP), Programa de Pós-graduação Em Engenharia de Produção* *Laboratório de Produção e Meio Ambiente, São Paulo, Brazil* *Co-Editor in Chief of Journal Cleaner Production* Title: Plastics and bioplastics littering: A literature review and examples from Brazil **Bernardo Piccioli Fioroni** *Environmental Sector of Utilitalia srl, National Network of Public Water, Environment and Energy Enterprises, Roma* Title: The waste management of compostable plastics in Italy
12:30 to 13:30	Lunch

13:30 to 15:30	**Plenary Presentations** **Coordinator** **Soraya El-Deir** *Federal Rural University of Pernambuco, Brazil* **Speakers** **Imke de Koch** *Stellenbosch University* Managing Technology within the Context of Sustainability Transitions **Gabriella Maselli** *University of Salerno* Economic Analysis Models for Cleaner Production Investments **Annalisa Mauro** *International Land Coalition* Relevance and Evolution of Land Tenure Rights, Interconnected System and Pathways for Climate Solutions. **Rosaria Chifari** *Fundació ENT* Biocircularcities: Exploring the Circular Bioeconomy Potential in Cities. Aims, Methods and Preliminary Results
15:30 to 16:00	Coffee Break
16:00 to 17:30	**Oral Presentations**
17:30 to 19:30	**Special Conferences** **ACPN Medal Award** **Young Researcher** **Maddalena Ripa** *Autonomous University of Barcelona* Circular Economy beyond Technology. Lessons, Narratives and Research Directions. **Senior Researcher** **Federico Pulselli** *University of Siena* Environmental Accounting Experiences for Cleaner and Sustainable Production and Policy
19:30 to 20:00	ACPN's Centers Meeting *(only invited experts)*
20:00 to 22:00	Confraternization Dinner

Special Conferences

ACPN Medal Award

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Circular Economy beyond Technology. Lessons, Narratives and Research Directions.

Maddalena Ripa – Young Researcher

Autonomous University of Barcelona (UAB)

Campus de la UAB, Bellaterra

Barcelona (Spain)

The case for solving the environmental crisis through a circular economy (CE) transition is gaining momentum. Nevertheless, environmental issues are often characterised as complex issues, because their causes may be multiple and interrelated, their impacts may be uncertain and potential solutions may cause unintended consequences. What is the CE able to do, not able to do, pretending to do, or ignoring in the face of these challenges? In this talk, based on recently published papers and on ongoing research, I will discuss different ways of framing circular economy, along with implications for research and practice. What I propose is an integration of theoretical and methodological approaches of multiple disciplines with the aim to deliver more than the sum of its parts and to broadening and deepening an understanding of the issues as interconnected social, political, economic and technical problems.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Environmental Accounting Experiences for Cleaner and Sustainable Production and Policy

Federico M. Pulselli – Senior Researcher

Ecodynamics Group – Dept. of Physical Sciences Earth and environment

University of Siena (Italy)

We live in a time of global experiments, some of which threaten humanity, especially the most vulnerable part of it, and ecosystems. Increasing our knowledge is part of the solution, because it enables identification of problems and possible solutions, and facilitates individual and collective involvement in more sustainable behaviours. Quantifying the human influence on the environment, by means of environmental accounting tools, is a prerequisite for understanding the dynamics of man-nature systems and orienting choices. The environmental accounting is a physics-based monitoring system able to represent the reality in different units other than money. As nowadays almost any decision is based on short-term economic/financial convenience, focussing on other complementary units or dimensions enables visualization of more information and many opportunities to improve our lifestyle, environmental performances, and sustainability of our actions and systems.

A number of different environmental accounting tools exists, and some of them progressively present new and intriguing applications and implications. Just think at the Overshoot Day that derives from the Ecological Footprint methodology, or the Life Cycle Sustainability Assessment that results from the combination of economic, social and environmental aspects within the Life Cycle Thinking logic.

The research on the development of these methods, also aimed at increasing their informative potentialities, is a fertile research field. Here, advancements in the possible application of some environmental accounting tools are presented. The proposal includes: a possible extension of the Life Cycle Assessment (LCA) rationale to evaluate elements of circularity and industrial symbiosis plans; Greenhouse Gas (GHG) accounting specificities applied to micro and macro systems; design of accounting frameworks based on the Ecological Footprint to standardize environmental accounting of particular organizations; visualization of the foundations of Emergy synthesis for communication purposes and to reach a wider audience.

These experiences are aimed at stimulating awareness and knowledge, thus facilitating identification of suitable and sustainable solutions, measures and policies al different levels.

This page is intentionally blank

Accepted Abstracts

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

A Holistic Assessment Framework to Encourage and Promote Industrial Symbiosis Practices

RUINI, A.[a], SPORCHIA, F.[a,b]*, BRUNO, M.[a], ESPOSITO, G. [a], ZARROLI, G. [a], MARCHETTINI, N. [a], BASTIANONI, S.[a]

a. Ecodynamics Group, Department of Physical Sciences, Earth and Environment, University of Siena, Pian dei Mantellini 44, 53100, Siena, Italy

b. Departament of Science, Technologies and Society, University School for Advanced Studies IUSS Pavia, Piazza della Vittoria 15, 27100, Pavia, Italy

**Corresponding author, fabio.sporchia@student.unisi.it*

Abstract

Industrial Symbiosis (IS) has been claimed to be a useful tool to diminish the contribution to climate change and other environmental impacts: this practice lowers the demand for virgin raw materials, energy consumption, and landfill waste disposal, as well as the related environmental impacts. European Commission indicates IS as an efficient way to use resources and it has been supporting the publication of strategic documents, policies, and programs providing monetary support to promote sustainable development and circular practices. Furthermore, the Member States of EU have been encouraged to take measures to facilitate the application of IS practices.

Meanwhile, IS studies have flourished in the past decade. Current research focuses not only on the evaluation of IS's impact on the environment, the economy, and society, but also on the identification of ways to promote the integration in a network, understand its vulnerabilities, and find new solutions. Since enterprises are the main drivers and implementers of IS, it is fundamental to highlight the competitive advantages that they can gain from IS, by identifying and quantifying the impacts and benefits of the overall system and how these can benefit every single enterprise.

Narrowing the analysis to the dimensions of sustainability of IS, most studies in literature focus on the estimation of the overall environmental performance of an IS system. However, only a few of them attempt to assess the share of impacts and benefits among the IS components have been proposed, and a universally accepted allocation procedure does not exist yet.

There are several methods and indicators to evaluate the environmental performance of an IS, among which: Input-output analysis, ecological network analysis, life cycle assessment (LCA), environmental impact assessment, carbon footprint analysis, material flow analysis, exergy analysis, emergy analysis, ecological footprint analysis. One of the most common approaches is LCA, which is a method based on accepted scientific standards and guidelines. However, its application presents some limitations such as the definition of the functional unit: the IS provides more than a single output and this results in a multifunctionality problem. This issue can in principle be solved by applying one of the several existing allocation procedures. However, conflicting recommendations are provided by the various official guidelines (i.e., ISO 14044, ISO/TR 14049, ISO/TS 14067, the ILCD Handbook, BP X30-323-0, PAS 2050, the Greenhouse Gas Protocol, EN15804, PEF Guide, and guidance documents for EPDs and PCRs).

Moreover, in some cases, these methods do not ensure a win-win situation for all the IS components, even when an overall environmental benefit is secured. A common characteristic of the existing allocation procedures is that they consider the IS system as the juxtaposition of several steps where each step is formed by two enterprises that exchange materials, energy, water, or/and by-products. The existing allocation procedures individually analyze every single step as an isolated system and redistribute the impact of each single step only between the two enterprises that are involved in it. This type of approach does not consider the IS as a complex system even if the IS is a network in which the overall interactions between its components are pivotal to reaching the overall environmental (and also economic) benefit.

Here, we suggest a change in perspective and propose a holistic approach for analyzing and quantifying the benefit that the IS can bring to its components. The allocation method that derives has to redistribute the impacts and benefits of the network among all the actors involved in the IS. To this aim, the process of allocation to enterprises has to be separated from the process of quantifying the overall impact of IS. In this perspective it becomes an efficient tool to promote IS and, in general, a more circular way of production.

Keywords Industrial Symbiosis (IS), Life Cycle Assessment (LCA), holistic approach, systemic approach, framework.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Are Women Drivers of Sustainability? The Moderating Effect of Women on Boards in the Relationship between ESG Performance and Firm Financial Stability

SLOMKA-GOLEBIOWSKA, A. [a], DE MASI, S. [b*], GABRIELCZYK, P. [c], BECAGLI, C. [b]

a. Warsaw School of Economics, Warsaw (PL)

b. Università degli Studi di Firenze, Florence (I)

c. University of Lodz, Lodz (PL)

**Corresponding author, sara.demasi@unifi.it*

Abstract

Incorporating Environmental, Social, and Governance (ESG) issues into corporate strategy has become a business imperative today. Companies around the globe are making efforts to reduce the carbon footprint or radically transform business models to gain a competitive advantage and minimize the impact on the environment. The Board of directors is responsible for designing and implementing a corporate strategy that is in line with the firm risk appetite and executed by appropriate risk management. Past research documents that there is a link between better management of ESG factors and better management of risk. Despite the evidence that ESG performance is correlated with risk management, no studies have investigated yet how the board composition might influence the relationship between ESG performance and risks. Prior research shows that women directors care about the environment and demonstrate that women directors are more concerned with ESG factors issues than their male counterparts are.

The purpose of the study is to provide comprehensive evidence that the impact of ESG performance on firm risk management depends on how much gender diversity characterizes the board. To reach this goal, our study examines the moderation effect of women on boards on the relationship between ESG performance and firm creditworthiness.

To analyze our hypotheses, we use a sample of the largest listed companies that are based in countries in Europe that have introduced gender quota laws. A direct consequence of the gender laws was that not only did boards increase the number of women directors, but they also were able to reach what is called the critical mass of women (it means three or more women sitting on the board). We build on the critical mass theory which argues that having a critical mass of women on the board can affect the ability of women to influence strategic decision-making. Since women have different knowledge, experiences, and values compared to men, their influence on ESG factors may be different than men on boards.

The introduction of gender quota laws took place during different periods in different countries. This creates a quasi-natural experiment, which allows us to test the effect of the critical mass of women on the relationship between ESG and firm risks. The final sample consists of 235 companies and 2469 yearly observations (from 2004 to 2020). To overcome the possible endogeneity problems, we employ the GMM estimation method.

Following recent literature on firm risks and ESG, we use Z-score as our primary measure of firm creditworthiness. Our main results confirm that the ESG score and its sub-scores (Environmental, Social, and Governance scores) are positively and significantly associated with firm stability. This means that firms with higher ESG ratings are associated with higher firm stability, and hence lower firm risks. Our study demonstrates that women moderate the relationship between ESG and firm risks. We document that the critical mass of women (three women directors or more) is a channel through which ESG activity impacts firm creditworthiness. We find that in boards with at least three women directors, the ESG score contributes to increasing the firm creditworthiness. Our findings suggest that in companies that are sensible to ESG issues, the existence of a critical mass of women on boards amplifies the company's attitude towards sustainability, that in turn, improves the firm creditworthiness.

Keywords: ESG, sustainability, risk, women on boards, financial stability

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Assessment of the Circularity of Adopting Cleaner Production in Post-Harvest Agribusiness

ARNS, V. D. [a,b,c*], OLIVEIRA NETO, G. C.[b]

a. Textile Engineering, Universidade Estadual de Maringá, Paraná
b. Industrial Engineering Post-Graduate Universidade Nove de Julho, São Paulo
c. Cocamar Cooperativa Agroindutrial, Maringá, Paraná
**Corresponding author, geraldo.prod@gmail.com*

Abstract

The agribusiness sector, when addressing the reduction of losses and waste, along with a sustainable management of supply, becomes viable through the adoption of cleaner production actions (Mahroof et al., 2021). These assumptions create innovations to support the reduction of food losses, playing an important role in the circular economy (Ada et al., 2021). The definition of cleaner production in 1989, by the United Nations Environment Program, conceptualized the production process, as preventing and minimizing risks to the environment and population, considering the life cycle of products and processes (Bass, 1995), which is crucial for food industrialization within agribusiness. In addition, there are studies that created an index to measure the performance of organizations in sustainability, based on the dimensions of circularity of products and processes, cleaner production, and the use of new technologies (Gupta et al., 2021).

Therefore, topics associated with climate change mitigation (circular economy, carbon emissions, food waste, eco-efficiency, green manufacturing) as well as current technological trends (Industry 4.0 technologies) are being studied by several areas with a strong impact on food production (Romero-Silva; De Leeuw, 2021). However, it is necessary to address environmental involvement to reduce resource consumption and waste generation, reducing the ecological footprint, increasing the circularity of products and processes (Gavrila; De Lucas Ancillo, 2021).

Issues such as circular economy, scarcity of resources, lean production, energy problems, food production, management and process modeling, waste reduction, reuse of raw materials and social aspects must be expanded to develop the field of study of sustainability for society's development (Furstenau et al., 2020). Encouraging the use of digital technologies to overcome the challenges of implementing an effective structure facilitates the circular food chain supply system (Ada et al., 2021), within the concept of a circular economy, which is one of the solutions for the generation of residues and scarcity of resources (Lieder; Rachid, 2016).

In this context, this study evaluated the adoption of cleaner production in post-harvest sector along with circular economy, due to its importance for the world's food production sustainability; as a result, only one study addressed cleaner production and post-harvest circular economy; based on this research, no study was identified to evaluate post-harvest circularity in agribusiness, which is a research gap. Thus, the case study was adopted through data collection, interviews, and observation, allowing the identification of cleaner production practices and circular economy for agribusiness.

Stands out that the evolution of agribusiness sustainability is a priority, due to the current waste and the growing demand for food, identified as two of the main challenges of the agribusiness sector; being a complex topic, the publications point to the trend of adoption of new technologies from industry 4.0 and concepts of circular economy to deal with the subject in an ecological, intelligent and active way (Fernandez, Carlos M. et al. 2021).

The research results identified the circularity index for strategies that can be adopted for production and direction of post-harvest process residues, analyzing the possibility of use and destination of these residues as: agricultural composting, bio-fuel production, pigment production, biodegradable polymerie system production, bioactive compound production, food flavoring compound production, citric acid production, enzyme production.

As such, it was analyzed the circularity of generating and allocating the waste from the post-harvest process grain processing; considering 100% the rate of regeneration and conservation; for different destinations such as: landfill, reuse, remanufacture, recycling, compost and energy recovery. The circularity indicator measures from 0 to 1, where 1 corresponds to a circular process. In the analyses, the use of the residues generated in the post-harvest process for reuse and composts reached an index of 1, representing a circular process for this model; when the residues are destined for remanufacturing, the index reduces to 0.98; the destination for recycling presents a result of 0.88; if it is used in energy recovery it reduces to 0.75 and when destined to landfills, the index reduces to 0.55, being the lowest circularity rate of the post-harvest process residues destination. The adoption of circular economy practices promotes sustainable production, thus providing a greater utilization, reducing losses and production waste, from the receipt to the storage of food, bringing opportunity for the development of the sector, widely discussed by the carbon footprint, with the need to reduce emissions; the water footprint, through the optimization of processes and adoption of new technologies and; offering new opportunities, development, security and justice.

Keywords: agribusiness,circular economy, industry 4.0, post Harvest, grain storage

Can Pension Funds Nudge a Sustainable Development?

BOCCHIALINI, E.[a], COLIVICCHI, I.[a], IELASI, F.[a*]

a. University of Florence, Italy

**Corresponding author, federica.ielasi@unifi.it*

Abstract

Sustainable energy sources and clean technologies can be financed through various types of financial investments, supported mainly by institutional investors, as well as by governments and other public entities. Institutional investors, according to the specific management mandate and the fiduciary relationship with shareholders, can participate in these projects through equity investments (including mutual funds and ETFs), bonds (both corporate and government ones, with specific reference to green bonds) and alternative funds (such as direct investments through private equity or green infrastructure funds). Among institutional investors, pension funds have risk-adjusted return objectives and valuation time horizons that are particularly consistent with sustainable and responsible investments (SRI). Indeed, SRI integrate the financial analysis with the environmental, social and good governance (ESG) analysis, have a medium-long term orientation and the aim of creating value for the investor and the society as a whole. The introduction of new regulatory requirements on sustainable finance, as well as a growing attention to sustainability by savers and employees, also push pension funds to incorporate the ESG approach as an integral part of their investment process. However, the uptake of pension funds specializing in green and sustainable investments is still limited in practice. The research, in addition to identify the possible causes, provide some strategic management guidelines useful to pension fund managers for the selection of financial portfolios by taking into account ESG factors, within the context of the various investment lines that characterize a pension fund.

The asset allocation of a pension fund must guarantee the achievement of the so-called actuarial balance: the disinvestment over time of the securities included in the portfolio must be able to generate inflows that are consistent, in amount and timing, with the needs for benefits' payment to shareholders, taking into account the specific characteristics of the population covered by the fund.

This research aims to provide answers to the following research questions: Does the gradual replacement of securities selected by applying ESG criteria to not-ESG-screened securities allow the pension fund to maintain the actuarial balance of the various investment lines of a pension fund? Is it possible to build financial portfolios fully selected by applying ESG criteria while maintaining the actuarial balance determined for a not-ESG-screened portfolio?

The analysis is conducted through the development of business cases, the application of actuarial balance models, as well as sensitivity tests through the application of passive strategies with respect to different ESG benchmarks, up to the complete replacement of the original not-ESG benchmark.

The balance between income (for contributions) and expenses (for benefits) can be variously defined in a supplementary pension scheme. It can be considered a collective balance, or an individual balance. In our paper, an individual balance is considered. Moreover, the equilibrium can be actuarial and financial.If we consider the whole remaining lifetime of the policyholder (initially at work, later possibly retired), the individual balance between contributions and benefits is therefore of a mixed type (partly financial, partly actuarial) and operates in the following way:

• in the initial period of activity of the insured person (therefore, in the period of payment of contributions), the balance is of a financial nature;

• in the subsequent period of retirement of the insured (therefore, in the period of disbursement of the annuity), the balance is actuarial.

Considering the time of retirement and the fixed annual term of the life annuity, the principle of individual actuarial balance establishes that, for each insured in the fund, in any instant k of the period of activity, the sum of the current expected value of the future contributions, and the reserve equals the expected present value of the corresponding benefits.

We assume that the life annuity is financed through the payment of annual constant premiums for the entire duration of the deferral of the annuity. The premium depends on the initial age (x) of the policyholders (male or female) and the duration (n years) of the deferral annuity after retirement.

For the correct calibration of the investment portfolios and the application of actuarial methodologies, a proprietary and confidential panel dataset was collected on the whole population of subscribers of the different business lines of an Italian open pension fund, proposed by an insurance intermediary.

The performance of sustainable investments is tested by analyzing the pension investment choices of 1,496 members from January 2014 to December 2018, for a total of 6,083 year-individual observations. The main variables used to describe the participants' investment behavior and socio-demographic characteristics are: individual contribution, company contribution, total contribution, contributory uppercut, investment line, switch and advance behaviour, gender, age, home region, educational qualification, sector of activity/work, marital status.

The results contribute to the literature on sustainability and decarbonisation of institutional investors' portfolios, providing useful implications to both the regulator and the asset managers of pension funds.

Keywords: sustainable development, sustainable finance, decarbonization, pension funds, actuarial equilibrium

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Carbon Footprint Assessment of Multiple "Cleaner Energy Mix" Scenarios in Circular Economy Transition for Italy

GHISELLINI, P.[A*], PASSARO, R.[A], ULGIATI, S.[A,B,C]

a. University of Naples "Parthenope", Department of Engineering, Naples (Italy)

b. University of Naples *"Parthenope", Department of Science and Technology, Naples (Italy)*

c. State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing (China)

**Corresponding author, patrizia.ghisellini@uniparthenope.it*

Abstract

Purpose: European Union (EU) countries including Italy are currently adopting several measures in order to reduce their dependence from Russian imports of natural gas (European Commission, 2022a, b). The dramatic war between Russia and Ukraine is currently requiring the need for diversifying the natural gas suppliers of EU. However, this process is also further accelerating the energy sources diversification due to the commitments in perceiving the decarbonization goals set by the European Green Deal (European Commission, 2022) and by the UN 7 SDG[1] (affordable and clean energy).
In this context, the Italian Government is evaluating how to diversify the imports of natural gas from Russia with other suppliers as well as diversify its energy mix looking at beyond the high fossil fuels dependence (ENEA, 2022). In the Italian energy mix, natural gas has a share by 38.5%, while oil by 35.5% and renewables by 17.3% (Italian Ministry of Environment and Protection of Territory and Sea et al., 2021). Natural gas is almost entirely imported from abroad since the domestic production is low (3.34 billion cubic meters) compared to the demand (76.1 billion cubic meters). The Italian Prime Minister also recently evidenced, with regard to the diversification of the energy mix, the need for further increasing the share towards renewables as well as consider the inclusion of "clean nuclear" (Il Mattino, 2022). Based on these premises and considering the energy sources diversification emergence the main goal of this work is to show the results of different scenarios alternative to the present natural gas-based energy mix and evaluating their carbon footprint.
Method: By using the Life Cycle Assessment (LCA) methodology this study is addressed to assesses the energy and environmental costs and benefits of each mix that considers a more relevant role of renewable energies as well as the possible introduction of nuclear energy.
The study will also offer an opportunity to discuss the concept and criteria for defining a clean energy source (Georgeson et al., 2016; Dincer and Acar, 2015) and offer an analysis of the environmental, energy and socio-economic strengths and weaknesses of renewable energies (Guangul and Chala, 2019) and nuclear energy (Agyekum et al., 2020; Jin and Kim, 2018; Tokimatsu et al., 2016; Ulgiati and Ghisellini, 2013).
Results: The analysis could provide useful insights to the different stakeholders of energy sectors (citizens, companies, public administrators, etc) as well as the Italian Government that is currently involved in the redefinition of the energy mix and evaluating policies and instruments aimed to support the energy transition. Nevertheless, the analysis could be helpful for other countries due to the importance of energy as a good in current society (Wiseman, 2018; Van den Berg and Bruinsma, 2008; Odum, 2007) and the urgent need for reducing the contribution from fossil energy use to the environmental challenges ahead (IPCC, 2021).
Keywords: Clean energy; circular economy, renewable energy, nuclear energy, Italy.

References:
Agyekum, E. B., Ansah, M. N. S., Afornu, K. B., 2020. Nuclear energy for sustainable development: SWOT analysis on Ghana's nuclear agenda. Energy Reports 6, 107–115.
Dincer, I., Acar, C., 2015. A review on clean energy solutions for better sustainability. International Journal of Energy Research.
ENEA, 2022, Analisi trimestrale del Sistema energetico italiano - Anno 2021 (In Italian), available at: https://www.pubblicazioni.enea.it/le-pubblicazioni-enea/analisi-trimestrale-del-sistema-energetico-italiano/fascicoli-2022/analisi-trimestrale-del-sistema-energetico-italiano-anno-2021.html Last accessed: 19/04/2022.
European Commission, 2022a, REPowerEU: Joint European action for more affordable, secure and sustainable energy, available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511. Last accessed: 11/03/2022.
European Commission, 2022b, REPowerEU: Joint European action for more affordable, secure and sustainable energy, Factsheet, available at: https://ec.europa.eu/commission/presscorner/api/files/attachment/871871/Factsheet%20-%20REPowerEU.pdf. Last accessed: 19/04/2022.
Georgeson, L., Maslin, M. & Poessinouw, M. 2016. Clean up energy innovation. Nature 538, 27–29. https://doi.org/10.1038/538027a.
Guangul, F. M., Chala, G. T., 2019. Solar Energy as Renewable Energy Source: SWOT Analysis. 978-1-5386-8046-9/19, IEEE.
Il Mattino, 10 March 2022. Guerra Ucraina, il "nuovo nucleare" e la strategia italiana per superare la crisi, available at: https://www.ilmattino.it/economia/news/nucleare_draghi_governo_nuovo_cosa_e-6554925.html. Last accessed: 11/03/2022.
IPCC, Intergovernmental Panel on Climate Change, 2021. Climate change, rapid, widespread and intensifying, available online at: https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/ Last accessed: 17/11/2021.
Jin, T., Kim, J., 2018. What is better for mitigating carbon emissions – Renewable energy or nuclear energy? A panel data analysis. Renewable and Sustainable Energy Reviews 91, 464-471.
Italian Ministry of Environment and Protection of Territory and Sea et al., 2021. Strategia Italiana di lungo termine sulla riduzione delle emission dei gas a effetto serra. Available online at: https://www.mite.gov.it/sites/default/files/lts_gennaio_2021.pdf. Last accessed: 12/05/2022.
Odum, H. T., 2007. Environment, power and society. For the twenty-first century the hierarchy of energy. Columbia University Press, New York.
Tokimatsu, K., et al., 2016. Role of innovative technologies under the global zero emissions scenarios. Applied Energy 162, 1483-1493.
Ulgiati, S., Ghisellini, P., 2013. Environmental, Economic and Financial Uncertainties of Nuclear Energy. A Closer Look Worldwide and in Italy. (Chapter 7). In: Science and the citizen - Contemporary issues and controversies. Editor Marco Mamone Capria, ISBN 978-1-291-44683-8, pp. 173-202, LULU Press Inc., 3101 HILLSBOROUGH ST., RALEIGH, North Carolina 27607, USA.
Van den Bergh, J., Bruinsma, F. R., 2008. Managing the Transition to Renewable Energy: Theory and Practice from Local, Regional and Macro Perspectives, Cheltenham, UK and Northampton, MA, USA: Edward Elgar Publishing.
Wiseman, J., 2018. The great energy transition of the 21st century: The 2050 Zero-Carbon World Oration. Energy Research & Social Science 35, 227-232.

1 https://www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-7

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Carbon Footprint Evaluation of the Administrative Services of an Italian Municipality as a Tool for Decarbonization Plans

MARCHI, M. [a*], NOCENTINI, E. [a], NERI, E. [a,b], ESPOSITO, G. [a,b], MACCANTI, M. [a], PATRIZI, N. [a], PULSELLI, F. M. [a]

a. Ecodynamics Group, Department of Physical, Earth and Environmental Sciences, Pian dei Mantellini 44, University of Siena, 53100, Siena, Italy

b. INDACO$_2$ srl, 53034, Colle di Val d'Elsa, Italy

**Corresponding author, marchi27@unisi.it*

Abstract

The Municipality of Grosseto (Tuscany, central Italy) has started a decarbonization path that relies upon the greenhouse gas (GHG) emissions inventories of its territorial system and the mitigation actions towards the objectives set by the Covenant of Mayors. Within the continuous monitoring process, the Municipality of Grosseto wanted to estimate the Carbon Footprint (CF) of the administrative products and services provided, which have high visibility and fallout on citizens. The aim of this study was to evaluate the CF of these products and services, as a tool to suggest strategies able to mitigate the related climate impacts.

The products and services examined in this survey were divided into two groups: 1) office administrative services (i.e. issue of Electronic Identity Cards, change of residence, issue of marriage licenses, production of waste tax bills, concessions of driveways, contributions for apartment rents, notification of legal documents, issue of access permits to restricted traffic zones, traffic tickets and issue of urban planning certificates); 2) macro-services (i.e. school canteens management, bulky waste collection, street sweeping and public green maintenance, which includes green areas management, swathe of roadsides, ornamental tanks cleaning and arboreal endo/exotherapy). Different Functional Units (FU) have been considered, in line with several types of products and services analyzed. The technical boundaries of the system were "from cradle to gate" for all the services. The CF was elaborated following a life cycle approach, in which both direct and indirect GHG emissions have been considered. The Life Cycle Inventory (LCI) was developed from primary data provided directly by the municipal administration, through the supply of simplified questionnaires. The study was carried out using the Ecoinvent 3.6 database to support the inventory analysis and the model was developed using the SimaPro 9.1.1 software. The CF includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions, translated into carbon dioxide equivalent (CO_2eq).

For what concerns the office administrative services, the major climate impacts were due to the notification of legal documents (3.94 kg CO_2eq/single document), the change of residence (3.27 kg CO_2eq/single document) and the concessions of driveways (1.95 kg CO_2eq/single document), in which direct GHG emissions from fossil fuels consumption for site-inspections played a predominant role (about 56%). The office administrative service with the lowest impacts was the release of access permits to restricted traffic zones with 0.091 kg CO_2eq/single document, mainly due to the sheets of paper consumption (76%). Between the supplied macro-services, the highest CF values were registered for the management of school canteens and green areas. The school canteens emitted 401.11 t CO_2eq/year and the input that contributes most to the CF was the amount of food consumed (90%), especially cheese (both fresh and seasoned, 18%) and beef meet (12%). The management of green areas was responsible for 240.26 t CO_2eq/year and the inputs that contributed mostly to the CF were direct emissions from fossil fuel consumption for equipment and transportation (74%), as well as those due to the composting of green residues (13%). On the other hand, the macro-service characterized by lowest emissions was the arboreal endo/exotherapy (4.66 t CO_2eq/year) and the main impacts were the direct ones deriving from fossil fuel consumption for devices and transportation (53%).

Multiple meetings and discussions with the technicians of the Municipality characterized the development of this research, which allowed to design a more sustainable management of the analyzed products and services. The first solution was the need for greater care in the development of a database, containing more structured and complete quantitative information. This study, in fact, allowed to draw up a state of the art relating to the availability of statistical data in the filing systems of the Municipality. Another aspect concerned the GHG emissions reduction from site-inspections. To decrease these impacts, three possible solutions were proposed: 1) to include a written regulation that establishes which inspections are necessary and which not (some trips could be substituted by georeferenced maps), 2) to renew the municipal vehicle fleet, 3) to organize inspections of neighboring areas within a single journey. Moreover, the introduction of digital appliances in various office services can represent a solution to reduce the impacts due to the sheets of paper consumption. Regarding the management of school canteens, the change of the current suppliers with local and ecofriendly farmers would certainly lower GHG emissions related to food processing and transportation, reducing impacts up to 50%. In addition to this, it would favor small businesses in the area and the local economy.

It was not possible to find in literature similar case studies, therefore, the innovative aspect of the proposed monitoring could be exploited in awareness campaigns among citizens. At the same time, other administrative services could be analyzed, implementing new mitigation policies.

Keywords: Carbon Footprint, administrative services, mitigation policies, municipal administration, climate impacts.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Economic Analysis Models for Cleaner Production Investments

MASELLI, G.; NESTICÒ, A.

Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano (SA)

gmaselli@unisa.it, anestico@unisa.it

Abstract

In recent decades, growing environmental concerns are driving the search for new technologies, policies and projects based on Cleaner Production (CP) in order to accelerate the transition towards Sustainable Development Goals (SDGs). In this context, it becomes increasingly urgent to characterise new decision support models capable of guiding governments towards more sustainable investment choices. These models must implement tools for the economic evaluation of actions and strategies: among them, Cost-Benefit Analysis (CBA) plays an important role.

In CBA, giving due weight to the social and environmental effects, also in the long term, of a project is essential. To this end, it is necessary to correctly choose the Social Discount Rate (SDR), a parameter that makes it possible to economically compare costs and benefits that occur at different times. Discountimg procedures based on constant rates are generally used in practice. In economic analyses, such discount rates underestimate long-term impacts.

The aim of this study is to demonstrate how the use of alternative economic discounting procedures to traditional models is a necessary step in the economic evaluation of intergenerational projects. Specifically, we propose a cost-benefit discounting approach that is: i) dual, i.e. based on the characterisation of a twofold discount rate, with the purpose of distinctly discounting the strictly financial effects of the project and the social and environmental effects; ii) declining, in order to give greater weight to the socio-environmental effects that are progressively more distant in time.

The main novelties of the model concern first the introduction of the environmental quality variable into the mathematical structure of the SDR; but also, the assessment of macroeconomic investment risk. Based on the proposed model, we estimate for the first time declining discount rates, both economic and environmental, for different national economies. The results highlight the ability of dual and declining SDR structures to make more equitable judgments of economic viability for cleaner production investments, with important repercussions in terms of Economic Policy.

Keywords: *Cost-Benefit Analysis; Social Discount Rate; Declining and dual discounting; Cleaner Production Investments.*

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Efficiency Evaluation in the Italian Waste Sector: Some Empirical Results

GASTALDI, M. [a], LOMBARDI, G. V. [b], RAPPOSELLI, A.[c*], ROMANO, G.[d]

a. University of L'Aquila, Italy

b. University of Firenze, Italy

c. University of Chieti-Pescara, Italy

d. University of Pisa, Italy

**Corresponding author, agnese.rapposelli@unich.it*

Abstract

There is an increasing recognition in developed nations of the importance of waste reduction, recycling and reuse maximization, in a Circular Economy perspective aiming at reducing waste impact on both public health and environment in the pursue of sustainable growth. The 2030 Agenda for Sustainable Development of the United Nations confirms the need for a substantial reduction of waste by 2030 (Goal 12.5).
In this context, the aim of this empirical study is to evaluate the economic and environmental efficiency of urban waste systems in 89 major towns of each Italian province for the years 2017 and 2018. To this purpose we employ the parametric approach to efficiency measurement, represented by Stochastic Frontier Analysis (SFA) technique, by implementing three SFA formulations in order to take into account three different distributional assumptions for the inefficency term of the model. In addition, we also include an undesirable output - the total amount of waste collected – as input in the models considered. Finally, we investigate the efficiency estimates obtained by focusing on some relevant variables, such as geographic area, population density, tariff paid for waste services and collection method.
The results obtained show that units located in Northern and Central Italy show higher efficiency scores than Southern Italy units. Besides, efficiency scores are higher in presence of population density up to 1500 inhabitants/km^2 and in presence of low tariff level. Finally, MSW systems that have adopted door-to-door collection register the highest efficiency scores throughout the study period.

Keywords: ecological and economic efficiency; urban waste systems; Stochastic Frontier Analysis (SFA); undesirable output.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Environmental Taxes and Transport Fuel Consumption Choices

BARDAZZI, R. [a], PAZIENZA, M. G.[a*]
a. Università di Firenze
**Corresponding author, mariagrazia.pazienza@unifi.it*

Abstract
European countries are about to face dramatic transformations necessary to follow up on the commitments made to reduce emissions with the Climate Law and the Green New Deal. Although not without criticism, carbon pricing has been identified as a key instrument to support these changes (Hepburn et al. 2020) because it can convey the signal of the real cost of carbon in relative prices. The evidence on energy demand shows that energy price elasticities depend on several structural characteristics. However, when considering price and tax elasticities as two distinctive factors, there is some evidence that energy demand is more reactive to changes in the tax rate, perceived to be more permanent than price changes (Bardazzi et al. 2009 for manufacturing firms, Tiezzi and Verde, 2016 for Us). If these hints are confirmed, carbon pricing could be used as an incentive to move from high polluting energy sources – as fossil fuels for transport - towards more environmentally friendly bundle such as better transport mix. On the other hand, this transition process may imply adverse distributional effects as not all the consumers have the same ability to interpret the signals and to change transport means. To study the efficacy of energy taxation and identify the most vulnerable consumers we aim at estimating price and tax elasticities for transport related fuels. Our two main research questions are: 1) is there a persistent difference between price and tax elasticities? 2) is it true that vulnerable consumers – those more exposed to transport affordability problems - exhibit lower adaptation ability? Our analysis is relevant for the future energy transition that is meant to be as fair as possible and to leave no one behind.
We use microeconomic data from Italian Household Budget Surveys (IHBS) for the period 1997-2019 concerning demographic characteristics and household expenditure on several energy products. We estimate gasoline and diesel demand elasticities with a double-hurdle pooled regression and with a dynamic model by transforming the microdata in a specifically-built pseudo-panel (Bardazzi and Pazienza, 2017; Faiella and Lavecchia, 2021). With the first approach we exploit the cross-sectional variability of the population, while using the latter we follow families over time as in panel data. Indeed, cross-sectional estimates cannot capture the dynamic nature of households' fuels consumption decisions that is influenced by the energy equipment, such as car ownership. Therefore, cross-sectional models may produce biased estimates of the long-run effects. Dynamic pseudo-panel estimates take into account a longitudinal perspective to overcome these limitations (Deaton, 1985) and assess if a state dependence exists due to the persistence of capital equipment ownership (Song et al 2021). Elasticities will be estimated according to several dimensions such as the household income distribution, the household type, the age and generation of the head, the condition of vulnerability to transport poverty.
Our study assesses if general findings from the related literature are confirmed by answering to our research questions. Preliminary results show that transport fuel household demand reacts more to the tax component than to the oil price, with a more significant impact for gasoline than for diesel. The estimated parameters of our empirical analysis can be used to evaluate the impact of alternative policy scenarios including the recent EC directive on energy taxation and eventual measures for vulnerable households to compensate the increasing tax burden for reaching a just energy transition.

Bardazzi, R., Oropallo, F., and M.Pazienza (2009). Complying with the Kyoto targets: an assessment of energy taxes effectiveness in Italy. In: A.Zaidi, A.Harding, P.Williamson. New Frontiers in Microsimulation Modelling, pp. 605-629, Farnham: Ashgate, ISBN:9780754676478.
Bardazzi, R., and Pazienza, M. G. (2017). Switch off the light, please! Energy use, aging population and consumption habits. Energy Economics, 65, 161-171.
Deaton, A. (1985), "Panel data from time series of cross-sections", Journal of econometrics, 30(1), 109-126.
Faiella, I., and Lavecchia, L. (2021). Households' energy demand and the effects of carbon pricing in Italy. Bank of Italy Occasional Paper, (614).
Hepburn, C., Stern, N., & Stiglitz, J. E. (2020). "Carbon pricing" special issue in the European economic review. European economic review, 127, 103440.
Song, S., Diao, M., & Feng, C. C. (2021). Effects of pricing and infrastructure on car ownership: A pseudo-panel-based dynamic model. Transportation Research Part A: Policy and Practice, 152, 115-126.
Tiezzi, S., & Verde, S. F. (2016). Differential demand response to gasoline taxes and gasoline prices in the US. Resource and Energy Economics, 44, 71-91.

Keywords: carbon pricing, energy consumption choice, transport mode, dynamic panels

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Evaluation of the Circularity of the Adoption of Cleaner Production in the Paper Industry

SOUZA, G. L. V. [a], OLIVEIRA NETO, G. C. [a]

a. Industrial Engineering Post-Graduate Universidade Nove de Julho, São Paulo
**Corresponding author, geraldo.prod@gmail.com.br*

Abstract

The Circular Economy (EC) can be defined as a regenerative system, where the input and waste of resources are minimized by the deceleration of material and energy circuits (Geissdoerfer et al., 2017), driven by the elimination of waste and pollution, circularization of products and materials, nature regeneration (Ellen Macarthur Foundation, 2022), being the micro or individual level of implementation when it occurs within companies (Ruggieri et al., 2016). Cleaner production (CP) is an environmental strategy of continuous application integrated to the various processes, products and services (UNEP, 2017). The concepts of CP are linked to measures to prevent environmental damage in industrial sectors, increasing eco-efficiency and reducing risks to human health (Ghorbannezhad et al., 2011), to contribute to the efficient control of waste generation along the product life cycle (Merli et al., 2018).
Industrial sectors can deplete finite resources and cause irreversible impacts (Xiao-Qing et al., 2012). Thus, CP offers opportunities to reduce the use of natural resources, promoting the use of renewable resources (Sousa-Zomer et al., 2018), to assist in the implementation of CE at the micro level (Sousa-Zomer et al., 2018). In this way, the CE promotes a paradigm shift to harmonize economic growth, environmental issues and resource scarcity (Merli et al., 2018). The move to CE offers an opportunity to recover valuable resources from waste (Yadav et al., 2021), being a strategy in increasing evolution, recognized by academics and public sectors (Merli et al., 2018). The CE can be driven by market pressure influences, meeting demands for sustainable products (Greer et al., 2020) and in the linear model transition process, CE has valuable support from CP (Kalmykova et al., 2018).
Worldwide, there is a huge amount of wastewater generated from different industrial sectors (Yadav et al., 2021). Thus, optimizing water management in industrial processes is essential to reduce and eliminate negative impacts (Molina-Sánchez et al., 2018). Regarding the paper sector, which is a major consumer of water, CP practices have been promoted in some regions, to observe emissions in the entire production chain (Susilawati; Kanowski, 2020). The paper industry has the highest biomass revenue for non-food production and generates a large amount of waste (Branco et al., 2018). This is because, according to the type of paper, the raw material can be various plant bioresources such as bamboo, eucalyptus, sugarcane bagasse, rice straw and wheat (Kumar et al., 2021). In the sludge of effluent from paper mills, there is an opportunity for use as an additive in the manufacture of bricks (Goel et al., 2021), and of technological nutrients, besides to water for reintroduction in the process (Molina-Sánchez et al., 2018).
Although CE application opportunities are discussed in the literature, circular practices are still weak in the traditional industrial environment (Xiao-Qing et al., 2012). However, paper mills have adopted strategies to optimize waste aiming at CE (Molina-Sánchez et al., 2018). As the paper industry is under pressure to reduce energy consumption, water and environmental impact, CE at its micro level has the function of supporting environmental concerns (Ghorbannezhad et al., 2011), such as lignocellulosic sediments, present in waste of the process and that represent risks to human health and the environment (Haller et al., 2021). With this, it was identified the absence of studies on the evaluation of the circularity of the adoption of cleaner production at the micro level of the paper mill. Therefore, to contribute to actions to save the planet, this study aimed to carry out an evaluation of the circularity of the adoption of cleaner production in a paper mill with a global presence, to verify the circularity index due to energy recovery, reduction of water consumption and paper recycling in the process. The method used was a case study with interviews and process observation to collect data on water, energy and paper waste consumption. From the data collected, the circularity index was estimated by applying the method proposed by Oliveira Neto et al. (2022).
The results showed savings in energy, water consumption and paper recycling achieved by means of the circular economy at the micro level (CP). Thus, the use of energy from renewable sources recovered from the facilities allowed a 10% reduction in the purchase of non-renewable energy, indicating an opportunity of 95% circularity in energy consumption. Regarding paper recycling, an increase of 6% in the use of recycled fibers was identified, which returned to the process, indicating a circularity of 105% and a 30% reduction in water consumption, with an approximate circularity index of 110%. Therefore, it was seen that the micro-level circular economy in the paper industry has improved the recycling and reuse of paper fibers, energy and water recovery in closed cycles, contributing to the reduction of the environmental impact of this industry and consequently reducing the pressures on the planet.

Keywords: Cleaner Production, Circular Economy, Sustainable Resilience, Paper Industry

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Evaluation of the Circularity of the Adoption of Cleaner Production in the Textile Industry

MELATTO, R. A. P. B. [a], OLIVEIRA NETO, G. C. [a], SOUZA, G. L. V. [a]

a. Industrial Engineering Post-Graduate Universidade Nove de Julho, São Paulo
** Corresponding author, geraldo.prod@gmail.com.br*

Abstract

The circular economy (CE) is a systems solution framework that addresses global challenges, aiming at eliminating waste and pollution, circulating products and materials, and regenerating nature (Ellen Macarthur Foundation, 2022), and can be implemented at the micro level (Companies or consumers) (Ruggieri et al., 2016). Regarding internal production and the production chain, CE helps in the economy and preservation of products, components and materials (Wysokińska, 2018). Cleaner production (CP) is an environmental strategy of continuous application integrated to the various processes, products and services (UNEP, 2017). CP in the civil construction sector contributes to energy efficiency (Norouzi et al., 2021); in the paper sector to reduce emissions and consumption (Susilawati; Kanowski, 2020); reducing waste in the agricultural sector (Mahroof et al., 2021) and reducing emissions and waste in the textile sector (Kang et al., 2018).
Regarding the adoption of CE at the micro level (CP), it is possible to achieve circular business opportunities that improve Environmental management and productive efficiency for the company (LU et al., 2020), that is, both CE and CP are innovative approaches that gain importance due to their contributions to sustainable performance (GUPTA et al., 2021). Regarding the textile sector, the CE addresses circular opportunities for materials, facilities, packaging, clothing and clothing collection programs (Esbeih et al., 2021), involving the production chain from the design, production, consumption and waste management phases of the product (Ogunmakinde, 2019).
Strategies to achieve sustainability goals have been discussed by researchers and public sectors (Happonen; Ghoreishi, 2022). Thus, CE has stood out for being a strategy that presents itself as a substitute for linear business models (Fidan et al., 2021). In this way, specialists in the textile sector have been involved in the development of actions to provide knowledge and opportunities for circular business, and to promote awareness of sustainability (Costa et al., 2021). In this sense, the development of natural fibers for textile application from food waste has been one of the bets in progress, such as the use of pineapple (Provin; Aguiar Dutra, 2021) and milk proteins for new textiles (Costa et al., 2021). Globally, the textile sector is of great concern due to the use of natural resources, fossil derivatives and problems associated with clothing disposal (Ribul et al., 2021a), resulting from population growth (Stenton et al., 2021a). Textiles discarded in landfills or incineration facilities (Piribauer et al., 2020) also pose serious environmental risks (Serra et al., 2021). So, in order to minimize the effects of environmental impacts, various forms of transformation of textile waste have been used to obtain new textile fibers, such as the use of acetate to transform cellulose-based waste present in paper and cotton (Haslinger et al., 2019). Also, recycled polyester yarn blends and recycled cotton can be used in some fabrics, minimizing the production of virgin fibers (Majumdar et al., 2020).
The mechanical recycling of cotton fiber has also been evaluated with the potential to reduce the environmental impact, due to the decrease in the use of virgin cotton fiber (Fidan et al., 2021). Thus, studies have been conducted to change the perception of textile waste generated in production processes, through the adoption of environmentally friendly practices at the micro level (Stanescu, 2021). In general, practices address new materials from waste (Piribauer et al., 2021; Fidan et al., 2021), textile recycling (Stanescu, 2021; Subramanian et al., 2021), development of textile fibers from non-textile waste (Stenton et al., 2021a; Stenton et al., 2021b). Thus, there is a lack of studies on the evaluation of the circularity of the adoption of CP at the micro level in the textile sector. Therefore, to contribute to actions aimed at preserving the environment, this study aimed to evaluate the circularity of the adoption of CP in the textile sector, to verify the circularity index due to mechanical splitting of cotton cellulose. To achieve the objective, a case study was used as a method, collecting data through process observations and interviews, in order to identify the amounts of virgin cotton fiber and defibered. Based on the data collection, it was possible to estimate the circularity index by applying the method proposed by Oliveira Neto et al. (2022).
The results showed savings in virgin cotton fiber obtained through the circular economy at the micro level (CP). Thus, the use of cotton fibers recovered from mechanical splitting achieved a 15% reduction in the purchase of virgin cotton fiber, indicating an opportunity of 99% circularity in the use of cotton fiber. Therefore, it was seen that the micro-level CE in the textile industry has improved the reuse of recovered fibers, being an important opportunity to reduce the Environmental impact in this sector.

Keywords: Cleaner Production, Circular Economy, Sustainable Resilience, Textile Industry

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Examining the Politics of Renewable Energy Transition Discourses in Australia

WOLLERSHEIM, L.[a,b*]

a. Australian Research Centre of Excellence for Electromaterials Science, Deakin University

b. Alfred Deakin Institute for Citizenship and Globalisation

**Corresponding author, linda.wollersheim@research.deakin.edu.au*

Abstract

This paper addresses the major challenge of accelerating renewable energy (RE) transitions to maximise co-benefits of climate change mitigation and adaptation. To realise this challenge, a more nuanced understanding of the power and influence of dominant discourses in government policymaking is required. As the International Renewable Energy Agency (IRENA) argues, the energy transition's speed and success is no longer dependent on technological advances but rather on how well it is connected to efforts of transitioning the broader socio-economic system itself and the level of societal inclusivity and participation. In this context, the transformation of energy systems is about more than replacing fossil-based with RE technologies and infrastructures, and about the role of required polycentric, integrated and deliberate government policy. This paper focuses on the case of Australia; a fossil-reliant, high greenhouse gas emitting country chosen for its infamous lack of enabling policy and regulation for renewables, paradoxically in a setting marked by outstanding RE growth potential. The politics of energy transition are highly contested in Australia, making it a rich case for discursive investigation. A modified IRENA (2018) framework is employed to classify key RE deployment and system integration policy instruments and regulatory reforms. This is followed by the application and testing of a novel discourse analytic framework (informed by Hajer's work, 1995; 2006), delivering useful insights about discursive practices and the underlying assumptions and power relationships shaping the design and implementation of policy and regulatory initiatives. Key story-lines, competing narratives and discourse-coalitions are examined that reproduce the logic of dominant discourses in selected national Australian energy policies. Policy impact analysis highlights technical and financial barriers for niche actors, specifically focusing on Renewable Energy Communities (RECs). The paper identifies the need for targeted policy support mechanisms to provide diversity of scale and governance in RE transitions, vital to accelerated decarbonisation and societal inclusivity and participation in transitions. This analysis is a timely contribution to scholarly and public debates on community-centered decarbonisation efforts, amid controversies over successive Australian governments' failure to set meaningful emission reductions targets.

Keywords: energy transition; energy policy; discourse analysis; Australia; Renewable Energy Communities

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

In Search for the Common Good: Different Ownership and Governance Models for Circular Economy

ROMANO, G. [a*], MINOJA, M. [b]
a. University of Pisa, Pisa
b. University of Udine, Udine
**Corresponding author, giulia.romano@unipi.it*

Abstract

In past years scholars have attempted to investigate how to increase the attention of firms and managers to integrate economic, environmental and social aspects in corporate strategy definition and performance assessment. The triple bottom line perspective (Elkington, 1994) has been applied and spread among scholars and practictioners. Further, the Economy for the Common Good (Felber, 2019) is considered an alternative sustainability management and control framework (Ejarque and Campos, 2020), aiming at supporting the integration of sustainability strategies into the business operations. The common good can also be framed in terms of joint value creation. One key theoretical and research question is which governance forms are the most suitable to motivate stakeholders to cooperate to joint value creation (Bridoux and Stoelhorst, 2019) in the face of collective action problems (Bridoux and Stoelhorst, 2016; Klein et al., 2019). Collective action problems emerge when actors face situations in which there is a tension between their (short-term) self-interest and the (long term) collective interest.

With reference to public services, the New Public Management approach (Hood, 1991; Osborne and Gaebler, 1992) has been questioned and the New Public Service concept has been introduced by Denhardt and Denhardt (2000, 2015), which stresses the need to explicitly consider democratic values and citizenship in public service provision, in order to obtain benefits "in terms of building communities, engaging citizens, and making government work more effectively" (Denhardt and Denhardt, 2015: 664) and, ultimately, to ensure that the public interest predominates (Denhardt and Denhardt, 2000). Indeed, in public service provision, improving efficiency and meeting performance targets should be balanced with other values linked with the well-being of communities.

The paper aims to discuss how different ownership and governance structures could support the transition to circular economy (CE) and the implementation of sustainability strategies by exploiting the "corporate value" of pursuing the common good. Similarities (such as the need of committed and visionary leaders, corporate social responsibility, and so on) and differences (the role of law and regulation, political influences, ond so on) will be highlighted and a framework to identify antecedents and outcomes is provided.

This study adopted a case-based approach for theory building (Yin, 1988; Eisenhardt et al., 2016). We identified different kinds of firms with private legal form but different ownership and governance structures, all aiming to pursue the common good by exploiting the transition to the CE. These three case studies are accomunated by sustainability organizational models, involvement in CE and sustainability strategies that demonstrated to be successful from an economic, environmental, and social perspective. Following Eisenhardt (1989), different data collection methods were combined: analysis of archival sources (e.g., financial statements, sustainability reports, and firms' websites) and in-depth semi-structured interviews.

It seems to emerge that the three cases of joint value creation through CE have in common some key elements:

- one trigger event or situations, that forces a company, an industry or a municipality to find innovative and creative ways to solve a problem;
- one or more visionary leaders that envisage the way to transform this problem into an opportunity of joint value creation;
- a value-based commitment to create the conditions for the exploitation of this opportunity;
- an innovative business model, built on the CE, which makes it possible the synergistic achievement of better performance in a triple bottom line perspective;
- a growth trajectory, based on the extension (in geographic and/or business terms) or transfer of such a business model.

The joint value creation through CE seems to be made possible by the adoption of different governance forms, as suggested by Bridoux and Stoelhorst (2019).

Case studies suggest that the hub and spoke form is better when market forces (as, for instance, the customers' preference for recycled products, or lower costs of recycled products compared to the traditional ones), per se, make it possible joint value creation. The other forms seem to be more effective when: i) market forces need to be complemented by other forms of incentives; ii) the joint value creation requires the active involvement and cooperation of a set of autonomous stakeholders.

The contributions that our paper intends to produce are the following:

- to apply the idea of common good to the domain of sustainability and, more specifically, of the CE;
- to show that joint value creation through the CE can be achieved, in principle, by the adoption of different ownership and governance forms;
- to infer from case study research a theoretical contribution about the conditions under which each individual type of ownership and governance form is the most suitable to conceive, design and achieve joint value creation through the CE;
- to propose a theoretical framework applicable not only to privately-held firms, but to both public (f.i., municipality-owned) and private (f.i., consortium) organizations;
- to extend the theoretical contribution of Bridoux and Stoelhorst (2019).

Keywords: circular economy; stakeholders; ownership; governance; joint value creation

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Multi-Objective Coordinated Development Optimal Paths for China's Steel Industry Chain Based on "Water-Energy-Economy" Nexus

YANXIN LIU [a*], ULGIATI, S. [b, c]

a. School of Management and Engineering, Capital University of Economics and Business, Beijing 100070, China

b. Department of Science and Technology, Parthenope University of Naples, Centro Direzionale-Isola C4, 80143, Napoli, Italy

c. School of Environment, Beijing Normal University, Beijing, China

**Yanxin Liu, lyxinnn@126.com*

Abstract

The increasing development of circular economy is promoting energy conservation and emission reduction strategies in most countries worldwide, and China as well. As a pillar of China's economic development, the steel industry has already started to seek innovative development paths. At present, the main reason that negatively affects the green transformation of China's steel industry is the water-energy constraint. According to the statistics of the Ministry of Water Resources, the annual water consumption of China's steel industry is about 4.2 billion cubic meters, accounting for about 3.4% of the total industry water consumption in China. As far as energy is concerned, non-renewable energy uses account for a much higher proportion than renewable ones. According to national statistics, coal used in 2019 steel production accounts for about 17% of China's coal consumption, which has been about 640 million tons. Although this massive consumption of water and energy resources has promoted the development of China's steel industry chain, it has also seriously affected its sustainability. To implement a sustainable development of steel industry within the perspective of circular economy, it is necessary to analyze the "water-energy-economy" nexus of the steel industry. This study analyzes a variety of steel products over the entire industrial chain, and simulates "water-energy-economy" potential changes of products by developing a multi-objective optimization model. In this model, Random Forest (RF) and GEne Network Inference with Ensemble of trees (GEINIE3) algorithms are combined to first evaluate the 2013-2019 "water-energy-economy" nexus. Then, improved Quantum Particle Swarm Optimization (QPSO) algorithm is applied to dynamically simulate potential changes of water, energy and economic performances in the steel industry chain under 12 different scenarios. Finally, an optimal development path from the perspective of optimizing economic performance within minimum water and energy use constraints is designed. Results point out, from the perspective of current "water-energy-economy" nexus, the coordinated development degree of China's steel industry chain is weak and a sufficient relationship "water-energy-economy" is missing. However, a non-negligible improvement has been achieved in recent years, especially concerning the downstream scrap steel products. Concerning "water-economy" and "energy-economy", the relationship between water and economy has changed from one-way dependence to two-way sustainable development, but the relationship between energy and economy is still one-way dependence. This means that the economic development of China's steel industry chain is heavily dependent on energy consumption. From the perspective of simulated "water-energy-economy" relationships, results help understand that improving resource utilization rate by assigning priority to the reuse of scrap steel, while restricting pig iron and primary steel use, helps maximize the coordinated development of "water-energy-economy" in the steel industry chain. To improve the multi-dimensional nexus among "water-energy-economy" of steel industry chain and promote its sustainable development, some policy implications are proposed from the perspective of industry chain, products and relationship between products, respectively. The research results may be helpful to Chinese industrial managers to formulate transition strategies and promote the sustainable development of steel industry chain within the perspective of circular economy.

Keywords: steel industry chain; water-energy-economy; multi-objective optimization; sustainable development path

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Objective Principles, Allocation Logic and Framework Construction of Carbon Responsibility Accounts

YUAN GAO[A], GENGYUAN LIU[A,B*], GIANNETTI, B. F.[A,C], AGOSTINHO, F.[A,C], ALMEIDA, C. M.V.B.[A,C]

a. State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, 100875, Beijing, China

b. Beijing Engineering Research Center for Watershed Environmental Restoration and Integrated Ecological Regulation, 100875, Beijing, China

c. Laboratory of Production and Environment (LaProMA), Paulista University (UNIP), Sao Paulo 04026-002, Brazil

**Corresponding author, liugengyuan@bnu.edu.cn*

Abstract

As global environmental concerns worsen, enterprises and consumers are increasingly recognizing the urgency of mitigating climate change. As a major player in economic activities, reducing greenhouse gas emissions has become a huge challenge for any individual company and its supply chain. All participants in the supply chain need to make efforts for climate mitigation. The existing carbon emission responsibility accounting mostly starts from the production-side of the enterprises. As an important participant in the supply chain, the final consumers are the ultimate service objects of all producers, and also have the role of carbon emission reduction and should share the carbon mitigation responsibility.

This paper aims to construct a carbon responsibility account system framework based on supply chain. Firstly, the paper reviews the historical development of carbon emission responsibility and the evolution of distribution principles, and describes the research on the distribution mechanism of carbon emission responsibility which is oriented by equity, efficiency and both equity and efficiency. By discussing the carbon responsibility allocation mechanism adopted in China and the new demand for the carbon emission responsibility allocation model based on supply chain under the new situation, the paper puts forward the idea of constructing the carbon responsibility account based on supply chain in China. Specifically, this paper proposes to be product-oriented, takes into account the direct and indirect carbon emissions in the production process of products, establishes a benchmark value of product carbon emissions, assigns responsibilities to all participants based on the supply chain, and then establishes a supply chain-based carbon responsibility account. The responsibility system framework constructed in this paper has wider and more promising application potential, but also faces many challenges and deficiencies, which is worthy of further research and improvement.

Keywords: carbon responsibility allocation, carbon responsibility account, supply chain, carbon emission, baseline value of product.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Pollution Intensifies Interregional Flows of Virtual Scarce Water Driven by Food Demand in China

HUI LI [A,B], YUHAN LIANG [B*], SAI LIANG [B], GENGYUAN LIU [A]

1 State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, 100875, China

2 Key Laboratory for City Cluster Environmental Safety and Green Development of the Ministry of Education, School of Ecology, Environment and Resources, Guangdong University of Technology, Guangzhou, 510006, China

**Corresponding author, liangyuhan126@126.com*

Abstract

Existing studies on the water–food nexus focus on water quantity while largely ignoring water quality. This study improves the quantification method of scarce water uses by considering both blue water and grey water. Based on a scarce-water extended multi-regional input–output model, we investigate the interregional flows of virtual scarce water driven by food demand in China. The results show that considering water quality provides new insights into the patterns of interregional flows of virtual scarce water driven by food demand. The virtual integrated scarce water (VISW) flows, which consider both water quantity and quality, are 13 times the volume of virtual quantity-based scarce water (VQSW) flows. Moreover, certain regions, such as Shanghai and Jiangsu, are recognized as net VISW importers, but are net exporters in terms of VQSW. There are significant differences in the critical interregional pairs identified based on net VISW flows (e.g., Shandong–Shanghai, Shandong–Shanxi, and Henan–Shanxi) and net VQSW flows (e.g., Xinjiang–Shanxi, Anhui–Shanxi, and Jiangsu–Hebei). To reduce water scarcity based on the combined effect of both quantity and quality, the critical VISW interregional pairs should enhance cooperation. This study highlights the importance of water quality in the assessment of virtual scarce water uses.

Keywords: Food, water scarcity, water quality, virtual scarce water, input–output analysis, trade

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Sustainable Consumption in the Fashion Industry and its Determinants: A Systematic Literature Review

SCHIAROLI, V. [a*], FRACCASCIA, L. [a,b], DANGELICO, R. M.[c]
a. Sapienza University of Rome, Rome
b. University of Twente, Enschede
c. Politecnico di Bari, Bari
**Corresponding author, valerio.schiaroli@uniroma1.it*

Abstract

In the last few years, clothing consumption has significantly increased, driven by the combined effects of the growing population, fast fashion trends, and shifts in consumption patterns (Ellen Mc Arthur Foundation, 2017; Boston Consulting Group and Global Fashion Agenda, 2019). Nowadays, the fashion industry causes large environmental impacts - generated along the entire supply chain, due to high water consumption for fibres production and treatment, the use of harmful chemical agents for the dyeing processes, and the enormous quantity of garments disposed of in the landfills among others (Mc Kinsey and Global Fashion Agenda, 2020) - and is responsible for 10% of global greenhouse gas emissions (European Commission, 2022). Hence, reducing such impacts at the global level is recognized as a priority (European Commission, 2019).
Both companies - which can develop new sustainable textile products, as well as innovative sustainable practices of clothing use and disposal - and consumers - who can make sustainable consumption choices - can play a key role in reducing the environmental pressure of the fashion industry. Accordingly, sustainable fashion consumption has received increasing attention in the literature in the last few years. Many studies have been carried out, aimed at investigating the factors driving consumers towards sustainable fashion consumption choices. Hence, in order to clarify such a complex topic, some literature reviews on sustainable fashion have recently been published. However, these reviews addressed single aspects, such as humans' perceptions of recycled textile products and circular fashion services (Wagner and Heinzel, 2020), collaborative fashion consumption (Henninger et al., 2021), laundry practices (Klint, 2022), and clothing recycling and reusing modes (Xie et al., 2021). Alternatively, to the best of our knowledge, there are no studies that address the fashion consumption phenomenon from the consumers' perspective, using a holistic approach (i.e., considering the phases of clothing purchase, use, and disposal). In this context, this paper develops a systematic literature review aimed at (1) mapping sustainable fashion consumption options studied in the literature (RQ1) and (2) investigating which factors affect consumers' behavior toward sustainable consumption options, together with their effects (RQ2).
Research keywords have been developed encompassing three domains of research, i.e., (1) consumer behavior, (2) sustainability, and (3) fashion industry. The research queries were launched on Scopus and Web of Science databases and, after the screening phase, a final sample of 228 articles was analyzed.
Results show a significant increase in the number of studies since 2016, which involve consumers of 44 different countries. The sustainable options in the fashion industry identified are organized according to three phases, i.e., (1) before product usage, (2) during product usage, and (3) after product usage.
Concerning RQ1, the diverse characteristics of sustainable garments related to their production and among which consumers can make their purchase choice were organized in raw materials (e.g., recycled, organic, biobased), design strategies (e.g., cyclability, durability, versatility), and production processes (e.g., local, fair, less resource use); a synthesis of the types of sustainable garments studied is provided. Regarding the consumption phase, consumers' sustainable clothing use habits and behavior were distinguished in personal fashion use (e.g., continue wearing, laundry, repair) and collaborative fashion consumption (e.g., renting, leasing). Regarding the disposal phase, seven sustainable clothing disposal behaviors emerged (e.g., donate, resell, recycle, repurpose). As the product type studied, the generic sustainable garment is the most addressed product, followed by recycled, organic, and second-hand clothing, whereas few studies investigated biobased and slow fashion products. Further, studies focusing on specific garment items (e.g., t-shirt, jeans) are rare.
Concerning RQ2, the majority of studies investigated consumers' intention and actual behavior towards sustainable options through quantitative methods, using diverse behavioral theories. Factors affecting such behaviors are categorized into three categories, depending on whether they concern (1) personal features of consumers, (2) product and marketing, and (3) social stimuli experienced by consumers. Contrasting results among different sustainable options and diverse contexts were found. Other studies used qualitative or experimental methods to investigate consumers' perceptions, drivers, and barriers toward sustainable behaviors related to purchasing, using, and disposing of fashion products.
Finally, a future research agenda is proposed suggesting product types, theories, factors, and contexts that would need a further investigation, as well as recommending new factors, products, and methods recently developed from which new knowledge can be built.
The implications of this study are manifold. As for scholars, the study provides a framework for sustainable fashion, reference papers, and several future research directions. As for companies, it provides an overview of consumer perceptions and behavior towards sustainable products and services offered that can be useful for developing appropriate marketing strategies and services, aimed at increasing sustainable consumer behavior.

Keywords: sustainable fashion consumption, consumer behavior, systematic literature review, green products.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

The Effects of the COVID-19 Pandemic on the GHG Inventory at Subnational Scale. A Case Study

SPORCHIA, F.[a,b*], ARENA, E. [a,c], PETRAGLIA, A.[d], MARCHI, M.[a], NICCOLUCCI, V.[a], BASTIANONI, S.[a], PULSELLI, F.M.[a]

a. Ecodynamics Group, Department of Physical Sciences, Earth and Environment, University of Siena, Pian dei Mantellini 44, 53100, Siena, Italy
b. Department of Sciences, Technologies and Society, University School for Advanced Studies IUSS Pavia, Piazza della Vittoria 15, 27100, Pavia, Italy
c. Department of Economics and Statistics, University of Siena, Piazza San Francesco 7-8, 53100, Siena, Italy
d. Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parco Area delle Scienze 11/a, 43124, Parma, Italy
**Corresponding author, fabio.sporchia@student.unisi.it*

Abstract

Among the environmental effects of the COVID-19 pandemic, one of the most direct, measurable, and significant pertains to the anthropogenic greenhouse gas (GHG) emission. While GHG emission reduction at global scale is relevant, at country level the climatic impact decrease is heterogeneous; this is also apparent comparing areas within the same countries, at sub-national level. This heterogeneity results from both the biophysical (e.g., latitude and altitude), social, and economic characteristics of each country or region. Studying the effects of the pandemic at sub-national level provides helpful insights on the most critical aspects characterizing the studied area. This information could support local policy makers in designing more effective local mitigating actions. We assessed the GHG emission reduction in the Province of Parma, one of the most industrialized areas of Italy, particularly for the food sector. The study stems from the comparison between the GHG inventories for 2019 and 2020 compiled following the IPCC guidelines, adapted to a sub-national system. The aim is to reveal the effects of the pandemic on this areal context in terms of GHG emission. The study utilizes the most detailed local activity data and includes all the sectors required by the guidelines, namely Agriculture Forestry and Other Land Use (AFOLU), Energy, Industrial processes and Waste, considering carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The total gross GHG emission for the province of Parma in 2019 reached 5'266'598 t $CO_{2\text{-eq}}$ whereas the total net GHG emission reached 3'862'052 t $CO_{2\text{-eq}}$ considering the CO_2 fixation operated by the forest areas that occupy half of the provincial area. In 2020 the gross and net GHG emission decreased by 12% and 16%, respectively. By individually comparing sectors it is evident that the decrease affected almost exclusively the Energy and Industrial processes sectors, whilst the AFOLU and Waste sector showed marginal variation. Indeed, the Energy sector decreased 15% and the Industrial processes sector reduced 17%. In the Energy sector, covering ~80% of the total inventory, we observed that such reduction is driven by various activities, more than compensating the increase observed for few other activities. For example, the largest reduction affected the consumption of agricultural diesel (-50%), the road transport (-27%) and the industrial energetic use of fossil fuel (-10%). On the other hand, the waste-to-energy power plant emission and the fugitive emission from the methane distribution network increased by 11% and 0.5%, respectively. Within the AFOLU sector a variation of the cultivated crops and related fertilizer choice was detected but the increase was compensated by the reductions. A similar trend was revealed for the livestock-related emission. Despite a slight change in the number of animals, the pandemic did not affect the emission of this sector. This is directly linked to the fact that the food sector was spared from the shut down that was imposed to production activities by the Italian government throughout 2020. Instead, the shut down and the lockdown significantly affected both the Industrial processes and the Energy sectors. In particular, analyzing the latter, several insights can be provided. For example, the remarkable reduction of the agricultural diesel compared with an almost unvaried agricultural activity and with a significant reduction of the diesel consumption suggests that the reduction was driven by possible avoided tax fraud. On the other hand, diesel- (-60%) and LPG-based (-22%) heating emission decreased significantly while methane-based only by 4.7% suggesting, on one hand, that heating devices are progressively shifting towards methane and, on the other hand, that heating only shifted from offices and industrial plants to residential buildings. A similar trend was observed for industrial energy production, where crude oil and diesel combustion emission decreased significantly more than methane ones. Instead, road transport emission reduction was linked to the forced confinement, as expected. Remarkably, waste-to-energy emission increased, due to an increased amount of waste input and to a higher content of carbon, probably linked, in turn, to an increased content of sanitary waste. Industrial processes (glass and ceramics) recorded a decrease in line with the national figures. The overall decrease is higher compared to the national (-3%), the EU (-2%), and the global context (-6% - only for CO_2). This suggests that Parma province's economy is highly relying on GHG emission, much more than the national and international average. Local absorption capacity of CO_2 covered around 30% of the overall gross emission, strengthening the fundamental role of forest ecosystems. The results provide insights into the features of the environment-economy of a territory characterized by a strong orientation towards the agri-food sector. Policy-makers should learn from the pandemic and get inspired from what a powerful monitoring tool such as the GHG inventory represents. The GHG inventory should flank the common economic-financial indicators to capture the complexity of the ecosystems in which we live, thus responding with adequate policies.

Keywords: GHG emission, Covid-19, Climate change mitigation, GHG inventory, pandemic effect

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

The Role of Knowledge Dissemination on Organic Cotton for Sustainable Fashion Improvement

SOMBRIO, L. [a], VIEGAS, C.V. [a*], SILVA, T.N.,[a] , PEDROZO, E.A.[a]

a. Federal University of Rio Grande do Sul, Management Post Graduation Program

**Corresponding author, cldviegas@gmail.com*

Abstract

As the second largest polluter sector worldwide (Oliveira et al., 2022), the fashion industry was responsible for 2.1 billion of greenhouse gases emissions in 2018 (Wen, 2022). Agroecological practices and the slow fashion movement – which emphasizes both ethical production and consumption practices side-by-side critical thinking on the origins of garment – claim for more space in the awareness of the whole supply chain stakeholders, mainly the producers, retailers and final consumers (Dhir et al., 2021). Amidst this scenario, the organic or agroecological cotton cultivation experiences a reborn in Brazil. According Mattos et al. (2020), collective efforts of farmers in coordination with the technological support of experts and with the participation of NGOs actors, are boosting the chances of sustainable living in a socioeconomic and agroecological system on which depend 2,339 families. However, there is dearth of studies warning on the threatens posed to organic cotton production as climate change, insect attacks and transgenic cultivation (Delate et al., 2020). Also, the harmful effects of the fast fashion are widely unobserved by many consumers (Pookulangara and Shephard, 2013). There is need of increasing knowledge and awareness about the benefits of green apparel involving organic cotton, and the design activity has a pivotal role in improving the dissemination of aspects as environmental proactivity. Fung et al. (2021) observe that design is still a very centralized activity in sustainable fashion development, and Wen (2022) highlights the need for collaboration towards more sustainable practices in the supply chain fashion management. This research reviewed the current status of the organic cotton in the context of knowledge and awareness that can be potentially disseminated by designers and other supply chain engaged stakeholder in their interface with both upstream and downstream actors of this supply chain. There were found 547 studies in Science Direct, 570 in Scopus and 380 in Web of Science showing the expression "organic cotton" in the article title. However, few studies expressly explore the relevance of knowledge and awareness dissemination on the sustainable aspects of the organic cotton in the fashion supply chain. Far now, it is known that direct and indirect experience with sustainable apparel, alongside high education level, act as predictors of subjective knowledge that positively influence the decision of consumer for ecological garment (Han, 2019). Oh and Abraham (2019) have found that moderate to high knowledge about organic cotton clothing influence the willingness to acquire such products, while Rese et al. (2022) state that knowledge about factors that drive sustainability buying are pivotal to the innovation in the textile industry. Once the industry moves towards increasing technological choices as full integration data through blockchain, and machine learning resources to better understand the market trends, there are questions still intriguing the scholars as: to what extent the knowledge about organic or agroecological cotton has been properly spread among consumers and supply chain decision makers? How to provide and keep reliable access to qualified information and knowledge about organic cotton and related technologies? This research aims at providing some contribution in order to fulfill these gaps. It is observable that designers and NGOs, regardless their efforts in establishing knowledge networks to disseminate pivotal aspects of the organic cotton along the supply chain, are still underexplored sources of academic investigation. Therefore, this research proposes an exploratory investigation on how to better frame the accumulated knowledge and experience of these actors to provide transparency regarding the organic/agroecological cotton for a wider audience.

Keywords: organic cotton; agroecological cotton; sustainable fashion; knowledge dissemination

Acknowledgement: CNPq (National Council of Scientific and Technological Development)

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Transformative R&I Policy for Sustainable Development: The Case of European Commission Initiatives

BIGGERI, M.*^, FERRANNINI, A.*^, MARTINO, R.° A, PEIFFER-SMADJA, O.§, RAVET. J.§

* *Department of Economics and Management, University of Florence*

^ *ARCO (Action Research for CO-development), PIN Scrl*

° *Department of Economics and Statistics, University of Siena*

§ *European Commission, DG Research & Innovation*

[a] *Corresponding author*

Abstract

It is a times of deep structural transformations towards new ways of structuring our economies and production systems, a new social dynamic, and more sustainable and innovative forms of development. In this scenario, the Covid19 pandemic has accelerated the transition towards a new and different framing to properly structure government intervention to serve the public interest.

As part of such inevitable revamping attention on the need for public action, the importance of Research and Innovation (R&I) policies to simultaneously deal with economic competitiveness as well as with public health, social inclusion and environmental protection is undeniable, especially when a broader vision and notion of sustainable development is embraced. R&I policy undoubtedly plays a pivotal role for the pursuit of – and transition towards – sustainable development. Current and future living conditions, multidimensional wellbeing and human capabilities are deeply influenced not only by new scientific discoveries or technological innovations, but also by social, cultural, financial, organisational and institutional innovations. Among others, R&I investments and efforts can change products and services, production processes and consumption patterns, business models and governance mechanisms, individual and collective behaviours and actions, potentially shaping social and economic structures consistently with sustainability requirements.

Within this debate, European R&I policy is aiming to act as a leverage for transformation in the transition towards sustainable development, empowering individuals, communities and Member States to meet societal needs and build sustainable and inclusive societies. To realise this ambition, the European Commission (2020) identified some key principles underpinning transformative R&I policy towards sustainable development – transformation, directionality, co-creation, diffusion, and uptake – which need to be fully embraced and made operational, going beyond a consolidated narrative.

The objective of this paper is twofold. First, we analyse the nexus between the current debate on R&I policy and the notion of sustainable development in the uncertain scenario of our present and future times, in order to understand to what extent and how R&I policy in the post-COVID scenario can represent a leverage for transformative change towards sustainable development. Second, we analyse how these key principles for transformative R&I are reflected and embedded in the design and implementation of current EU policies across different domains, in order to understand their effective contribution to the sustainability agenda.

This research combines a state-of-the-art review of the up-to-date academic literature and policy debate on transformative R&I with the analysis of five selected case-studies of current EU policy interventions: European Innovation Ecosystems; European Digital Innovation Hubs; LIFE Programme; European Urban Initiative; EU Programme for Employment and Social Innovation.

The investigation of each policy examines available public documentation combined with direct in-depth insights collected through semi-structured interviews to key informants, namely internal staff (heads of units and officers) within related European Commission Directorate Generals and Agencies.

The results show how innovation processes are at the core of European policies and their role in promoting transformative change towards sustainable development across different policy domains. All in all, this paper intends contributing to the debate by offering new evidence on how policymakers can use R&I policy for empowering individuals, companies, governments, and communities to meet social needs and promote sustainable and inclusive societies, consolidating the new framing on transformative R&I policy in Europe and across the world.

Keywords: Research and Innovation, transformative policy, sustainable development, European Commission

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

UV/H_2O_2 Treatment for Chloramphenicol Degradation: Process Analysis and Optimization

BRIENZA, M. [a,c], , GIULIETTI, M. [a], LAVECCHIA,R. [b], GARCIA-SEGURA, S. [a], ZUORRO,A.*[, b]

a. Arizona State University, Tempe

b. Sapienza University, Rome

c. University of Basilicata, Potenza

**Corresponding author, antonio.zuorro@uniroma1.it*

Abstract

Contamination of surface and groundwater by recalcitrant antibiotics has become a major engineering challenge. Less than 70% of the antibiotic can be metabolized by humans or animals, resulting in a significant accumulation of this recalcitrant compound in aquatic environments. Antibiotics are hardly removed by traditional wastewater treatment. Amongst emerging tertiary treatments, Advanced Oxidation Processes (AOPs) are a promising way to remove residue levels of contaminants. The present study focuses on the photo-assisted degradation of chloramphenicol (CHP) as target antibiotic, with the combined use of hydrogen peroxide (H_2O_2) and UVC radiation in aqueous effluents. A central composite design (CCD) based on the response surface methodology (RSM) was used to investigate the effects of the most important process parameters on CHP degradation and optimize yields and costs associated. A statistical regression model was developed which allowed for optimization of the treatment conditions. The efficiency was also estimated on antibiotic abatement and total organic carbon removal. The proposed degradation pathway of CHP was obtained by analyzing the intermediates.

Keywords: antibiotic, CCD, RSM, UVC, hydrogen peroxide

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Valorization of Constructed Wetland Derived Lignocellulosic Waste for Development of Biomass-based Polymer Composites

SHARMA, S. [A], ASOKAN, P.[B], ASOLEKAR, S. R. [A C*]

a. Environmental Science and Engineering Department, Indian Institute of Technology Bombay, India

b. CSIR-Advanced Materials and Processes Research Institute (AMPRI) Bhopal 462026, India

c Corresponding author, asolekar@iitb.ac.in; asolekar@gmail.com*

Abstract

In developing nations like India, lignocellulosic wastes from farms, wastelands, and cityscapes are either dumped in public dumpsites or burnt in fields by farmers after harvesting the agricultural produce, causing severe environmental impacts. Globally, the increasing urbanization and demands for construction materials have motivated researchers to explore sustainable and environment-friendly raw materials. In this context, the untapped resource of lignocellulosic wastes can indeed be considered as a potential raw material for their valorization through the "low-carbon" routes of converting them into low-cost and sustainable construction materials. The lignocellulosic waste considered in this research is the waste biomass harvested from a wastewater treatment facility based on the treatment technology named "CW4Reuse" – a variant of horizontal subsurface flow constructed wetland technology.

The harvested waste *Canna indica* (CI) biomass was processed to derive lignocellulosic fibers, and seven mix-ratios were prepared using polypropylene (PP) as the matrix phase for developing natural fiber-reinforced composites using melt blending and injection molding technique. The performance of the developed composites in terms of tensile, bending, and impact resistance were evaluated. The findings of this study showed an enhanced impact strength with fiber loadings, and the maximum strength achieved was 1573± 0.54 J/m^2. The average bending and tensile strength were found to be 46.2 ±0.36 MPa and 27.8 ± 0.72 MPa, respectively, which is relatively higher than that of wood and particleboard.

The flexural (2.3± 0.25 GPa) and tensile (3.16 ± 0.73 GPa) modulus of CI fiber-reinforced composite has exhibited significant enhancement as compared to neat PP (0.61 ± 0.18 GPa). The density of CI/PP composites (0.96-1.07) g/cm^3 is comparable to wood, whereas the water uptake capacity (0.17-1.7) % was found to be significantly lower than conventional wood-based materials (>10%), leading to added advantage for the structural integrity of the composites. The fiber reinforcement also positively impacted the crystallinity and thermal stability of the neat PP, as demonstrated by X-ray diffraction and thermogravimetric analysis. It is understood from the SEM microstructure studies that there is an increase in fiber debonding, strong fiber pull-out, and low formation of voids and polymeric agglomerates in the fractured surface of fabricated composites at higher fiber loadings. Based on the findings of this study, it is evident that the CI waste biomass-derived polymeric composites can be potentially used for automotive and architectural interiors in civil infrastructural applications.

It is estimated that the constructed wetland-based wastewater treatment plants currently have the potential of generating about 1,500 to 3,000 million MT/year of wet biomass in urban India (approx. 500 million population) and 4,000 to 8,000 MT/year of wet biomass in rural India (approx. 900 million population). This resource can be meaningfully valorized by setting up 100 – 200 treatment plants (capacity: 25-50 MT biomass processing per day) for manufacturing construction materials from biomass-based polymer composites. These small-scale units collectively represent 5 to 10% of plywood needed annually for furniture and an annual turnover of approx. USD 175 to 350 million in India, along with the creation of nearly 15,000 green jobs.

Keywords: Lignocellulosic waste, Valorization, Construction material, Wood substitute, Polymer composites

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Which Factors do Influence the Consumers' Adoption of Electric Vehicles? A Systematic Review

QUAGLIERI, L. [a*], MERCURI, F. [a], FRACCASCIA, L.[a]

a. Sapienza Università di Roma, Roma

**Corresponding author, luca.quaglieri@uniroma1.it*

Abstract

With the introduction of the 2030 Agenda in 2015, countries have committed to reducing the environmental impact of production and consumption activities, to reduce pollutant emissions at the country level. In this context, 27% of total EU-28 greenhouse gas emissions come from the transport sector (European Environmental Agency, 2020). In particular, road transport accounts for 75% of these emissions (International Energy Agency, 2021). Hence, governments around the world are required to implement incentive policies toward a more sustainable mobility. The electrification of private mobility, i.e., replacing internal combustion vehicles with zero-emission electric vehicles, can strongly contribute to this goal.

In the last few years, many studies have been devoted to investigating the consumers' propensity toward electric vehicles, in particular those factors able to impact the purchase intention (GibbsonAdu-Gyamfi et al, 2022; Buranelli de Oliveira et al, 2022). However, these are empirical studies, so highly case-specific. Alternatively, to the best of our knowledge, there are no studies that provide a comprehensive view of this phenomenon. This study contributes to filling this gap by developing a systematic literature review, driven by the following research questions: (1) which are the factors able to affect the consumers' purchase intention of electric vehicles? and (2) which theories have been adopted to study their effects?

Research keywords have been developed encompassing two research domains, i.e., (1) consumer behavior and (2) electric vehicles. The research queries were launched on Scopus and Web of Science databases, resulting in 713 papers published in the 2015-2022 period. According to the screening phase, only papers (1) reporting an empirical study, developing a theoretical model tested via numerical analysis, and (2) published in Q1 Scopus journals were selected for the final analysis. As a result, the final database was made of 51 papers.

190 factors were found to influence, directly or indirectly, the consumers' intention to adopt an electric vehicle. These variables were organized in a "funnel" logic, where each variable was grouped by conceptual categories, which were then organized into three distinct clusters: (1) economic cluster, (2) technology cluster, and (3) consumer personal cluster. The first cluster includes all those conceptual categories that concern variables of an economic nature, such as "Monetary benefits and incentives" and "Economic convenience". The second cluster includes all those factors focused on aspects strictly related to the technology of the electric vehicle, such as "Technology expectations" and "Ease of use of technology". Finally, the third cluster includes variables that had a "subjective" nature, such as "Environmental concerns", "Social pressures" or "Openness to new ideas". Further, the relationships among these variables in the purchasing process behavior have been highlighted.

This paper has theoretical, policy, and managerial implications. From the theoretical perspective, the study identifies all the factors able to affect the purchase intention of electric vehicles, highlighting those that require further investigation and proposing a future research agenda. Regarding the policy implications, the study can support policymakers in defining policies aimed at incentivizing the adoption of electric vehicles, based on the factors that have been recognized as the most effective in driving the consumer purchasing process. Finally, concerning the managerial implications, the study proposes strategies that companies can adopt to push the adoption and purchase of electric vehicles.

Keywords: sustainable mobility, electric vehicle, consumer behavior, purchase intention

Accepted Papers

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Analysis of Brazilian Regulatory Policy in Relation to the Transport Sector

ALMEIDA, J.L. [a]; SOUSA. A.S [b]; CARDOSO, M.F.O. [a,c*]; ARAUJO, L. I. [a,c]; COSTA, H.K.M. [a,c]; MOUETTE, D. [a,c]; SANTOS, E.M. [a,c].

a. University of São Paulo, São Paulo
b. Federal University of São Carlos, São Paulo
c. Institute of Energy and Environment of the University of São Paulo, São Paulo
**Sousa. A.S., eng.arianasousa@gmail.com*
**Cardoso, M.F.O, maxianefcardoso@usp.br*

Abstract

This research project aims to study the set of regulations and policies in Brazil concerning the Nationally Determined Contributions (NDC), voluntary guidelines for regulatory action for the emission of greenhouse gases created by the Paris Agreement. Having the legislation and information collected by regulatory agencies as the basis for the present study, it seeks to analyze the situation and impact of the transportation sector regarding GHG emissions and how actions are being taken to control and mitigate the effects generated by such emissions. As well as prospects and the sharp reduction of GHGs and the replacement of the energy matrix based on fossil fuels for a fuel-based said " low carbon."

Keywords: maximum of five. (font verdana, italic, 8-point)

1.Introduction

Humanity has witnessed a series of disasters and environmental collapses due to the large-scale use of fossil resources, which has led to an increase in the emission of polluting gases that potentiate the greenhouse effect (DULLIUS et al., 2017). Although many countries have been done efforts to minimize climate problems, such as the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, emissions of pollutants from the industrial activity are still an important source of air pollution. Overall, industries do not consider the short and long-term costs associated with increased deaths and diseases caused by pollution or they do not have proper instrument to deal with it as a role (TAYRA; RIBEIRO; NARDOCCI, 2012: Araujo, 2021).

Pollution is defined by Dashesky (2003) as a negative change to some part of the biosphere or aspect of our life, causing, if there is no intervention, annoyances, diseases, deaths, and even extinction of species. So, in the case of air pollution, what is impaired is air quality, with changes in physical characteristics, biological and biological organisms to the atmosphere, harming both living organisms and materials and means. In turn, already in 1990, the Resolution nº 3 of the National Environment Council (CONAMA), provides for air quality standards, provided for in the National Air Quality Control Program (PRONAR), as follows:

> *"considering the need to increase the number of air pollutants that can be controlled and controlled in the country, and defines as atmospheric pollutant any form of matter or energy with intensity and in quantity, concentration, time or characteristics in disagreement with established levels, and that makes or can make the air:*
>
> *I – inappropriate, harmful, or offensive to health;*
>
> *II – inconvenience to the public welfare;*
>
> *III – harmful to materials, fauna, and flora.*
>
> *IV – detrimental to the safety, use, and enjoyment of the property and the normal activities of the community." (Brazil, 1990)*

The Brazilian legislation comprehensively considers "concentrations of sulfur dioxide, total particulate matter in suspension, the product between total suspended particles and sulfur dioxide, carbon monoxide, ozone, inhale particles, smoke, nitrogen dioxide(...)" (BRAZIL, 1990), although there are specific standards for other pollutants components. In the present study, those listed by the previous resolution will be those considered because these are the most recognized by the literature, legislation, and national and international regulations and most documented by previous studies due to their more incredible notoriety in the issue of climate change both for their presence in greater quantity in the atmosphere and for their high harmful potential.

As a vital response to the growing concerns about the environmental issue, the Paris Agreement, approved by 195 countries during the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015, represent a milestone in policies to combat climate change. Its main objective is to limit temperature rise this century to levels significantly below 2°C compared to pre-industrial levels and make efforts to limit this increase to 1.5°C (HOLLANDA, 2016). It is important to reiterate that the observed and predicted increase is because of the greenhouse gases (GHG) concentration in the atmosphere. Thus, controlling the amount of these gases is crucial for achieving this goal. The high number of countries on the first date available for their signature indicates that the world is moving inexorably towards a low-carbon economy. Recognized the risk offered by the warming caused by the emission of GHG, especially carbon dioxide, which is the focus of reductionist and conservation policies aimed at sustainability and sustainable development. Andrade and Mattei (2013) highlight the increasing dependence on the global energy matrix of fossil fuels, which points to the need for discussions about the energy transition.

Among the responses of the Paris Agreement to the issue of global warming and GHG emissions reduction are the Nationally Determined Contributions (NDC), a voluntary commitment to reduce GHG emissions and then adapt to the impacts of climate change established between signatory countries that allow each country to adapt its actions, defining laws and public policies to the decarbonisation in the different segments of the economies – among these land use, industry, and energy according to their realities, needs, and available resources.

The general nature of NDCs revolves around the theme of controlling GHG emissions and adapting to the effects of climate change. The Brazilian environmental agenda is directly regulated by the Ministry of the Environment (MMA), and our intended NDC reaffirms its commitment to reduce net greenhouse gas emissions by 37% in 2025, officially commits to reduce Brazilian emissions by 43% in 2030, and also sets out the indicative goal of achieving climate neutrality – that is, net zero emissions, in 2060 (IBTS, 2020).

Given that the contribution of the Brazilian transport sector to GHG emissions is relatively significant, with about 27% of these, and the ambition of the country determined to reduce its emissions by 43% by 2030, it is necessary to analyze the proposals for intervention and mitigation of its transport sector. We discussed the relevant legislation related, comparing it with the existing rules and laws internationally, and its connection with the scope and effectiveness of Brazilian intended NDC linked to this sector.

2.Methods

This study seeks to analyze the regulatory and national policies set and their contribution to adherence to intended NDCs. Thus, a review was carried out in the scientific literature and on federal government database on normative instructions and selected three programs, the National Biofuels Policy (RENOVABIO, instituted by Law nº 13,576, of 2017 (Brazil, 2017), the Rota 2030 (Mobility and Logistics Program), by Law nº 13755, of 2018 (Brazil, 2018) and the Air Pollution Control by Motor Vehicles Program (PROCONVE), by Resolution CONAMA nº 18, of 1986 (Ibama, 2011), considering the national NDCs.

3. Analysis

Since has been proven that significant load of pollutants in the atmosphere cause deleterious effects in the human population and environment, the studies show analysis possibilities, prediction to proof and conclude the effects are sufficient to affect humanity and the environment as a whole and economic activities. In the last decades, there has been a rise in the ordinary sense of the local and world populations about the environmental topic, the need for recovery, mitigation, and a change of paradigm to control the consequences if there are no changes in the pace and mode of development of human activities. We also observed efforts and discussions in the direction of control, legislation, and regulation of human activities for the least possible impact on the already overloaded environment.

Given that, in the world, transportation is the largest consumer of petroleum-based fuels, accounting for 57% of global demand, and 93% of final energy use in global transportation originates from this derivative (Cazzola et al., 2016). Ensuring the sustainability of mobility of people and freight is a crucial challenge for the entire world in the coming decades. An important step has been taken in the establishment of Nationally Determined Contribution (NDC) targets.

The Renovabio policy (Law nº 13.546, of 2017), intends to promote the decarbonization of the transport sector in Brazil; the Program is based on three instruments (MME, 2020):

(i) the GHG emission reduction targets;

(ii) the certification of biofuels;

(iii) the Decarbonization Credits (CBios).

The Program delimits a model for reducing carbon emissions and provides predictability for environmental, economic, and social sustainability on the role of biofuels in the Brazilian energy matrix, contributing to expand biofuels market share and increase the production and use of biofuels concerning energy security and GHG mitigation in the transport sector. The Renovabio's prerogative is to value the environmental benefits generated through biofuels, measuring the amount GHG that is no longer emitted into the atmosphere once ethanol and biodiesel replace fossil fuels, fitting as a positive externality.

A system was created through which biofuel production needs validation, a note to assess how sustainable and efficient its production process was, based on the product's life cycle assessment (LCA). A scientific-based process seeks to quantify the volume of GHG generated by a given product throughout its production chain. The Renovabio considers both raw material (agricultural) and industrial production phases. The environmental energy efficiency score represents the difference between the fossil fuel and its produced biofuel substitute's carbon intensity (CI), according to SOARES (2020). The Cbio score is object of third-party validation and certification, under the regulation's umbrella of the National Agency of Oil, Natural Gas and Biofuels (ANP), as set out in Resolution nº 758, of 2018 (Brazil, 2018).

By centralizing the evaluation in the CI of each fuel with the potential to promote energy efficiency gains in the production those with lower levels of associated emissions will be able to issue a more significant number of CBios for commercialization. We are seeking to encourage the producer to invest in less carbon-intensive processes, differentiating the products and valuing production with better energy use. The efficiency notes of the production process and the factor for issuing CBios, published on the ANP website, through the Approved Certificates spreadsheet, the producing companies will be able to issue their CBios, and market them on the stock exchange. There is no pre-established value, only the cost of its bookkeeping with the financial agent responsible for its commercialization.

The efficiency score of the production process, and the factor for issuing CBios, disclosed on the ANP site (Approved Certificates), will allow producing companies to issue their CBios, and trade them on the stock exchange. There is no regulation for minimum or maximum price; however, the regulatory agency has the competence to set the amount of CBios to be hold by final agent (fuels' distributors) in case of being justifiable, interfering how market works in terms of CBios offer and demand. There is an expectation of values according to international markets around U$10.00/Cbio, the average price of carbon credits.

The Rota 2030 Program – mobility and logistics, comprises a part of the Federal Government's strategy for developing the automotive sector in the country, which provides for the expansion and global insertion of the Brazilian automotive industry through the export of vehicles and auto parts. This expansion of competitiveness is tied to technological differentiation, not only in reducing costs but increasing the investments in research and development (R & D), based on the principles of sustainability and citizenship. This Program has been implemented as a medium-term time public policy (fifteen years) divided into three cycles. Each five-year cycle will carry out a policy review, resulting in the instruments and targets' reorientation so that companies and agents can schedule their investments. The program presents a series of guidelines, including stimulus to produce new technologies and innovations; to increase economic and efficiency, and to promote the use of biofuels and alternative forms of propulsion to enhance the Brazilian energy matrix. In this way, the results achieved will be externalized to society through increased energy efficiency and safety of vehicles sold in the country (BRAZIL, 2022).

The Program presents a series of guidelines, among them to stimulate the production of new technologies and innovations; increase energy efficiency and promote the use of biofuels and alternative forms of propulsion, and enhance the Brazilian energy matrix having in its strategic structure the following objectives:

(i)establishment of mandatory requirements for the commercialization of new vehicles produced in Brazil or the importation of new vehicles;

(ii)tax benefits for companies that spend money on R&D in the country; and

(iii) regime for non-manufactured auto parts.

It is possible to follow the advanced results of the Rota 2030 Program through the Monitoring Group, which carries out the evaluation and monitoring by Law nº 13.755 of December 10, 2018. This legislation has brought a series of development incentives for the Brazilian automotive industry and has required the compliance with some requirements, such as energy efficiency, vehicle safety, and R&D expenditures (BRASIL, 2022).

The Air Pollution Control Program for Motor Vehicles (PROCONVE) and the Air Pollution Control Program for Motorcycles and Similar Vehicles (PROMOT) and other essential instruments created to establish guidelines, deadlines, and legal standards for permissible emissions for the different categories of vehicles, national and imported, were both established through CONAMA Resolution nº 18 of May 6, 1986, and CONAMA Resolution nº 297 of February 26, 2002, respectively. They are based on international experiences in which the main goal was to reduce air pollution from mobile sources such as motor vehicles by setting maximum emission limits using the command-and-control instruments, strengthening the technological development of manufacturers, and establishing vehicle technological requirements, whose proof will be possible through standardized tests (IBAMA, 2011).

5.Conclusion

To analyse the feasibility, effectiveness, efficiency, and applicability of measures to control and reduce carbon emissions, it is essential to analyse the primary laws and standards related in the country, as well as collect information from agencies and entities responsible for the synthesis of data on the subject both nationally and internationally, to finally be able to observe whether there is adherence to nationally contributions from the collected data. Thus, the following steps involve the analysis of materials relevant to the theme understudy, following the following steps:

1. Collection of data from legislation, public policies and agencies, and programs such as CET, CETESB, ADTRAN, IBAMA, IBTS, PROCONVE, and PROMOT, among others, to obtain data regarding the evolution of NDCs, such as the volume of vehicles and specific emissions in the transport sector;

2. Analysis of the data collected on the international scenario of regulation of CO2 emissions and vehicular fuels and comparison with the Brazilian reality;

3. To point out essential changes and proposals in terms of public policies and standardization regarding road transport that would facilitate the achievement of the goals proposed in the Paris agreement.

4. Conclusion of the analysis on the issue of GHG emissions and reach of NDCs in the transport sector from the economic and environmental points of view and possible publication of the results.

Acknowledgment

We thank the financial support of the Human Resources Program of the National Agency of Petroleum, Natural Gas and Biofuels - PRH-ANP, supported with resources from the investment of oil companies in the P,D&I Clause of ANP Resolution No. 50/2015 (PRH 33.1 - Referring to NOTICE No. 1/2018/PRH-ANP; Fine/FUSP/USP Agreement Ref. 0443/19). We appreciate the support of RCGI - Research Centre for Gas Innovation, located at the University of São Paulo (USP) and funded by FAPESP – São Paulo State Research Support Foundation (2014/50279-4 and 2020/15230-5) and Shell Brazil, and the strategic importance of support given by the ANP (National Agency for Petroleum, Natural Gas and Biofuels) through the regulatory incentive associated with the investment of resources from the Research Clauses, Development and Innovation and the support received by Dominique Mouette, with the National Council for Scientific and Technological Development, CNPq, Brazil, process 315374/2021-7.

References

Andrade, A. L.C; Mattei, L. 2013." The (in) sustainability of the Brazilian energy matrix." Revista Brasileira de Energia, Vol. 19, N 9. 2, 2nd Sem. 2013, pp. 9-36

Araujo, I. L. The Brazilian Carbon, Capture and Storage (CCS) institutional framework: the new carbon market business in an energy transition economy, 2021. 229p. Tese (Doutorado em Ciências). Universidade de São Paulo, 2021.

BRAZIL. LAW No. 13,576 of December 26, 2017. It provides for the National Biofuels Policy (Renovabio). Brasilia, BRA.

BRAZIL. Law No. 13,755 of December 10, 2018. Establishes mandatory requirements for the commercialization of vehicles in Brazil; establishes the Rota 2030 **Program -** Mobility and Logistics; provides for the tax regime of unproduced auto parts; and amends Laws No. 9,440, of March 14, 1997, 12,546, of December 14, 2011, 10,865, of April 30, 2004, 9,826, of August 23, 1999, 10.637, of December 30, 2002, 8,383, of December 30, 1991, and 8,989, of February 24, 1995, and Decree-Law No. 288 of February 28, 1967. Available in: <http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2018/lei/L13755.htm>. Accessed May 25, 2022.

BRAZIL. ANP Resolution No. 758 of November 23, 2018. Regulates the certification of the efficient production or import of biofuels that deals with Article 18 of Law No. 13,576, of December 26, 2017, and the accreditation of provincial firms.

BRAZIL. CONAMA Resolution No. 3 of June 28, 1990. National Council for the Environment. 1990. Brasilia, BRA.

BRAZIL. Ministry of Economy. Route 2030 - Mobility and Logistics. March 2022. Available in:<https://www.gov.br/produtividade-e-comercio-exterior/pt-br/assuntos/competitividade-industrial/setor-automotivo/rota-2030-mobilidade-e-logistica>. Accessed May 25, 2022.

CAZZOLA, P. et al. Global EV outlook 2016. International Energy Agency, France, 2016.

Dashesky H. Steven. Dictionary of Environmental Science. 3° ed. São Paulo: Editora Gaia LTDA, 2003

Tullius, Alexandre, et al. "Urban sustainability through the analysis of renewable technologies in public transport in the city of Curitiba." Environmental Management and Sustainability Journal 6.2 (2017): 73-88.

Hollanda, L., et al. 2016. "A comparative analysis of the energy transition in Latin America and Europe". FGV Energy. 72 p. Available in: <https://fgvenergia.fgv.br/sites/fgvenergia.fgv.br/files/artigos/paper_kas-fgv_port_web_0.pdf>. Accessed: 25 April 2022.

IBTS. (2020) Transport in Brazil - Panorama and Prospective Scenarios to meet the Nationally Determined Contribution. Rio de Janeiro, BRA.

IBAMA. 2011. Program to control air pollution by motor vehicles - Proconve/Promot. 3.ed. Brasilia: Ibama, 584 p. (Environment Collection. Guidelines Series - Environmental Management, no. 3). Brasilia, BRA.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Available in: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.

Ministry of Mines and Energy (MME). 2010.Brazilian energy review - fiscal year 2009. Brasilia, BRA.

Ministry of Mines and Energy (MME). 2017. Renovabio. Available in: mme.gov.br. Access: 23 Jun. 2020. Brasilia, BRA.

SOARES, Gustavo. Renovabio Part II - How does the CBios market work and what is the importance of RenovaBio for bioeconomics?. BIOGÁS A BLOG ABOUT BIOECONOMY. Available in: https://bio-soares.blogspot.com/2020/05/renovabio-parte-ii-como-funciona-o.html. Access on: May 5. 20202

Tayra, F., Ribeiro, H., Nardocci, A.C. 2012. Economic Assessment of Pollution Costs in Cubatão - SP based on health expenditures related to diseases of respiratory and circulatory systems. Soc Health Magazine. São Paulo, v.21, n.3, p.760-775, São Paulo. BRA.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Analysis of the Contributions of Micro-Enterprises to Sustainable Consumption

MONTEIRO, A. C.S.[a], XAVIER, L. A.[a], ALVES, J.L.S [b*], MEDEIROS, D. D.[a]

a. Universidade Federal de Pernambuco, Recife

b. Universidade Federal do Amazonas, Manaus

**Corresponding author, jordania@ufam.edu.br*

Abstract

Studies on Sustainable Production and Consumption (SCP) have become increasingly commonplace due to constant discussions concerning environmental preservation. For this reason, this research aims to analyze Sustainable Production and Consumption practices at micro-enterprises in the State of Pernambuco, Brazil. For data collection purposes, a questionnaire prepared based on the available literature on the subject was used, containing blocks of indicators on the most relevant topics concerning SCP. The questionnaire was applied personally or via e-mail with representatives of micro-enterprises, operating in the industry and services sectors. Along with the results, it was possible to characterize the most used practices by the analyzed companies. Both occasional practices, as seen. For the group studied, administrative practices were the most implemented, and the issues related to their environmental impact reduction were the least implemented. Furthermore, the main benefits provided to companies that use SCP practices and how these benefits can increase their market competitiveness were identified.

Keywords: SCP. Environmental preservation. Micro-enterprises. Industry and Services.

1. Introduction

The inappropriate use of natural resources has intensified in recent decades, causing, among other consequences, the decay of ecosystems, rising temperatures that heightens the risk of forest fires, and change in natural cycles resulting from bold human intervention, favoring environmental degradation (De Gouvello et al., 2010; Besser & Hamed, 2021). In this context, environmental issues have achieved such visibility that they drove the companies to incorporate environmental management and promote the creation of favorable, sustainable, environmental actions (Yang et al., 2010; Wilson & Bryant, 2021).

Under these circumstances, the main way to slow down environmental destruction would be to raise awareness and change habits for better use of natural resources. These adaptations were no longer possible using 'end of pipe' actions, which consist in acting to solve the problem without questioning it, but not eliminating it, requiring huge investments in pollution treatment equipment. Thus, due to the comprehensiveness of its concepts that seek the effective use of resources and generation of less waste, aligning positive financial results, innovation, and environmental protection, the Cleaner Production (CP) emerged as one of the solutions to replace the 'end of pipe' manner, (UNEP, 2003; Diezmartinez, 2021). Furthermore, if companies use their resources intelligently, they will achieve long-term competitive advantages (Michaelis, 2003; Liu et al., 2021).

Clean production was becoming increasingly relevant due to scarcity and pollution-aware practices, besides being a government pressure response towards the consumer market (BerkeL, 2011). Its ease of implementation was a determining factor for it to expand and for companies to adopt its practices. However, with increased consumption and population growth, the concept of expansion need came so that "in addition to environmental issues, it incorporated the consumption perspective and social variables" (Vieira & Amaral,2016; Neto et al., 2022), thus emerging the concept of Sustainable Consumption and Production (SCP).

The change of concept from Cleaner Production to Sustainable Consumption and Production was officially recognized at the World Summit on Sustainable Development in Johannesburg in 2002. It was when its importance for sustainable development was acknowledged. In 2003, in the Marrakech Process, a commitment was made to "promote the development and implementation of SCP policies, programs and projects, providing support to governments, the private sector and other actors in the implementation of SCP activities at national or regional levels" and to develop a 10-year program to accelerate the transition to SCP (UNEP, 2011).

The environmental situation in Brazil is often considered critical due to the uncontrolled population growth and the country's economic base, which force the execution of works that accompany the development. However, the lack of government commitment postpones the completion of basic rights, such as basic sanitation and others, contributing to the increase in the pollution index (Jabbour et al.,2012).

With the globalization of the markets, Brazilian companies have gained international prominence by transparently showing their concern for environmental practices in response to demands related to sustainable development. Until the 1990s, the companies' environmental information was mostly related to environmental management and legal commitment; however, as of from 2010 and on, environmental impacts and the consumption of natural resources took on greater importance in their analyses (Rosa et al., 2015).

Therefore, the creation of Sustainable Production and Consumption – SCP policies became necessary. As technologies emerged, natural-resource use was reduced, while consumption and production grew dramatically. Although sustainable development is on the rise, many countries continue on the unsustainable development path, causing increasingly strong environmental impacts (Vergragt et al., 2016).

Thus, it is relevant to highlight that each company must do its part by contributing to sustainable development, even with small actions in their production processes. Sustainable consumption and production are considered fundamental ways to solve the environmental resources problems that humankind is facing (Xu et al., 2018).

This study analyzed Sustainable Production and Consumption (SCP) practices at Brazilian micro-companies located in the State of Pernambuco. We used a questionnaire identifying the benefits these practices bring, as well as their importance to increase the competitiveness among micro-companies. The study also contributed to the literature on the subject and to the possibility of replication for other companies - some practices may already be in use but are not characterized due to the lack of knowledge for managers.

2. Methodology

The approach used in this study was mixed, characteristically combining two methods and making it possible to present the leveling between the methods in its results. From the perspective of methodological strategics, the research is a case study that approaches an investigation to preserve the holistic and significant characteristics of the real events (Yin, 2009).

2.1 Characterization of the exploratory study

The research was conducted in micro-enterprises in the State of Pernambuco, located in the Northeast Region of Brazil. The participants have the National Register of Legal Entities (CNPJ) active in the state.

The majority of the companies were found considering their proximity through research carried out on the internet. A total of 10 micro-companies participated in this research.

Non-probability sampling was used due to its low cost and low need of time, shortening the time needed to carry out the research. Since the n is considered small, the sample was analyzed by descriptive statistics and the research was conducted for convenience.

It is important to emphasize that the research was approved by the Research Ethics Committee, according to Resolution 466/12 of the National Health Council, and data collection was only carried out after the opinion of the Ethics Committee. All research participants signed the Informed Consent Form.

2.2 Data collection

Data collection was conducted via a questionnaire, built based on studies conducted by several authors found in several scientific study databases, in addition to official documents disclosed by the Brazilian Ministry of the Environment. The instrument is composed of 50 structured questions related to sustainable production and consumption practices, these questions are designed as key indicators for measurement and divided into eight dimensions, while the answers are given through a growing degree of intensity with the use of a five-point Likert scale. These were sent by e-mail or applied personally.

The first part of the questionnaire involves professional questions about the respondent, related to education, position held and length of time in the company, and whether the respondent has any systems certification.

The second part of the questionnaire was divided into specific groups: General Indicators, Administrative Practices, Natural Resources, Environment, Waste/Recycling/Effluents, Selective Collection, Suppliers, and social practices regarding Sustainable Production and Consumption actions in the company. To facilitate the visualization of the tabulated results, the groups were identified by acronyms, as illustrated in Table 1.

Table 1. Dimensions and analysis indicators for identifying the responsible contribution of micro-enterprises to sustainable consumption

Dimensions	**Description**	**Indicators**	**Acronyms**
General Indications	Addresses the adoption and implementation of sustainable consumption, production practices, and cleaner production, in addition to the implementation of a quality program.	Adoption of SCP and CP Practices.	G1
		Top Management Support.	G2
		Quality Programs.	G3
Administrative Practices	It deals with the conscientious use of administrative resources, materials, and incentives for sustainable practices by employees.	Use of recycled paper.	AP1
		Conscious use of paper.	AP2
		Reuse of (draft) paper.	AP3
		Conscious use of electricity by employees.	AP4
		Encouraging the use of mugs.	AP5
Natural Resources	It questions aspects of the economics of natural resources, as well as their rational use and the balanced relationship between human activities and nature.	Reduction in electricity consumption	NR1
		Use of LED or energy-saving lamps.	NR2
		Actions to reduce peak-hour electricity consumption.	NR3
		Using presence sensors to save energy.	NR4
		Use of energy from renewable sources (wind; solar).	NR5
		Reduction of water consumption.	NR6
		Water reuse.	NR7
		Development of internal campaigns to make employees aware of water, energy, and other input consumption.	NR8
		Improvement of the Quality of goods/ or services through process standards.	NR9
		Reuse of any natural resource used in its production process.	NR10

		Use of biofuels (biodiesel, biogas, ethanol).	NR11
Environment	It portrays the consideration that companies give to their image, the obligations and prevention of environmental accidents, the impacts that companies generate on the environment, the concern with impact reduction, and the presence of an environmental management system and sustainable production and consumption programs.	To have a sector exclusively responsible for the environment.	E1
		Actions to reduce the impact on the environment.	E2
		To have environmental preservation projects.	E3
		Conducts reforestation.	E4
		To have an Environmental Management System (EMS).	E5
		To have a Sustainable Production and Consumption program.	E6
Waste / Recycling / Effluents and Selective Collection	The questions consider the directives of the Sustainable Production and Consumption Plan (PPCS) together with the targets of the National Solid Waste Plan (PNRS) and the National Plan on Climate Change (PNMC), regarding the selective collection, reverse logistics, and waste recycling.	Disposal of solid waste according to the National Solid Waste Policy Law.	REC1
		Conducts waste treatment.	REC2
		To have practices that influence the reduction of waste emissions.	REC3
		To have a practice that influences the reduction/waste of raw material consumption.	REC4
		Recycling/reuse of waste generated.	REC5
		Carries out effluent treatment.	REC6
		Performs reverse logistics.	REC7
		Has a 5S program.	REC8
		Performs selective collection.	REC9
		Uses recyclable packaging.	REC10
		Has a partnership with a recycling cooperative.	REC11
Suppliers	I asked whether respondents seek suppliers who use sustainable practices, whether they train them for this behaviour, and whether they prioritize nearby suppliers to reduce logistics costs.	Suppliers using sustainable practices.	S1
		Program to train suppliers in sustainable practices.	S2
		Prioritize purchases from nearby suppliers to reduce logistics costs.	S3
Social Practices	It asks whether companies are concerned about the well-being of their employees and the community in which they operate.	Actions for the well-being of employees, society, and the environment.	SP1
		Has an internal reporting channel (harassment, embarrassment, i.e)	SP2
		Support/performance of social work with the surrounding community.	SP3
Benefits	It addresses the benefits acquired by companies with the adoption and implementation of sustainable consumption practices.	Apply sustainable practices, seeking to become more competitive.	B1
		Customer satisfaction survey.	B2
		Consider the demands of customers relating to sustainable production processes.	B3
		Reduction of production costs.	B4
		Increase in production capacity.	B5
		Rate of benefit to the company.	B6
		Customer loyalty rate.	B7
		Increasing the number of customers.	B8

The questions were answered according to a five-point Likert scale, where: 1= 0% (There are no actions applied; 2= 20% (The company management has action projects); 3= 40% (Actions are at the beginning of application); 4= 70% (Actions were partially applied) and 5= 100% (Actions were fully applied), plus the option N/A (Not Applicable) if any question does not apply to the company.

Each group of questions also includes an evaluation that allows the respondent to say in what percentage

– from 0 to 100% – each action is practiced in the company. This was because the actions may be implemented, however, still did not work as expected.

The third part of the questionnaire addresses questions that assess to what degree the respondent believes that the practices are seen as benefits to the company, used again the Likert scale of 5 points, where: 1=Strongly Disagree, 2=Partially Disagree, 3=Neither Disagree or Agree, 4=Partially Agree and 5=Strongly Agree. The same percentages were applied to the group of specific questions.

Thus, in the software used, the scale was maintained and its respective percentages were identified in the labels. This was also valid for the "practiced" column, and in the "benefits acquired" block. The labels were identified with the same description as the scale means in the questionnaire, ranging from "Totally Disagree" to "Totally Agree."

3. Presentation of SCP practices in micro-enterprise in Pernambuco

Firstly, the companies and the respondents will be characterized in terms of size and sector of activity, then, the data of the respondents will be presented according to their position/function, time in the company, and level of education.

3.1 Characteristics of the Companies and respondents

Companies were characterized according to the sector in which they operate. Questionnaire respondents were collaborators equipped with the necessary knowledge to provide sustainable production and consumption practices employed by companies, irrespective of the position held. The characteristics of companies, professionals, information, position held, and the corresponding length of time in the company are illustrated in Table 2.

Table 2. Characterization of the companies and respondents

COMPANY ACTIVITY	RESPONDENT	COMPANY TIME (YEARS)
Hairdresser	Partner-Owner	38
Cosmetics Trade	Partner-Owner	12
Food Industry	Managing-Partner	20
Health Club	Assistant Producer	7
Drinks Industry	Manager	15
Food Service	Managing-Partner	13
Accounting and Courses	Director - Responsible	6
Food Service	Partner-Owner	8
Bakehouse	Owner	15
Paint Industry and Trade	Administrative Supervisor	9

The set of companies studied was well diversified and covered the sectors of goods and services. Most of the respondents were the owners of micro-enterprises with a market time that ranged from 7 to 38 years.

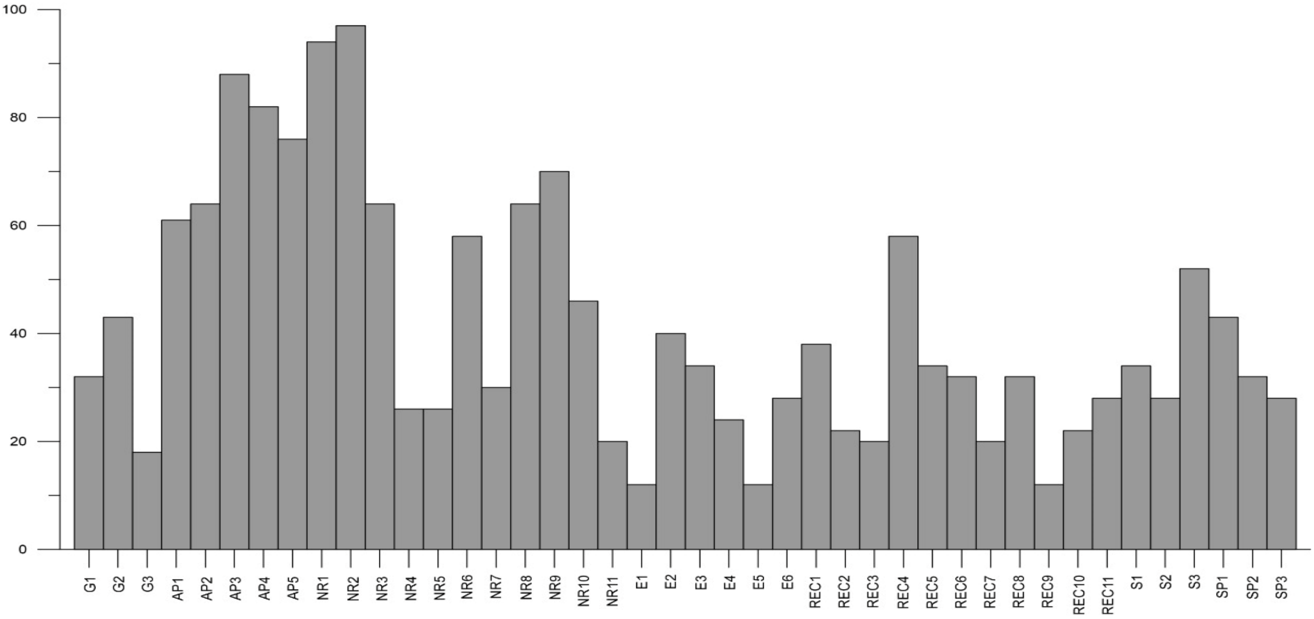
3.2 Results of sustainable consumption practices implemented by micro-companies

The indicators were analyzed through the averages of the responses of each participating company. Fig. 1 illustrates the percentage of the implementation of each indicator of sustainable consumption practices for the group of micro-companies studied.

One can observe that out of the five most practiced sustainable consumption practices, three are related to the conscious use and reduction of electric power consumption and the use of economical light bulbs (NR2, NR1, AP4). Reusing office papers and encouraging the use of mugs at the company (AP4, AP5) are also among the five most implemented practices.

These five sustainable consumption practices have a direct impact on company costs, which is why they are the most widely implemented; firstly, the microentrepreneur thinks about reducing costs and expenses and not the environment, and indirectly he contributes to sustainable consumption. As expressed by Xu et al. (2018), the motivation for the development of sustainable practices of many stakeholders involved in the process comes from their interests and not from environmental concerns. For this reason, the development of a market with sustainable consumption practices is unbalanced.

Fig. 1. Indicators of sustainable consumption practices of micro-enterprises



In contrast, the five sustainable consumption practices the least implemented by companies, apart from the presence of a sector responsible exclusively for environmental issues (E1) and the presence of an environmental management system (E2), in third place the micro-companies studied do not carry out the selective collection in their establishments (REC 9), and also do not implement quality management programs (G3), and finally, do not implement the use of more sustainable fuels (NR11).

About indicators E1 and E2, micro-companies have both internal and external barriers to solving their environmental problems and adopting and implementing an Environmental Management System, but the internal barriers are higher because of the negative culture of the company regarding the environment. It makes the adoption of the EMS fail at the first obstacle, coupled with low awareness and lack of pressure from customers, maintaining this initiative on a non-priority plan for this category of the company (Hillary, 2004).

Another practice less implemented by the microenterprises studied, is the performance of selective collection. Despite being a widespread practice worldwide, Brazil is still far behind in this aspect, which can be corroborated in the study of Hettiarachchi et al. (2018), who reports that countries in Latin America and the Caribbean do not have practices of selective collection on a large scale and, that only about 4% of all the rubbish produced is recycled due to the lack of public policies. Ibáñez-Forés et al. (2018) confirm in their research that Brazil still neglects selective collection and the correct destination of solid waste, despite having great potential to generate secondary raw materials from recycling.

The fourth indicator less implemented by microenterprises was the quality management programs. This fact may have occurred because entrepreneurs at first do not see or do not know the benefits of it, associating the quality of management with high costs, associated with the myth that they need a large and innovative structure (Pearson, 2015).

The implementation of the use of more sustainable fuels has little adherence among micro-enterprises, it is a reality in developing countries that opt for energies from traditional, convenient sources such as electricity and fossil fuels, as presented in the studies of Shrestha et al. (2005). When analyzed by the dimension to which the indicators belong, the results found are presented in Fig. 2.A.

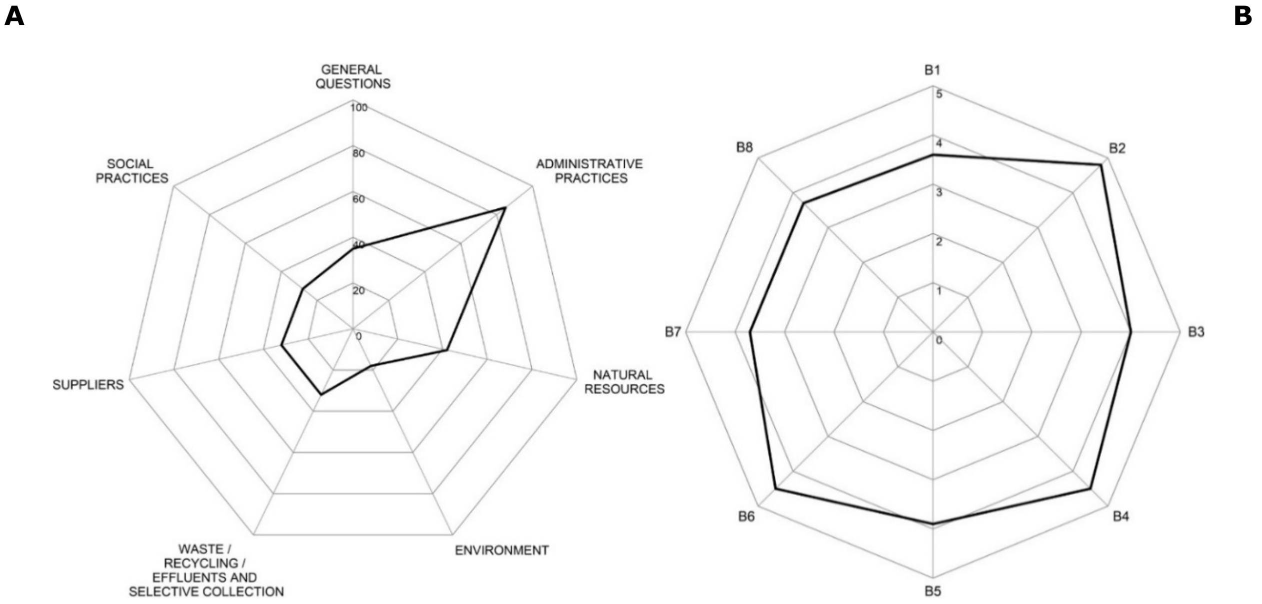


Fig. 2.A Dimensions of sustainable consumption practices. **2.B** Perception of the benefits acquired with sustainable consumption practices by micro-enterprises

In the researched group, the administrative practices were the most implemented by micro-companies, and these practices are related to the indicators of the use of recycled paper; conscious use and reuse of paper; the use of electric power responsible by employees; and, the incentive to use mugs to reduce disposable cups, corroborating with the most implemented indicators by the analyzed micro-companies. In this sense, organizations are moving toward implementing sustainable consumption practices, which may be related to planned strategic efforts and daily efforts to denaturalize consumption patterns in the workplace, which may be limited to their capacity (structure, knowledge, financial) (De Figueiredo et al., 2020).

On the perception of entrepreneurs as to the benefits acquired by adopting sustainable consumption practices, the result is presented in Fig. 2 B.

In the question on SCP practices and competitiveness, from a total of 10 micro-companies, 6 of them partially or totally agree that the use of SCP practices is directly linked to making them more competitive, 2 companies neither agree nor disagree, and 2 companies partially or totally disagree with the statement. The result shows that although sustainable practices are increasingly common, not only due to legislative pressures but also due to pressures from society, it is still not unanimous among micro-companies that it can make them more competitive.

In the question on satisfaction research, it was possible to assess that micro-companies are concerned with customer opinion, considering improving their service, processes, and products, besides the possibility of making them loyal. In the question about customer demands, the results show that most companies responded that they partially or totally agree with the statement. This question comes to confirm how strong the opinion of customers is, causing companies to seek ways to satisfy them, aware that this can directly influence the company's image.

The question on cost reduction illustrated that the vast majority of companies totally agree that this practice reduces costs, given that there are several ways to reuse, recycle or even adhere to renewable sources in their processes. Even though it requires an initial investment, in the short, medium, or long term, the financial return and contribution to environmental preservation are evident.

The answers concerning the increase in productive capacity demonstrate that 6 companies partially or totally agree, 3 companies were indifferent and 1 company partially or totally disagreed. Possibly, one of the reasons for the difference of opinions was due to the sector of the companies, which has activities between industry and services.

When asked about the benefits of sustainable practices, most companies agreed either partially or totally, i.e., irrespective of the sector in which they operate, sustainable practices may bring benefits. The benefits can be seen in several ways, and among them, the companies mentioned the reduction of costs with energy, paper purchase, reduction of transportation costs, improvement in the company's image, personal satisfaction for the collaborators, and also improvement of the cleaning and organization in the company.

The results about customer loyalty show that 6 companies partially or totally agree, 2 companies were indifferent and 2 companies partially or totally disagreed. Customer loyalty depends on several aspects, however, companies are gradually becoming aware that sustainable practices become increasingly important to reach this goal.

In the last question of this block, concerning the increase in the number of clients, the most relevant data reveal that most companies replied that this issue is indifferent, i.e., that there is no direct relation between adhering to sustainable practices and obtaining more clients. For micro-companies, despite the unanimous agreement on the benefits that sustainable practices bring, it can be noticed that some issues are still a challenge to be worked on, since companies may not yet attribute the proper importance to the use of sustainable practices and their total functioning, to have a perception of the benefits.

4. Final Considerations

Although the companies studied have adopted some measures to promote sustainable consumption practices, little progress has been made and the shortcomings are still large.

Micro-companies mostly use the simpler, low investment practices, yet they had positive participation in all blocks of questions, emphasizing their interest in implementing or even expanding sustainable practices, aiming at offering better quality products/services and even improving the company's image.

This factor occurs because, as of this research, it was possible to observe that there is a lack of knowledge for micro-enterprises about the several actions that may be sustainable. This might be because entrepreneurs still believe in the myth that only large implementations make a difference in day-to-day life, however, simple activities such as, for instance, using mugs instead of disposable cups, turning off monitors when leaving the workstation, and reusing inputs used in their processes, may generate benefits such as cost reductions.

Therefore, there is a reflection on the results presented, so that companies understand the importance of implementing sustainable practices, both for their benefit and for the society that has become increasingly concerned with issues of environmental degradation.

As Martínez and Poveda (2022) point out, it is important to promote sustainable consumption practices suitable for micro-enterprises, so that entrepreneurs understand the advantages of cleaner production practices as a strategy to improve the process, increase customers, reduce costs and ensure product quality.

5. Acknowledgement

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Fundação de Amparo à Ciência e Tecnologia de Pernambuco (FACEPE).

References

Besser, H., & Hamed, Y. (2021). Environmental impacts of land management on the sustainability of natural resources in Oriental Erg Tunisia, North Africa. Environment, Development, and Sustainability, 1-29.

De Figueiredo, M. D., de Castro, N. M., & Silva, M. E. (2020). A practice-based learning approach toward sustainable consumption in the workplace. Journal of Workplace Learning.

De Gouvello, C., Soares Filho, B. S., Nassar, A., Schaeffer, R., Alves, F. J., & Alves, J. W. S. (2010). Brazil low-carbon country case study. Washington, DC: World Bank.

Diezmartinez, C. V. (2021). Clean energy transition in Mexico: Policy recommendations for the deployment of energy storage technologies. Renewable and Sustainable Energy Reviews, 135, 110407.

Hettiarachchi, H., Ryu, S., Caucci, S., & Silva, R. (2018). Municipal solid waste management in Latin America and the Caribbean: Issues and potential solutions from the governance perspective. Recycling, 3(2), 19.

Hillary, R. (2004). Environmental management systems and the smaller enterprise. Journal of cleaner production, 12(6), 561-569.

Ibáñez-Forés, V., Bovea, M. D., Coutinho-Nóbrega, C., de Medeiros-García, H. R., & Barreto-Lins, R. (2018). Temporal evolution of the environmental performance of implementing selective collection in municipal waste management systems in developing countries: A Brazilian case study. Waste Management, 72, 65-77.

Jabbour, C. J. C., Da Silva, E. M., Paiva, E. L., & Santos, F. C. A. (2012). Environmental management in Brazil: is it a completely competitive priority? Journal of Cleaner Production, 21(1), 11-22.

Liu, S., Yu, Q., Zhang, L., Xu, J., & Jin, Z. (2021). Does intellectual capital investment improve financial competitiveness and green innovation performance? Evidence from renewable energy companies in China. Mathematical Problems in Engineering, 2021.

Martínez, C. I. P., & Poveda, A. C. (2022). Strategies to improve sustainability: an analysis of 120 microenterprises in an emerging economy. Global Sustainability, 5.

Michaelis, L. (2003). The role of business in sustainable consumption. Journal of Cleaner Production, 11(8), 915-921.

Neto, G. C. D. O., Leite, R. R., Lucato, W. C., Vanalle, R. M., Amorim, M., Matias, J. C. O., & Kumar, V. (2022). Overcoming Barriers to the Implementation of Cleaner Production in Small Enterprises in the Mechanics Industry: Exploring Economic Gains and Contributions for Sustainable Development Goals. Sustainability, 14(5), 2944.

Pearson, M. (2015). The small business owner's simplified guide to ISO 9001 and Business Improvement. BSI Group, London.

Rosa, F.S., Guesser, T., Hein, N., Pfitscher, E. D., & Lunkes, R. J. (2015). Environmental impact management of Brazilian companies: Analyzing factors that influence disclosure of waste, emissions, effluents, and other impacts. Journal of Cleaner Production, 96, 148-160.

Shrestha, R. M., Kumar, S., Martin, S., & Urmee, T. (2005). Application of productive uses of renewable energy for small, medium, and micro-enterprises.

UNEP. (2011). Paving the Way for Sustainable Consumption and Production: The Marrakech Process Progress Report.

United Nations Environment Program (UNEP). 2003. Proceedings of the UNEP workshop to develop a global POPs monitoring program to support the effectiveness evaluation of the Stockholm convention, 24-27 March 2003. UNEP Chemicals, Geneva, Switzerland.

Van Berkel, R. (2011). Evaluation of the global implementation of the UNIDO-UNEP National Cleaner Production Centres (NCPC) Programme. Clean Technologies and Environmental Policy, 13(1), 161-175.

Vergragt, P. J., Dendler, L., De Jong, M., & Matus, K. (2016). Transitions to sustainable consumption and production in cities. Journal of Cleaner Production, 134, 1-12.

Vieira, L. C., & Amaral, F. G. (2016). Barriers and strategies applying Cleaner Production: a systematic review. Journal of Cleaner Production, 113, 5-16.

Wilson, G. A., & Bryant, R. L. (2021). Environmental management: new directions for the twenty-first century. Routledge.

Xu, S., Chu, C., Zhang, Y., Ye, D., Wang, Y., & Ju, M. (2018). Entangled stakeholder roles and perceptions of sustainable consumption: An evaluation of sustainable consumption practices in Tianjin, China. Journal of environmental management, 223, 841-848.

Yang, C. L., Lin, S. P., Chan, Y. H., & Sheu, C. (2010). Mediated effect of environmental management on manufacturing competitiveness: an empirical study. International Journal of Production Economics, 123(1), 210-220.

Yin, R. K. (2009). Case study research: Design and methods (Vol. 5). Sage.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Bibliometric/Scientometric Study on Solid Waste Management in the Covid-19 Pandemic

SILVA, T.S.[a], SANTANA, N. M. [b], ANGELO, G.F [a].,SILVA, T.V.B. [a], STREIT, J.A.C. [a] EL-DEIR, S. G. [a,c*]

a. Environmental Management Research Group in Pernambuco (Brazil)

b. Econosp, Recife – PE (Brazil)

c. Federal Rural University of Pernambuco- UFRPE, Pernambuco (Brazil)

**Corresponding author: soraya.el-deir@ufrpe.br*

Abstract

In early 2020, the world population was surprised by the pandemic caused by the coronavirus (SARS-CoV-2) which derives Covid-19, generating a major concern in society due to the rapidity of spread in various regions of the world, presenting different socio-environmental impacts. In view of the Covid-19 pandemic, solid waste management can lead to contamination, thus increasing the number of victims of SARS-CoV-2 in all countries, which represents a risk of transmission. The objective of the research was to evaluate the progress of scientific research focused on the thematic axis, Covid-19, solid waste, and the environment, emphasizing the relevance of the articles through the state of the art. To this end, a review of articles on the ScienceDirect platform was carried out through the systematization of steps, seeking to identify the solid waste management procedures adopted by some countries during the confrontation of the Covid-19 pandemic. The increase in the production of articles is noticeable, especially from 2021, evidencing the thematic axis of the research study area that is on the rise. With this, it was found that Covid-19 and Solid waste has received little attention in the academic area and application in solid waste management in the pandemic.

Keywords: Dissemination; Environment; SARS-CoV-2

1. INTRODUCTION

The global crisis caused by the SARS-CoV-2 virus (Covid-19), which is responsible for the pandemic, has caused a great challenge for humanity, affecting the economy, social and environmental issues. Pandemic-level diseases have irreversible consequences for society, especially in the area of public health. At the end of 2019, in Wuhan, China, there was the beginning of what was later understood as a pandemic, the Covid-19 virus [1]. This was identified as a zoonotic coronavirus, similar to the Severe Acute Respiratory Syndrome (SARS) coronavirus and the Middle East Respiratory Syndrome (MERS) [1], which caused serious problems at the national and international levels.

The transmission of this virus is by respiratory droplets from one person to another by direct route and contact with contaminated surfaces, by the indirect route [2]. The World Health Organization (WHO) warns about the proliferation of cases of pneumonia, resulting from Covid-19 and the appropriate combat measures for each person, such as physical isolation, use of masks, hygiene and sterilization with gel alcohol [3]. As a result of these measures, the Covid-19 pandemic changed several human behaviours, causing social and economic impacts, such as the need to review solid waste management, due to the high risk of contamination of the disease [4, 5].

In relation to the Covid-19 pandemic and Solid Waste Management (GRS), inadequate collection practices stand out, which can lead to contamination of solid waste, being a worrying transmission risk in the pandemic [6]. Therefore, the safe handling and final disposal of these wastes are vital elements for living with SARS-CoV-2 [7]. For workers who work directly and indirectly in the different forms of collection, this risk is heightened [8]. Although relevant and significant attention has been given to public policies aimed at managing Covid-19 in the health sector, in another field of research there was a deficit of observation, as in the area of solid waste. Despite the clear links between health, solid waste and development in the expected changes in nature with the composition of materials in a pandemic [9, 10]. From this perspective, several studies have analysed the adherence and permanence of SARS-CoV-2 on inanimate surfaces, which makes it essential to create strategies to minimize the possibility of a trail of contagion of this pathogen [11, 12, 13, 14].

Thus, this article aims to evaluate the progress of scientific research focused on the Covid-19 thematic axis, Solid Waste and the Environment, emphasizing the relevance of studies at the international level. The use of data mining and knowledge management and process by bibliometric and scientific metric study were carried out, using articles from the ScienceDirect platform, seeking to identify the solid waste management procedures adopted by some countries in the academic area during the face of the Covid-19 pandemic. In this way, the use of data mining served as a basis for understanding the state of the art and helping to advance scientific knowledge.

2. THEORETICAL FOUNDATION

2.1. Covid-19 pandemic

Since December 2019, significant data have caused alarm in society due to the rapidity of the virus's contagion. The World Health Organization [15] coronavirus panel record, up to February 11, 2022, showed a total of cases globally, 404,910,528 confirmed cases, including 5,783,776 deaths and a total of 10,095,615,243 vaccine doses have been administered. Given this information, it cannot be denied that the pandemic so far remains a challenge for global public health.

Coronaviruses are single-stranded RNA viruses that can infect not only humans, but also a wide variety of animals [16]. These viruses were first studied in the 1960s [17], in cultures of patients with the common cold [18]. In 2020, the World Health Organization expressed concern about the spread of Covid-19 to public health. There are two main features that have caused this virus to spread far beyond geographic borders, clinical and rapid person-to-person transmission and the movement of people between countries. The clinical feature suggests that the disease barely responds to conventional treatments; therefore, treating those in critical condition is a challenge. In transmission, the environment also plays an important role in the global development of Covid-19 [19].

Due to the severity of the spread of SARS-CoV-2, in 2021, the World Health Organization recently declared South America as the new epicentre of the Covid-19 pandemic, as Brazil became one of the most affected countries [20]. In addition to the economic impacts, public health and social isolation also caused direct and indirect environmental effects. According to some authors [5], who presented recommendations to minimize the contagion trail of Covid-19, this study pointed out that it is essential to raise awareness and engagement of society and the planning and support of all affected countries, following the reality of each region.

2.2. The challenge of solid waste management in the face of Covid-19

Solid waste management is another extremely important aspect that can contribute to the spread of the pandemic in the community, but which has not received much scientific attention [21]. Regarding the pandemic and waste management, scientific research indicates that these can be a vehicle for the transmission of the coronavirus and that they represent a risk for the population and operators who work directly in the different forms of collection, treatment and final destination [8, 22].

According to some authors [18], it is important to emphasize that the contagion not only of some known pathogens, but also of the new coronavirus, when waste management is inadequate, aggravates the confrontation of this health and environmental problem. These problems involving solid waste have economic advantages that reflect on the health issue, favouring the reduction of diseases [23, 24].

Some European countries have adopted strategies to prevent the spread of the virus, such as establishing a minimum time of 72 hours to carry out garbage collection, in order to reduce the risk of contamination by handling [25]. This is due to the long persistence of the virus on some inanimate surfaces, such as ceramics (5 days), aluminium (up to 8 hours), at a temperature of 21ºC; plastic (up to 6 days), between 22 and 25ºC; and metal (5 days), glass and wood (4 days) at room temperature [11, 26, 27]. However, these fomites (these are the commonly known building blocks of the environmental aspect of Covid-19) can be inactivated through surface disinfection procedures, with 62% to 71% ethanol, 0.5% hydrogen peroxide or 0.1% sodium hypochlorite, in 1 minute. Other factors relevant to the survival of the virus on inanimate surfaces are air; wastewater and meteorological factors, such as wind speed, absolute humidity, incidence of sunlight, atmospheric pressure, among others [19].

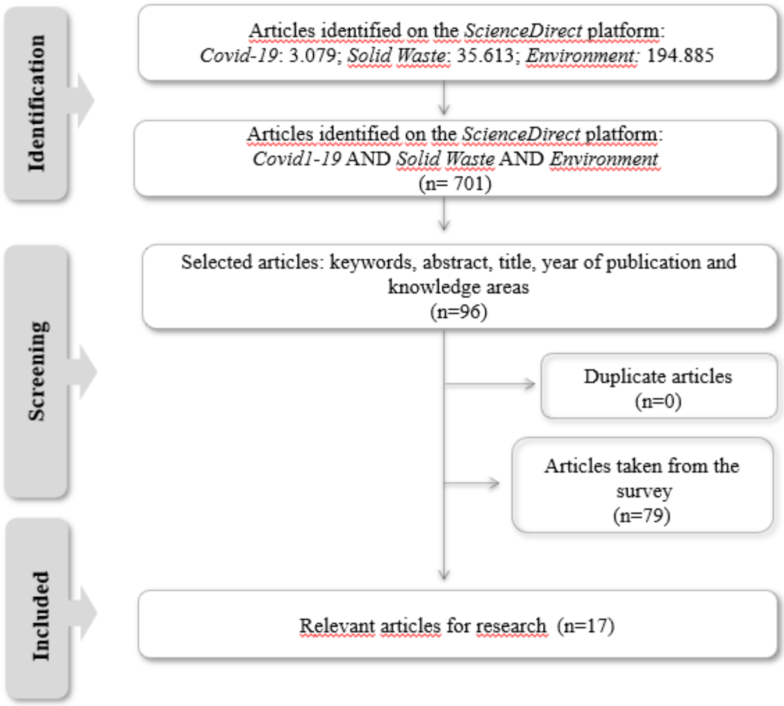
World Health Organization [3] has provided guidance on a safely manage of waste and water residual. In this way, other organizations have developed guidelines with the objective of raising awareness and encouraging local actions related to the safe management of recyclable solid waste for protection and prevention directed towards health, and the environment, including workers who have direct contact with this material [28, 29].

3. METHODOLOGY

For the development of this study, a bibliographic survey was carried out to approximate the thematic axis. This method consists of reading public material, increasing the initial knowledge about the topic [30], as well as determining a bibliometric study, employing a qualitative and quantitative approach, which gives the research a higher quality in the description, in the evaluation and in monitoring scientific production [31]. The bibliometric analysis allows the researcher to approach the object of study, as well as allowing the analysis of statistics from the academic literature, from different perspectives [1]. Scient metrics is the term used to describe the study of science: growth, structure, interrelationships and scientific productivity, being relevant to understanding the evolution of knowledge on a given topic [32, 33].

The structuring of the article was carried out through the systematization of a set of steps, in order to investigate the state of the art of the work on solid waste management guidelines due to Covid-19. In view of this, the methodology of the article was decomposed into three stages: (i) data collection, (ii) data processing and (iii) data analysis (quantitative and qualitative of bibliometric and scient metric data) (Figure 1).

Figure 1 - Research flowchart with the thematic axes addressed



3.1. Data collection

The research was carried out in the ScienceDirect database, seeking scientific articles published from December 2019 to February 2021, using the platform of the Periodicals Portal of the Coordination for the Improvement of Higher Education Personnel (Capes). For the query, the keywords Covid-19 AND Solid Waste AND Environment were used as search criteria. Then, 701 articles in English were found in the total of the search. In order to obtain more accurate results, a filter was applied in which scientific articles, journals and the areas of knowledge were selected: Engineering and Environmental Sciences, totalling a quantitative of 96 published articles, in addition, previous articles were analysed in full, after this evaluation, 17 publications remained relevant to the theme proposed in the development of the research. The articles not used in the research served as support and basis for the discussion of this work.

3.2. Data processing

The collected data were separated by category: year of publication, authors, institution, journal, country and the Impact Factor (IF), which is the main metric that qualifies scientific publications based on article citations [34]. Scientific articles were evaluated quantitatively and qualitatively, using Descriptive Statistics, with the help of the Microsoft Office Excel program. With the information from the research, graphs and charts were prepared to assist in the discussions of textual analyses in a quantitative and qualitative way.

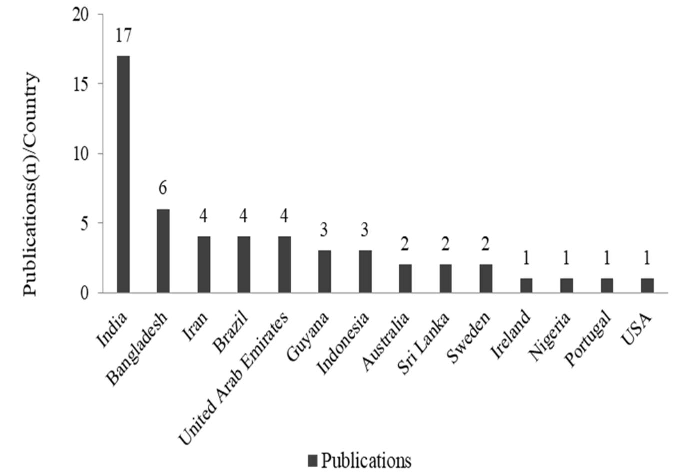
3.3. Data analysis

The textual analysis was performed using the Iramuteq software (*Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires*). This program allowed the grouping of words according to repetition in the set of analysed texts. Therefore, the frequency of words was determined, which allowed the creation of the cloud by compatibility, referring to the titles, abstracts and keywords of the sample articles [35, 36]. A network mapping was performed using the VOSviewer software, which made it possible to observe the relevance of the articles [37, 38].

4. RESULTS AND DISCUSSION

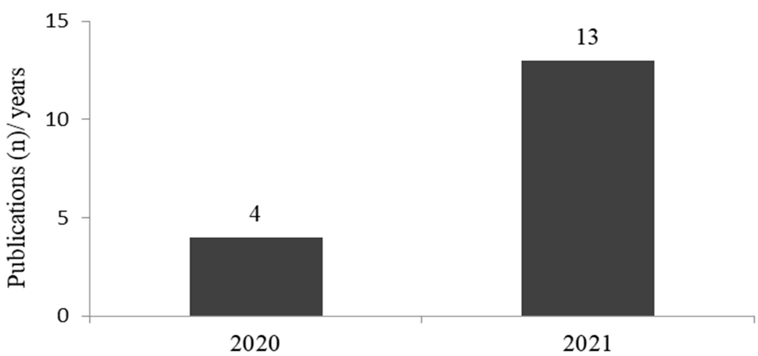
Publications referring to the thematic axis Covid-19 and solid waste management totaled 96 articles, and with the reading of these, 79 were removed from the sample because they did not deal with the focus of bibliometrics, even if presenting the keywords in the text, resulting in a sample end of 15 articles. In these, 51 authors were identified, being these from different countries (Figure 2). The countries that most developed academic research related to the topic India and Bangladesh. These articles reflect on different measures taken to minimize the outbreak in these countries [39].

Figure 2 – Publications on Covid-19 and solid waste management by country, during the period from December 2019 to February 2021



It is observed that in India there was a contribution of 33.3% of the publications, corresponding to 17 authors who published articles, while Bangladesh resulted in 11.8% of the publications, and 06 authors. Next, the countries Iran, Brazil and the United Arab Emirates stand out, where each country contributed with 7.8% of the studies, which corresponds to 04 authors publishing in journals. Guyana and Indonesia, 5.9% each, and 3 authors. For the countries of Australia, Sri Lanka and Sweden, this percentage was below, resulting in 3.9% each, which corresponds to 2 authors per publication. Finally, Ireland, Nigeria, Portugal and the USA contributed with 2%, totaling 1 author per publication. This topic has not received due importance as a potential trail of contagion causing the spread of the virus in society [21]. Another factor previously addressed by the authors is the lack of environmental and social structure, which can increase the likelihood of human contact with contaminated solid waste (Figure 3).

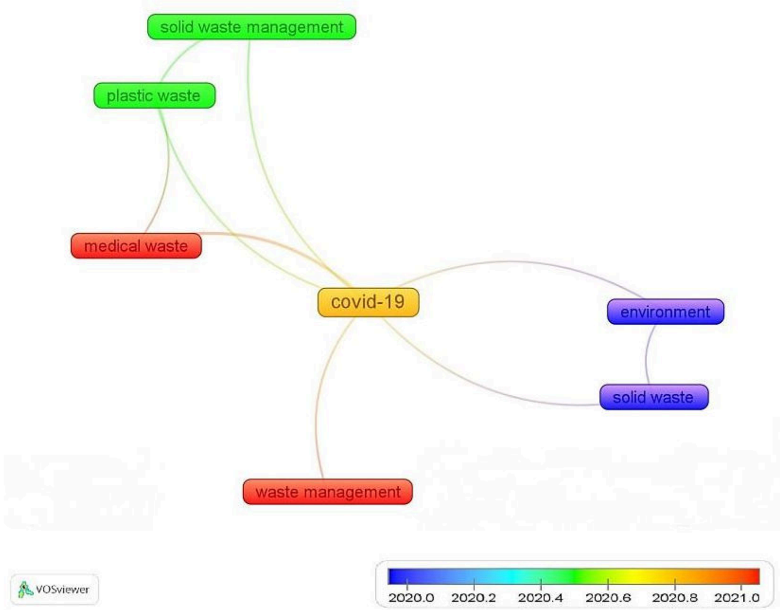
Figure 3 - Publications and contributions of scientific articles during the years 2020 and 2021



In addition, the situation of the Covid-19 pandemic caused limitations among several countries, which led to significant changes and increases in the storage of various wastes, resulting in a challenge for the proper disposal of these materials [39]. According to Zhou et al. (2021), although there was an insufficient amount of research aimed at examining the impacts on society through the generation and management of waste during the pandemic, there were discussions about the themes and the

relationship between them. The impact caused by the waste technology route, including the protection and health of humans during the Covid-19 pandemic, was evaluated, but the research focused mainly on the summary of previous studies, causing a deficiency in the clarification of society. and the guidelines and recommendations of environmental policies on waste management [40, 41].
When analyzing the articles in a scientific metric way, studies focused on Covid-19 and waste management are presented with greater relevance, in the first half of 2020, the thematic axes for the development of publications were directed to Covid-19 19 with follow-up on the environment and solid waste. In the second half of 2020, the articles addressed solid waste management in the broader context of the pandemic. The first quarter of 2021 showed a significant number of publications focused on the areas of waste management and hospital waste (Figure 4), featuring an increase in gloves, masks and Personal Protective Equipment (PPE). This change in the focus of publication was foreseen due to the increase in registered cases, causing a growing volume in the generation of Health Service Waste, caused by sanitary control measures in hospital environments and by the general population, which raised the care to avoid the spread of the contagion trail of the virus [42].

Figure 4 - Overlay of the topics covered during the research period



Regarding the frequency of words in scientific articles, it was possible to visualize the terms that presented the greatest highlights in the textual analysis. With regard to repetition, the cloud portrays a high frequency because it is associated with the thematic axis of the research, such as Covid-19, Solid Waste and Environment. In the analysed articles, the main terms used in the titles, abstracts and keywords to build the word cloud were waste (133 repetitions), Covid (74 repetitions), pandemic (45 repetitions), management (44 repetitions) plastic (42 repetitions), solid (24 repetitions) and environment (20 repetitions) (Figure 5).

Figure 5 - Most used words in the analysed articles

Of the 17 articles analysed, they were published in different journals, which had a different impact factor or did not even have such information on the website. The journal Science of the Total Environment was the most used by researchers, which resulted in 7 publications, totaling 41.2% of contribution to scientific research. In second place is the journal Resources, Conservation & Recycling with 3 publications and 17.9% (Table 1). Regarding the evaluation metrics of the journals, 5 have the Impact Factor ranging between 4,300 (Journal of Environmental Chemical Engineering) and 8,086 (Resources, Conservation & Recycling). In view of this, most of the analysed works are of good quality, since they were submitted to rigorous evaluation processes for publication in highly regarded journals.

Table 1 – Classification of journals in relation to Impact Factor (FI)

5.

Journal	**Publications (n)**	**Contribuitions (%)**	***FI***
Chemosphere	1	5,9	5,778
Ecotoxicology and Environmental Safety	1	5,9	4,872
Environmental Challenges	1	5,9	-
Environmental Nanotechnology, Monitoring & Management	1	5,9	-
Journal of Environmental Chemical Engineering	1	5,9	4,300
Journal of Environmental Management	1	5,9	5,647
Research in Globalization	1	5,9	-
Resources, Conservation & Recycling	3	17,6	8,086
Science of the Total Environment	7	41,2	6,551

CONCLUSION

This work provided a comprehensive analysis of scientific publications on the relationship between Covid-19 and waste management through bibliometric analysis and scientific metrics, showing that the area of study is growing broadly focused on waste management. . It was found that there was more production of scientific articles in the countries of India, Bangladesh, then Brazil, the United Arab Emirates and Guyana, which reflected a greater concern in this area of study in the socio-environmental context. It is noticed that waste management and the impacts aimed at the trail of contagion of Covid-19 have received little attention in the academic area and the applicability in management through instruction and recommendation, especially when referring to health waste, where Inappropriate practices can promote the spread and transmission of the virus within communities.

It is concluded that academic research is directed to Health Service Waste, and the issue of urban waste management is not being properly addressed by science. Finally, it should be noted that this work has limitations, since there are other article platforms that could be investigated, as well as other search protocols could be executed. In view of the greater objective of contributing to the fight against the Covid-19 pandemic, it is suggested that future studies apply the theoretical findings discovered here in research through case studies with solid waste management stakeholders.

ACKNOWLEDGEMENTS

To the Government of Brazil, for the financial support through the Coordination for the Improvement of Higher Education Personnel and the National Council for Scientific and Technological Development, of the Ministry of Science, Technology and Innovation. We also thank the Government of the State of Pernambuco for the financial support through the Foundation for the Support of Science and Technology of the State of Pernambuco.

REFERENCES

[01] LIU, Y.; GAYLE, A. A.; WILDER-SMITH, A.; ROCKLÖV, J. (2020) The reproductive number of COVID-19 is higher compared to SARS coronavirus. **Journal of Travel Medicine,** v. 27, n. 2. DOI: https://doi.org/10.1093/jtm/taaa021

[02] FATHIZADEH, H.; Maroufi, P.; Momen-Heravi, M.; Dao, S., Ganbarov, K. Pagliano, P.; Kafil, H.S. (2020) Políticas de proteção e desinfecção contra SARS-CoV-2 (COVID-19). **Le infezioni in medicina**, v. 28, n. 2, pág. 185-191.

[03] WHO. World Health Organization. (2020a) **Water, sanitation, hygiene, and waste management for the COVID-19 virus: interim guidance**. Washington: WHO.

[04] PRATA, J.A.; Mello, A.S..D; Costa e Silva, F.V.; Faria, M.G.D.A. (2020) Mediações pedagógicas de ensino não formal da enfermagem durante a pandemia de COVID-19. **Revista Brasileira de Enfermagem**, v. 73. DOI: https://doi.org/10.1590/0034-7167-2020-0499

[05] PENTEADO, C. S. G.; CASTRO, M. A. S. (2021) Covid-19 effects on municipal solid waste management: What can effectively be done in the Brazilian scenario. **Resources, Conservation and Recycling**. v.164, p.105152. DOI: https://doi.org/10.1016/j.resconrec.2020.105152

[06] GALENO, S. B.; FERNANDES, M. L. B.; SILVA, S. B. (2018) A gestão de resíduos sólidos na justiça eleitoral de Pernambuco; Considerações para o programa de educação para a sustentabilidade. In: MELLO, D. P..; EL-DEIR, S. G; SILVA, R. C. P.; SANTOS, J. P. O; (Orgs.). **Resíduos sólidos: gestão pública e privada**. 1ª ed. Recife: EDUFRPE, p. 165-181.

[07] ABREU, R. E. O.; GOMES, E. S.; TAVARES, C. M. (2021) Risco de contágio por Covid-19 no descarte de resíduos sólidos no litoral de Pernambuco. In: EL-DEIR, S. G. (Org.) **Resíduos sólidos: COVID-19.** 1ª Edição Especial. Recife: EDUFRPE, p.63-71.

[08] ARAÚJO, E. C. S.; SILVA, V. F. (2020) A gestão de resíduos sólidos em época de pandemia do Covid-19**. Revista GeoGraphos**, v. 11, n. 129 pp., 192-215.

[09] UN-Habitat. UN - United Nations. Habitat. 2020. (2020) **Strategy Guidance: Solid Waste Management Response to COVID-19**. Accessed June 4, 2020.

[10] NZEADIBE, T. C.; EJIKE-ALIEJI, A. U. (2020) Solid waste management during Covid-19 pandemic: policy gaps and prospects for inclusive waste governance in Nigeria. **The International Journal of Justice and sustainability**. v. 25, p. 527-535. DOI: https://doi.org/10.1080/13549839.2020.1782357

[11] KAMPF, G.; BRÜGGEMANN, Y.; KABA, H. E. J.; STEINMANN, J.; PFAENDER, S.; SCHEITHAUER, S.; STEINMANN, E. (2020) Potential sources, modes of transmission and effectiveness of prevention measures against SARS-CoV-2. **The Journal of Hospital Infection**, 2020. DOI: https://doi.org/10.1016/j.jhin.2020.09.022

[12] VAN DOREMALEN, N., MORRIS, D.H., PHIL, M., HOLBROOK, M.G., GAMBLE, A., WILLIAMSON, B.N., TAMIN, A., HARCOURT, J.L., THORNBURG, N.J., GERBER, S.I., LLOYD-SMITH, J.O., de WIT, E., MUNSTER, V.J. (2020) Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. **The new England Journal of Medicine**, v. 382, p. 1564–1567. DOI: http://doi.org./10.1056/nejmc2004973

[13] CARRATURO, F.; GIUDICE, C. D.; MORELLI, M.; CERULLO, V.; LIBRALATO, G.; GALDIERO, E.; GUIDA, M. (2020) Persistence of SARS-CoV-2 in the environment and COVID-19 transmission risk from environmental matrices and surfaces. **Environment Pollution**, v. 265, October. Article 115010. Doi: 10.1016 / j.envpol.2020.115010

[14] ALVES, N. B. P.; SÁ, A. C. N.; SILVA, T. A. S. S.; EL-DEIR, S. G. (2021) Influência da pandemia por Covid-19 na geração de resíduos de serviços de saúde: uma revisão. In: EL-DEIR, S. G. (Org.) **Resíduos sólidos: COVID-19.** 1ª Edição Especial. Recife: EDUFRPE, p.240-250.

[15] WHO. World Health Organization. (2021) **WHO Coronavirus (COVID-19) Dashboard**. February 2022.

[16] KOORAKI, S. HOSSEINY, M.; MYERS, L.; GHOLAMREZANEZHAD, A. Coronavirus (COVID-19) Outbreak: What the department of Radiology Should Know**. Journal of the American College of Radiology, v**. 17, n. 4. DOI: https://doi.org/10.1016/j.jacr.2020.02.008

[17] TYRRELL, D.A; BYNOE, M.L. (1966) Cultivation of viruses from a high proportion of patients with colds. **Lancet,** v.287, n.7428, p.76–77. DOI: :https://doi.org/10.1016/S0140-6736(66)92364-6

[18] SAADAT, S.; RAWTANI, D.; HUSSAIN, C. M. (2020) Environmental perspective of COVID-19. **Science of the Total Environment**, v.728, 138870. DOI: https://doi.org/10.1016/j.scitotenv.2020.138870

[19] RAHIMI, N. R.; FOULADI-FARD, R.; AALI, R.; SHAHRYARI, A.; REZAALI, M.; GHAFOURI, Y.; GHALHARI, M. R.; ASADI-GHALHARI, M.; FARZINNIA, B.; GEA, O. C.; FIORE, M. (2021) Bidirectional association between COVID-19 and the environment: A systematic review**. Environmental Research.** v. 194, p. 110692. DOI: https://doi.org/10.1016/j.envres.2020.110692

[20] URBAN, R. C.; NAKADA, L. Y. K. (2021) Covid-19 pandemic: Solid waste and environment impacts in Brazil. **Science of the Total Environment**. v.755, 142471. DOI: https://doi.org/10.1016/j.scitotenv.2020.142471

[21] HURAIMEL, K. A.; ALHOSANI, M.; KUNNHABDULLA, S.; STIETIYA, M.H. (2020) SARS-CoV-2 in the environment: Modes of transmission, early detection and potential role of pollutions. **Science of the Total Environment**, v.744, 140946. DOI: https://doi.org/10.1016/j.scitotenv.2020.140946

[22] SILVA, T.S.; SILVA, T. V. B.; ÂNGELO, G. F.; EL-DEIR, S. G. (2021) Análise de risco; Pontencial de contágio da Covid-19 no acondicionamento de resíduos sólidos em coletores. In: EL-DEIR, S.G. (Org.) **Resíduos Sólidos:** COVID-19. 1ª Edição Especial. Recife: EDUFRPE, p.227-238.

[23] SILVA, D. D. S.; RODRIGUES, J. B.; ERICEIRA, M. P.; SILVA, A. C. (2020) Análise da disposição irregular de resíduos sólidos urbanos; estudo de caso em área de disposição inadequada no bairro COHAB em São Luís–MA. In: SANTANA, R. F.; ARAGÃO JÚNIOR, W. R.; EL-DEIR, S. G. (Org.). 1ª ed. **Resíduos sólidos**: desenvolvimento e sustentabilidade. Recife: EDUFRPE, p. 407-414.

[24] ARAÚJO, V. G. M.; ARAGÃO JÚNIOR, W. R.; BARBOSA, G. S.; EL-DEIR, S. G. (2021) Utilização de tecnologias da informação e comunicação (TIC) na educação para sustentabilidade em tempos de pandemia. In: EL-DEIR, S. G. (Org.) **Resíduos sólidos: COVID-19.** 1ª Edição Especial. Recife: EDUFRPE, p.24-37.

[25] RAGAZZI, M.; RADA, E. C.; SCHIAVON, M. (2020) Municipal solid waste management during the SARS-COV-2 outbreak and lockdown ease: Lessons from Italy. **Science of the Total Environment**, v. 745. Article 141159

[26] SHARMA, H. B.; VANAPALLI, K. R.; CHEELA, V. R. S.; RANJAN, V. P.; JAGLAN, A. K.; DUBEY, B.; GOEL, S.; BHATTACHARYA, J. (2020) Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. **Resources, Conservation and Recycling**, v. 162, 2020. Article 105052.

[27] FREITAS, B. D. L. C.; TAVARES, C. M.; OLIVEIRA, S.A.; MENDONÇA, A. T. (2021) Potencial contágio dos transuentes por Covid-19 nos shopping centers da RMR, Pernambuco. In: EL-DEIR, S. G. (Org.) **Resíduos sólidos: COVID-19.** 1ª Edição Especial. Recife: EDUFRPE, p.72- 81.

[28] NZEDIEGWU, C.; CHANG, S.X. (2020) Improper Solid Waste Management Increases Potential for COVID- 19 Spread in Developing Countries. **Resources, Conservation and Recycling**. v.16, p.104947. DOI: https://doi.org/10.1016/j.resconrec.2020.104947

[29] SILVA, T. S.; ÂNGELO, G. F.; LIMA, I. L. P. SOUZA, A. L. (2021) Análise dos protocolos de gerenciamento de resíduos sólidos recicláveis de instituições públicas na prevenção da Covid-19. In: EL-DEIR, S.G. (Org.) **Resíduos sólidos:** COVID-19**.** 1ª Edição Especial. Recife: EDUFRPE, p.163-176.

[30] GIL, A. C. (2017) **Métodos e técnicas de pesquisa social**. 6. ed. São Paulo: Atlas.

[31] MARAZZITI, D.; CIANCONI, P.; MUCCI, F.; FORESI, L.; CHIARANTINI, I.; VECCHIA, D. Climate change, environment pollution, Coovid-19 pandemic and mental health. **Science of the Total Environment.** v.773, 145182, 2021. DOI: https://doi.org/10.1016/j.scitotenv.2021.145182

[32] DEUS, R. M.; BATTISTELLE, R. A. G.; SILVA, G. H. R. (2015) Resíduos sólidos no Brasil: contexto, lacunas e tendências. **Engenhearia Sanitario e Ambiental**.v. 20, n. 4, p. 685-698.

[33] MONTEIRO, E. B. B.; SILVA, K. A. da; EL-DEIR, S. G. (2020) Desmaterialização no gerenciamento dos resíduos sólidos: um estudo bibliométrico e cientométrico. In: SILVA, T. S. da; MARQUES, M. M. N.; EL-DEIR, S. G. (Orgs.). **Desmaterialização dos resíduos sólidos:** estratégias para a sustentabilidade. 1a ed. Recife: EDUFRPE, p. 22-36.

[34] VILLANUEVA, T.; DONATO, H.; ESCADA, P.; DE SOUSA, C.; REIS, M.; MATOS, R. (2020) Thoughts about the Impact Factor. **Acta Médica Portuguesa**, v. 33, n. 10, p. 633-634. DOI: https://doi.org/10.20344/amp.14773

[35] MELCHIOR, C; ZANINI, R. R. (2019) Mortality per work accident: A literature mapping**. Safety Science,** v. 114, p. 72-78. DOI: https://doi.org/10.1016/j.ssci.2019.01.001

[36] ARAGÃO JÚNIOR, W. R.; OLIVEIRA JÚNIOR, A. I.; GUEDES, F.L.; SANTOS JÚNIOR, J. I. (2021) Pilares da Indústria 4.0 na gestão de resíduos sólidos: Análise por meio de estudo bibliométrico. In: ALMEIDA, I. M. S.; GUEDES, F. L.; MENEZES, N. S. (Org.). **Resíduos sólidos:** Gestão e tecnologia. Recife: EDUFRPE/Gampe, Cap. 1, p.31-50.

[37] ELAHEH, F.; MD NOR, M.; ABBAS, G. B.; NADER, A. E.; NASRIN, M. (2018) Five Decades of Scientific Development on "Attachment Theory": Trends and Future Landscape. **Pertanika Journal Social Sciences & Humanities**, v. 26, n. 3, p.2145–2160.

[38] FERREIRA, J. B.; SILVA, L. A. M. (2019) O uso da bibliometria e sociometria como diferencial em pesquisas de revisão. **Revista Brasileiea de Biblioteconomia e Documentação**, v. 15, n. 2.

[39] GANGULY, R. K.; CHAKRABORTY, S. K. (2021) Integrated approach in municipal solid waste management in Covid-19 pandemic: Perspectives of a developing country like India in a global scenario. **Case Studies in Chemical and Environmental Engineering**. v.3, 100087. DOI: https://doi.org/10.1016/j.cscee.2021.100087

[40] KLEMES, J.J.; FAN, Y.V.; TAN, R.R.; JIANG, P. (2020) **Minimizing the present and future plastic waste, energy and environmental footprints related to COVID-19**. **Renew. Sustain. Energy Rev**., v. 127, p. 109883. DOI: 10.1016/j.rser.2020.109883

[41] ZHAO, H.; LIU, H. Q.; WEI, G.; WANG, H.; ZHU, Y.; ZHANG, R.; YANG, Y. (2021) Comparative life cycle assement of emergency disposal scenarios for medical waste during the Covid-19 pandemic in China. Waste **Management** v.126, p.388-399. DOI: https://doi.org/10.1016/j.wasman.2021.03.034

[42] HANTOKO, D.; LI, X.; PARIATAMBY, A.; YOSHIKAWA, K.; HORTTANAINEM, M.; YAN, M. (2021) Challenges and practices on waste management and disposal during Covid-19 pandemic. **Journal of Environmental Management**. v. 286, 112140. DOI: https://doi.org/10.1016/j.jenvman.2021.112140

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Brazilian Strategies and Policies for Greenhouse Gas Mitigation: Analysis of Possible Impacts on the Implementation of BECCS, based on International Experiences

SILVEIRA, B. H. M. [a*], COSTA, H. K. M. [a], DOS SANTOS, E. M.[a]

a. Institute of Energy and Environment, University of São Paulo, São Paulo

**Corresponding author, brendasilveira@usp.br*

Abstract

The bioenergy with carbon capture and storage (BECC) technology is a fundamental tool to respond to the climate crises and achieve the targets set in the Paris Agreement in 2015. Brazil presents favorable conditions for BECCS mostly because of the country's biofuel industry, but also because of its carbon storage capacity. However, the large-scale implementation of BEECS will require the adoption of long-term and reliable policies and incentives. In this context, this article performs a literature review to understand the key aspects that are necessary to build a policy aiming at promoting BECCS, and how these aspects have been addressed in countries leading the implementation of BECCS, and in Brazil. The review showed that a government policy to promote BECCS must: explicit the relevance of negative emissions technologies (NETs) and BECCS, create incentives focused on NETs and BECCS, promote economies of scale, and create mechanisms to properly account for lifecycle emissions. In the leading countries (Denmark, Norway, Sweden, United Kingdom, and the United States) the strategies are mostly focused in explicating the relevance of BECCS, creating direct incentives using funds and market-based instruments, and targeting specific business cases to lower future costs. In Brazil, the approaches are destined to highlighting the relevance of BECCS, initiating the creation of market-based incentives, and developing mechanisms to properly account for lifecycle emissions.

Keywords: BECCS, policies, incentives, Brazil, negative emissions

1. Introduction

The use of fossil fuels for energy generation, both electricity and heat, made possible to achieve the economic growth and development witnessed since the industrial revolution, but also increased the emission of greenhouse gases to the atmosphere (Goldemberg and Lucon, 2012). As a result, the energy sector is described in the literature as a main contributor for the climate crises (Babin et al., 2021). In this context, this sector faces the challenge of finding sustainable technologies that allow for the expansion of energy production but also the mitigation of greenhouse gases (GHG), as emphasized in the 7th Sustainable Development Goal (SDG).

Bioenergy with carbon capture and storage (BECCS) is an important technology in this framework, since it provides energy from the transformation of biomass, captures the carbon dioxide emitted during this process, and stores it in deep geological formations (Babin et al., 2021; Stavrakas et al., 2018). Therefore, because bioenergy is initially neutral in carbon dioxide emissions[2], the addition of the carbon capture and storage (CCS) technology in its lifecycle makes it possible to achieve negative emissions

[2] To be effectively considered neutral, it is necessary to account for the emissions along the entire value chain (Babin et al., 2021; Daioglou et al., 2019; Stavrakas et al., 2018)

(Consoli, 2019). Due to this, BECCS is fundamental to achieve the targets set in the Paris Agreement (Rogelj et al., 2018).

However, to reach the emissions reductions intended for BECCS, this technology needs to start operating in large-scale by 2040 (Bellamy et al., 2021; Daioglou et al., 2019), which will not be possible without the adoption of strong economic incentives (Fridahl et al., 2020). These incentives are necessary mostly because of the high costs and uncertainties surrounding BECCS (Babin et al., 2021; BEIS, 2021). Nonetheless, this technology also faces barriers that are not common to other sustainable technologies, which are: the interdependence among industries (capture, transportation, and storage) (IEA, 2018; OCDE and IEA, 2016), and the lack of revenues when the CO_2 captured is not destined to an enhanced oil recovery plant (EOR) (IEA, 2018; Ricci, 2012).

Thus, the implementation of BECCS depends on the adoption of policies that are directed to valuing the environmental benefit provided (Fridahl et al., 2020). Examples of policies that value mitigation technologies are: carbon taxes, fossil-fuel taxes, cap-and-trade system, carbon markets, and subsidies (Zweifel et al., 2017). For example, carbon markets have been implemented in the United Kingdom, Japan, and Mexico (Chiu et al., 2015). However, Ricci (2012) defend that these policies are not enough to incentivize BECCS.

In parallel, also focusing on the achievement of the targets set in Paris Agreement, Brazil has adopted, since 2016, Policies and Programmes to mitigate the GHG emissions in the country (Presidência da República, 2021, 2017). Of these, it is important to highlight the Renovabio Programme, and the Future Fuel Programme (Silveira et al., 2022). Also, in December 2020 Brazil submitted to the United Nations Framework Convention of Climate Change (UNFCCC) an updated version of its National Determined Contribution (NDC), and in April 2022 submitted a second update (Brazil, 2022, 2020)

In this sense, the implementation of BECCS in Brazil could help the country achieve the mitigation targets set but are also important at an international scale (Hayman et al., 2021). Brazil presents favorable conditions for developing BECCS, such as: the country's biofuels industries, the concentration of most biofuel refineries in the southeast region, and the high potential of CO_2 storage in the Paraná, Campos, Santos, Potiguar and Reconcavo basins (Ketzer et al., 2016).

Hence, given the particularities surrounding the technology and its potential in Brazil, this article performs a literature review on what aspects should a policy focus on when aiming at promoting BECCS. In addition, this article maps the strategies implemented in Brazil and in the countries that are leading the implementation of BECCS, and evaluates how they address these aspects.

Thus, this article is divided in five sections, with this introduction being the first. The second section describes the methodology. Section 3 describes the main aspects that a policy should address to stimulate BECCS and the international experience relating to them. Section 4 describes the Brazilian policies adopted since the Paris Agreement that can have an impact on the implementation of BECCS in the country. Finally, section 5 presents the conclusions of this article.

2. Methodology

To reach the proposed objectives, the methodology consists of a literature review. The bibliography raised are the result of searches performed in the Science Direct and Google Scholar databases. The results are presented according to topics that are recurrent in the bibliography analyzed.

In addition, given the importance of building economic incentives to promote the operation of BECCS, it is logical that the countries that present BECCS plants in operation and in development stages have already provided these incentives or signalized their implementation. Table 1 demonstrates the countries that present BECCS plants and their current stage, based on the "Global Status of CCS 2021" report (Global CCS Institute, 2021). Of these plants, only 2 (both in the United States) destine the captured CO_2 to EOR, which means the rest (41) depends solely on government policies to generate income.

Therefore, to find documents more detailed about regulations and policies, a search was performed on the Global CCS Institute website – since they prepare summaries of legal updates regarding CCS –, and on these countries' governments websites. For Brazil, the legal and regulatory information was gathered from the websites of the country's Ministry of Mines and Energy, and National Agency of Oil, Gas and Bioenergy.

Table 1. Status of BECCS plants in 2021 according to the country where they are based

Country	**Advanced Development**	**Early Development**	**In Construction**	**Operational**	**Total**
Denmark	1				1
Norway	1		1		2
Sweden	1				1
United Kingdom		1			1
United States	34	2		3	39
Total	**37**	**3**	**1**	**3**	**44**

Source: authors' elaboration, based on Global CCS Institute (2021).

3. Relevant policy aspects for BECCS promotion

The literature reviewed pointed that the policies that aim at promoting BECCS must focus on overcoming three main barriers: regulatory, economic, and environmental. The regulatory barriers relate to the BECCS' dependence on governmental strategies, and the need to build long-term reliable regulations. On the other hand, the economic barriers involve the high costs faced to implement BECCS and the need to create economies of scale. At last, the environmental barrier consists of monitoring and verifying the emissions throughout this technology's lifecycle.

In this context, a first step described as fundamental in the literature is the adoption of mitigation targets that explicitly mention the relevance of NETs, because it signalizes the commitment of creating long-term regulations and incentives to promote these technologies (Fridahl and Lehtveer, 2018). More specifically, the adoption of net zero targets is fundamental for the large-scale implementation of BECCS (Schenuit et al., 2021). As an example, Sweden and Germany have endorsed net zero targets for 2045, and France, Denmark, and the United Kingdom for 2050 (Carver, 2021; Watson et al., 2021).

However, this is only the first step, and to effectively promote BECCS, the legislation must create policies explicitly focused on BECCS (Fridahl and Lehtveer, 2018). On the one hand, to plants that are still in the research and early development stages, it is important that mechanisms are created to guarantee the functionality of the project, such as funds (Bellamy et al., 2021; IEA, 2018; Watson et al., 2021). In this case, it is possible to highlight the Geological Survey of Denmark, the funding of CCS projects by the Norwegian government – such as in the case of the Norcem Heidelberg Cement AS and the Forto Oslo Varme plants –, the Industrial Leap Programme in Sweden (Möllersten et al., 2021), the United Kingdom's Strategic Priorities Fund (BEIS, 2021; Watson et al., 2021), and the American Recovery and Reinvestment Act in the United States (Bright, 2021; Rassool et al., 2020).

On the other hand, to promote the large-scale productivity, the legislation must endorse the issue of creating mechanisms to generate revenues for BECCS (Bellamy et al., 2021; Fridahl and Lehtveer, 2018). Based on this, the literature suggests the creation of market-based solutions (Ricci, 2012), such as the creation of credits for negative emissions and the trading of these credits under carbon markets; the use of negative emission credits to abate taxes; and the adoption of fixed-price mechanisms for the electricity generated from BECCS plants (Babin et al., 2021; Stavrakas et al., 2018).

Herein, market-based instruments have been implemented in the United States with the adoption of the 45Q tax credit, which provides tax credit for capture operators for each tone of CO_2 stored or utilized (Bright, 2021). In addition, an update in the California Low Carbon Fuel Standard (LCFS) in 2018 allowed CCS projects to qualify to generate credits. The current credit price is \$200/tCO_2, and the CCS plant needs to be associated with the production of transportation fuels to be able to qualify (Rassool et al., 2020). Furthermore, the United Kingdom Department of Business, Energy & Industrial Strategy is developing research to explore the potential of the UK emissions trading scheme (ETS), and the Swedish Energy Agency has been assigned to study the adoption of market-based incentives for NETs in Sweden (Möllersten et al., 2021).

Moreover, in view of the economic barriers faced, mostly represented by the high costs to develop BECCS, Abdulla et al. (2021) indicate the need to create economies of scale. The creation of scale can be achieved in the capture and in the transportation stages. In the first, the literature highlights the need of initially creating BECCS' business cases in industries and sectors that present cheaper costs to capture the CO_2 (Schenuit et al., 2021; Stavrakas et al., 2018).

On the other hand, the transportation stage represents an important bottleneck for the large-scale implementation of BECCS, because most plants do not have the capacity of capturing enough CO_2 alone that would make the use of the transportation infrastructure economically viable (Stavrakas et al., 2018).

Also, because of the geographic distribution of the plants, there is still the need of building new transportation infrastructure (Fridahl, 2018; Ketzer et al., 2016). In this context, the effort of trying to create economies of scale are probably more necessary for BECCS than for fossil-only CCS, because "dedicated bioenergy power or heat plants are generally smaller" (Stavrakas et al., 2018, p. 9).

As for the international experience, the implementation of BECCS in specific industries or sectors aiming at de-risking the technology has occurred in Sweden through the promotion of a CCS pilot at the Amager Bakke incineration plant (Möllersten et al., 2021). In the same line, Norway has addressed this issue by promoting the capture stage at the Norcem Heidelberg Cement AS and the Fortum Oslo Varme waste-to-energy, and by developing the needed infrastructure, through the Langskip CCS network (Möllersten et al., 2021). The California Low Carbon Fuel Standard (LCFS) is also worth mentioning, since only CCS plants associated with the production of transportation fuels can qualify for the Programme.

At last, the policies need to aim at overcoming the environmental barrier. This barrier relates to the need of assuring the achievement of negative emissions when implementing BECCS, given that this characteristic of the technology is the main reason why it is promoted (Babin et al., 2021; Fridahl and Lehtveer, 2018; Stavrakas et al., 2018). Thus, it is important to build a mechanism that oversees the emissions throughout the lifecycle of BECCS, which means accounting for emissions during the production of agrochemicals and pesticides, in land-use and land-use change, during the transportation of both feedstock and CO_2, and others (Watson et al., 2021). In this manner, it is worth mentioning the United Kingdom's strategy presented in the document "Net Zero Strategy: Build Back Greener", which signalizes the intention to develop a robust approach to the Monitoring, Reporting and Verification (MRV) of emissions along the BECCS value chain (BEIS, 2021).

4. Brazilian legal and regulatory approaches to promote the mitigation of GHG emissions

The first Brazilian intended Nationally Determined Contribution (iNDC) was submitted to the UNFCCC in September 2016 and communicated the country's commitment to reduce its GHG emissions by 37% below 2005 levels in 2025, and by 43% in 2030 (Brazil, 2015). To help achieve these goals, in December 2017 Brazil implemented the National Policy on Biofuels, also known as the Renovabio Programme, which aims at increasing the share of biofuels in the country's energy matrix (Presidência da República, 2017).

In this context, the Renovabio Programme introduced the Decarbonization Credit (CBio), which assigns a credit to biofuel producers based on the difference in emissions between this producer's biofuel and its fossil fuel substitute (ANP, 2020). To receive the credit, the biofuel producer needs to request it, and to effectively receive the credit, the biofuel production process is fully evaluated (MME, 2019; Presidência da República, 2017). The methodology used to calculate the biofuel's carbon intensity, named RenovaCalcMD, considers the emissions along the entire value chain, including land use change – biofuels produced in native areas (both in Brazil and abroad) are immediately excluded –, fertilizers production, electricity consumption, transportation, and others (Matsuura et al., 2018).

Meanwhile, the fossil fuel distributers need to follow mandatory individual emissions targets, that are estimated by authorities based on the national GHG emissions target (MME, 2019; Presidência da República, 2017) Therefore, in the short term, the distributers can only achieve the targets if they buy the CBio credits. These credits are traded in organized markets, and even in auctions (Silveira et al., 2022). In result, considering both the obligated (fossil fuel distributers) and non-obligated (public) parts, 15 million CBio credits were traded in the 2019-2020 period in the B3 (Brazilian stock market) platform (ANP, 2021).

Another relevant instrument of the Renovabio Programme is the 20% bonus on the CBio credit emission given to biofuel producers that prove negative emissions along its product's lifecycle (MME, 2019). Thus, there is an explicit mention of the relevance of NETs for the country, and because it is destined directly to the biofuels industry, it means an explicit mention of BECCS.

In addition, the National Energy Policy Council (CNPE) instituted, in 2021, the Future Fuel Programme, which is also a mechanism under the Renovabio Programme, and aims at establishing the regulatory conditions for implementing CCS in Brazil, among other goals for renewable and negative emission technologies (Presidência da República, 2021). To do so, the ProBioCCS Subcommittee was stablished with the goal of discussing, developing, and presenting the regulatory framework describing the conditions, the responsible agents, and future necessary steps for effective implementation of CCS in Brazil (Vinhado, 2021).

Therefore, in view of what has been presented in the literature as relevant government approaches for the development of BECCS, the Renovabio Programme can benefit this technology, because: 1) explicitly mentions NET in government policies; 2) incentivizes the biofuel industry in Brazil, which according to Ketzer et al. (2016) presents lower capture costs, and thus can provide economies of scale; 3) stablishes a methodology to account for the emissions along the entire value chain.

Beyond Renovabio, in December 2020 Brazil submitted an update to its first NDC, confirming the commitments previously made, and adding a "long-term objective of reaching climate neutrality in 2060" (Brazil, 2020, p. 1). Nevertheless, in March 2022 Brazil submitted a second update to its first NDC, in which the country confirms the commitment of reducing GHG emissions by 37% in 2025 when compared to 2005 levels but adds the commitment of reducing its emissions by 50% in 2030 (compared to 2005 levels) and achieving climate neutrality by 2050 (Brazil, 2022). In this context, this approach signalizes the relevance of NETs for Brazil, since climate neutrality can only be achieved with the adoption of negative emissions technologies to compensate for hard-to-abate sectors (Bellamy et al., 2021; Möllersten et al., 2021; Schenuit et al., 2021).

In conclusion, the Brazilian approaches are progressing to address the regulatory issue facing the CCS activity in the country by stablishing the "rules of the game", but still need to advance in creating incentives. Regarding the environmental barriers, the RenovaCalcMD method can be used to check and improve the negative emissions delivered through BECCS. However, Brazil has not yet developed mechanisms to address the economic barrier, which focuses on creating economies of scale and reducing costs. In countries like Norway and Sweden, this issue is addressed by targeting specific business cases and investing in infrastructure expansion.

4. Conclusion

In the context of facing climate change and seeking for tools to help achieving the targets set in the Paris Agreement, the bioenergy with carbon capture and storage technology plays a fundamental role. The implementation of this technology in Brazil is important not only for the country, but also internationally. Thus, this article performed a literature review to map the key points a policy should address when it comes to promoting BECCS. The review also raised the government approaches and strategies that have been adopted in Brazil and in the countries leading the implementation of BECCS.

As a result, the literature indicates that the governments must build policies aiming at overcoming regulatory, economic, and environmental barriers. The regulatory barriers are related to the need of creating incentives for BECCS. On the other hand, the economic barriers involve the high costs faced to implement BECCS and the need to create economies of scale. At last, the environmental barrier consists of monitoring and verifying the emissions throughout this technology's lifecycle.

As for the international experience, the countries that are leading the implementation of BECCS are: Denmark, Norway, Sweden, United Kingdom, and the United States. In all these countries, BECCS has been explicitly mentioned in one or more governmental documents. They mostly focus on creating incentives using funds and market-based instruments, and on targeting specific business cases to create economies of scale and to lower future costs. It is worth highlighting the Norwegian Government's funding of the Norcem Heidelberg Cement AS and the Fortum Oslo Varme waste-to-energy, and the 45Q tax credit mechanism in the United States.

In Brazil, on the other hand, the existing policies can benefit BECCS, because they explicitly mention the technology (an initial step pointed in the literature review), address the need of determining the rules to regulate the technology's operation in the country, and provide an incentive through the Decarbonization Credit (CBio). At last, the methodology used to calculate the carbon intensity in biofuels (RenovaCalcMD) addresses the environmental barrier cited in the literature.

Acknowledgements

We thank the support from the National Agency for Petroleum, Natural Gas and Bio-fuels Human Resources Program (PRH-ANP), funded by resources from the investment of oil companies qualified in the R,D&I clauses from ANP Resolution number 50/2015 (PRH 33.1 – Related to Call number 1/2018/PRH-ANP; Grant FINEP/FUSP/USP Ref. 0443/19).

We are also grateful to the "Research Center for Gas Innovation - RCGI" (Fapesp Proc. 2020/15230-5), supported by FAPESP and Shell, organized by the University of São Paulo, and the strategic importance of the support granted by the ANP (National Agency of Petroleum, Natural Gas and Biofuels of Brazil) through the R&D clause.

Funding

This research was funded by ANP/FINEP/FUSP/USP, grant number 0443/19, and by RCGI/FAPESP, grant number 2020/15230-5.

References

Abdulla, A., Hanna, R., Schell, K.R., Babacan, O., Victor, D.G., 2021. Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments. Environ. Res. Lett. 16, 1–10. https://doi.org/10.1088/1748-9326/abd19e

ANP, 2021. RenovaBio: ANP publica atualização das metas individuais das distribuidoras para 2021 [WWW Document]. Ministério Minas e Energ. URL https://www.gov.br/anp/pt-br/canais_atendimento/imprensa/noticias-comunicados/renovabio-anp-publica-atualizacao-das-metas-individuais-das-distribuidoras-para-2021 (accessed 3.6.22).

ANP, 2020. Certificados da Produção ou Importação Eficiente de Biocombustíveis [WWW Document]. Ministério Minas e Energ. URL https://www.gov.br/anp/pt-br/assuntos/renovabio/certificados-producao-importacao-eficiente-biocombustiveis (accessed 7.19.21).

Babin, A., Vaneeckhaute, C., Iliuta, M.C., 2021. Potential and challenges of bioenergy with carbon capture and storage as a carbon-negative energy source: A review. Biomass and Bioenergy 146. https://doi.org/10.1016/j.biombioe.2021.105968

BEIS, 2021. Net Zero Strategy: Build Back Greener. HM Government.

Bellamy, R., Fridahl, M., Lezaun, J., Palmer, J., Rodriguez, E., Lefvert, A., Hansson, A., Grönkvist, S., Haikola, S., 2021. Incentivising bioenergy with carbon capture and storage (BECCS) responsibly: Comparing stakeholder policy preferences in the United Kingdom and Sweden. Environ. Sci. Policy 116, 47–55. https://doi.org/10.1016/j.envsci.2020.09.022

Brazil, 2022. Brazil Frist NDC - Second update [WWW Document]. UNFCCC. URL https://www4.unfccc.int/sites/NDCStaging/Pages/Party.aspx?party=BRA (accessed 5.27.22).

Brazil, 2020. Paris Agreement Brazil's Nationally Determined Contribution (NDC) (Updated submission) [WWW Document]. UNFCCC Secr. URL https://www4.unfccc.int/sites/NDCStaging/Pages/Party.aspx?party=BRA (accessed 3.2.22).

Brazil, 2015. Intended Nationally Determined Contribution: Towards achieving the objective of the United Nations Framework Convention on Climate Change [WWW Document]. UNFCCC Secr. URL http://www4.unfccc.int/Submissions/INDC/Published Documents/Brazil/1/BRAZIL iNDC english FINAL.pdf

Bright, M., 2021. Surveying the U.S. Federal CCS Policy Landscape in 2021. Global CCS Institute.

Carver, D., 2021. Global net zero commitments [WWW Document]. UK Parliam. URL https://commonslibrary.parliament.uk/global-net-zero-commitments/ (accessed 5.24.22).

Chiu, F.P., Kuo, H.I., Chen, C.C., Hsu, C.S., 2015. The energy price equivalence of carbon taxes and emissions trading-Theory and evidence. Appl. Energy 160, 164–171. https://doi.org/10.1016/j.apenergy.2015.09.022

Consoli, C., 2019. Bioenergy and Carbon Capture and Storage. Glob. CCS Inst. 1–14.

Daioglou, V., Doelman, J.C., Wicke, B., Faaij, A., van Vuuren, D.P., 2019. Integrated assessment of biomass supply and demand in climate change mitigation scenarios. Glob. Environ. Chang. 54, 88–101. https://doi.org/10.1016/j.gloenvcha.2018.11.012

Fridahl, M., 2018. Bioenergy with carbon capture and storage: From global potentials to domestic realities, European Liberal Forum. European Liberal Forum, Brussels.

Fridahl, M., Bellamy, R., Hansson, A., Haikola, S., 2020. Mapping Multi-Level Policy Incentives for Bioenergy With Carbon Capture and Storage in Sweden. Front. Clim. 2. https://doi.org/10.3389/fclim.2020.604787

Fridahl, M., Lehtveer, M., 2018. Bioenergy with carbon capture and storage (BECCS): Global potential, investment preferences, and deployment barriers. Energy Res. Soc. Sci. 42, 155–165. https://doi.org/10.1016/j.erss.2018.03.019

Global CCS Institute, 2021. The Global Status of CCS 2021: CCS accelerating to net zero. Australia.
Goldemberg, J., Lucon, O., 2012. Energia, Meio Ambiente e Desenvolvimento, 3ª edição. ed. EdUsp, São Paulo.
Hayman, G.D., Comyn-Platt, E., Huntingford, C., Harper, A.B., Powell, T., Cox, P.M., Collins, W., Webber, C., Lowe, J., Sitch, S., House, J.I., Doelman, J.C., Van Vuuren, D.P., Chadburn, S.E., Burke, E., Gedney, N., 2021. Regional variation in the effectiveness of methane-based and land-based climate mitigation options. Earth Syst. Dyn. 12, 513–544. https://doi.org/10.5194/esd-12-513-2021
IEA, 2018. Five keys to unlock CCS investment. Paris.
Ketzer, J.M.M., Machado, C.X., Rockett, G.C., Iglesias, R.S., 2016. Atlas brasileiro de captura e armazenamento geológico de CO2. Pontífica Universidade Católica do Rio Grande do Sul.
Matsuura, M.I.S.F., Scachetti, M.T., Chagas, M.F., Seabra, J.E.A., Bonomi, A.M., Bayma, G., Picoli, J.F., Morandi, M.A.B., Ramos, N.P., Cavalett, O., Novaes, R.M.L., 2018. RenovaCalcMD: Método e ferramenta para a contabilidade da Intensidade de Carbono de Biocombustíveis no Programa RenovaBio.
MME, 2019. PORTARIA Nº 419, DE 20 DE NOVEMBRO DE 2019 [WWW Document]. Diário Of. da União. URL https://www.in.gov.br/en/web/dou/-/portaria-n-419-de-20-de-novembro-de-2019-228863910 (accessed 7.19.21).
Möllersten, K., Zetterberg, L., Nielsen, T., Torvanger, A., Siikavirta, H., Kujanpää, L., Hannula, I., 2021. Policies for the promotion of BECCS in the Nordic countries. Nordic Council of Ministers.
OCDE, IEA, 2016. Carbon Capture and Storage: Legal and Regulatory Review, 5th ed, International Energy Agency. IEA, Paris.
Presidência da República, 2021. Despacho Presidêncial: Resolução N° 7, de 20 de abril de 2021, Diário Oficial da União. Brasília.
Presidência da República, 2017. Lei Nº 13.576, de 26 de Dezembro de 2017, Secretaria Geral. Brasília, DF.
Rassool, D., Consoli, C., Townsend, A., Liu, H., 2020. Overview of organisations and policies supporting the deployment of large-scale CCS facilities. Global CCS Institute.
Ricci, O., 2012. Providing adequate economic incentives for bioenergies with CO 2 capture and geological storage. Energy Policy 44, 362–373. https://doi.org/10.1016/j.enpol.2012.01.066
Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R., Vilariño, M.V., 2018. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development., in: Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the the Context of Strenthening the Global Response to the Threat of Climate Chan. IPCC, p. 82pp.
Schenuit, F., Colvin, R., Fridahl, M., McMullin, B., Reisinger, A., Sanchez, D.L., Smith, S.M., Torvanger, A., Wreford, A., Geden, O., 2021. Carbon Dioxide Removal Policy in the Making: Assessing Developments in 9 OECD Cases. Policy Pract. Rev. 3, 1–22. https://doi.org/10.3389/fclim.2021.638805
Silveira, B.H.M., Costa, H.K. de M., Santos, E.M. dos, 2022. Análise do CBio como passo inicial ao desenvolvimento de BECCS no Brasil, in: ANAIS DO 3º SIMPÓSIO INTERDISCIPLINAR DE CIÊNCIA AMBIENTAL. IEE-USP, São Paulo, pp. 291–304.
Stavrakas, V., Spyridaki, N.A., Flamos, A., 2018. Striving towards the deployment of bio-energy with carbon capture and storage (BECCS): A review of research priorities and assessment needs. Sustainability 10, 2206. https://doi.org/10.3390/su10072206
Vinhado, F. da S., 2021. Subcomitê ProBioCCS [WWW Document]. Ministério Minas e Energ. URL https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro/subcomites-1/probioccs-1/atas-da-reunioes (accessed 3.2.22).
Watson, J., Broad, O., Butnar, I., 2021. A Policy Framework for Bioenergy with Carbon Capture and Storage (BECCS), in: Together for Climate Action - Campaign for Net Zero. p. 7.
Zweifel, P., Praktiknjo, A., Erdmann, G., 2017. Energy Economics: Theory and Applications, Springer Texts in Business and economics. Springer. https://doi.org/10.4324/9781315114064

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Bringing Cultural Shift through Green Campus Initiative: *Strategic Eco-Technological Interventions in Academic Institutions in the State of Maharashtra, India*

BUTT, A. M.[a], PRABHU, S. D.[a], PABREKAR, P. N.[b], JOSHI, V.[b], UPPAL, A.[b], VINAYAK, N.[b], and ASOLEKAR, S. R.[a] *

a. *Indian Institute of Technology Bombay, Environmental Science and Engineering Department, Mumbai 400076, India*

b. *Rashtriya Uchchatar Shiksha Abhiyan, Government of Maharashtra, Mumbai 400005, India*

** Corresponding Author: asolekar@iitb.ac.in*

Abstract

A number of institutions and academic campuses in India have been progressively focusing on making a strategic shift to becoming a Green Campus. However, the concept of Green Campus is a loosely defined construct whose scope is not well-defined. Therefore, the Government of Maharashtra is spearheading the "Green Campus Initiative" for the educational institutions in the State of Maharashtra, India, *via* Rashtriya Uchchatar Shiksha Abhiyan in collaboration with IIT Bombay. As a part of this mission, this study identifies the potential strategies and eco-technological interventions to be implemented by academic institutions for transitioning to greener campuses. Accordingly, the 'Green Campus Guidelines' are developed in this study, for the benefit of the academic institutions. The Guidelines are subdivided into the following focus areas: (1) Water and Wastewater, (2) Solid Waste, (3) E-Waste and Laboratory Waste, (4) Air Pollution and Air Quality, (5) Episodic Pollution, (6) Ecology and Green Cover, and (7) Awareness and Capacity Building for Sustainable Living. In order to implement these Guidelines, a biphasic work-flow plan is developed wherein short-term interventions are carried to be out in Phase 1 and long-term interventions are to be carried out in Phase 2. In addition, this study quantifies the potential benefits that could be obtained by implementing these Guidelines by all colleges and universities in the State of Maharashtra, India – which has about 4.27 million students enrolled in various undergraduate and post-graduate programs in 6,960 colleges and universities with the help of 0.16 million full-time faculty members. It is estimated in this study that the environmental footprints of these institutions comprise of 135-220 MLD of water consumption and 2,730 MTPD of solid waste generation. This study highlights that potentially 33-50% reduction of freshwater consumption is possible in every institution through decentralized treatment and reuse of treated domestic wastewaters. The Dry Recyclable Waste fraction (50.16% of solid waste) can be gainfully recycled. The Wet Biodegradable Waste (5.83%) can be used for production of biogas. Further, the Waste Biomass (42.6%) can be converted to briquettes (refuse derived fuel) and compost. As a result, only 1.4% of solid waste (Dry Non-recyclable Waste) will have to be disposed of to the authorised engineered landfill facility after implementation of the 'Green Campus Initiative'. Implementation of the technological and managerial interventions proposed in this study would potentially catalyse the "cultural shift" through imbibing green thinking among the students, teachers and support staff in a given academic institution.

Keywords: Green Campus; Eco-Campus; Sustainable Development Goals; Reuse; Circular economy

1 Introduction

Governments as well as Corporates have started adopting policies to promote development without damaging the environment seriously or irreversibly. In India, the *National Education Policy* (2020), devised by the Ministry of Education (MoE), Government of India, New Delhi, focuses the holistic and multidisciplinary approach to develop all capacities of students in an integrated manner. This includes embedding environmental education at all stages of undergraduate education, which would sensitize students in the areas including climate change, pollution, energy and water conservation, waste management, sanitation, conservation of biodiversity, forests and wildlife, and, sustainable development and living (NEP, 2020). The overall objective of the approach adopted in the policy is directed at preparing the students for becoming the agents for a sustainable future. This paper explores the opportunities for development of environmentally responsible educational institutes.

A Green Campus is an educational campus where environmentally friendly practices are adopted to promote sustainable well-being. Greening the campus is all about adapting strategies to: minimize the environmental footprint caused by the activities inside the institution as well as utilizing the available resources efficiently. It also requires the campus to adapt enough green cover, tree plantation as well as biodiversity management practices (Gandasari et al., 2020).

1.1 ***Improved Sustainability through Green Campus Initiatives***

Institutions across the world have been working towards 'Greening' their campus and adapting a sustainable livelihood. Some of the initiatives may include adaptation through policies, modification of the curriculum, increased green cover, adaptation of the concept of Green Buildings, wastewater treatment, *etc.* Many institutes in India are already on the path towards Green Campus, for example:
Wageningen University & Research (WUR), The Netherlands, ranked as the Most Sustainable Campus in the World for the fifth consecutive time during 2016 to 2021 (UI Green Metric, 2021). WUR has set up a Green Office which stimulates sustainable practices in the institution. WUR along with initiatives towards water and waste management has taken initiatives to develop knowledge and competencies of their students to become sustainable professionals (WUR, 2021). University of Oxford, United Kingdom, has devised an Environmental Strategy which are focused on ten priorities *i.e.* Research, Curriculum, Carbon emissions from University buildings, Biodiversity, Sustainable food, Sustainable resource use, International travel, Local travel, Investments, and, Learning from the pandemic. The university has also set targets to achieve net zero and to achieve biodiversity net gain by 2030 as part of this strategy (University of Oxford, 2021).
Universal Business School, Mumbai, considered as the first Green Business School has recycled 100% of their domestic wastewater through sewage treatment plants inside their campus. It also has introduced a 'Green Curriculum' to integrate environmentally informed decision-making approaches in subjects such as finance, marketing and production (India Education Diary, 2020). IIT Roorkee has Established an Institute-level 'Green Office' as well as a 'Green Committee' responsible to guide, oversee, and review the implementation of 'Green Initiatives' across the campus. The institute has also developed an institute level Green Policy and Energy Conservation Policy (IIT Roorkee, 2021). Mangalore University, ranked as the Most Sustainable Campus in India (UI Green Metric, 2021) has implemented institute level initiatives to reduce emissions and waste while also increasing their ecology through landscaping. It has also conducted a Biodiversity assessment and developed a biodiversity conservation plan based on the assessment (Subrahmanya et al., 2021). We focus upon educational institutes to act as the foundation for a student to learn and develop knowledge and awareness about a sustainable livelihood.

1.2 ***The Motivation and Specific Objectives***

Green Campus is a loosely defined construct, which is being implemented enthusiastically all over the world by academic campuses and gated institutions including hospitals, office complexes, residential colonies, research establishments, software and IT parks. Clearly, all such interventions seemed to have used a variety of frameworks and focused on different aspects while greening their campuses. There are different challenges and focus areas for any academic institution to transition from "Business as Usual" to a "Green Campus".

Therefore, Rashtriya Uchchatar Shiksha Abhiyan (RUSA), Government of Maharashtra, Mumbai, have envisioned to develop the "Green Campus Guidelines" that are more relevant for the educational institutions in the State of Maharashtra, India. Accordingly, these Guidelines are developed for the benefit of the academic institutions to invest in not only undertaking environmentally friendly initiatives towards improving resource efficiency but also incorporate the "green mindset" in the students while complimenting the pedagogy at the institution. It is hypothesized that the transition to a Green Campus would be efficient and seamless if a biphasic approach is adopted in which simple and non-capital-intensive approaches are tried first and more complex initiatives are reserved for the later stage. Accordingly, the two specific objectives of this study are:

1) Suggestions for essential and indicative initiatives to be adopted and a method of prioritizing initiatives and

2) Developing an action plan for phase-wise implementation of the interventions so as to ensure smooth transition to Greener Campus.

2 The study area

The State of Maharashtra in India (refer to **Figure 1**) had a population of 112,374,333 as on 2011 (Ministry of Home Affairs 2011). Maharashtra has about 65 Universities, 4,494 Colleges affiliated to these Universities, and 2,393 Stand Alone Institutions with 163,132 full time teachers and a total of 4,265,472 students enrolled at different levels. 3,599,671 are full time students out of which 391,944 students are residing in hostel facilities of the institutes (Ministry of Education, 2020).

Fig. 1. The study area *i.e.* the state of Maharashtra, located in the western part of India

3 Guidelines for Development of Green Campus

The Green Campus Guidelines are developed to act as a guiding principle to enable any campus to understand their impact on the environment as well as provide a list of interventions to be undertaken towards achieving the status of a Green Campus. The Guidelines are developed to strengthen the institution's administrational activities in minimising the environmental impact caused by the day-to-day activities in a campus, this includes water consumption, wastewater discharge, waste disposal, air pollution, noise pollution, *etc*. The different focus areas, hence, considered in the Guidelines are: Water and Wastewater, Solid Waste, E-Waste and Laboratory Waste, Air Pollution and Air Quality, Episodic Pollution, Ecology and Green Cover, and Awareness and Capacity Building for Sustainable Living.

The interventions for each focus area and the typical interventions that can be a part of the focus areas can be seen in **Table 1**. Each focus area is further divided into multiple work components which act as separate workflows for the dedicated focus area. For example, Air Pollution and Air Quality is further divided as Air Pollution and Air Quality Audit, Transportation, Construction, and Noise Pollution. For each of these work components, a set of interventions is required to be undertaken in two Phases (Phase 1: Short Term and Phase 2: Long Term) depending on the time required for implementation and ease of implementation.

Table 1. The focus areas and phase-wise interventions of the Green Campus Guidelines

Sr. No.	Work Components	Intended Outcomes	Typical Interventions in Phase 1	Typical Interventions in Phase 2
1	**Water & Wastewater**			
	✓ Water Audit ✓ Municipal Drinking Water Supply	❖ Savings in water consumption and thereby, decrease in	o Understanding the water footprint of the campus	o Development of long-term goals

Sr. No.	Work Components	Intended Outcomes	Typical Interventions in Phase 1	Typical Interventions in Phase 2
	✓ Borewell, Dugwell & Tanker Water ✓ Rainwater Harvesting ✓ Domestic Wastewater (Sewage) ✓ Overhead Tank Cleanliness & Maintenance ✓ Sanitation & Hygiene	wastewater generation ❖ Decrease in wastewater discharge through reuse ❖ Improved quality of water ❖ Improved sanitation and hygiene	○ Periodic inspection of plumbing units ○ Installation of treatment facilities for wastewater reuse ○ Setting up a cleaning routine	○ Increase awareness towards minimal water usage ○ Tertiary treatment of wastewater ○ Modernisation of plumbing
2	**Solid Waste**			
	✓ Waste Audit ✓ Wet Biodegradable Solid Waste ✓ Dry Recyclable Paper Waste ✓ Dry Recyclable Plastic Waste ✓ Dry Recyclable Glass Waste ✓ Waste Garden Biomass	❖ Minimization of food waste ❖ Decreasing the disposed waste to landfills	○ Improving preparation and storage practices for food ○ Segregation of recyclable waste ○ Bans of non-recyclable	○ On-campus composting of biodegradable waste ○ Dedicated Student committee towards recyclable waste
3	**E-Waste & Laboratory Waste**			
	✓ E-Waste and Hazardous Waste Audit ✓ Electronic Waste (E-Waste) ✓ Discarded Chemicals ✓ Discarded Glassware	❖ Proper disposal of e-waste and hazardous waste to avoid any mixing ❖ Reduced hazardous waste	○ Audits to map the sources of waste ○ Proper segregation of e-waste and hazardous waste ○ Reduced usage of hazardous chemicals	○ Reduction of e-waste through technological upgradation ○ Integration of a chemical management system
4	**Air Pollution & Air Quality**			
	✓ Air Pollution & Air Quality Audit ✓ Transportation ✓ Construction ✓ Noise Pollution	❖ Reduced emissions and energy usage ❖ Proper approach towards emission causing activities ❖ Reduced noise pollution	○ Assessment of air pollution and its sources ○ Usage of energy efficient methods of transportation ○ Restricting any noise causing activities to certain time periods	○ Devising policies and intra-campus guidelines for energy management ○ Converting intra-campus vehicles to energy efficient vehicles
5	**Episodic Pollution**			
	✓ College Elections ✓ Religious Festivals ✓ Cultural Events & Gatherings ✓ Holi	❖ Reduced waste and water consumption during festivals ❖ Incorporation of environmentally friendly practices in events	○ Restrictive usage on water intensive activities and any pollution causing activities ○ Promoting eco-friendly decorations	○ Promotion of eco-friendly methods for idol, Nirmalaya immersion, etc ○ Organising events towards environmental benefits
6	**Ecology and Green Cover**			
	✓ Census & Ecosystem Assessments ✓ Conservation of Flora and Fauna ✓ Tree Plantation Drive ✓ Conservation of Water Bodies & Ecosystem on Banks	❖ Preservation of flora and fauna in and around the campus	○ Identification and documentation of ecology ○ Development of habitat preservation plans ○ Restrict any waste-water discharge to natural waterbodies	○ Conducting periodic EIA and biodiversity studies ○ Promoting awareness towards ecology and green cover ○ Beautification of campus
7	**Awareness & Capacity Building for Sustainable Living**			

Sr. No.	Work Components	Intended Outcomes	Typical Interventions in Phase 1	Typical Interventions in Phase 2
	✓ Sustainable Initiatives ✓ Student Behaviour for Sustainable Livelihood	❖ Creating awareness and responsibility in students towards sustainable living	o Conducting awareness workshops on environmental management o Initiatives to promote sustainable livelihood	o Development of sustainability/ green campus committees o Including Green campus initiatives into the curriculum

3.1 ***Short-Term Generic Interventions***

In Phase 1, the academic institutions are expected to undertake certain generic interventions which can be completed in a short period (9 to 18 months). Those interventions are categorically listed in Table 1. All the seven broad focus areas are expected to be addressed during Phase 1, namely: Water and Wastewater, Solid Waste, E-Waste and Laboratory Waste, Air Pollution and Air Quality, Episodic Pollution, Ecology and Green Cover, and Awareness and Capacity Building for Sustainable Living. The specific potential interventions corresponding to each focus area are also listed in Table 1. As shown in **Figure 2(a)**, the Dean of the Institute will appoint a Green Campus Task Force team which is responsible for the implementation of the Green Campus Guidelines. An audit is conducted to identify the potential opportunities with the suggested short-term objectives in each focus area. Each focus areas have work components having a set of suggested interventions which are to be completed until the outcomes are satisfactory before moving to Phase 2 of the Guidelines.

3.2 ***Long-Term Interventions***

In Phase 2, the academic institutions are expected to undertake certain long-term interventions which can be aimed to be completed in a long period of time. Those interventions are categorically listed in Table 1. All the seven broad focus areas are expected to be addressed during Phase 1, namely: Water and Wastewater, Solid Waste, E-Waste and Laboratory Waste, Air Pollution and Air Quality, Episodic Pollution, Ecology and Green Cover, and Awareness and Capacity Building for Sustainable Living. The specific potential interventions corresponding to each focus area are also listed in Table 1. As shown in **Figure 2(b)**, the Task Force team shall conduct a secondary audit to identify the potential opportunities with the suggested long-term objectives in each focus area. Each focus areas have work components having a set of suggested interventions which are to be completed until the outcomes are satisfactory before they are documented and reported.

4 Results and Discussion

In the State of Maharashtra (population approx. 130 million, land area approx. 307,000 km^2), there are approx. 7,000 institutions engaged in colleges and universities having different sizes as well as student and teacher populations (Ministry of Education, 2020). It is envisaged that the Guidelines developed in this study, can not only help in monitoring and regulating the resource consumption patterns of an educational institute in its campus but also reduce its environmental footprint. With this in mind, an effort is made to quantify the resource consumption and environmental footprint of all colleges and universities in the State of Maharashtra, India in order to estimate the potential long-term benefits through implementation of the interventions in these Guidelines.

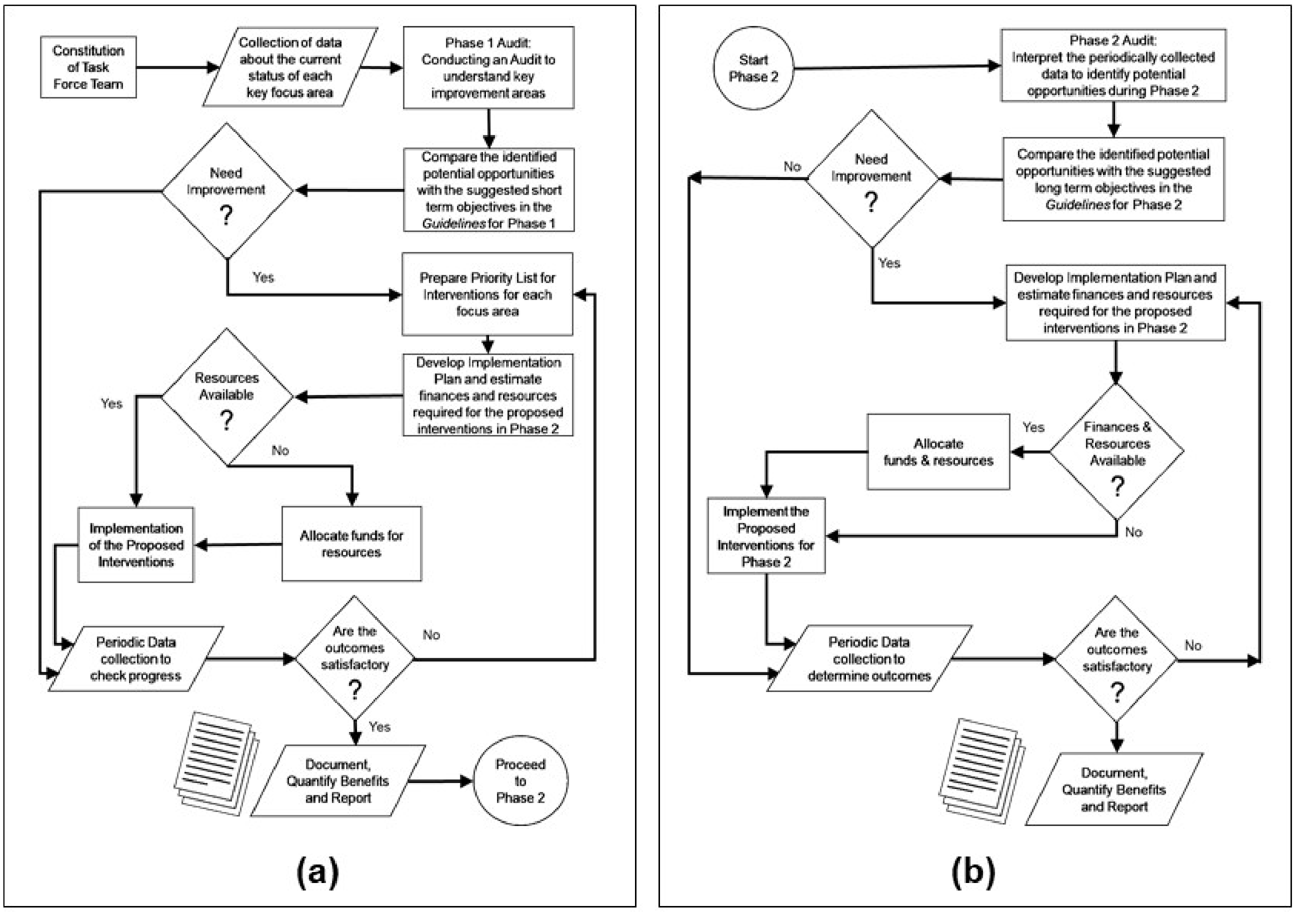


Fig. 2. Work-Flow Diagram for Implementing (a) Phase 1 of the Guidelines and (b) Phase 2 of the Guidelines

Focus Area 1 addresses water and wastewater-related interventions. The cumulative water consumption by the colleges and universities in the State of Maharashtra is estimated through the number of students, teachers and staff at the campuses across the institutes, as seen in **Table 2**. The per capita water requirement for a resident individual can be considered as 135 litres per day while for a commuting individual can be considered as 45 litres per day (Bureau of Indian Standards, 2007). In reality, there are several external restrictions depending on the region which could affect the water supply such as water scarcity and droughts, unavailability of a clean water source, and, imbalance in population and water availability.

Assuming that all freshwaters supplied to academic campuses end-up as domestic wastewaters, 135-220 MLD wastewaters, currently generated by academic institutions in the State of Maharashtra, are typically discharged to the respective municipal wastewater treatment plants. It is proposed in this study that the academic institutions can in fact contribute to improving water conservation and reuse by the decentralised wastewater treatment plants on academic campuses. Such interventions will also help bringing a "cultural shift" and promote sustainable living on academic campuses and impart lifelong learning on sustainability (SDG 6: Clean Water & Sanitation, SDG 12: Responsible Consumption and Production, SDG 17: Partnership for the Goals). The educational campuses in Maharashtra can reduce their net freshwater consumption through treatment and reuse of domestic wastewater. The conventional treatment technologies typically suffer from certain limitations including high capital and operating costs, skilled workforce, technical expertise and foul odour. However, there is a class of treatment technologies commonly referred to as Nature-based Solutions (NbS) or Natural Treatment Solutions (NTS) which do not have these limitations (IUCN, 2016). One such NbS is a technology known as Constructed Wetlands. A form of this treatment technology known as '*CW4Reuse'* has been widely researched by the 'Preventive Environmental Management' research group lead by the senior author of this paper.

Table 2: Categorical estimates of daily freshwater consumed by institutes of higher education in the state of Maharashtra, India

Sr. No.	Sources of Freshwater Consumption		Estimated Water Consumption
1	Students residing in Hostels on campus		39-53 MLD
2	Students commuting to campus (day scholars)		80-144 MLD
3	Teachers & staff residing on campus		10-13 MLD
4	Teachers & staff commuting to campus		6-10 MLD
		Total =	135-220 MLD
	Estimated freshwater consumption per institution		19.4-31.7 KLD
	Estimated freshwater consumption per 1000 individuals		34.4-56.3 KLD

* 1KLD = 1,000 litres; 1 MLD = 1,000 KLD
Note: Base population in academic institutions in the State of Maharashtra = 3,917,778 (full time students + teachers + support staff + families residing on campuses)

For example, incorporation of an HSSF-CW based decentralised domestic wastewater system has been demonstrated in the town of Mhaswad, State of Maharashtra, India (250 m^3/d) and the works carried out for the restoration of the Mansagar Lake in the Town of Jaipur, State of Rajasthan, India (Lekshmi et al., 2020a; Lekshmi et al., 2020b; NITI Aayog, 2015). Further, the application of *CW4Reuse* technology has been demonstrated for academic campuses at Charotar University of Science and Technology in Ahmedabad, Gujarat, India as well as at a gated residential religious institution in the town of Katel, Maharashtra, India (Sutar et al., 2021). It can be seen from the studies that the treated water can be reused for several purposes such as irrigation and gardening, landscaping and horticulture, contribution to campus pond as well as, toilet-flushing after disinfection – which are the potential circular economy benefits. Therefore, domestic wastewater can be treated and safely reused using CWs to achieve a net reduction by 33% to 50% in freshwater consumption (depending on the extent of treatment).

Similarly, Focus Area 2 addresses solid waste-related interventions that an institute can undertake in the short-term as well as long-term. The basis used for estimation of solid waste generation was a study conducted at IIT Bombay under the guidance of the senior author of this study, which quantifies the various categories of solid waste generated in the IIT Bombay campus having a residential population (students, teachers and staff) of approx. 20,000 individuals (Singh, 2020; Sarwani, 2020). Based on this study, estimates were prepared for the cumulative solid waste generation for all universities and colleges in the State of Maharashtra, India as seen in **Table 3**. It can be seen from the Table 3, that the cumulative solid waste generation is estimated at 2,730 MTPD.

It can be seen from **Figure 3** that of the total solid waste generated, 50.16% is Dry Recyclable Waste, 42.6% is Green Biomass Waste, 5.83% of Wet Biodegradable Waste and a minor fraction of 1.4% is Dry Non-recyclable Waste – which will have to be disposed of to the authorised engineered landfill facility by the respective institutions. The Dry Recyclable Waste could be segregated at source and sent for gainful recycling through authorised recycling agencies. The dry portion of Biomass Waste can be converted to briquettes (refuse derived fuel) and the green fraction of Waste Biomass can be converted into compost and used in the gardens of the respective academic campuses (decentralised treatment). The Wet Biodegradable Waste can be used into production of biogas through a bio-methanation plant.

Table 3: Categorical estimates of Solid Waste generated at campuses of colleges and universities in the State of Maharashtra, India in metric tonnes* per day (MTPD). Typical composition of municipal solid waste and the corresponding per capita daily waste generation rates for various categories used in these estimates are sourced from Singh (2020) and Sarwani (2020).

Sr. No.	Waste Category	Estimated Daily Waste (MTPD)
1a	Wet Biodegradable Waste (Hostels + Residential)	125
1b	Wet Biodegradable Waste (Academic)	34

2a	Dry Waste (Hostels + Residential) 96.1% is recyclable and 3.9% is non-recyclable	17
2b	Dry Waste (Academic) 97.3% is recyclable and 2.7% is non-recyclable	1,390
3a	Garden Biomass Waste (Green + Dry) (Universities + Stand Alone Institutions)	983
3b	Garden Biomass Waste (Green + Dry) (Colleges)	180
	Total Daily Waste for all educational institutes of higher education across the State of Maharashtra, India	2,730

* 1 metric tonne (MT) = 1,000 kg; MTPD = metric tonne per day

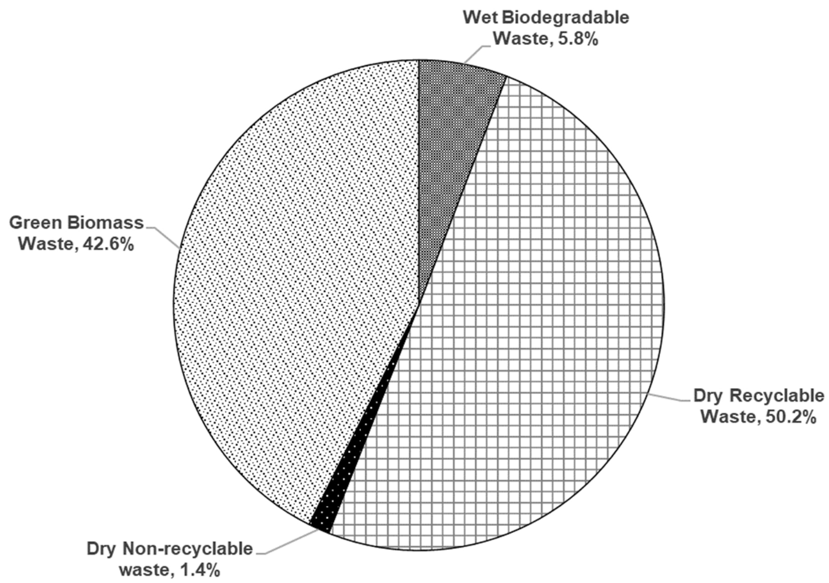


Fig.3: Typical composition of four fractions of Solid Waste including Wet Biodegradable Waste, Green Biomass Waste, Dry Recyclable Waste, and Dry Non-recyclable Waste from academic campuses in the state of Maharashtra, India

In contrast to Focus Areas 1 and 2, the scopes of Focus Areas 3 to 6 are very broad and vary for every institute depending upon the field and level of education, currently available facilities and size of the institution. The quantification of the potential benefits of these Focus Areas is contingent upon several detailed institute-specific data which are currently unavailable. The Guidelines developed in this study address this gap by providing a monitoring mechanism and framework for every institute to become a green campus. It is recommended in this study that each institution should monitor and quantify their efforts to report through a 'sustainability report' which would help in creating a transparency and raising awareness of the institute's efforts towards the environment. The Focus Area 7, which addresses Awareness & Capacity Building for Sustainable Living, suggests that regular workshops, awareness activities as well as a green curriculum will act as a pedagogic approach to influence the students towards a green culture. Along with the interventions in Focus Areas 1 to 6, the educational institute will be able to bring a cultural shift at the institute level.

5 Conclusions

This study focuses on the potential strategies and eco-technological interventions which can be undertaken by educational institutions in order to transition from "Business as Usual" to a "Green Campus". Accordingly, this study presents the Guidelines for development of a Green Campus and the potential benefits which would be obtained related to resource efficiency, environment, ecology, and sustainable thinking. Further, the analyses in this study quantify the resource consumption and environmental footprint of all colleges and universities in the State of Maharashtra, India in order to estimate the potential long-term benefits through implementation of the interventions in these Guidelines. Following are the salient conclusions:

- Educational Institutions have a definitive role to play in impacting the environment and ecosystem on academic campuses through minimising environmental footprint and consumption of resources. The "Green Campus Initiative" has a great potential in recruiting the students and teachers in greening the academic campuses.
- The other important outcome anticipated by the implementation of the technological and managerial interventions proposed in this study could be related to spearheading the "cultural shift" through imbibing green thinking among the students, teachers and support staff in a given academic institution. Also, through the proposed initiatives, the academic campuses can potentially become the pilot demonstration sites for "testing the greening interventions" in the community and simultaneously create the opportunities for the campus dwellers to learn through practice.
- A large portion of the water consumption by all colleges and universities in the State of Maharashtra, India (135-220 MLD) can be reduced by 33% to 50% through reuse of treatment and disinfected domestic wastewaters using the decentralised nature-based Natural Treatment Technologies (NTSs). For example, the *Horizontal Sub-surface Flow Engineered Constructed Wetland* technology developed at IIT Bombay, known as *CW4Reuse*, has been successfully demonstrated for such applications on academic campuses.
- The total solid waste generation by all colleges and universities in the State of Maharashtra, India is estimated to be ~2,730 MTPD. A significant portion of this is the Dry Recyclable Waste fraction (50.2% *i.e*. 1,370 MTPD) consisting of paper, glass, polymers, and metals can be gainfully recyled with the help of authorized agencies. The other significant portion is the dry and green Waste Biomass (42.6% *i.e.* 1,163 MTPD) – which can be gainfully reused by converting the dry fraction into briquettes (refuse derived fuel) and the green fraction can be converted compost and used within the academic premises.
- Among the minor fractions of the solid wastes, the Wet Biodegradable Waste (5.83% i.e. cumulatively 159 MTPD in the State of Maharashtra, India) can be potentially subjected to biogas plant or bio-methanation plant and the biogas as well as digested slurry can be used as fuel and fertilizer. Also, the 1.4% fraction (cumulatively ~38 MTPD in the State of Maharashtra, India) could be the Dry Non-recyclable Waste – which should be disposed of to the authorised engineered landfill facilities in the vicinity of respective academic institutions.
- It is strongly recommended in this study that each academic institution in the State of Maharashtra, India should launch the 'Green Campus Initiative' and monitor, quantify, and monetize the potential benefits. Such a 'sustainability report' should be published every 3-5 years by each institution and build awareness the institute's contribution towards SDG 6: Clean Water & Sanitation, SDG 12: Responsible Consumption and Production, SDG 17 Partnership for the Goals.

6 References

Bureau of Indian Standards, 2007. *IS 1172: Code of Basic Requirements for Water Supply, Drainage and Sanitation (Fourth Revision)*.

Gandasari, Imas, Oot, Hotimah, and Mieke, Miyarsah. 2020. "Green Campus As a Concept in Creating Sustainable Campuses." *KnE Social Sciences*. doi: 10.18502/kss.v4i14.7853.

IIT Roorkee, 2021. "Green Campus Initiative." Retrieved May 10, 2022 (https://www.iitr.ac.in/GP/).

India Education Diary, 2020. "Universal Business School Has Taken a Leap Forward by Taking an Initiative to Make the Students Environmentally Conscious – India Education ." Retrieved May 10, 2022 (https://indiaeducationdiary.in/universal-business-school-taken-leap-forward-taking-initiative-make-students-environmentally-conscious/).

IUCN, 2016. *Nature-Based Solutions to Address Global Societal Challenges*. edited by E. Cohen-Shacham, G. Walters, C. Janzen, and S. Maginnis. IUCN International Union for Conservation of Nature.

Lekshmi, B., Shruti Sharma, Rahul S. Sutar, Yogen J. Parikh, Dilip R. Ranade, and Shyam R. Asolekar. 2020. "Circular Economy Approach to Women Empowerment Through Reusing Treated Rural Wastewater Using Constructed Wetlands." Pp. 1–10 in *Waste Management as Economic Industry Towards Circular Economy*. Singapore: Springer Singapore.

Lekshmi, B., Rahul S. Sutar, Dilip R. Ranade, Yogen J. Parikh, and Shyam R. Asolekar. 2020. "Enhancement of Water Reuse by Treating Wastewater in Constructed Wetlands: Minimization of Nutrients and Fecal Coliform." Pp. 213–23 in.

Ministry of Education, Government of India, New Delhi, 2020. "All India Survey on Higher Education." Retrieved May 12, 2022 (https://aishe.gov.in/aishe/viewDocument.action?documentId=277).

Ministry of Home Affairs, Government of India, 2011. "Census of India 2011." Retrieved May 12, 2022 (https://censusindia.gov.in/census.website/data/population-finder).

Ministry of Human Resource Development Government of India, 2020. *National Education Policy 2020* .

NITI Aayog, UNDP. 2015. *Lake Restoration: Two Successful Models of Lake Restoration in Rajasthan (Mansagar) and Karnataka (Kaikondrahalli). In Social Sector Service Delivery: Good Practices Resource Book; NITI Aayog: New Delhi, India,*.

Sarwani, B., 2020. Appropriate Technologies and Business Model Based on Circular Economy Approach Aimed at Building a 'Zero Waste Community' [Master's dissertation; Supervisor: Shyam R Asolekar], Indian Institute of Technology Bombay, Mumbai, India

Singh, R., (2020). Solidification and Stabilisation of Hazardous Wastes [Doctoral thesis; Supervisor: Shyam R Asolekar], Indian Institute of Technology Bombay, Mumbai, India

Subrahmanya Yadapadithaya, P., Prashantha Naik, and Kishori K. Nayak. 2021. "Implementation of Environment Friendly Strategies for Energy Conservation and Mitigation of Climate Change-A Holistic Approach in Mangalagangotri Campus."

Sutar, Rahul S., B. Lekshmi, Dilip R. Ranade, Yogen J. Parikh, and Shyam R. Asolekar. 2021. "Towards Enhancement of Water Sovereignty by Implementing the 'Constructed Wetland for Reuse' Technology in Gated Community." Pp. 157–63 in *Sustainable Environment and Infrastructure*.

UI Green Metric, 2021. "Overall Rankings 2021 - UI GreenMetric." Retrieved May 10, 2022 (https://greenmetric.ui.ac.id/rankings/overall-rankings-2021).

University of Oxford, 2021. "Environmental Sustainability Strategy | Sustainability." Retrieved May 11, 2022 (https://sustainability.admin.ox.ac.uk/environmental-sustainability-strategy).

Wageningen University & Research (WUR), 2021. "Green Office Wageningen." Retrieved May 11, 2022 (https://www.greenofficewageningen.nl/).

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Coercive Isomorphism in the Brazilian Packaging Chain: Opportunities Towards the Circular Economy

CERQUEIRA-STREIT, J.A. [a*], GUARNIERI, P. [a], AGUIAR, M.F [b], JUGEND, D. [b]

a. University of Brasília-UnB, Brasília, Brazil

b. São Paulo State University, UNESP, Bauru, Brazil

**Corresponding author: jorgealfredocs@gmail.com*

Abstract

Despite the potential economic, social, and environmental gains that the Circular Economy (CE) can enable, the path toward implementing this logic demands systemic and challenging business models and value chains changes. The Covid-19 pandemic has demonstrated the fragility of the Brazilian supply chain and the dependency on the importation of items made from plastic, aluminium, and other metals. Even before the pandemic, the Sectoral Agreement pertaining to the packaging industry still presented modest results in Brazil. In this context, the Institutional Theory presents at least three contrasting mechanisms for isomorphic changes that support the legitimation and institutionalisation of certain practices. The objective of this article was to analyse one of its mechanisms of change: the coercive isomorphism as an opportunity for the institutionalisation of CE in the Brazilian packaging sector. For this purpose, a qualitative research was conducted, involving documental analysis and in-depth interviews with 53 (fifty-three) stakeholders of the packaging sector from twenty different Brazilian states, which were analysed using the NVivo® software. From the perspective of coercive isomorphism, we could observe strategic, legal, and structural issues difficulting the transition to CE in Brazil. Moreover, among the main results, it is possible to highlight the relevance of providing tax benefits, including the I waste pickers in the formal reverse logistics system, and the role of Non-governmental organisations -NGOs and government agencies in supporting the monitoring of this process. This study has limitations, one of which is not presenting and discussing new tools and legislations that can alter the operation of the Brazilian packaging chain (launched at the end of 2021 or 2022). Academic and managerial contributions can be obtained from this study. To researchers, it is shown how an instrument of institutional theory (coercive isomorphism) can be useful for the development of a case study. For managers, it is expected that the analysis of the participant's perception of the Brazilian environmental legislation can contribute to the decision-making process of public and private managers and stimulate awareness.

Keywords: Circular economy; Isomorphism; Reverse Logistics; Institutional Theory; National Solid Waste Policy.

1. Introduction

There is a lack of consensus regarding the concept of circular economy (CE) (Homrich et al., 2018; Kirchherr, Reike, & Hekkert, 2017; Silva et al., 2019), as an emerging and still little institutionalised approach (Repo et al., 2018). Nevertheless, its principles and proposal have been increasingly gaining attention from policymakers, industries, and academia (Gregorio, Pié, & Terceño, 2018). Although many definitions coexist, the authors point out the CE as an alternative to the current economic model, which follows a linear pattern characterised by the actions of take-make-dispose. In this sense, the focus of CE is mainly on closing the productive cycle through strategies that include sharing goods, reusing, refurbishment, and recycling, among others (Sehnem et al., 2019), involving a wide range of actors from different sectors in different levels: micro, meso, and macro (from local to global) (Morseletto, 2020).

The packaging industry chain in Brazil has always relied on recycling materials such as plastic, paper, cardboard, aluminium, and other metals. This sector is characterised by a high level of informal working and depends on the role of the recyclable materials waste pickers to effectively close the productive loop (Rutkowski & Rutkowski, 2015; Dutra et al., 2018). Since 2010, the Brazilian Policy of Solid Waste Management (BPSWM), which was sanctioned by the law 12.305/10, seeks to structure a system for the reverse logistics (RL) of packaging in general, including the waste pickers' cooperatives (Brazil, 2010). However, more than a decade after sanctioning this law and firming the sector agreement, there is still a lack of elements leading to the operationalisation of a logistics system at a national level, enabling the recovery of potentially recyclable residues and, minimising landfilling (Steigleder, 2021).

According to the Institutional Theory, the publication of laws and regulations can impose pressure on organisations and cause a standardisation of behaviours, a process known as coercive isomorphism. In addition to avoiding sanctions provided by law, other factors can trigger this process, including the tendency to follow the decisions of market leaders (mimetic isomorphism) and the search for projects that could respond to the demands of society (normative isomorphism) (DiMaggio & Powell, 1983). These actions could promote legitimacy and, consequently, the maintenance of organisations over time (Deephouse, 1996).

Although the concept of CE has been intensively studied in recent times, it still requires further studies (Homrich et al., 2018), especially considering the issues related to the transition to CE and its economic and social implications in countries like Brazil (Guarnieri, Bianchini, & Rossi, 2020). In this sense, Pieroni et al. (2018) suggest that interviews with organisations that put circular principles into practice might be a good strategy to comprehend their business models and the existing trade-offs.

Given the complex scenario in which the Brazilian packaging supply chain is installed, aligned with the necessity of studies aimed at strengthening the theoretical foundation on CE, the following question motivated this research: *how does coercive isomorphism contribute to an institutional change toward the circular economy of packaging in Brazil?* Thus, this paper aims to analyse the role of coercive isomorphism as a mechanism of isomorphic change leading to the institutionalisation of the CE in the Brazilian packaging sector. The remainder of this article is structured as follows. Section 2 describes the methodology, presenting the details of the case study conducted with the packaging supply chain participants. In Section 3, the results are presented, encompassing the responses from the participants, together with the discussions according to the thematic categories related to the Institutional Theory. Lastly, the final remarks and limitations of this research are presented in Section 4, highlighting the directions for future research.

2. Methods

2.1 Research attributes

This article can be classified as applied research considering its nature, which aims to analyse a practical situation aiming to generate new and relevant scientific knowledge (Patton, 1990). Concerning to its objectives, it is classified as descriptive. From the perspective of the approach to the problem, it is characterised as qualitative research. By choosing this viewpoint, the researcher demonstrates interest in capturing social aspects of the organisations' dynamics in an attempt to identify behavioural patterns (Miles & Huberman, 1994).

A case study approach was used as technical procedure. When conducting a case study, researchers do not aim to intervene but to reveal the way and the reason why a phenomenon occurs (Yin, 2015). In this study, the focus was on Brazil and its current solid waste management system. In-depth interviews based on a semi-structured script were carried out to obtain the data. According to Saldanha (2014), interviews are one of the main instruments to obtain information through verbal reports of someone who generally has the knowledge and the experience to add value to the study. The choice by the case of Brazil is justified considering the recent legislation related to solid waste, including general packaging and several initiatives implemented in this context in the last ten years.

From the standpoint of the Institutional Theory, "institutionalisation" and "legitimacy" are expressions that have a similar meanings. Both terms refer to a state or a process and derive from the values and expectations that society converges on something, someone, or some organisation (Deephouse, 1996).

The seminal study of Dimaggio & Powell (1983) prescribes three mechanisms capable of leading organisations to adopt similar behaviors (isomorphism), culminating with institutional innovations and an altered environment. In this paper, we will focus on the coercive isomorphism. Coercive isomorphism is related to the action of the State; through the laws and guidelines, it uses its hierarchical power to pressure organisations to comply with the legislation, under penalty of administrative, tributary, and even criminal sanctions.

Mimetic isomorphism involves repeating consolidated models legitimised by other organisations and seen by the market and society as successfully applied. Thus, this type of isomorphism entails imitation. The last and third type is normative isomorphism, originated from the professionalisation process and related to the constant betterment of work methods by the exchange among experts and their pressure for organisations to demonstrate the adoption of legitimised or acceptable practices (Dimaggio & Powell, 1983). This theory was used as a lens to elaborate the script of interviews.

Researchers in the management field, according to Gibbert & Ruigrok (2010), should prioritize two types of validation: the construct and the internal. In this study, the validation of the construct was based on the validation of the interview script by judges. Five Ph.D. professors from different universities and specialists in Circular Economy in the field of management and engineering proposed improvements, which were accepted by the researchers. Internal validity occurred through the triangulation of data collection instruments, because the results contained in the literature (document analysis) were contrasted with the opinion of stakeholders working in the packaging sector in Brazil (in-depth interviews).

To have access to crucial informants by key informants, we used the snowballing technique (Biernack & Waldorf, 1981). Rather than using this procedure to measure the strength and influence of the actors, the objective was to facilitate access to professionals that were not part of the researchers' network. Additionally, applying this tactic made it possible to identify the role of each actor and gain a detailed understanding of the solid waste management net on the national scale.

Fifty-three interviews were conducted between March and June 2021. Given the social distance measures imposed by the Covid-19 pandemic, the researchers carried out all the interviews using video calls through Zoom. The recorded audios were transcribed, resulting in the text being further analysed.

Lastly, the final stage of the study comprised a content analysis of the interviewees' responses. The qualitative content analysis encompasses the identification of themes, the search for patterns, and the interpretation of the data leading to the explanation of the phenomenon (theory development) (Saldanha, 2014).

In this regard, the technique applied in the content analyses was the theme category, marked by a positivist inspiration, describing objectively and systematically interpreting a given message (Bardin, 2011). Following the recommendation of Alves et al. (2015), the software NVivo® was used to support researchers in categorising and analysing the data.

3. Results and discussions

The coercive pressures force organisations to adapt to legal and fiscal obligations. In other words, coercive isomorphism happens when people and organisations begin to adopt a similar behavior due to the imposition of the State. (Dimaggio & Powell, 1983). Many times, environmental innovations are neglected by firms. For this reason, regulation plays a pivotal role in stimulating companies to adopt or not a certain environmental behaviour (Junior & Souza, 2018).

Most of the fifty-three participants interviewed in this study believe that proper compliance with the Solid Waste National Policy could lead Brazil to advance toward the CE significantly. The objectives, principles, and instruments of the policy aim to enable that the solid waste management to respect the order referred to in the ninth article of this law: non-generation must be prioritised concerning reduction, which must be applied previously to reutilisation and recycling, and the solid waste treatment and final environmentally-adequate waste disposal are the last of the alternatives (BRAZIL, 2010a).

Table 1 shows which actors answered that believe (or not) that the current national environmental policy induces or forces organisations to change their behaviour. Moreover, Table 1 also indicates the thematic categories created taking the reasons given in the responses. It is relevant to mention that the actors might have commented about reasons framed in more than one category.

Induces or forces organisations	**Justification**	**Reference (case study)**	**Reference (literature)**
YES	More inclusion and less garbage dumps	PPE5, PPM4, CAT2, PPF3, PPF5.	(Silveira, 2021)
	Improvement initiatives in specific industrial sectors	PPE4, ESP8, PPF4, PPF5, PPE7, EMP6.	(Coalizão de Empresas/Companies Coalition, 2017)
	Actions of Public Prosecution	PPF1, EMP3, ONG3, PPM2, EMP4, PPE5, PPM5, ESP1, ESP7, PPE6, PPE7, ONG9, PPE1, ESP9.	(MPMG, 2013)
NO	Prevalence of political interests	PPF2, PPF3, EMP3, ONG8, EMP8, CAT3, ESP10, CAT4.	(Couto & Lange, 2017)
	Prevalence of industrial interests	ESP1, ESP4, CAT1, ONG4, ESP8, ESP9, EMP6, PPF1, ESP3.	(ABRAMPA, 2020)
	Lack of incentives and/or benefits	ESP5, PPM2, PPM3, ESP6, PPE2, PPE5, PPM7, PPE6, PPE8, PPF4, ONG2, EMP9.	(Goron, 2014).
	Lack of monitoring	EMP2, PPE3, EMP3, ONG3, PPE2, PPM1, EMP4, EMP5, PPM4, PPM6, ONG5, PPM7, ESP2, ONG1, ONG6, ONG7, ONG9, EMP1, EMP7, PPE9, ESP3.	(Leite et al., 2021)

Table 1 – Actors' perception of the effect of environmental legislation on the chain

The general idea is that Law 12.305/10 has great relevance, but it still needs serious enforcement for its authentic execution. After analysing the Zero Waste Alliance in Brazil (ARZB) and the implementation of the BPSWM, Leite et al. (2021) also concluded that the lack of monitoring had been one of the major obstacles for the country to advance on this matter. These authors and most of the interviewees believe that the companies that generate waste and the other chain actors, will only take more effective actions when they become fined through a better mechanism of control (Leite et al., 2021).

This lack of concern of the companies is attributed to the lack of enforcement of the instrument that the law prescribes for implementing a Reverse Logistics: the Sectoral Agreement (Silveira, 2021). During the two decades before the discussion of the sanction of the law (Domingues et al., 2016; Silveira, 2021), it was possible to note that the companies could gradually diminish their responsibilities.

In Europe, programs related to the Extended Producer Responsibility (EPR) have switched responsibilities from municipal governments to producing companies. The government provides incentives for the companies to take actions directed to minimising the generation of waste and increasing the recycling levels, through ecodesign, for example (Rubio et al., 2019). Generally, the same companies that actuate in Europe do not promote the same programs in Brazil, where the guiding principle is the shared responsibility through the product lifecycle, which is more permissive than the EPR.

The quote from the director of a non-profit, non-governmental organisation (NGO1) that has been promoting the inclusion of waste pickers in the formal system for more than twenty years corroborates the above mentioned:

> *NGO1: Our problem is flexibilisation. In Brazil, we have a culture of the private sector holding great relevance in decision-making. If you take, for example, the Brazilian Congress, a large part is composed of this sector, I guess more than 50%. So, these big economic groups are predominant in these decision spaces.*

In a usual manner, the stakeholders are the ones who also believe that BPSWM still has not reached its goals, given the lack of incentives and benefits. According to Goron (2014), human nature is selfish, presenting a tendency to change behaviour after observing some advantages. In order to facilitate this process, the Brazilian tax law provides tax incentives referent to public expenditure (such as grants or subsidies) and those related to public revenue (such as waivers and deferral) (Goron, 2014). To promote the implementation of BPSWM, the author recommends the tax exemption, which corresponds to the legal remission of a specific tax (Goron, 2014).

In this sense, the quote from PPE2, a public prosecutor from Rio Grande do Sul State Labour Department, illustrates the opinion of those who represent this category:

> *PPE2: The law that does not provide a tax incentive and is not capable of monitoring actions is a law doomed to failure. If I apply a law that induces a good behaviour promising a reward for those who demonstrate achieving the goal, then the compensation is deserved. Industry reverses the logic of the system. It is not the government that will monitor the law enforcement, but an economic agent that will report to the government the achieved goals.*

Two more reasons indicate that coercive isomorphism still does not play a vital role for Brazil to achieve circularity in the packaging sector. Part of the chain participants alleges that the interests of the industry prevail, while other participants claim that the government interests surpass.

The case study conducted by Guarnieri, Cerqueira-Streit & Batista (2020) indicates that the Brazilian industry does not take so much effort into complying with the Sectoral Agreement. The initiatives of implementing voluntary delivery points (PEVs) and supporting recyclable material waste pickers were focused on the twelve cities that hosted the 2014 World Cup, a small and unrepresentative number compared with the 5570 municipalities in Brazil (IBGE, 2021). Furthermore, since 2017, when Phase 1 was finished, there have not been actions toward Phase 2 of implementing a packaging reverse logistics system. On this matter, the Ph.D. and sustainability expert (ESP4) interviewed, also pointed out the companies are responsible for this delay in the transition toward a circular economy.

> *ESP4: You cannot expect a discourse of the companies, not even benevolences. In my view, this legislation is essential, but there is still a lack of actions that contribute to its application. In the real world, the legislation forces the company to change. It is the possibility of being fined or facing an interdiction. You cannot put all this responsibility on the consumers.*

Some interviewees claimed that political interests also interferes on the non-adoption of mechanisms that could lead to a favourable isomorphic change, corroborating what Couto e Lange (2017) suggested in their study on how political aspects can influence reaching the goals of Law 12.305/2010. The Brazilian Constitution imposes the responsibilities for several collective rights to the Public Federal Ministry, among them the environmental (BRAZIL, 1988, art. 129). The State public prosecutors have been acting on several fronts to implement the Law 12.305/10, for example, by requiring that municipalities close down garbage dumps and landfills, considering the reallocation of recyclable materials waste pickers. In case of irregularities, such as child labour, the prosecutors must promote the legal accountability of the municipality.

Figure 1 shows, in the format of a diagram, the interviewees' responses divided into two groups and categories inside these groups.

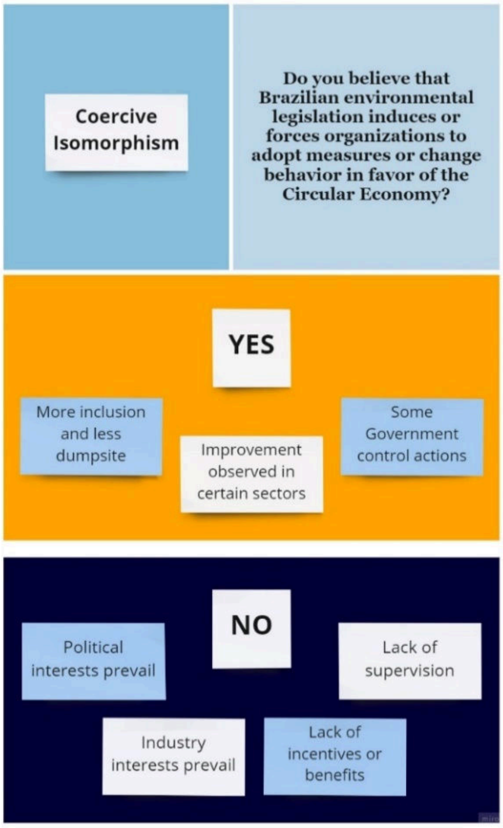


Figure 1 - *Brainstorm diagram*: coercive isomorphism

Considering now the group of participants who answered "Yes" to the Brazilian environmental legislation capacity of stimulating changes towards CE, most of them believe that the articulation of the State prosecutors has been pivotal to implementing the BPSWM. More recently, during the COVID-19 pandemic, the Brazilian National Council of Public Prosecution (CNMP) demanded the municipalities take actions to guarantee the health of those most vulnerable professionals involved in solid waste management: the recyclable materials waste pickers. Furthermore, the Brazilian Association of the Environmental Public Ministry (ABRAMPA) has opposed companies leaving the Sector Agreement firmed in 2015 (ABRAMPA, 2015).

Companies such as AbInbev, Nestlè, and Unilever have proposed a term of commitment (TC) to substitute the Sector Agreement. Although the law cites this instrument, according to ABRAMPA (2020), the current proposal is purely intentional, lacking a demonstration of the plans to implement a reverse logistics system. Moreover, this term does not meet the minimum requirements presented on Decree no. 7.404/2010, which rules the BPSWM (BRAZIL, 2010b; MMA, 2020).

By trying to comprehend the influence of coercive isomorphism, we observe that the interviewees have shown their points of view regarding the current Brazilian environmental legislation. In this sense, the question was about the capacity to induce or force organisations to adopt measures or change behaviours toward CE. On the one hand, the ones that answered "Yes" – the legislation induces or forces organisations – cited the inclusion efforts of waste pickers, the minimisation of garbage dumps in the country, and some environmental advances in different productive sectors.

On the other hand, most interviewees do not believe that environmental legislation forces or induces a behavioural change toward CE. Their justifications can be grouped into four groups: i) the predominance of political interests, ii) the predominance of the interest of industries, iii) the lack of incentives and/or benefits and iv) the lack of monitoring.

4. Final Remarks

The objective of this case study was to analyse the role of coercive isomorphism as a mechanism of isomorphic change leading to the institutionalisation of the CE in the Brazilian packaging sector. From the perspective of the Institutional Theory, we applied a content analysis to verify the responses of fifty-three participants in the packaging chain. After transcribing the interviews, we used the software NVivo to support the discussion of the institutionalisation phases.

Regarding the capacity of the environmental legislation to induce or force organisations to obtain a more circular behaviour, we can highlight at least four statements:

1) Often, multinational companies that operate in Europe do not promote the same programs in Brazil, where the guiding principle is the shared responsibility through the product lifecycle, a more permissive version of the EPR.

2) Granting tax concessions could bring many advantages, given that the State would not spend so many financial resources, imposing pressure on citizens;

3) To persuade the industry to take more effective actions, it would be desirable to update the BPSWM, making a clear distinction of the roles of each actor;

4) Despite still facing fundamental problems, some improvements can be noticed in organisations of recyclable material waste pickers regarding their inclusion and the closing of garbage dumps, mainly due to the action of State prosecutors.

Since the Brazilian (and global) context is constantly changing, future research is necessary. One of the limitations of this study was not presenting and discussing new tools and legislations that can alter the operation of the Brazilian packaging chain. For example, the Central of Custody (launched in August 2021) is a unified platform that aims to gather the recycling results through independent verification mechanisms.

Managerial and academic contributions can be obtained from this study. The analysis of the participant's perception of the Brazilian environmental legislation can contribute to the decision-making process of public and private managers and stimulate awareness. To researchers, the recommendation is to conduct other case studies, preferably longitudinal studies, providing a deeper understanding of each observed factor.

References

ABRAMPA, Associação Brasileira dos Membros do Ministério Público de Meio Ambiente, 2020. *Nota Técnica da ABRAMPA: Sobre a proposta de Termo de Compromisso de grupo de empresas a ser celebrado com a União para fomento à Economia Circular e Logística Reversa de Embalagens em Geral*. Belo Horizonte, Brazil.

Alves, D., Figueiredo Filho, D., & Henrique, A., 2015. O poderoso NVivo: Uma introdução a partir da análise de conteúdo. *Revista Política Hoje*, *24*(2), 119–134.

Bardin, L., 2011. *Análise de Conteúdo*. Edições 70.

Biernack, P., & Waldorf, D., 1981. Snowball Sampling. *Sociological Methods & Reseach*, *10*(2), 141–163.

BRAZIL., 1988. *Constituição da República Federativa do Brasil*.

BRAZIL., 2010a. *Lei nº 12.305 de 2 de agosto de 2010.*
BRAZIL., 2010b. *Decreto nº 7.404 de 23 de dezembro de 2010*.
Coalizão de Empresas/ Companies Coalition, 2017. *Relatório Técnico Acordo Setorial De Embalagen Em Geral: Fase 1*.
Couto, M.C.L., & Lange, L.C., 2017. Análise dos sistemas de logística reversa no Brasil. *Engenharia Sanitaria e Ambiental*, *22*(5), 889–898.
Deephouse, D.L., 1996. Does Isomorphism Legitimate? *Academy of Management Journal*, *39*(4), 1024–1039.
Dimaggio, P.J., & Powell, W.W., 1983. The Iron Cage Revisited : Institutional Isomorphism and Collective Rationality in Organizational Fields. *American Sociological Review*, *48*(2), 147–160.
Domingues, G.S., Guarnieri, P., & Cerqueira-Streit, J.A., 2016. Princípios e Instrumentos da Política Nacional de Resíduos Sólidos: Educação Ambiental para Implementação da Logística Reversa. *Revista Em Gestão, Inovação e Sustentabilidade*, *2*(1), 191–216.
Dutra, R.M., Yamane, L.H., & Siman, R.R., 2018. Influence of the expansion of the selective collection in the sorting infrastructure of waste pickers' organisations: A case study of 16 Brazilian cities. *Waste Management*, *77*(July), 50–58.
Goron, H.S., 2014. Incentivos fiscais e a Política Nacional de Resíduos Sólidos. In *Tributação ambiental: reflexos na Política Nacional de Resíduos Sólidos*. 229–245. Editora CRV.
Gregorio, V.F., Pié, L., & Terceño, A., 2018. A systematic literature review of bio, green and circular economy trends in publications in the field of economics and business management. *Sustainability (Switzerland)*, *10*(11), 4232.
Guarnieri, P., Bianchini, A., & Rossi, J., 2020. The Institutionalisation of the Transition Towards Circular Economy: a Comparison Between Italy and Brazil. *5th Symposium on Urban Mining and Circular Economy*.
Guarnieri, P., Cerqueira-Streit, J., & Batista, L., 2020. Reverse logistics and the sectoral agreement of packaging industry in Brazil towards a transition to circular economy. *Resources, Conservation and Recycling*, *153*, 104541.
Homrich, A.S., Galvão, G., Abadia, L.G., & Carvalho, M.M., 2018. The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production*, *175*(1), 525–543.
IBGE, Instituto Brasileiro de Geografia e Estatística, 2021. *Panorama dos municípios do Brasil*.
Junior, O., & Souza, M.T., 2018. A regulamentação como indutora de tecnologias ambientais para a redução de emissões tóxicas em veículos leves no Brasil. *Cadernos Ebape.Br*, *16*(4), 748–760.
Kirchherr, J., Reike, D., & Hekkert, M., 2017. Conceptualising the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*(September), 221–232.
Leite, C., Grimberg, E., Torres, F., Orlow, N., & ARZB., 2021. Aliança Resíduo Zero Brasil: ações e perspectivas para a implementação da Política Nacional de Resíudos Sólidos. In *10 anos da Política Nacional de Resíduos Sólidos: caminhos e agendas para um futuro sustentável*. 92–104. IEE-USP: OPNRS.
Miles, M., & Huberman, M., 1994. *Qualitative data analysis: An expanded sourcebook* (Vol. 2). SAGE Publications.
MMA, Ministry of Environment, 2020. *Versão Preliminar do Plano Nacional de Resíduos Sólidos*. Brasília-DF.
Morseletto, P., 2020. Targets for a circular economy. *Resources , Conservation & Recycling*, 153, 104553
MPMG, Ministério Público de Minas Gerais., 2013. *O catador é legal: Um guia na luta pelos direitos dos Catadores de Materiais Recicláveis*.
Patton, M., 1990. Designing Qualitative Studies. In SAGE (Ed.), *Qualitative evaluation and research methods*, 169–189.
Pieroni, M., Blomsma, F., McAloone, T., & Pigosso, D., 2018. Enabling circular strategies with different types of product/service-systems. *10th CIRP - Conference on Industrial Product-Service System*, *73*, 179–184.
Repo, P., Anttonen, M., Mykkänen, J., & Lammi, M., 2018. Lack of Congruence Between European Citizen Perspectives and Policies on Circular Economy. *European Journal of Sustainable Development*, *7*(1), 249–264.
Rubio, S., Ramos, T.R.P., Leitão, M.M.R., & Barbosa-Povoa, A.P., 2019. Effectiveness of extended producer responsibility policies implementation: The case of Portuguese and Spanish packaging waste systems. *Journal of Cleaner Production*, *210*, 217–230.

Rutkowski, J.E., & Rutkowski, E.W., 2015. Expanding worldwide urban solid waste recycling: The Brazilian social technology in waste pickers inclusion. *Waste Management and Research*, *33*(12), 1084–1093.

Saldanha, G., & O'Brien, S., 2014. Research methodologies in translation studies. In *Routledge* (4). Routledge.

Sehnem, S., Campos, L.M.S., Julkovski, D.J., & Cazella, C.F., 2019. Circular business models: level of maturity. *Management Decision*, *57*(4), 1043–1066.

Silva, F.C., Shibao, F.Y., Santos, M.R., & Barbieri, J.C., 2020. Análise de Stakeholders em Indústria do setor plástico: Uma aplicação da norma Abnt Nbr Iso 14001:2015. *Revista de Gestão Social e Ambiental*, *13*(2), 40–57.

Silveira, R. M. da C. (2021). *Caminhos da inclusão social à luz da política nacional de resíduos sólidos*. Letra Capital.

Steigleder, A. M. (2021). Logística Reversa de embalagens em geral e a coleta seletiva: uma correlação necessária. In *10 anos da Política Nacional de Resíduos Sólidos: caminhos e agendas para um futuro sustentável*. 30–41. IEE-USP: OPNRS.

Yin, R. K. (2015). *Estudo de Caso: Planejamento e Métodos* (5th ed.). Bookman.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Commodities Prices and Trends in a Globalized and Circular Economy. A Local Perspective

TADDEO, R.[a*], SIMBOLI, A.[a], CASOLANI V.[a]

a. University "G. D'Annunzio" of Chieti-Pescara, Pescara (Italy)

**Corresponding author, r.taddeo@unich.it*

Abstract

In recent years, as never before, temporary and structural events such as natural disasters, logistical and distribution problems, socio-political and pandemic, the depletion of supply sources, had a negative impact on the availability and prices of many raw materials. To this scenario, rebound effects of policies and practical actions to support the transition towards circular economic systems must be considered, such as the substitution effects, e.g. linked to the use of secondary raw materials resulted from the recycling processes or, more in general the output of closed-loop options.

The article intends to highlight the technical, economic and environmental potential and criticalities of these options and propose an eco-industrial perspective of analysis, for the enhancement of local economies and territories.

Keywords: Commodities prices, Global economy, Circular economy, Industrial Ecology, Local territories

1. Introduction

"Commodity markets are under tremendous pressure, with some commodity prices reaching all-time highs in nominal terms". This sentence, pronounced by one of the Senior Analysts of the World Bank, summarises the contents of the latest Commodity Markets Outlook Report (WBG, 2022), which takes stock of the recent developments of a growing trend in the commodities markets, that has started a few years ago and shows no signs of reducing, producing negative cascading effects on businesses, supply chains, consumers and, more generally, on economic systems all over the world.

Analyzing World Bank and Nasdaq data relating to the last decade, it is evident that, for many raw materials and resources for industrial use (e.g. Steel, Copper, Zinc, Palladium, Natural Gas, Wood, Cereals, Cotton), to an ever-increasing underlying trend, periodically, sudden changes linked to temporary phenomena are added up to a rapid surge that characterizes the last two years, with increases reaching 200% of the average price prior to 2020 (Nasdaq, 2022) (Fig.1).

For several years, scholars have been trying to study the reasons of this escalation and what factors contributed to achieving, in such a short time, this result (Nicoleta, 2011), both to predict possible further developments, but also to understand if there are solutions to reduce, or at least, contain their negative effects.

Among the phenomena that, which, according to recent chronicles have contributed most to these increases, we can recognize: i) natural events (earthquakes, fires, storms), such as the "Vaia" storm that hit central Europe in 2018; ii) pandemic events, such as the SARS-COVID19 epidemic; iii) infrastructural and logistical problems, such as the blockading of the Suez Canal in March 2021; iv) socio-political events, such as the recent war in Ukraine. It is clear that the effects of these phenomena have manifested themselves rapidly and globally.

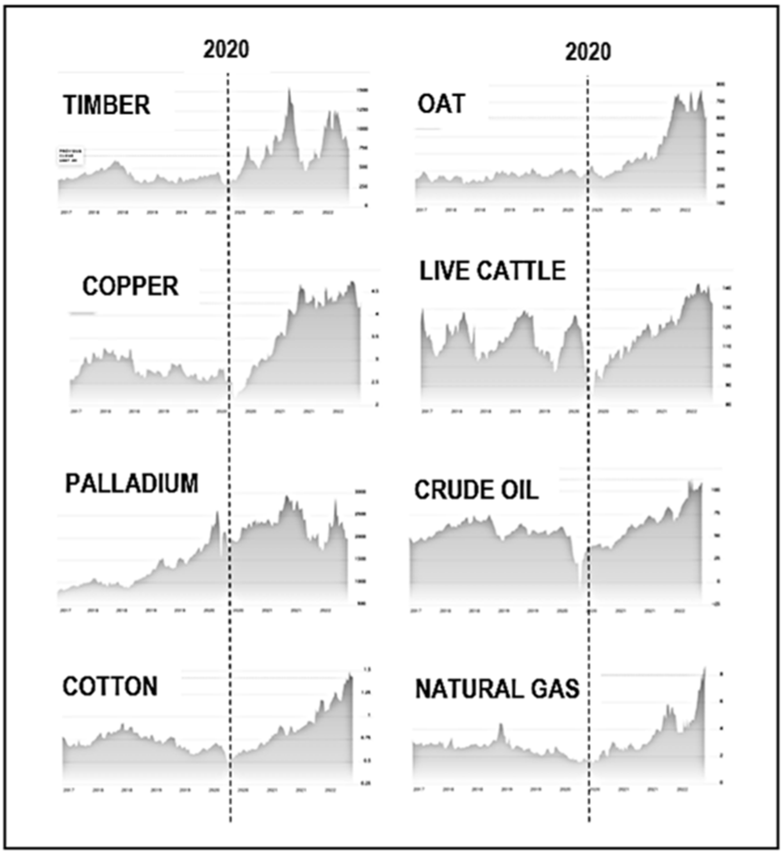


Fig.1. Recent trends of some commodities prices (Source: Commodities Market Data & News, Nasdaq, 25.05.2022).

When the paradigm of globalization caught on (Iwabuchi, 2002), for the removal of restrictions, duties and customs barriers for the mobility of people and goods, fragmentation of supply chains, through outsourcing and relocation of production activities, logistics integration, we were not yet aware of the speed with adverse events could also have been spread from one point of the globe to another and also the extent of "rebound" effects that they could have generated and which is threatening the economic sustainability of many businesses. In fact, in addition to the temporary increases (and the consequent "settling" delays), the main issue is related to the structural increases linked to the problems of availability of some production factors, especially raw materials.

This article, through a critical analysis of the recent global trends which are deeply modifying and redesigning the world's socio-economic and geo-political balances, aims to propose some reflections on the environmental implications and the related challenges of these changes, analyzed in the framework of Circular Economy, highlighting potential and criticalities of secondary raw materials as substitute of virgin raw materials and emphasizing the potential role of local economy in an eco-industrial perspective. The results are also analyzed in the view of previous studies and empirical analyses conducted by the authors in recent years on the themes of the circular economy, industrial ecology and the development of these approaches in local contexts.

2. Commodities prices, sustainability and the Circular Economy paradigm

In the light of what expressed in the introductory remarks, it becomes essential to broaden the spectrum of analysis to consider the environmental and, more generally, the sustainability reflections of the phenomena up to now described, in order to include the new paradigm of Circular Economy (CE), bearing in mind that the two concepts (sustainability and Circular Economy) are not coincident, nor even necessarily linked in a linear way.

Taking, for example, the problem of the possible depletion of the availability of some raw materials (e.g. the so-called "rare earths" or critical raw materials (CRM)), in addition to determining ecological imbalances and the aforementioned "market" effects on the prices of such materials and products in which they are used, can generate many problems: i) geopolitical, because their distribution on the globe is not uniform, (Graedel et al., 2019) (Fig.2); ii) technological, because these materials are indispensable in many of the strategic sectors of the so-called digital and green economy; iii) social, if we consider, for example, how these materials are extracted from scraps and treated in some developing countries. These dimensions cannot be addressed in isolation, but rather require a holistic and integrated approach.

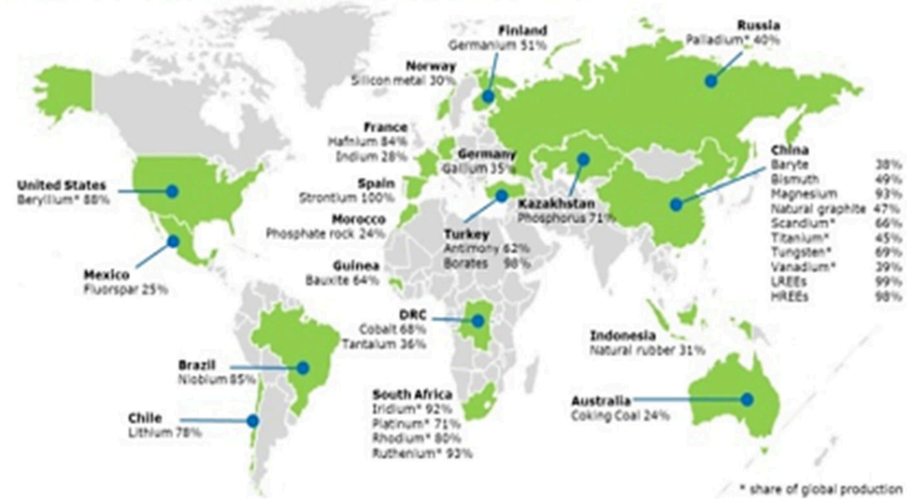


Fig.2. Biggest supplier countries of CRMs to EU (Source: EU Commission Report on the criticality assessment, 2020).

The underlying logic of the CE concept was probably born in 1989, when two scholars envisioned a more integrated model of industrial activity that would be environmentally sustainable on a global level (Frosch and Gallopoulos, 1989).

The concept of CE, which has been spreading widely in recent years, summarizes the current need to move towards more sustainable socio-technical systems. CE entails a systemic transformation of whole economic systems, at various scales, covering production, use/consumption and end-of-life phases, so that the value of material and energy flows can be maintained in the technosphere as long as possible (decoupling effect), while reducing environmental impacts in terms of resource depletion and pollution (Kirchherr et al., 2017).

CE is progressively establishing itself as a new socio-technical and economic paradigm. It is well known that paradigmatic jumps require an "adaptation" of the system, from both a structural-morphological (e.g. roles, technologies) and functional-operational point of view (e.g. rules and routines), from the various actors involved. In this case they are the different economic agents, and as such they operate according to the rules of economy (cost-effectiveness). The speed with which the principles of the CE are spreading (also due to the pressures exerted by some recent environmental emergencies, such as marine litter, global warming) raises some concerns on systems' ability to metabolize and implement these changes in an effective way.

However, still today the question arises as to whether and to what extent the "closed loop" systems of a CE can generate a mass of flows capable of representing an effective substitute for virgin raw materials. In the Circularity Gap Report, recently released (Circle Economy, 2022), it has been estimated that the world economy is only 8.6% circular; this value suggests a significant circularity gap of more than 90% (in only two years, global circularity wilted from 9.1% in 2018 to 8.6% in 2020). In addition, the research indicates that by 2050 the material use will amount to between 170 and 184 billion tons (in 2015 it was of 84.4 billion tons). This data should make policy makers and economic actors reflect and understand that we are still quite far from a real 'circular economy'. The strategies to embed circularity into the economy and to define a sustainable course to resource efficiency are different, but they have to be used in a systematic way and not as spot solutions. It is important to note that many of the practices we define as examples of CE are not correct. Take recycling, for example, it is a relevant element of CE and has the potential to increase circularity for some materials, but circularity cannot be achieved on the basis of recycling alone (Haas et al., 2015).

3. Prices and trends of secondary raw materials

From a technical point of view, a circular paradigm should include more options for closing the loops, starting from the famous 5Rs proposed by the European Directive 2008-98 EC (2008): Reduce, Reuse, Repair, Recycle, Recover, up to the current 10 -or more- recently recognised (Reike, 2018).
When fully operational, the benefits of their systemic application, especially those Rs directly related to material flows, would be important, in particular on the alteration of the balance of the global ecosystem, both from the point of view of the withdrawal of resources and the release of waste substances, and able to generate positive effects in terms of:

- reduction of extracted raw materials;
- reduction of energy consumption during the extraction phase;
- reduction of transport impacts;
- reduction of impacts in the processing phases (waste and energy);
- reduction of materials to be disposed of at the end of their life.

However, to ensure their implementation to be effective, as well as efficient, there are some conditions that must be respected:

- the closed loop must guarantee the restoration of suitable conditions of usability of products, components, materials (effective substitutability for actors and consumers, and respect for competitiveness, e.g. the substitution/replacing of virgin paper with recycled one, accordingly to the Integrated Product Policy - IPP);

- the closed loop process must have less impact than the primary production process, assessed through a life cycle analysis (including the phases of collection, selection, pre-treatment and the inevitable disposal of some component parts and materials);
- the closed loop must be compatible, in terms of volumes, temporal distribution of flows and stocks, variability, with the processes it will feed.

Furthermore, prices of secondary raw materials are also not free from influences, both internal and external. They can include:

- the listing of secondary raw materials. Basically the price is linked to the price of the raw material;
- market demand for secondary raw materials. This is the factor that most of all determines the strong instability of prices. Currently, the largest share of commercialized material depends on big contractors, which have the power to strongly influence prices, especially in the case of plastics;
- market offer for secondary raw materials. The main producers are the treatment and recovery centres of the materials coming from urban waste collection;
- law provisions. This aspect can concern, for example, a strategy of buying minimum fractions of recycled material to feed industrial production cycles (as already happens in public administrations through the adoption of Green Public Procurement - GPP). Possible incentives for the recovery and recycling of materials given the increasing problems linked to the management of landfills can be also addressed;
- technological development. New technical and management solutions for recovery can increase the quantity and quality of processable and resalable materials, as well as affect transformation (and disposal) costs;
- intrinsic quality of material. Depending on the type of material, the production process to which it has been subjected and the use it has performed during its life, the methods of use change and consequently also its economic value;

- purity, size and shape of the scraps. The value of the scrap will be the higher the closer it gets to the purity and conformity requirements of the secondary raw materials required by the market. The presence of contaminating substances negatively affects the evaluation of the materials (e.g.: different substances from the primary material that can deposit on the surface but also to those parts composed of a different material that it was not possible to separate). With the same condition, size and shape affect the analysis to the extent that they can complicate the phases of storage, transport and actual recycling;
- supply chain costs. In this category, costs of collection, transportation and selection can be mentioned.

Also these considerations should make us reflect both on how far the economic system is still from being considered effectively "circular", but above all, on how much this circularity can be transferred in terms of sustainability (Walker et al., 2021 and 2022).

4. Global and local scale: the "biological" and the eco-industrial approaches

The question remains of what level of analysis is the most suitable for implementing circular options. This issue is still widely debated also in the literature, someone is calling for initiatives at a global level (Yong et al., 2019), others, for a return to territories (Tapia et al., 2021), emphasizing the key role of the local dimension.
Some basic considerations, related to the costs and impacts of transportation in a life cycle perspective are undeniable; however, there are also other aspects to consider, perhaps more "soft", but equally important. For example, on a global scale, there is a persistent problem related to operational complexity and inevitable geographical disparities, difficulties in supply chains traceability and control and impacts related to transportation activities, which make fully circular principles and models less applicable. In this sense, local-scale systems have greater potential of revaluation. The overall picture is so complex that it would be practically impossible to hypothesize that all the possible aspects could be enclosed in a large-scale single model, and in a balanced functional relationship.
Recent studies propose hypotheses and approaches for the analysis of economic systems characterized by a simple and extraordinarily effective inspiration: the biological systems. These studies, grouped under the "Industrial Ecology" (IE) concept (Graedel, 1996), was definitively established at a global level in the late 1980s and proposed a new concept in which an industrial system is viewed not in isolation from its surrounding systems but in concert with them. IE seeks to optimize the total materials cycle from virgin material to finished product and to ultimate disposal moving from the natural ecosystems metaphor, which starts from a certainty: in the natural world, no waste is produced; waste is essentially a social or human construct. *"In a biological ecosystem, some of the organisms use sunlight, water, and minerals to grow, while others consume the first, alive or dead, along with minerals and gases, and produce wastes of their own. These wastes are in turn food for other organisms, some of which may convert the wastes into the minerals used by the primary producers, and some of which consume each other in a complex network of processes in which everything produced is used by some organism for its own metabolism"* (Jelinsky et al., 1992).
In this kind of system, the concept of "waste" (intended as an object or substance which an actor intends to discard) is practically lost in favour of a cyclical vision of flows, whose technical and economic value is maintained within the system, (almost) decoupling them, for quite a long period of time from their reference biological system. For these reasons, the IE can be recognized to all intents and purposes as the scientific basis of the CE and the methodological approaches and tools of the IE can effectively be used to guide change towards the CE.
The most effective approaches in this sense, in the IE research field, are the so-called "Place based" (Simboli et al., 2012). Place-based approaches to IE can promote more sustainable paths of local development or redevelopment through innovative methods, tools and applied solutions able to improve the socio-economic and the environmental performances of local economies, through a collaborative and synergic management of material flows, resources and energy. Most of them are based on the concept of Industrial Symbiosis (IS) (Graedel, 1996; Lowe, 1997; Chertow, 1999; Côté and Cohen-Rosenthal, 1998; Desrochers, 2002).
In 2004, a study proposed a spatial analysis of this phenomenon and demonstrated how, at a regional level, a fair compromise can be found between technological and organizational skills, economic feasibility and the degree of involvement of the actors in this type of initiative (Sterr and Ott, 2004) (Fig.3).

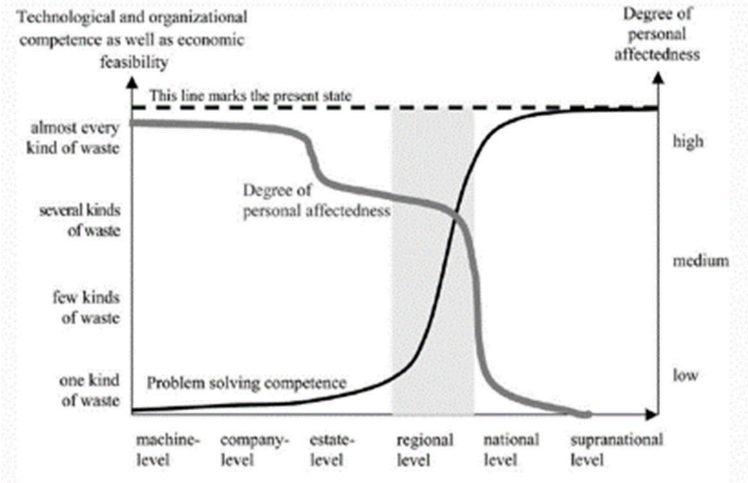


Fig.3. Applicability of the regional dimension for IE development (Source: Sterr and Ott, 2004).

Empirical evidence emerging from recent studies conducted by the authors (Taddeo et al. 2012; Simboli et al., 2014; Simboli et al., 2015; Taddeo 2016) also indicate that local territories and, in particular, those chacachterized by the co-presence of different dimensions, the s.c. "hybrid" contexts, express a great potential in closing the loop of materials.

In figure 4, the main result of a study conducted by the authors, is presented. This study started with a retrospective investigation for a technical and socio-economic qualification of such contexts, continued with the development of a specific approach based mainly on contributions from Urban Metabolism and IS, and an analysis for the specific synergies that are potentially associated. The results obtaind have been summarized in an integrated analytical framework, which illustrates the main flows and synergies among the different dimensions of these contexts (Simboli et al., 2019).

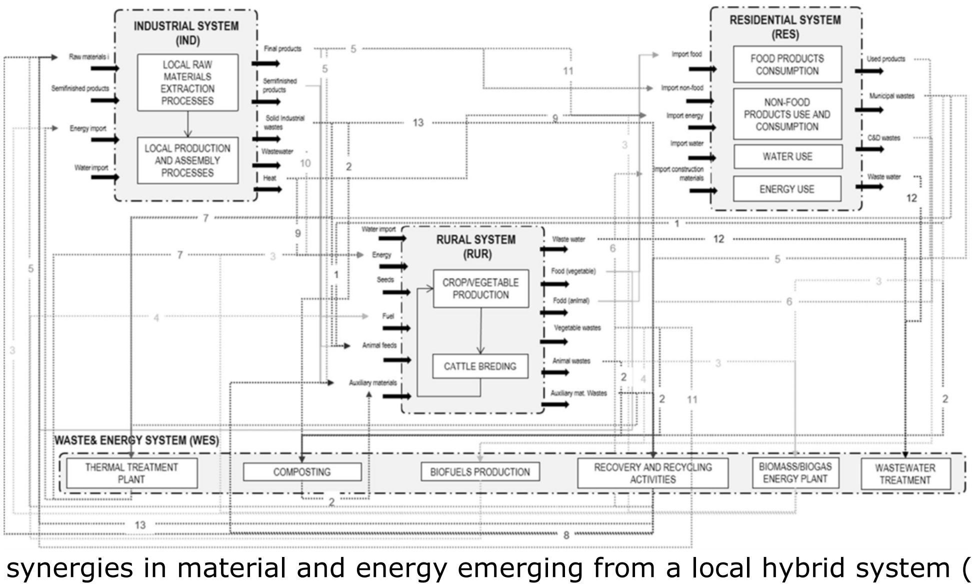


Fig.4. Potential synergies in material and energy emerging from a local hybrid system (Source: Simboli et al., 2019).

This study demostrated that an integrated vision of the different dimensions can be useful for efficiently identifying and managing material and energy flows beyond the typical use and consumption in local systems as well as for developing improvement actions, favoured by greater heterogeneity and proximity, along with more effective policies for a sustainable approach to local development in a circular perspective, thus demonstrating capable of reducing the physical and economic dependence of local actors on global supply chains and markets.

5. Conclusions

While resource use globally is growing at high rates and has even accelerated in the last decade (Schaffartzik et al., 2014), it is becoming evident that the scale of humanity's metabolism is unsustainable and must be reduced. Promising opportunities are at "meso" level of scale, in which networks of complementary entities perform complex functions. It is especially related to issues such as transportation, waste and reprocessed materials management and external costs, that could adversely affect the economic and environmental scenario in the case of macro level analysis (Roberts, 2004; Zhang et al., 2008), and poorly valued and exploitable in a "micro" level of analysis. In the paradigm of CE, and moving from the insights of IE framework, it has been suggested that the "meso" scale is the one in which maximum efficiencies are achieved in the development of closed-loop initiatives, both for the organizational-managerial complexity connected to them, and for the availability of flows and technological skills for their realization. The future developments of this research will have to go in beyond the prospective vision of such scenarios to include the options for closing cycles in models that can effectively support the decisions of sustainable economic growth, at a local and, therefore, global level.

References

Chertow, M.R., 1999. The eco-industrial park model reconsidered. Journal of Industrial Ecology. 2, 8-10.
Circle Economy, 2022. The Circularity Gap Report 2022. Amsterdam, Circle Economy.
Côté, R.P., Cohen-Rosenthal, E., 1998. Designing eco-industrial parks: a synthesis of some experiences. Journal of Cleaner Production. 6, 181-188.
Desrochers, P., 2002. Industrial ecology and the rediscovery of interfirm recycling linkages: historical evidence and policy implications. Industrial and Corporate Change. 11, 1031-1057.
Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
Frosch, R.A., Gallopoulos, N.E., 1989. Strategies for manufacturing. Scientific American. 261, 144-152.
Geng, Y., Sarkis, J., Bleischwitz, R., 2019. Globalize the circular economy. Nature. 565, 153-155.
Graedel, T.E., 1996. On the concept of industrial ecology. Annual Review of Energy and the Environment. 21, 69-98.
Graedel, T.E., Reck, B.K., Ciacci, L., Passarini, F., 2019. On the spatial dimension of the Circular Economy. Resources. 32, 1-10.
Haas, W., Krausmann, F., Wiedenhofer, D., Heinz, M., 2015. How Circular is the Global Economy? An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. Journal of Industrial Ecology. 19, 765-777.
Iwabuchi, K., 2002. Recentering globalization. In Recentering Globalization. Duke University Press.
Jelinski, L. W., Graedel, T. E., Laudise, R. A., McCall, D. W., Patel, C. K., 1992. Industrial ecology: Concepts and approaches. Proceedings of the National Academy of Sciences of the United States of America. 83, 793-797.
Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling. 127, 221-232.
Lowe, A.E., 1997. Creating by-product exchanges: strategies for eco-industrial parks. Journal of Cleaner Production. 5, 57-65.
Nasdaq, 2022. Commodities Market Data & News. https://www.nasdaq.com last accessed May 2022.
Nicoleta, L., 2011. Key factors influencing commodity prices: the impact of the recent global economic and financial crisis. Virgil Madgearu Review of Economic Studies and Research. 4, pp. 105-115.
Reike D., Vermeulen W.J.V., Witjes S., 2018. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling. 135, 246-264.
Roberts, B.H., 2004. The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study. Journal of Cleaner Production. 12, 997-1010.

Schaffartzik, A., Mayer, A., Gingrich, S., Eisenmenger, N., Loy, C., Krausmann, F., 2014. The global metabolic transition: Regional patterns and trends of global material flows, 1950–2010. Global Environmental Change. 26, 87-97.
Simboli, A., Taddeo, R., Morgante, A. 2012. Place-based approaches to Industrial Ecology. Considerations about the application in long-standing industrial clusters. In: Ioppolo, G. (Eds.), Environment and Energy. FrancoAngeli, Milano, pp. 177-189.
Simboli, A., Taddeo, R., Morgante, A., 2014. Analysing the development of Industrial Symbiosis in a motorcycle local industrial network: the role of contextual factors. Journal of Cleaner Production. 66, 372-383.
Simboli, A., Taddeo, R., Morgante, A., 2015. The potential of Industrial Ecology in agri-food clusters (AFCs): a case study based on valorisation of auxiliary materials. Ecological Economics. 111, 65-75.
Simboli, A., Taddeo, R., Raggi A., 2019. The multiple dimensions of urban contexts in an industrial ecology perspective: an integrative framework. International Journal of Life Cycle Assessment. 24, 1285-1296.
Sterr, T., Ott, T., 2004. The industrial region as a promising unit for eco-industrial development reflections, practical experience and establishment of innovative instruments to support industrial ecology. Journal of Cleaner Production. 12, 947-965.
Taddeo, R., 2016. Local industrial systems towards the eco-industrial parks: the model of the ecologically equipped industrial areas. Journal of Cleaner Production. 131, 189-197.
Taddeo, R., Simboli, A., Morgante, A., 2012. Implementing Eco-Industrial Parks in existing clusters. Findings from a historical Italian chemical site. Journal of Cleaner Production. 33, 22-29.
Tapia, C., Bianchi, M., Pallaske, G., Bassi A.M., 2021. Towards a territorial definition of a circular economy: exploring the role of territorial factors in closed-loop systems. European Planning Studies. 29, 1438-1457.
Walker, A.M., Opferkuch, K., Roos Lindgreen, E., Simboli, A., Vermeulen, W.J.V., Raggi, A. 2022. Assessing sustainability across circular inter-firm networks: Insights from academia and practice. In: Wojnarowska, M., Ćwiklicki, M., Ingrao, C. (Eds.), Sustainable Products in the Circular Economy. Impact on Business and Society. Routledge, Abingdon (forthcoming).
Walker, A.M., Vermeulen, W.J.V., Simboli, A., Raggi, A., 2021. Sustainability assessment in circular inter-firm networks: An integrated framework of industrial ecology and circular supply chain management approaches. Journal of Cleaner Production. 286, 125457.
World Bank Group (WBG) 2022. Commodity Markets Outlook: The Impact of the War in Ukraine on Commodity Markets, April 2022. World Bank, Washington, DC.
Zhang, X., Stromman, A.H., Solli, C., Hertwich, E.G., 2008. Model-centered approach to early planning and design of an Eco-Industrial Park around an oil refinery. Environmental Science and Technology. 42, 4958-4963.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Decision-Making Method for Application of Underground Technologies in Porous Geological Reservoirs

CÂMARA, G. A. B. [a*], GÁLVEZ-MARTOS, J. L. [b]

a. Universidad Rey Juan Carlos, Móstoles

b. IMDEA Energy, Móstoles

**Corresponding author, george.camara@urjc.es*

Abstract

Stimulate the increase of Smart Energy solutions have become one of the main challenges for a sustainable world. The integration between several options of renewable energy generation and its storage, besides the integration with non-renewable generation, is part of this reality. Smart Energy issues related to energy efficiency and renewable energy, such as sustainable energy, carbon dioxide (CO_2) capture, storage and utilization technologies (CCUS) and smart energy systems with energy storage, can have in common the use of geological reservoirs. The search of energy security via renewable generation, promoting the use of low-carbon energy technologies, and consequently the transition to a low-carbon economy, requires Residues Storage (RS) or Energy Storage (ES) in a certainly large scale implementation. Current ways for selecting Underground Technologies (UT) for geological porous media are based on specific analyzes and application for one (01) UT. The objective of this work is to create a specific decision-making method for the use of geological reservoirs, considering their possible future uses for RS and ES. The methodological approach was classified on three (03) phases (Screening, Characterization, and Scenarios). The phase 01 of the proposed method was applied on Bahia State in 05 (five) fields of the Recôncavo Basin, the oldest Brazilian hydrocarbon basin. 37 parameters were selected from 07 themes (Geology, Technical, Environmental, Safety, Social Aspects, Economy and Finance, and Infrastructure Assessment) defined via literature review, online surveys, interviews with experts, and workshops. It was established a range from zero (0) to one (01) by parameter classification, considering "Go - No Go" and/or assessing their performance. Six UTs were evaluated: Enhanced Oil Recovery (EOR-CO_2); Carbon Capture and Storage (CCS); Compressed Air Energy Storage (CAES); Underground Storage Gas (USG) for Natural Gas and Hydrogen (H_2), and Power-To-Gas (P2G). Initial results indicate that there are fields with aptitude for the application of more than one UTs. The UTs in advanced technological stage or maturity obtained better scores. It is possible to affirm that the screening phase, considering the multi themes and technologies, can be a way for selecting the better UT. In the future, after phase 02 and 03 application, it will be possible to obtain the sedimentary basin potential looking to all UTs.

Keywords: Underground Technology, Geological Reservoir, Recôncavo Basin, Screening.

1. Introduction

Hydrogen (H_2) and other gases are considered as one of the more important options for the energy transition and the Green Economy, especially due to the renewable's intermittence and lack of dispatchability. Underground Technologies (UT) have gained attention as an option for Residual Storage (RS) and Energy Storage (ES), in special the Underground Storage Gas (USG) for Natural Gas, H_2 and Power to Gas (P2G) via H_2 and Carbon Dioxide (CO_2) methanation, Compressed Air Energy Storage (CAES) and Carbon Capture and Storage (CCS). Competition for the use of porous media geological formations is mainly between natural gas and H_2, and to a certain extent also compressed air and carbon dioxide (Bünger et al., 2016).

The UTs can become an excellent option for renewable sources support. However, the choose of the best UT need to be assessed in a case-by-case basis. And, in this selection, the local and regional aspects need to be considered. It is important to understand the local energy needs and the local context. Besides that, the participation of the civil society, private sector and academia is essential for the best decision to be made by competent authorities.

One factor that needs to be taken into account is the technology readiness level of each UT. Van Gessel et al. (2017) on Energy Storage Mapping and Planning (ESTMAP) summarised the actual underground technologies evolution stages (in porous media - Depleted hydrocarbon reservoir and Aquifers). In general, they classified the UTs´ technological status as follows: USG Natural Gas (USG NG) a mature technology, widely implemented; USG H_2 and CAES prospective technologies (pre-commercial pilots and conceptual designs); and CO_2 storage, proven technology, sparsely implemented. Table 1 presents the UTs project amount in World and Figure 1 shows the current UTs technological stage based on Van Gessel et al. (2017).

Tab. 1: UT´s projects in geological reservoir porous media in World. Source: Own elaboration based on CEDIGAZ (2019), NETL (2020), GCCSI (2021A) and (2021B).

RESIDUOS STORAGE						**ENERGY STORAGE**					
CCU			**CCUS**			**USG**				**CAES**	
EOR-CO_2			**EOR-CO_2**	**EOR-CO_2 and CCS**	**CCS**	**USG NG**		**USG P2G**	**USG H_2**		
Miscible	**Immiscible**	**Miscible/ Immiscible**				**Aquifers**	**Depleted fields**	**Depleted fields**		**Depleted fields**	**Aquifers**
89	8	1	21	1	4	77	486	2	0	1	0

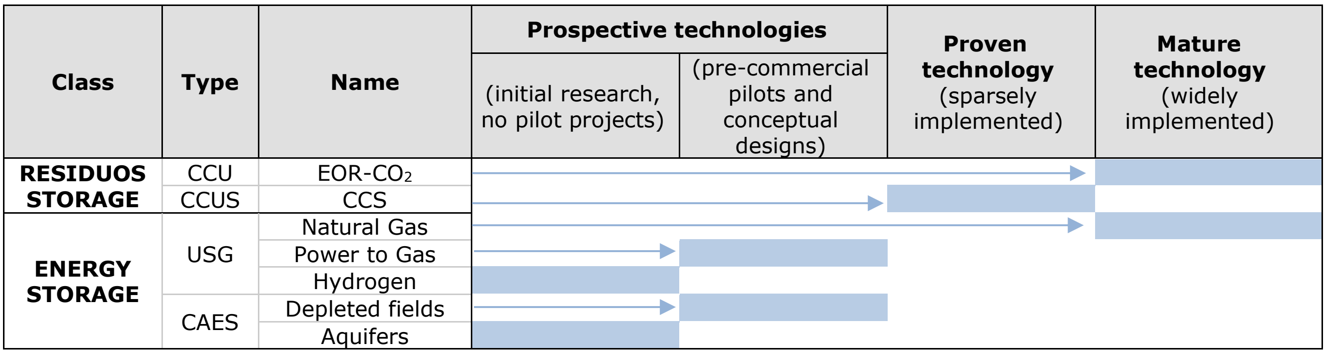


Fig. 1: Current UT´s technological status. Source: own elaborated based on Van Gessel et al. (2017)

Against this background, the objective of this work is to describe a specific decision-making method for the use of geological reservoirs, considering their possible future uses for Residual Storage or Energy Storage. The decision-making methodological concept proposed consists of three phases of which the first phase (Phase 01) consists of an initial analysis to be performed for a geological reservoir, checking the best UT for its characteristics and particularities. A case study, Recôncavo Basin, is then developed and evaluated.

2. Method and Literature Review

For the development of the UT Decision-making method a literature review was performed, after which the Themes´ structure and Parameters and Criteria were established. In total seven (07) Themes were identified. In support to these Themes three (03) important aspects were recognized: Regulatory, Governance and Technological Evolution. Table 2 presents the Themes and their description.

Tab. 2: Themes and Description

Themes	**Description**
Geology	This topic describes the issues and geological characteristics related to the reservoir (i.e. Geological requirements for reservoir use). The porous rock reservoir encompasses a broad range of geologic features. Basically, parameters used to evaluate the geological aspects of the formation like porosity, permeability, thickness, depth, closure, geology type, caprock properties, reservoir dimensions, etc.
Technical (Reservoir Engineering)	This item is related with the geological reservoir use performance. Issues such as pressure limits, caprock and reservoir rock characteristics/performance, residual hydrocarbons, minimum miscibility pressure, production curve, etc.
Infrastructure Assessment	Some criteria should be accounted for and used to identify and discard sites unsuitable for Underground Technologies. The Infrastructure Assessment is supported by Geographic Information System (GIS). In an advanced phase, "*in loco*" activities can be necessary.

Environmental	Environmental restrictions that are not established in regulatory framework (CAES, USG H_2 and P2G do not have a regulatory framework structured) such as life cycle analysis, Greenhouse Gases (GHG) emissions, and Environmental Impact Assessment (EIA). In this theme, the issues related to human health are included.
Safety	Issues related to Risk Assessment of the Underground Technologies. Focus on potential fluid/gas leakages of the geological reservoir and their consequences.
Social Aspects	This item is related to Social Aspects issues in the pre-selected local area. This item includes issues such as cultural aspects, key historical, social, geographical, economic, industrial, and political characteristics of the site. In an advanced phase "*in loco*" activities can be necessary for checking the risks related to the Public Perception of the project.
Economy and Finance	Economic issues related to Economic Engineering like capital investment, cash flow, Capex, Opex, payback time, return of investment, etc.

The decision-making methodological concept proposed in this study is composed by an initial analysis to be performed for a geological reservoir, checking the best UT for its characteristics and particularities. Then, a regional analysis will be completed geological reservoir by geological reservoir. This is critical because the analysis process is related to 6 (six) different UTs. In a region, geological reservoirs with similar geological characteristics can exist, but the superficial conditions may be completely different. That can favor a specific condition for a particular UT.

Figure 2 illustrates the conceptual model. It is important to highlight that there are a lot of possibilities for UTs uses and the methodology is intended to explore the maximum potential of the region/sedimentary basin. During the analysis, it is critical to check UTs technological stage and to put the focus on only one UT for a geological reservoir can be a strategic mistake.

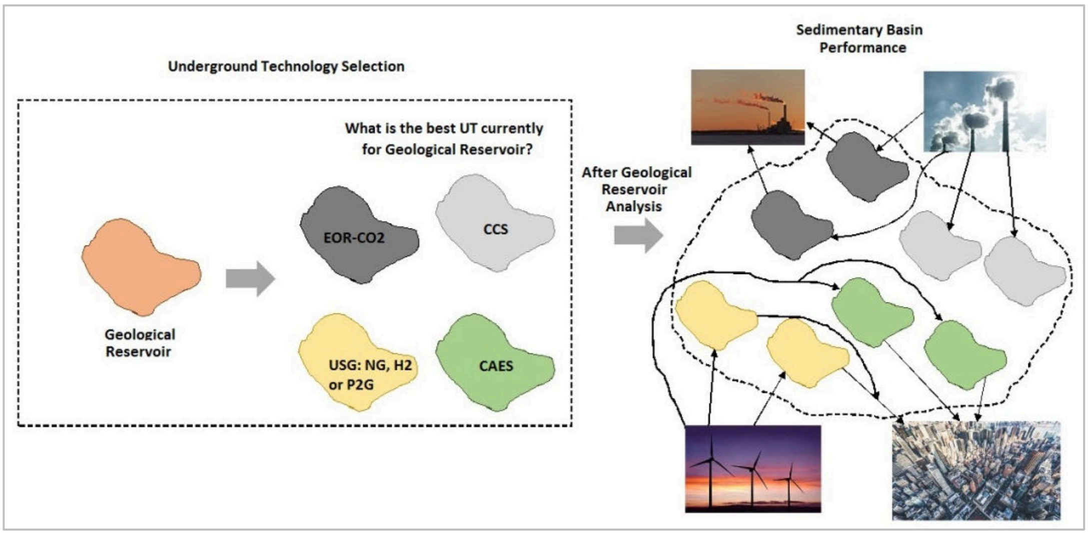


Fig. 2: Decision-making method conceptual representation

The process of the UT´s evaluation needs to consider the regional aspects and the tools must be adaptable for each situation. Besides that, the method for data gathering must be simple, and dynamic such as surveys, interviews, meetings, workshops, focal groups, among others. To support the decision, a continuous evaluation of the UT´s State of the Art is critical. Figure 3 shows a proposal of the sequence and activities on UT´s evaluation process.

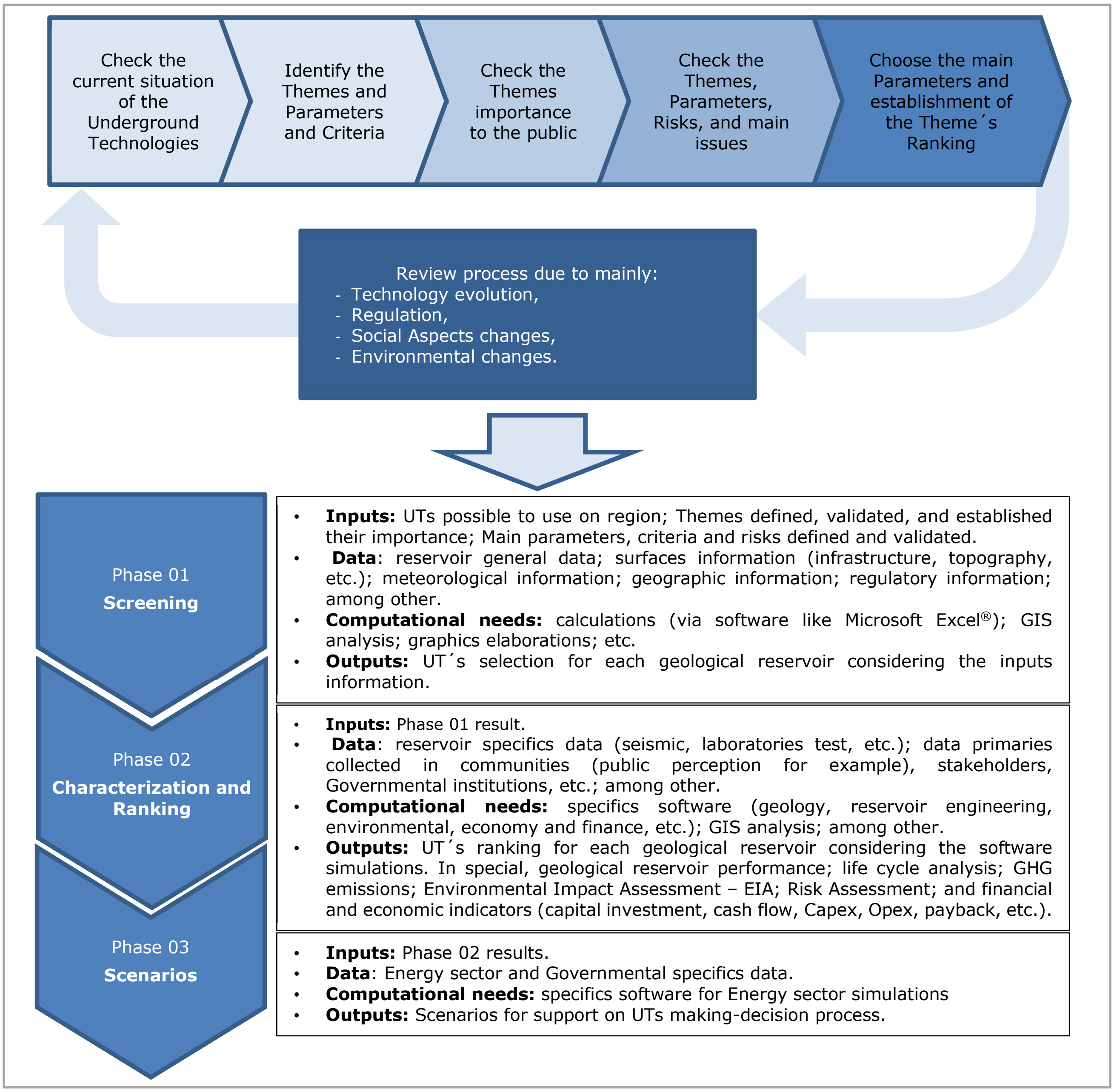


Fig. 3: Proposal of the sequence and activities on UT´s evaluation process

3. Phase 01 (SCREENING) Application: Case Study (Brazil/Bahia)

The region selected for the case study is located in Brazil, on Bahia state, between Salvador and Feira de Santana cities, called Recôncavo Basin. Recôncavo Basin is the oldest sedimentary basin in production in Brazil and is classified as a mature sedimentary basin regarding the level of knowledge and exploration. The first commercial oil discovery in Brazil was done there. In October 2021 the Recôncavo Basin had a daily average of 35.724,14 barrel of oil equivalent (boe), of which 21.609,60 are oil barrels and 14.114,54 are natural gas boe (Brazil, 2021A). On December 31st, 2020, there were 93 fields in production in Recôncavo Basin (Brazil, 2021B).

3.1 UT applications experience in Recôncavo Basin

UTs tests and applications in Recôncavo Basin are not recent. Petrobras made CO_2 injection pilot projects in some geological reservoirs in Recôncavo Basin. In 1987, an EOR-CO_2 project was started in Buracica field. Associated to this initiative, in 2007, Petrobras and IFP run a joint research project on CCS technology to determine the feasibility of CO_2 injection and underground storage in order to investigate the role of the CO_2 in the Buracica field reservoirs after 20 years of CO_2 injection. In 2009, 12,000 ton of CO_2 were injected in Rio Pojuca's saline aquifer focused on CCS technology (Ketzer et al., 2015; Dino, R., & Le Gallo, Y., 2009, and Hatimond et al., 2011).

According to Global CCS Institute, in 2009 too, Petrobras started the CO_2 injection, around 370 tonnes per day, into Miranga field. This project had the purpose to test the CO_2 injections technologies for the Santos Basin's offshore pre-salt cluster (GCCSI, 2021B). Rockett et al (2011) estimated, based on petroleum reserves, that Recôncavo Basin has a theoretical CO_2 storage capacity in petroleum fields of 64,9 Mega tonnes.

Another UT studied for its application in Recôncavo Basin was USG NG. In 2016 the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) approved the Santana Field Development Plan. Santana Development Plan had planned the natural gas injection of 1.4 MMm^3/day and withdraws capacity of 2.7 MMm^3/day (Brazil, 2016). In this same year ANP did a public consultation for expressions of interest on USG NG applications in four fields in Recôncavo Basin: Camaçari, Lagoa Verde, Pojuca Norte e Miranga Leste (Brazil, 2018).

3.2 Application of the UT evaluation process

In this case study, the methodological tools used to collect data and accomplish the steps indicated on model of the Fig.3 are presented in Figure 4. The figure shows the steps on conceptual modeling, and tools applied in each step.

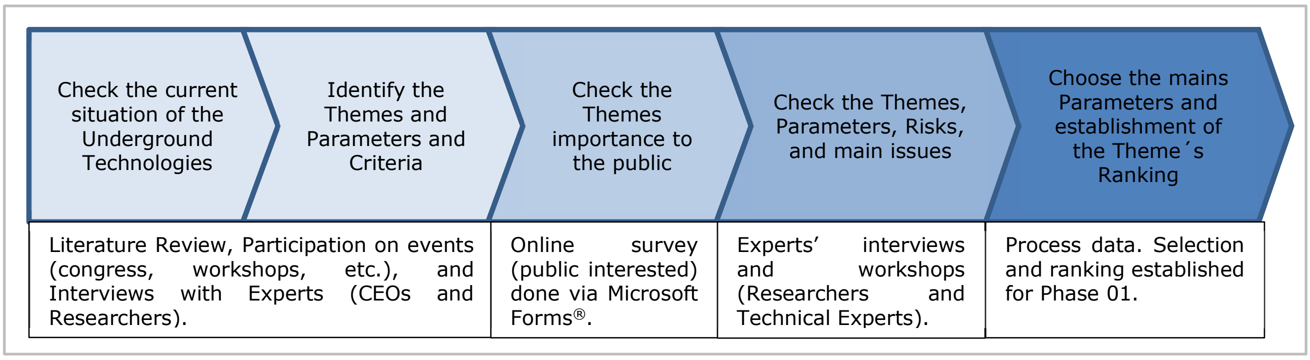


Fig. 4: Model conceptual and methodological tools applied in study case

The methodological tools have specifics purposes and finality. Below, the description of the goals and the target audience for each methodological tool are shown in Table 3. It is important to highlight that literature review and participation on events was the basis for a theme structure, and parameter and criteria identification.

Tab. 3: Methodological tool for data collection

Online Survey	Expert Interview	Workshops
Public: professionals, government employee, researchers, and professors.	Public: energy sector professionals, researchers, and professors.	Public: professionals, government employee, researchers, and professors.
Main Targets: Importance of the Themes; Check difficulty to obtain data on the Themes; Check difficulty of Themes analysis; and, establish an importance scale by Themes.	Main Targets: Present and validate the results obtained in the Online Survey on Themes; Check and validate the main Parameters and Criteria of the Themes identified in the State of the Art research; Check for the existence of methodologies that were not identified in the State of the Art research; and, Identify computational solutions applicable to the Themes.	Main Targets: Present and validate the results obtained in the Online Survey and Experts Interviews; Discuss the importance of UTs in the energy transition; and, Discuss the possibility of regulations/laws aimed at UTs and how the topics should be addressed (what is the level of detail and requirement in the regulations).

The online survey had 23 respondents and was possible to check the tendencies and public understanding about UTs´ themes and importance. Five questions were made about the Themes related to: Importance, Weight, Data Collection, Analysis Capacity, and Margin of Error. Considering on a scale from one (01) to five (05) being five (05) most relevant/complex.

Survey respondents were mostly from Oil and Gas industry. In general, the online survey indicated that Geology, Technical and Environmental are considered the most important themes. However, they are, especially Geology and Technical, highly complex and bring a high complexity related to data collection, analysis, and margin of error (uncertainty). Online survey results indicate that these themes require more attention and priority.

These results were presented to 15 experts from Brazil on Expert Interview step. Respondents were mostly PhDs and were working in topics related with the themes and the energy sector. A lot of experts understood that 01 of themes had evaluation "Down" in 04 questions, and in the question related to "Complexity of collect data" one theme had evaluation "Up".

In general, the experts agree with the online survey results but had some disagreement, variating from 0 to 2 "Down" or "Up" that can be considered acceptable. However, main disagreements are concentrated on these issues:

- Importance: Social Aspect considerate "Down" by 5 experts; Weight, Social Aspect considerate "Down" by 7 experts, and Economy and Finance considerate "Down" by 3 experts;
- Capacity: Technical aspects considered "Down" by 5 experts; and
- Margin of error (uncertainty): Economy and Finance considered "Down" by 3 experts.

Figure 5 summarizes the results brings details about which theme was considerate "Down" or "Up" by question in experts analysis.

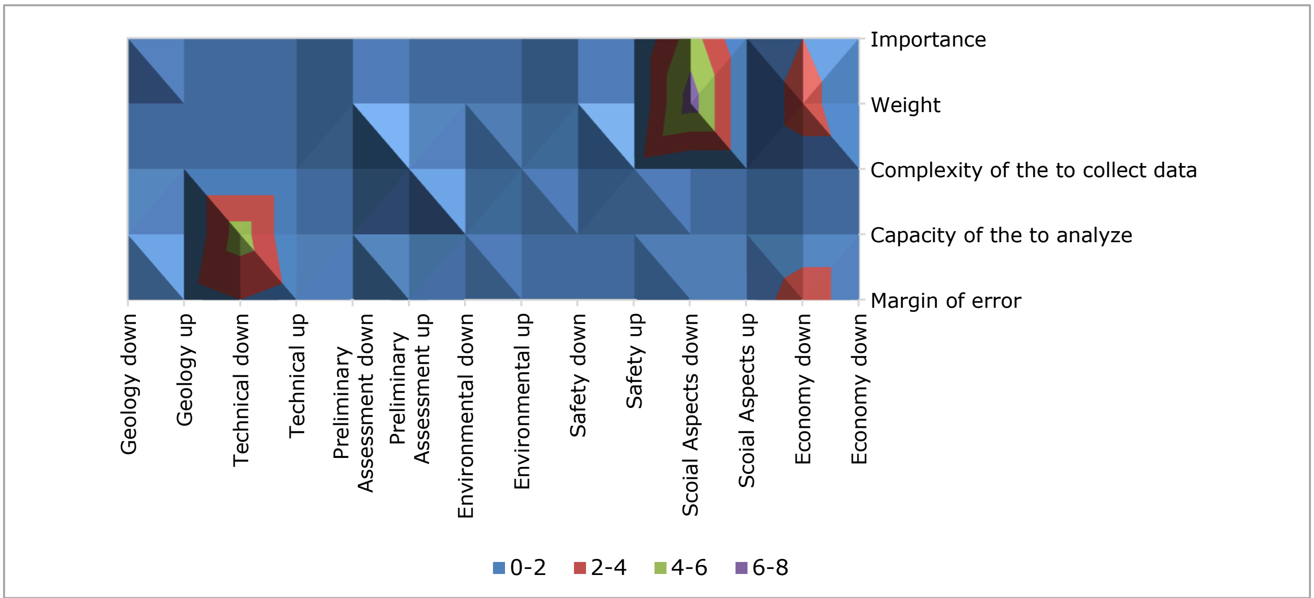


Fig. 5: Experts´ analysis detail of the survey results by question and theme

After survey results and experts´ analysis, it is possible to define a logical sequence of the themes, related to importance. Then this logical sequence must be a guideline for an UTs analysis application in Brazil, mainly to Recôncavo Basin. It is important highlight that this sequence is specific for UTs application in Brazil and Recôncavo Basin due to survey and experts´ analysis had been made with a particular public. The respondents and experts' opinion reflect the understanding of regional aspects and country peculiarities. Two workshops were held for discussing the results, one with a research group and another with the staff of the ANP and National Mining Agency (ANM).

Other important issue that must be considered is that this logic sequence translates current UTs understanding by a particular public and at a specific time. This understanding can change due to external circumstances or UTs technological evolution. The final Themes importance sequence was: 1) Geology, 2) Technical, 3) Environmental, 4) Safety, 5) Social Aspects, 6) Economy and Finance, and 7) Infrastructure Assessment.

The experts were asked about the main parameters and risks. Critical parameters listed by experts were 47 (forty-seven). 37 were used in Phase 01 on this case study. Figure 6 shows the distribution of the parameters by Themes used in the case study. These parameters were applied in five (05) fields, Araçás Leste, Fazenda Azevedo Oeste, Beija Flor, Camaçari, and Santana. The analyses were performed on open access data available from ANP[3] and based on two concepts for selected parameters:

- "Go – No Go": parameters and criteria that have values established in the literature. These values (ranges) need to be achieved. If not, the reservoir (interval) was discarded. The score adopted was zero (0) when it does not comply and the reservoir is automatically and one (01) when the criteria was complied. In some situations, especially for prospective technologies that the literature does not provide enough information on the threshold values for the criteria and values (or considered a strategic decision like the reservoir size for CCS), it was established a score of the zero point five (0.5).

- Performance: these parameter types are not critical for UTs application but are decisive for decision-making. The performance is assessed through the comparison of scores obtained by UTs or fields scores obtained. The UT or field with better performance has a maxim value (01) and others will have a score based on the maxim score obtained by the best score.

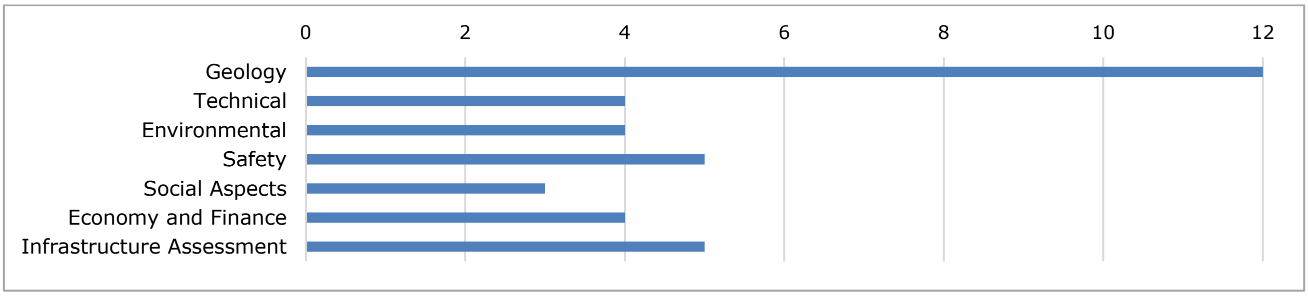


Fig. 6: Parameters used on Phase 01 case study

Table 4 presents the selected parameters by Themes and its classification. Besides that, Tab. 4, shows the main literature references in which the values (limits) and criteria of the parameters were collected. Microsoft Excel® was used as main software tool and supported by traditional Excel® functions used on Technical, Environmental, and Economy and Finance Themes like: Kinder Morgan CO_2 Flood Scoping Model; GHG Protocol Brazilian Program[4]; and Worksheet for the Economic Evaluation of Product and Service Development Projects[5].The spatial analysis required by some parameter, specially related to Infrastructure Assessment Theme, were done using Q-GIS[6] software and open access databases[7].

Tab. 4: Parameters applied and classification, and main literature references

Theme and Parameters Classification: "Go – No Go"(GNG) or Performance (P)	**Main Literature References**

[3] www.gov.br/anp/pt-br

[4] Access on March 2022. Available on: http://ferramenta.ghgprotocolbrasil.com.br/index.php?r=site/conteudo&id=1

[5] Elaborated by Gomes, L. P. (2014), Universidade de São Paulo (USP). Access on May 2022. Available on: http://www.portaldeconhecimentos.org.br/index.php/por/content/view/full/16825.

[6] Q-GIS is a free GIS developed by QGIS.org (2022. QGIS Geographic Information System. QGIS Association. http://www.qgis.org).

[7] The files that compose the project base on Q-GIS were colleted on follow sites: http://geo.anp.gov.br/home; https://portaldemapas.ibge.gov.br/portal.php; https://www.gov.br/anm/pt-br/assuntos/acesso-a-sistemas/geoinformacao-mineral; https://gisepeprd2.epe.gov.br/WebMapEPE/; https://mt1.google.com; https://ows.terrestris.de/osm/service; https://servicos.geo.sei.ba.gov.br

<table>
<tr><td>Geology
- Sealant/Cap Rock type (GNG)
- Reservoir Rock type (GNG)
- Presence of fault (GNG)
- Presence of fractures (GNG)
- Sealant/Cap Rock Thickness (GNG)
- Reservoir dimensions: thickness (GNG)
- Porosity (GNG)
- Depth (GNG)
- Permeability (GNG)
- Density (API Gravity) (GNG)
- Viscosity(GNG)
- Fluid type (GNG)</td><td rowspan="7">- Ling, K., Shen, Z., Han, G., He, J., & Peng, P. (2014, August). A review of Enhanced Oil Recovery methods applied in Williston Basin. In SPE/AAPG/SEG Unconventional Resources Technology Conference. OnePetro.
- Taber, J. J., Martin, F. D., & Seright, R. S. (1997). EOR screening criteria revisited-Part 1: Introduction to screening criteria and enhanced recovery field projects. SPE reservoir engineering, 12(03), 189-198.
- Taber, J. J., Martin, F. D., & Seright, R. S. (1997). EOR screening criteria revisited—part 2: applications and impact of oil prices. SPE reservoir engineering, 12(03), 199-206.
- Ramírez, A., Hagedoorn, S., Kramers, L., Wildenborg, T., & Hendriks, C. (2010). Screening CO2 storage options in the Netherlands. International Journal of Greenhouse Gas Control, 4(2), 367-380.
- Vangkilde-Pedersen, T., Kirk, K., Smith, N., Maurand, N., Wojcicki, A., Neele, F., ... & Lyng Anthonsen, K. (2009). EU GeoCapacity–Assessing European Capacity for Geological Storage of Carbon Dioxide. Project no. SES6-518318.
- Succar, S., & Williams, R. H. (2008). Compressed air energy storage: theory, resources, and applications for wind power. Princeton environmental institute report, 8, 81.
- Medeiros, M., Booth, R., Fairchild, J., Imperato, D., Stinson, C., Ausburn, M., ... & Plourde, K. (2018). Technical Feasibility of Compressed Air Energy Storage (CAES) Utilizing a Porous Rock Reservoir (No. DOE-PGE-00198-1). Pacific Gas and Electric Company, San Francisco, CA (United States).
- Ettehad, A., Jablonowski, C., & Lake, L. W. (2010). Gas storage facility design under uncertainty. SPE Projects, Facilities & Construction, 5(03), 155-165.
- Brazil. Empresa de Pesquisa Energética/EPE (2018). Nota Técnica da EPE - Estocagem Subterrânea de Gás Natural. p. 91. Rio de Janeiro. November 2018.
- Tarkowski, R., Uliasz-Misiak, B., & Tarkowski, P. (2021). Storage of hydrogen, natural gas, and carbon dioxide–Geological and legal conditions. International Journal of Hydrogen Energy, 46(38), 20010-20022.
- Amid, A., Mignard, D., & Wilkinson, M. (2016). Seasonal storage of hydrogen in a depleted natural gas reservoir. International journal of hydrogen energy, 41(12), 5549-5558.
- Scafidi, J., Wilkinson, M., Gilfillan, S. M., Heinemann, N., & Haszeldine, R. S. (2021). A quantitative assessment of the hydrogen storage capacity of the UK continental shelf. International Journal of Hydrogen Energy, 46(12), 8629-8639.
- Matos, C. R., Carneiro, J. F., & Silva, P. P. (2019). Overview of large-scale underground energy storage technologies for integration of renewable energies and criteria for reservoir identification. Journal of Energy Storage, 21, 241-258.
- Bouteldja, M., Acosta, T., Carlier, B., Reveillere, A., Jannel, H., Fournier, C. (2021). Hystories (Hydrogen Storage in European Subsurface) - Definition of Selection Criteria for a Hydrogen Storage Site in Depleted Fields or Aquifers. Deliverable D1.1-0 05. March 2021.
- Jannel, H. & Torquet, M. (2021). Hystories (Hydrogen Storage in European Subsurface) - Conceptual design of salt cavern and porous media underground storage site. Deliverable D7.1-0. June 2021.
- Kruck, O., Crotogino, F., Prelicz, R., & Rudolph, T. (2013). Assessment of the potential, the actors and relevant business cases for large scale and seasonal storage of renewable electricity by hydrogen underground storage in Europe. KBB Undergr. Technol. GmbH.
- RAG Austria AG, AXIOM angewandte Prozesstechnik GesmbH, Verbund Ag Montanuniversität Leoben, Universität Für Bodenkultur Wien, Energieinstitut an der Johannes Kepler Universität Linz (2020). Underground Sun Storage: Final Report Public 13 - January 2020. Project number: 840705. Pag 172.</td></tr>
<tr><td>Technical
- Initial reservoir pressure (GNG)
- Reservoir volume/capacity (GNG)
- Working Gas (GNG)
- Cushion Gas (GNG)</td></tr>
<tr><td>Environmental
- Regulatory restrictions (GNG)
- Potable groundwater presence (GNG)
- Environmental accidents/Incidents (P)
- Estimated GHG emissions (GHG Emission factor of the project) (P)</td></tr>
<tr><td>Safety
- Operational Security accidents/Incidents (P)
- Critical integrity issue reported (P)
- Number of wells in reservoir/interval, and field (P)
- Field performance, age of the wells (P)
- Field performance, wells per km^2 (P)</td></tr>
<tr><td>Social Aspects
- Accident/Incident reported by operator to ANP and Locals Authorities (P)
- Field distance to population density area (P)
- Historic/experience of the population with mineral exploration activities (P)</td></tr>
<tr><td>Economy and Finance
- Estimated Net Present Value (P)
- Estimated Internal Rate of Return (P)
- Estimated Payback (P)
- Estimated Return on Investments (P)</td></tr>
<tr><td>Infrastructure Assessment
Distance from the UT project to:
- Power generation centers (thermal plants) (P)
- Pipelines connected to Natural Gas net (P)
- Industrial centers (CO_2 sources) (P)
- Industrial centers (H_2 sources) (P)
- Main roads (P)</td></tr>
</table>

The results obtained for the parameters and the resulting analyses are shown in Figure 7. There are fields that have capability for more than one UT. This demonstrates that phase 02 activities should focus on theses identified UTs. Figure 8 presents the map containing the localization of the analyzed fields, energy infrastructure, and main urban areas. The fields were chosen due to available data and its localization in Recôncavo Basin.

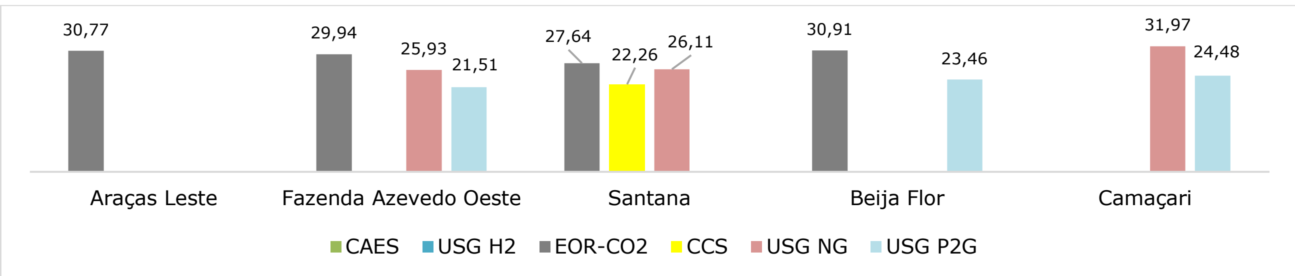


Fig. 7: UT performance score by field

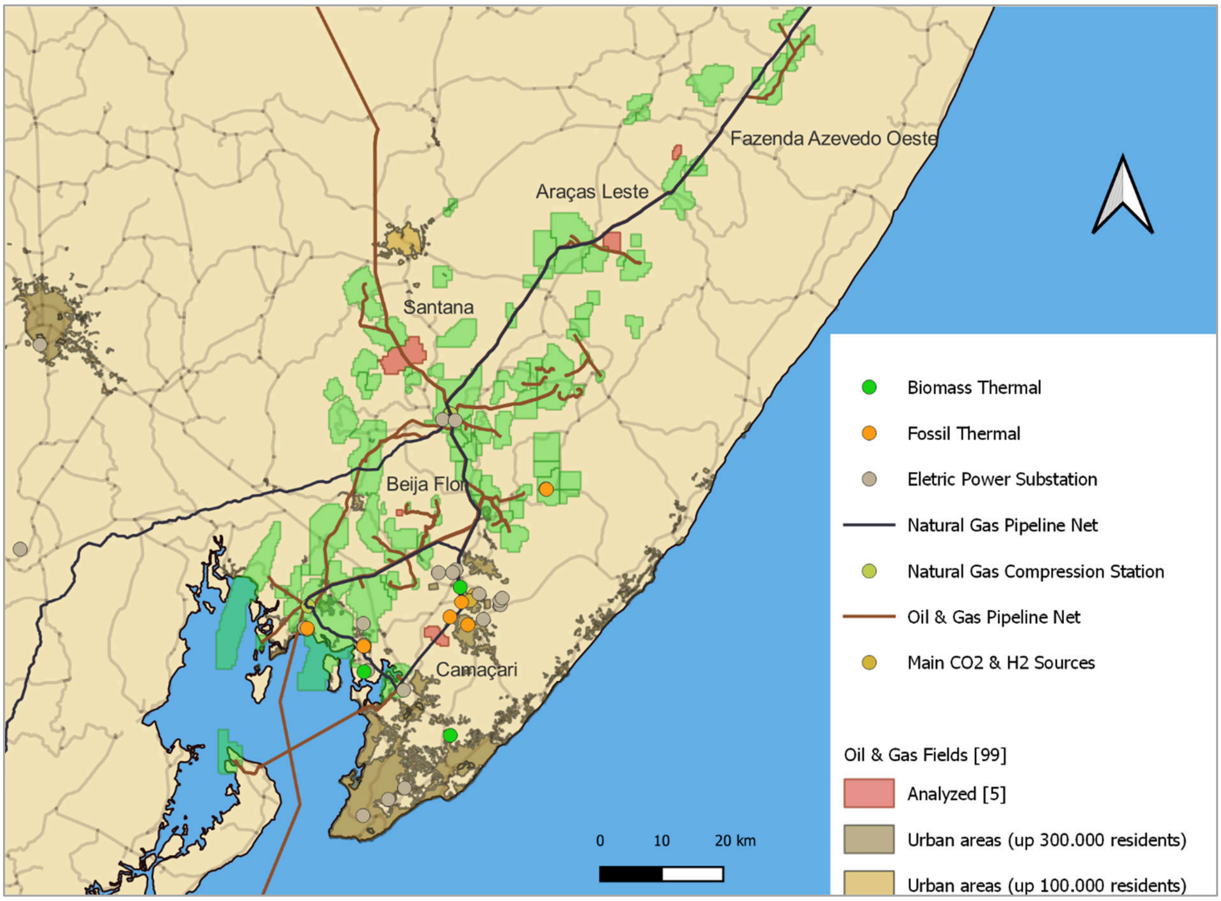


Fig. 8: Analyzed fields, energy infrastructure, and main urban areas.

4. Conclusions

The decision-making methodological concept proposed in this work was applied and interesting results were obtained. It demonstrates that Underground Technologies (UT) selection needs to be performed via a multidisciplinary vision and put focus on all existents UT. The screening process based on only one UT can affected the local and regional potential.

The methodological concept proposal can support the public and private sectors. For example, it a public consultation by ANP interesting results in 2016 for expressions of interest for the application of the USG NG in Camaçari field. After the results obtained in this work, P2G could be included in a new public consultation. It is important to highlight that Camaçari field is located close to industrial centers, CO_2 and H_2 potential suppliers. Especially for the private sector, the ANP resolution for field decommissioning (Brazil, 2020) requires the operator to study new uses of reservoirs of the fields; the developed methodology in this study would definitely support them.

In the current moment, the energy transition challenge and the incorporation of renewable sources are critical. Therefore, new phases of this methodology need to be tested along with pilot projects, especially for the prospective technologies at early stage of development, implemented in Recôncavo Basin.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754382, GOT ENERGY TALENT. The content of this article does not reflect the official opinion of the European Union. Responsibility for the information and views expressed herein lies entirely with the author(s).

References

Brazil - Agência Nacional de Petróleo, Gás Natural e Biocombustíveis - ANP (2016). Plano de Desenvolvimento do Campo de Santana, 2016. Available on: www.gov.br/anp/pt-br. Accessed in November 2021.

Brazil - Agência Nacional de Petróleo, Gás Natural e Biocombustíveis - ANP (2021B). Anuário estatístico brasileiro do petróleo, gás natural e biocombustíveis: 2021 / Agência Nacional do Petróleo, Gás Natural e Biocombustíveis. Rio de Janeiro: Available on: www.gov.br/anp/pt-br. Accessed in November 2021.

Brazil – Agência Nacional de Petróleo, Gás Natural e Biocombustíveis - ANP (2020). Resolução ANP n° 817/ 2020. Available on: www.gov.br/anp/pt-br. Accessed in November 2021.

Brazil – Agência Nacional de Petróleo, Gás Natural e Biocombustíveis- ANP (2021A). Painel Dinâmico de Produção de Petróleo e Gás Natural. Agência Nacional de Petróleo, Gás Natural e Biocombustíveis (ANP). Available on: www.gov.br/anp/pt-br. Accessed in November 2021.

Brazil – Empresa de Pesquisa Energética. EPE (2018). Nota Técnica, de 09.11.2018. Available on: http://www.epe.gov.br. Accessed in May 2022.

Bünger, U., Michalski, J., Crotogino, F., & Kruck, O. (2016). Large-scale underground storage of hydrogen for the grid integration of renewable energy and other applications. In Compendium of hydrogen energy (pp. 133-163). Woodhead Publishing.

CEDIGAZ (2019). Underground Gas Storage in the World - 2019 Status - Cedigaz Insights N°35 December 2019 17 pages. Available on: https: https://www.cedigaz.org/shop-with-selector/?type=publications. Accessed on: December 30, 2020.

Dino, R., & Le Gallo, Y. (2009). CCS project in Recôncavo Basin. Energy Procedia, 1(1), 2005-2011.

GCCSI - Global CCS Institute (2021A). The Global Status of CCS: 2021. Australia.

GCCSI - Global CCS Institute (2021B). CO2RE database in: https://co2re.co/StorageData. Accessed on: November 30, 2021.

Hatimondi, S. A., Musse, A. P. S., Melo, C. L., Dino, R., & Moreira, A. D. C. A. (2011). Initiatives in carbon capture and storage at PETROBRAS Research and Development Center. Energy Procedia, 4, 6099-6103.

Ketzer, J. M., Machado, C. X., Rockett, G. C., & Iglesias, R. S. (2015). Brazilian atlas of CO2 capture and geological storage.

NETL - National Energy Technology Laboratory (2020). National Energy Technology Laboratory/Database. Available on: https://netl.doe.gov/coal/carbon-storage/worldwide-ccs-database. Accessed on: December 30, 2020.

Rockett, G. C., Machado, C. X., Ketzer, J. M. M., & Centeno, C. I. (2011). The CARBMAP project: Matching CO2 sources and geological sinks in Brazil using geographic information system. Energy Procedia, 4, 2764-2771.

Van Gessel, Leynet A., Mulder A., Koorneef J., Harcouet-Menou V.. (2017). ESTMAP Energy Storage Data Collection Report. EC Project no.: ENER/ C2/2014-640/S12.698827; p. 03.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Entrepreneurs' Perception of Fish and Seafood Consumption in States Affected by the Oil Spill on the Brazilian Northeast Coast

DOS SANTOS, M. A. [a], FEITOSA, A. D. [a], ALVES, J. L. S. [b*], DE MELO, F.J.C [c], DE MEDEIROS, D. D [a]

a. Universidade Federal de Pernambuco
b. Universidade Federal do Amazonas
c. Universidade de Pernambuco
Maricélia Almeida dos Santos, mariceliaalmeida19@gmail.com
Amanda Duarte Feitosa, amandacapes2016@gmail.com
Jordania Louse Silva Alves, jordania@ufam.edu.br
Fagner José Coutinho de Melo, fagner.melo@upe.br
Denise Dumke de Medeiros, denise.medeiros@ufpe.br
**Corresponding author, jordania@ufam.edu.br*

Abstract

The oil spill on the Brazilian northeast coast in 2019 was considered one of the biggest environmental disasters in the country's history, with over 4000 kilometers of coastline reached by oil. Although the oil is no longer hitting the beaches, reflections are inevitable. Regarding gastronomy, the consumption of fish and seafood decreased, which caused lower sales for both fishermen and related restaurants. Therefore, this research aims to analyze the perception of entrepreneurs regarding the consumption of fish and seafood in the face of the oil spill on the coast of northeastern Brazil. For data collection, an interview script was created and applied to 15 restaurants located in three Brazilian states. To analyze the interview data, descriptive analysis was used for parts I and II of the interview script, and qualitative analysis was performed for open questions. Concerning the survey results, the perception of the entrepreneurs and the managers were that sales of fish and seafood dishes fell, which in some cases led to the closing of the establishment.

Keywords: Environmental accident, Oil, Consumer, Restaurant

1. Introduction

In Brazil, the year 2019 was marked by major environmental tragedies, among which the biggest environmental accident in Brazilian history stands out: the oil spill on the northeastern coast. A large amount of oil could be seen along the northeast between August 2019 and March 2020, even reaching some states in the southeast part of the country (IBAMA, 2020).

The damage associated with the accident could be seen and felt with the death of fauna, the impact of estuaries, mangroves, tides, beaches, and coral reefs, as well as the significant and lasting socioeconomic impacts on tourism and fishing (Magris and Giarrizzo, 2020). In this context, the object of study of this research is the Brazilian northeast coast.

It is necessary to evaluate the perception of the establishment's owners regarding the event. The fishing activity and consumption of these products are of great relevance to the economy, as well as to society's survival.

In this way, the objective of the research is to analyze the perception of entrepreneurs about the consumption of fish and seafood after the oil spill on the beaches of northeastern Brazil, as well as to analyze the economic impact arising from this problem.

2. Methods

This research classifies as applied, as it contemplates real situations and local interests. As a technical procedure, the research was conducted through semi-structured interviews with the owners and managers of restaurants that sell seafood to obtain information on the subject studied. Furthermore, as it is based on the perception of entrepreneurs, it is considered qualitative and with an exploratory objective (Voss et al., 2002). The methodology of this work was composed of six steps, as shown in Figure 1.

Fig. 1. Flowchart of the research steps

The sample plan of the study is defined as non-probabilistic, with sampling by accessibility due to the COVID-19 pandemic. The collection was carried out through WhatsApp and Google Meet. Thus, a maximum limit of respondents was not established, and the interview ended when the time limit was reached. The interview was applied in the northeast region and as a criterion for inclusion in the research, restaurants should sell fish and/or seafood. Thus, 15 restaurants authorized by the letter of consent, were part of the study, where interviews were conducted with owners and managers. The application period lasted from August 30 to October 18, 2021.

Regarding ethical aspects, the Research project was approved by the Research Ethics Committee - CEP of the Federal University of Pernambuco in February / 2021, with the number of Presentation Certificate for Ethical Appreciation - CAAE 41120520.5.0000.5208.

Regarding the collection instrument, the semi-structured interview script was based on a literature review. Thus, the interview was applied to restaurant owners and managers to obtain information related to their businesses and how they positioned themselves in the face of the oil spill accident on the Northeastern beaches.

The interview script was divided into four parts: the interviewee's sociodemographic profile, company characteristics, business behavior, and entrepreneurs' perception of fish and seafood consumption after the oil spill, as shown in Table 1, containing 33 questions.

Table 1 Preparation of the semi-structured interview

Category	Item	Description
Part I -		To know the profile of the interviewee,

sociodemographic profile of the interviewee	1-4	questions about age, gender, education level, and occupation in the company were present.
Part II- Characteristics of the company	5-10	The characteristics of the company are needed to know the interviewed restaurant. Thus, questions were raised about the state in which the organization is located, how long it has been in the market, average revenue, and the number of existing employees.
Part III - Organizational behavior	11-17	To understand the behavior of the company studied, it is necessary to know the types of fish and seafood sold, suppliers, their main customers, the menu options, how demand occurs, and how these products are managed, in addition, to knowing the average daily sales and average prices of products (Anderson and Asche; Garlock, 2018; Fiorella et al., 2021; Pettersen and Asche, 2020; Grema et al., 2020; Wickliffe et al., 2019; Dey et al., 2017).
Part IV - Entrepreneurs' perception of sales of fish and seafood dishes after the oil spill	18-33	This part of the interview was carried out to analyze the socio-economic impacts caused by the accident. Therefore, questions were raised about the sales situation, amount of products in stock, which arguments were to try to convince customers to buy the products, as well as questions about the main challenges faced by its business with the oil spill (Fiorella et al., 2021; Lamere and Mäntyniemi; Haapasaari, 2020; Pettersen and Asche, 2020; Maître et al., 2020; Dey et al., 2017; Ha et al., 2020; Grema et al., 2020).

The initial contact was made over the phone and later sent by e-mail. Thus, the interview took place online through Google Meet. This instrument was used, considering the pandemic crisis scenario (caused by Covid-19) making it impossible for the interview to be conducted in person.

3. Literature review

In this section, the main concepts used to prepare the research will be presented: the oil spill at sea and its impacts, service quality, consumer behavior, and product management.

3.1 The oil spill at sea and its impacts

Petroleum is a complex mixture of hydrocarbons, with a small fraction in its composition of heteroatoms, such as sulfur and nitrogen, metals, and carboxylic acids, and can be presented in three states of matter, solid, liquid, and gas (Suliman et al., 2020).

Most of the time, the transport of oil in Brazil occurs by sea through oil tankers. Even in the face of the economic benefits that oil brings, there are associated risks in the development of this activity, such as accidents like oil spills, which affect both the environment and society (Galieriková and Materna, 2019).

From the contact that oil has with sea waters and spreads quickly, with the help of winds and ocean currents, it is highly important for the government to constantly monitor this type of disaster (Galieriková and Materna, 2019).

3.2 Service quality

Services are economic activities capable of generating benefits for consumers by fulfilling their desires (Lovelock and Wright, 2004).

According to Slack, Chambers, and Johnsston (2013), services can be classified into professional services, service stores, and mass services. From this perspective, restaurants fit into the service store classification, in which service quality consists of two views, product quality is considered a tangible factor, and service quality is an intangible factor (Tuncer et al., 2020).

With what services encompass, much more effort is needed to achieve the quality expected by customers. As quality depends on the opinion of the consumer, it becomes necessary for service providers to seek to know the needs of their target audience and to align the quality defined by the organization's standards with the quality expected by customers (Shah et al., 2020)

Service providers must strive to meet or exceed customer expectations, as they are increasingly demanding (Slack et al., 2013). Therefore, it is necessary for them to be concerned with the provision of services, because, for consumers, the quality of services will be the difference between the expectation and the perception regarding the performance of the service experienced (Zeithaml et al., 2011).

3.3 Consumption behavior in environmental disasters

Accidents can be seen worldwide, such as the Chornobyl (1986) and Fukushima (2011) nuclear accidents. In the face of these disasters, the consequences are inevitable, as there is the pollution of water, air, and soil with radioactive materials, which also allows contamination through food intake (MAÎTRE et al., 2020).

Human health can be affected by the development of cancer and, in more extreme cases, since radioactive materials can remain for a long time in human tissue, death (Lien et al., 2020).

When disasters of this magnitude happen, the damage done goes beyond the radioactive issues involved. After the accident, it is necessary to develop strategies that mitigate the environmental and socioeconomic effects caused, such as food contamination (Maître et al., 2020).

Given the risk of food contamination with radioactive materials, there is a change in the consumption behavior of products from the affected areas, as consumers avoid buying regional products, which in turn, triggers economic and social problems for producers, entrepreneurs, and assimilated belonging to the region (Lien et al., 2020; Maître et al., 2020).

4. Results and Discussions

A semi-structured interview script was used, as explained above. The interviews were all conducted online. Table 2 shows the main characteristics of the restaurants participating in the study. 53% of the restaurants are located in the State of Pernambuco, 47% are traditional fish and seafood restaurants and 53.4% have been in the market for 10 years or more.

As for the average annual revenue, 53.4% earn US$ 20.000,00 or more annually, with a staff of 9 or less (53%) (For reference, the minimum wage in Brazil is US$ 242 monthly).

Regarding the answers to the open questions, entrepreneurs in the three states buy fresh fish and seafood from local fishermen, large wholesalers located close to their restaurants, and specialized companies. Dishes based on fish and seafood common in participating establishments in Bahia are Dourado, moqueca, crab shell, broths, shrimp, fish bait, lobster, and mariscada (a dish made up of various seafood, such as oysters, squid, and shrimp).

For the state of Pernambuco, the most cited are shrimp, lobster, yellow hake, fish, salmon, and Dourado. In Paraíba, red snapper, guarujuba and shrimp stood out. The average daily sales range from US$ 120 for micro-enterprises to US$ 30,000.00 for large restaurants in the three states.

Regarding the prices of the dishes, the average is US$ 28 for two people and US$ 7 for executive dishes. According to the answers obtained, it is inferred that the customers of Bahian restaurants, Pernambuco, and Paraíba are tourists and residents.

The greatest demand for the dishes contained in the menu varies from establishment to establishment, but the most cited were seafood, fish moqueca, shrimp, and fish bait in Bahia, and for Pernambuco, fish, stew, breaded shrimp, and shrimp broth. After the purchase of fish and seafood, asepsis and portioning are carried out and they are stored in a freezer. When the order arrives at the restaurant's kitchen, it is prepared and served to the customer, being classified as à la carte restaurant.

The fourth part of the interview is composed of questions related to the sales of fish and fruits after the oil spill. Questioned about the average amount of these products in stock when the accident occurred, the response range varied from 30 (for micro restaurants) to 150 kilos (for large restaurants).

Table 2 Characteristics of participating restaurants

Variable		**n**	**(%)**
State	Bahia	6	40%
	Paraíba	1	7%
	Pernambuco	8	53%
Type	Traditional	7	47%
	Beach Restaurant	5	33%
	Japanese food	1	7%
	Delivery	2	13%
Existence time	Between 2-3 years	2	13,3%
	4 to 7 years	3	20%
	7 to 10 years	2	13,3%
	10 years or older	8	53,4%
Average annual revenue	US$ 12.000,00 or less	5	33,3%

	Between US$ 12.001,00 and US$ 20.000,00	2	13,3%
	US$ 20.001,00 mil or more	8	53,4%
Employee chart	9 or less	8	53%
	From 10 to 49	4	27%
	50 or more	3	20%

Regarding the behavior of sales, according to the responses, for 47% of the restaurants, sales decreased in the range of 20 to 40% (43% are located in Bahia and 57% in Pernambuco). In 7% of the restaurants, sales stopped completely and for 46% no changes were noticed in sales (33% in Bahia and 67% in Pernambuco). For most restaurants, negotiations were not carried out with suppliers, but in others, there was a negotiation, with installments, for example.

For the restaurants that had sales drops, representing about 54% of the sample, the period of low demand for these products was between September 2019 and January 2020, staying around for four months, but there was no decrease in the prices of the dishes. When asked if sales have already normalized, the answer was positive for all restaurants. Faced with the crisis, strategies such as the diversification of the menu were used, including products based on vegetables, freshwater fish, meat, and chicken, in addition to the use of social networks to clarify the origin of the products or show the functioning of the kitchen.

As for the change in customers' habits, the interviewees stated that there was a change, where the demand for meat and chicken dishes was evidenced. To attempt to make customers ingest seafood-based dishes, the arguments used consisted of showing clarification notes from the suppliers and explaining that the products were in stock before the appearance of oil. Most of the time, this argument was not effective and led to the non-consumption of these products.

Regarding the knowledge of studies on the contamination of these products with oil, all participants answered that they had the knowledge and stated they followed the news. Beach restaurants claimed they sawfish and seafood bathed in oil.

Faced with the accident, most restaurants had to reduce their staff by about 50%, where it was necessary to bear the costs of dismissal and carry out new internal management, with new divisions of tasks, for example. Concerning the damage faced by restaurants that suffered the impacts of the oil spill, reports show that the main losses were related to the number of products in stock, loss of human capital, and the drop in the sales of these products. Finally, it was asked about the biggest challenge faced by these establishments. In most answers, it was the formulation of a new menu, working with a reduced number of employees, trying to convince the customer, or showing the products still uncooked to prove that there was no oil. In some cases, the suspension of restaurant activities happened, intensified by the pandemics in 2020.

From the answers obtained from the interview, it was possible to observe the opinion of restaurant owners and managers regarding the consumption of fish and seafood, along with the consequences for their businesses in the face of the disaster. Given the reports obtained, it was found that the smallest companies were the ones that suffered the most, as they did not have a strategy to overcome the crisis.

Thus, the need for planning on the part of restaurant managers is evident, which included risk management and contingency plans so that they can respond more quickly, in the face of a possible disaster and manage to remain in the market.

The enterprises can have information notes in their establishments, provided by their suppliers, to prove the assured quality of the products sold, thus avoiding the non-consumption of these products. Open visits to the kitchen, so that the customer can follow the process, and work with more transparency will also be helpful. Acting in this way can lead to the strengthening of the business, both in terms of the brand and credibility, increased sales, more generation of jobs, and the strengthening of gastronomic tourism for the region.

Moreover, another interesting point is that even in the face of the accident some restaurants that are part of the research did not feel any change in the consumption of fish and seafood. Since one of the main sources of information was the television, which received information from the responsible government agencies, the information on the assured quality of the products was acquired by the suppliers.

5. Conclusions

This research aimed to analyze the perception of entrepreneurs in the consumption of fish and seafood prepared in restaurants in the face of the oil spill on the coast of northeastern Brazil in 2019. For that, an interview script was prepared based on the review of the literature, this instrument was applied, and from there, data were collected and analyzed.

From the results of the interview, it was seen that 57% of the restaurants registered a change in sales, with a drop between 20 and 40% in the sales of these products, leading to negative consequences for their restaurant businesses. Given the results presented, it is clear that the study's objective was achieved.

Still, it seems that given the occurrence of an environmental accident, the impacts are not restricted only to the environment. There is a change in consumer behavior, which leads to the generation of an impact on the enterprises, with a decrease in sales, which can lead to unemployment and, in more critical situations, the closing of the business (MAITRÊ, et al., 2020).

In this way, this work presents academic importance, and the relevance of greater monitoring and control by the responsible bodies to prevent oil spills at sea. In this way, there will be no negative consequences on nature and the whole society.

Thus, it is necessary to promote strategies that can mitigate possible impacts, giving greater support to local fishermen through financial aid, helping enterprises through training, and granting credit to manage their business. Yet, more studies aimed at proving that fish are free of toxicity, and bringing more security to consumers are also needed.

In this context, the study guides society regarding the consumption of fish and seafood, taking into account food safety. Therefore, restaurant owners need to know the consumption behavior of consumers and work with strategies aimed at meeting their needs, in addition to understanding the perception of consumption in the face of environmental disasters.

This work is in line with the objectives established with the 2030 Agenda of the United Nations Brazil for Sustainable Development, with emphasis on responding to item 14 "life on water", in addition to contributing to other items through the efficient management of resources available in nature, as well as in the quality of life.

6. Acknowledgement

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Fundação de Amparo à Ciência e Tecnologia de Pernambuco (FACEPE).

References

ANDERSON, J. L.; ASCHE, F.; GARLOCK, T., 2018. Globalization and commoditization: The transformation of the seafood market. Journal of Commodity Markets. 12, 2–8.

DEY, M. M.; SURATHKAL, P.; CHEN, O. L.; ENGLE, C. R., 2017. Market trends for seafood products in the USA: Implication for Southern aquaculture products. Aquaculture Economics and Management. 21, p. 25–43.

FIORELLA, K. J.; Bageant, E. R.; Mojica, L.; Obuya, J. A.; Ochieng, J.; Olela, P.; Otuo, P. W.; Onyango, H. O.; Aura, C. M.; Okronipa, H., 2021. Small-scale fishing households facing COVID-19: The case of Lake Victoria, Kenya. Fisheries Research. 237.

GALIERIKOVÁ, A.; MATERNA, M., 2019. World Seaborne Trade with Oil: One of Main Causes for Oil Spills? Transportation Research Procedia, 44, 297–304.

GREMA, H. A. KWAGA, J. K. P.; BELLO, M.; UMARU, O. H., 2020. Understanding fish production and marketing systems in North-western Nigeria and identification of potential food safety risks using value chain framework. Preventive Veterinary Medicine. 181.

HA, T. M.; SHAKUR, S.; PHAM DO, K. H., 2020. Risk perception and its impact on vegetable consumption: A case study from Hanoi, Vietnam. Journal of Cleaner Production. 271.

IBAMA, 2020. Manchas de Óleo: Boletim da Fauna. https://www.ibama.gov.br/phocadownload/emergenciasambientais/2020/manchasdeoleo/2020-02-12-ibama-manchasdeoleo-boletim-fauna.pdf. (accessed 23 November 2020).

LAMERE, K.; MÄNTYNIEMI, S.; HAAPASAARI, P., 2020. The effects of climate change on Baltic salmon: Framing the problem in collaboration with expert stakeholders. *Science of the Total Environment*. 738.

LIEN, K. W.; LING, M. P.; PAN, M. H., 2020. Assessing Japan Imported Food Products Radiation Doses and Exposure Risk Following the Fukushima Nuclear Accident. *Exposure and Health*. 12, 215–225.

LOURENÇO, R. A. COMBI, T.; ALEXANDRE, R.; TAROU, S., 2020. Mysterious oil spill along Brazil's northeast and southeast seaboard (2019–2020): Trying to find answers and filling data gaps. Marine Pollution Bulletin. 156.

MAGRIS, R. A.; GIARRIZZO, T., 2020. Mysterious oil spill in the Atlantic Ocean threatens marine biodiversity and local people in Brazil. Marine Pollution Bulletin. 153.

PETTERSEN, I. K., ASCHE, F., 2020. Hedonic price analysis of ex-vessel cod markets in norway. *Marine Resource Economics*. 35, 343–359.

SHAH, F. T., SYED, Z., IMAM, A., RAZA, A., 2020. The impact of airline service quality on passengers' behavioral intentions using passenger satisfaction as mediator. Journal of Air Transport Management. 85.

SLACK, N.; CHAMBERS, S.; JOHNSSTON, R. 2013. Operations management. 7. Pearson, US.

SULIMAN, M.A.; OLAREWAJU, T.A.; BASHEER, C.; LEE, H.K., 2020. Microextraction and its application for petroleum and crude oil samples. *Journal of Chromatography A*. 1636.

TUNCER, I.; UNUSAN, C.; COBANOGLU, C., 2020. Service Quality, Perceived Value and Customer Satisfaction on Behavioral Intention in Restaurants: An Integrated Structural Model. Journal of Quality Assurance in Hospitality and Tourism. 0, 1–29.

VOSS, C.; TSIKRIKTSIS, N.; FROHLICH, M., 2002. Case research in operations management. International Journal of Operations & Production Management. 22, 195-219.

WICKLIFFE, J. K. SIMON-FRIEDT, B.; HOWARD, J. L.; FRAHM, E.; WILSON, M. J.; PANGENI, D.; OVERTON, E. B., 2019. Consumption of Fish and Shrimp from Southeast Louisiana Poses No Unacceptable Lifetime Cancer Risks Attributable to High-Priority Polycyclic Aromatic Hydrocarbons. Risk Analysis*.* 38, 1944–1961.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Environmental Indicator of the use of Material Resources in Public Schools in the City of Salvador - Bahia

JESUS, J.O.N.[a*]; ASSUERO, V. L[a]; CAUÃ, M. M[b]; SOPHIA, S. B[b]; ELLEN B. N. S[b]; OLIVEIRA-ESQUERRE, K.[a]

[a]*Federal University of Bahia (UFBA), Industrial Engineering Program (PEI), Salvador, Bahia, Rua Professor Aristídes Novis, 02, Federação, 40210-630, Brazil.*

**Corresponding author, jose.oduque@hotmail.com*

Abstract:

With a total of 232 schools, the state public education network in the city of Salvador in the state of Bahia, serves 218,194 thousand students. Due to the high number of students and employees in the population, public schools monthly demand a high number of material resources, water and energy flows to carry out teaching activities. As a result, methodologies focused on environmental modeling, such as Life Cycle Analysis (LCA), have been widely used as a strategy to reduce the environmental impact of schools. The objective of this work is to evaluate, through the LCA, the environmental profile of 04 public schools located in the municipality of Salvador in the state of Bahia and to propose scenarios for the mitigation of their environmental impact. The application of LCA followed the methodological framework recommended in ISO 14044 (2006), according to the four standardized phases. The impact assessment considers the ILCD 2011 Midpoint+ package of methods for the environmental categories, AWARE (Remaining Available Water) for water footprint and CED (Cumulative Energy Demand) for energy demand in the SimaPro 8.4 software. The life cycle inventory was prepared from data obtained through technical visits to the 04 schools, documental research, inventory database, school records and literature. The categories with the highest relative participation in the potential impacts identified were particulate matter, ecotoxicity and human toxicity, with emphasis on schools 03 and school 04. As for the water footprint category, it is evident in the modeling that school 03 is the one that presented less impact, this is because the school has a water management program and minimization of its use in the school environment. Thus, this study serves to develop strategies for environmental and energy improvement to increase the eco-efficiency of Brazilian public schools, especially those located in the region of Salvador in Bahia.

Keywords: Public Schools, Life Cycle Analysis, Environmental Indicator

1. Introduction

With the approach of higher education institutions to the universe of public schools in Brazil, students gain more time and space to study, learn and develop pedagogical actions in different contexts, which combine sport, art, work, science and culture (ACCETTA et al., 2021). In complementary activities, students also have scientific initiation and research classes, citizenship and student participation, ethnic-racial, cultural and identity relations, environmental education, digital communication and media use, acquiring new behavioral routines. The Data Science in Public Education project works on the development of tools and means to support the training of students and the training of teachers from public schools in Salvador in the area of data science in order to recognize, build and propose solutions to problems of society. In 2019, 500 students participated in the initial stage of enchanting the exact sciences area through the Girls in Data Science Project, supported by CNPq/MCTIC, Public Notice No 31/2018 - Girls in Exact Sciences, Engineering and Computing. 50% of these visited the university and participated in the formative and informative processes with dynamics carried out in the schools in five schools: Colégio Estadual Evaristo da Veiga, Colégio Estadual Henriqueta Martins Catharino, Colégio Estadual Ypiranga, Escola Municipal Cidade de Jequié and Colégio Estadual Mário Costa Neto.

In 2020, with the support of Itaú Social, this initiative was expanded with the Data Science in Public Education Project, to include high school classes and the entire school public, regardless of biological sex. Colégio Estadual da Bahia (Central) joins the other 5 schools in this partnership with the university. The team works on four fronts: (1) Data Science: bringing students and schools closer to the universe of data, in order to take ownership of data and information systems and enable decision-making; (2) Artificial Intelligence: encouraging access to the technological universe, through experimentation and interaction with free and easily accessible tools; (3) Investigative Practices: promote educational experiments through empirical exercises, observation practices, discussion of processes and production of scientific knowledge in different areas of knowledge, (4) Protagonisms: sharpen students' criticality and invite them to debate and action to promote an environment that encourages social justice. Due to the Covid-19 Pandemic, mediations, guidelines, meetings in context took place in online format throughout 2020 and 2021, and became face-to-face in 2022.

Currently, about 50 students receive junior scientific initiation grants. All didactic material is based on the daily life experienced by students in their neighborhoods, but also on the (re)knowledge of the city. Students between 12 and 17 years old built electronic games that deal with the mobility of wheelchair users in the community and discussed accessibility in public transport for the visually impaired population, proposed the use of tools that reduce food waste at school and also collected data on bullying in the school context. Through theoretical and empirical approaches to science, based on evidence, the activities contributed to broaden the perception of students and teachers about their daily lives, whether at the neighborhood scale or at the city scale through evidence, bringing them closer to the areas of data science. , artificial intelligence and scientific thinking. Regarding environmental practices inserted in the school context, students have the opportunity to learn about the tools that are used for data collection, selection and analysis, such as the LCA. The objective of this work is to evaluate, through the LCA, the environmental profile of 04 public schools located in the municipality of Salvador in the state of Bahia and to propose scenarios for the mitigation of their environmental impact.

2. Methodology

This work evaluated, through the LCA, the environmental profile of 04 public schools located in the city of Salvador in the state of Bahia and proposed scenarios for the mitigation of their environmental impact. The application of LCA followed the methodological framework recommended in ISO 14044 (2006), according to the four standardized phases. The impact assessment considers the ILCD 2011 Midpoint+ package of methods for the environmental categories, AWARE (Remaining Available Water) for water footprint and CED (Cumulative Energy Demand) for energy demand in the SimaPro 8.4 software. The life cycle inventory was prepared from data obtained through technical visits to schools, documental research, inventory database, school records and literature. We collected data from the 04 schools to build an inventory water and energy flows (table 1) of the use of material resources (table 2). For the background lifecycle inventory, the ecoinvent database (WERNET et al., 2016) version 3.3 was used with cutoff criteria (alloc rec) and market (which includes transport estimates) in the Simapro software.

Table 1 Inventory of the flow of water and energy used monthly in the 04 public schools.

Materials	Amount	Unit	*GSD2
Water	235,83	m³	1,05
Electricity	3576	kWh	1,5

Source: Own elaboration
*GSD2: square geometric standard deviation.

Table 2 Monthly inventory of the use of consumables for the construction of classes in 04 public schools.

Material	The amount	Unit	*GSD2
hydrogenated alcohol	0,01	m³	1,07
Alcohol gel	0,01	m³	1,05

Cotton	0,5	kg	1,5
blow balls	0,5	kg	1,05
balloons	0,5	kg	1,05
whiteboard pens	50	unity	1,05
Magnetic board pens	50	unity	1,5
Clips	5.000	unity	1,07
Elastex	500	unity	1,07
sponge for dishes	15	unity	1,07
white chalk	100	unity	1,5
colored chalk	100	unity	1,05
Bobby pins	5.000	unity	1,07
General cleaning supplies	1	m^3	1,05
Toilet paper	3500	unity	1,07
craft paper	12500	unity	1,05
plastic for classifier	5	unity	1,05
Kraft tape roll	25	meters	1,05
double sided tape roll	100	meters	1,05
duct tape roll	10	meters	1,05
Large roll of colored tape	10	meters	1,05
Plastic bags	350	unity	1,05
printer ink	10	unity	1,05
toner	20	unity	1,05

Source: Own elaboration
*GSD2: square geometric standard deviation.

3. Results

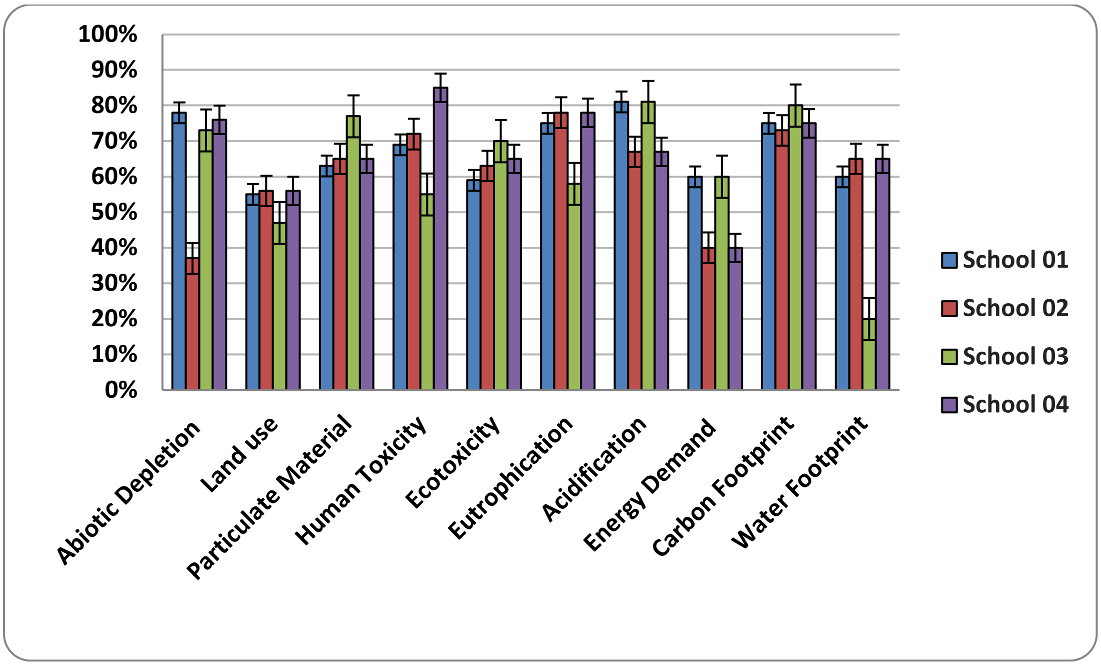


Table 3 – Results of the environmental assessment using the inventory of the 04 schools

Schools	Abiotic Depletion	Land use	Particulate Material	Human Toxicity	Ecotoxicity	Eutrophication	Acidification	Energy Demand	Carbon Footprint	Water Footprint
School 01	78%	55%	63%	69%	59%	75%	81%	60%	75%	60%
School 02	37%	56%	65%	72%	63%	78%	67%	40%	73%	65%
School 03	73%	47%	77%	55%	70%	58%	81%	60%	80%	20%
School 04	76%	56%	65%	85%	65%	78%	67%	40%	75%	65%

As the use with greater relative participation in the potential impacts, categories of particulate matter, ecotoxicity and toxicity were identified, with emphasis on schools 03 and school 04, as shown in table 3. As for the category of particulate matter, it is noticed that materials that produces microparticles in its use and in its production process and in schools. Regarding categories of ecotoxicity and human toxicity, it was noted that the resources available in didactic schools mostly contained substances that are harmful to health and the environment, such as inks and toner from printers that require proper disposal. in the environment. In the other categories, note that the environmental performance of school 02 is lower in relation to the potential impacts of school 03 and school 04. In this way, the disclosure of the impact categories proposed by ACV in the school environment is highlighted. As for the water footprint category, it is more evident in the modeling that school 03 is the one with the lowest impact, this is because the school has a water management program and minimization of its use in the school environment.

4. Conclusions

The greatest contributions of environmental impacts of the 04 schools were the categories of particulate matter, ecotoxicity and human toxicity. For the categories of energy demand and carbon footprint, the greatest impacts are also related to school 03 and school 04, on the other hand, school 01 and school 02 had advantages over schools 01 and 02 in the Water footprint and eutrophication categories. Thus, this study can be used for the development of environmental and energy improvement strategies to increase the eco-efficiency of the Brazilian public-school environment. Environmental management strategies must be set up in public schools in order to mitigate environmental impacts and contribute to a more sustainable learning process.

5. Acknowledgement

We thank the National Council for Scientific and Technological Development (CNPq) for the support and funding of this research and the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – funding code 001.

6. References

Angelina Accetta Rojas . Gestão e formação cultural no ensino superior: a criação da galeria virtual no contexto da pandemia COVID-19. ue, 21 Dec 2021 in Extraprensa - Cultura e Comunicação na América-Latina.

Arantes, D. Camila C. Túlio A. P. Ribeiro, José E. S. Paterniani, Marina S. S. Tateoka, Gabriela K. E Silva. 2014. Uso de coagulantes naturais à base de moringa oleifera e tanino como auxiliares da filtração em geotêxtil sintético não tecido.

Aware (Available Water Remaining). 2016. Is the recommended method from WULCA to assess water consumption impact assessment in LCA, the method was also endorsed by the EU Joint Research Center.

Bratby, J. 2006. Coagulation and Flocculation in Water and Wastewater Treatment – Third Edition Editors' Choice. John Bratby, IWA Publishing.Cencic, O., Rechberger, H., 2008. Material Flow Analysis with software STAN. J. Environ. Eng. Manage. 18 (1), 3-7.

European Commission – EC. 2012. Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods, first ed. Publications Office of the European Union, Luxembourg.

Graham, K. S.; Lee, A. C. H. & Barense, M. D. 2008. Impairments in visual discrimination in amnesia: Implications for theories of the role of medial temporal lobe regions in human memory. European Journal of Cognitive Psychology, 20(4), 655-696.

Goedkoop, M.; Oele, M.; Leijting, J.; Ponsioen, T.; Meijer, E. 2016. Introduction to LCA with SimaPro, ed. Pré, Amersfoort.

Iso - International Organization for Standardization. 2006. ISO 14044: Environmental managements - life cycle assessments – requirements and guidelines.

Jungbluth, N.; Frischknecht, R. 2010. Part II: 2. Cumulative energy demand, in: Hischier, R.; Weidema, B.; Althaus, H.-J.; Bauer, C.; Doka, G.; Dones, R.; Frischknecht, R.; Hellweg, S.; Humbert, S.; Jungbluth, N.; Köllner, T.; Loerincik, Y.

Mangrich, A. S. et al. 2014. Química verde no tratamento de água: Uso de coagulante derivado de tanino de Acácia mearnsii. Revista Virtual de Química, Curitiba, v. 6.

Ozacar, M.; Şengil, I.; Teker, M. 2002. Adsorption of Acid Dyes on Alunite-ZnO Mixtures from Aqueous Solutions," SAÑ Fen Bilimleri Dergisi, 5(1), 63–68.

Rosalino, M. R. R. 2011. Potenciais Efeitos da Presença de Alumínio na Água de Consumo Humano.

Tzoupanos, N. D. Zouboulis A. I. Zhao Y. C. 2008. The application of novel coagulant reagent polyaluminium silicate chloride) for the post-treatment of landfill leachates.

Weidema, B. P.; Wesnæs, M. S. 1996. Data quality management for life cycle inventories-an example of using data quality indicators. Journal of Cleaner Production. V. 4, pp. 167-174.

Wernet, G.; Bauer, C. Steubing, B. Reinhard, J.; Moreno-Ruiz, E.; Weidema, B. 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment. V. 21, pp. 1218-1230.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Informal Economy and Data Availability: Understanding the Recirculation of Medicines in Brazil

VIEGAS, C.V. [a*], BOND, A.[b,c], COIMBRA, M.[c,] SARTORI, A[d]., RUBEM BERTOLO[e]

a. Universidade Federal do Rio Grande do Sul
b. University of East Anglia, School of Environmental Sciences
c. University Potchefstroom. School of Geo and Spatial Science, North-West
c. State Health Authority, Rio Grande do Sul, Brazil
d. Pharmacy Regional Council, Rio Grande do Sul, Brazil
e Unopar University, Brazil
**Corresponding author, cldviegas@gmail.com*

Abstract

The reverse flows of medicines for a possible reuse are not a novelty. There are many studies trying to overcome the hurdles for the recirculation of such goods in order to attain the needs of low-income persons and to curb wastage and improper use of medicines. Nevertheless, as the arrangements for medicines returns vary across countries, there is need to pay attention to the structures and organization of the management of medicines returns. In Brazil, the Solidary Pharmacy model has expanded in many municipalities, running against the Federal directives that categorise as wastes any medicine in a state of disuse, regardless of their intrinsic condition. The model of the Solidary Pharmacies is still understudied with respect to the dichotomy between its legal basis side by side with the informal economy it boosts while indirectly freeing-up income that would be employed to buy medicines for other needs of people that cannot afford medicines. Attempts to explore this dichotomy through a formal data collection based on a questionnaire addressed to 28 Solidary Pharmacies in three different states failed given the informal nature of these Solidary Pharmacies. A different search strategy was then employed through the investigation of unstructured information of the Solidary Pharmacies using the Internet. As a result, data from eight such pharmacies were obtained through Google searches, albeit with significant gaps. It was possible to find that the Solidary Pharmacies demonstrate a complicated model of medicines reverse flows, as they mix informal outcomes with governmental structures. Regardless the lack of robust data publicly available, many Solidary Pharmacies free-up significant amounts of income to local needy persons. Their main failure is the absence of publicly-available data on physical amounts and monetary values of the medicines redispensed. Further research efforts are necessary to fill this gap.

Keywords: Solidary Pharmacies; medicines reverse flows; informal economy; circularity; public data.

1. Introduction

Medicines wastage in diverse sources such as hospitals, medical clinics, distribution, retail systems, and throughout public residences, is a widely discussed problem (Mariarcher et al., 1998; Mackridge et al., 2007; Viegas et al., 2019). To address this, schemes of pharmaceutical goods returns have been formally reported in some US States since 2004 (Grasso and Galvin, 2009), in Greece, through the GivMed initiative (Alhamad and Donyai, 2020) and at least in some Brazilian States (Viegas et al., 2021). At the same time, recent research demonstrates medicines shortages in public health system are occurring due to demand-supply imbalances and the stringent governmental procurement policies, aggravated by the effects of the COVID-19 pandemic (de Vries et al., 2021). Also, the environmental and health damages caused by incorrect disposal of medicines (Ze-hua et al., 2011; Martínez-Alcalá et al., 2018) raise concerns about the need for robust public policies that boost the awareness of populations about correct drugs disposal. However, systems of pre-expiry and expired medicines returns are not part of formal public policies in the majority of countries. Although recent studies give space to describe medicines returns as a type of Circular Economy (CE) practice (Alshemari et al., 2020; Patil et al., 2021), the CE is not widely regulated as a public policy in many countries (Mangla et al., 2018). Medicines returns activities, mainly on a small scale, are typically performed as informal activities that additionally generate informal incomes (by freeing-up finances that would otherwise be spent on medicines).

There is consensus that many types of medicines should be expressly excluded from any recirculation possibility. This includes namely: manipulated medicines or others suspected of having been violated; poorly identified, with illegible name or in a foreign language; products without expiration date or dosage, batch concentration, as well as fractions of medicines that do not have batch identification and expiration date; drugs without physical integrity, which present stains, lumps, discoloring, humidity damage, apparent deformation and other damages; and eye drops, ointments, syrups with broken seals or easily damaged through heat exposure (thermolabile)(Rio Grande do Sul State, 2019).

Currently, some countries such as the US and Greece, maintain medicines return programs in collaborative schemes involving government, producers and retailers, while others such as Canada, Australia and New Zealand incentivise returns of such products only for environmentally correct final disposal (Alshemari et al., 2020). In Brazil, medicines returns for a new use – limited to those medicines not expressly excluded as per list above - are not subject to standardized procedures. Federal legislation and National Health Surveillance Authority (Anvisa) rules understand medicines as wastes that need to be safely disposed of in hazardous wastes landfills or through incineration (Anvisa, 2018; Brazil, 2020) while several municipalities in Brazil, and particularly the Rio Grande do Sul State have enacted laws enabling the possibility of medicines redispensation - in case of not expired products and under the quality assessment and supervision of pharmaceutical professionals. In fact, in Brazil, medicines reuse is a practice supported by the so-called Solidary Pharmacies in diverse municipalities, although no official operational procedures and records on the performance of such establishments are explicitly available to the citizens.

Under the current Federal Brazilian Constitution (Brazil, 1988), municipalities, States, Districts, and the Federal government have common and competing competency to enact laws on health and environment. It enables the possibility of diverging orientation about the destination of medicines technically considered able for a new consumption cycle. Nevertheless, scientific knowledge has experimented a fast advance with respect to the technological requirements for medicines reuse (Hui et al., 2020) and recirculation strategies (Alshemari et al., 2020).

From the perspective of the pharmacists in charge of redispensing, the main requirements for delivering medicines to a new consumption cycle comprise storage conditions assessment (temperature, moisture, light); guarantee of package integrity (without stain, smell); verification of last dispensing date, tamper-proof packaging, traceability of origin in order to avoid counterfeit, observation of legal, regulatory and cost-effective issues, and assurance that the pharmacist's responsibility is fulfilled (Hui et al., 2020). The accomplishment of such requirements demands not only specialised and up-to-date knowledge, but also significant time dedication from the pharmacists.

The present research highlights the unstructured documented *modus operandi* in eight Brazilian Solidary Pharmacies in three Brazilian States (São Paulo, Santa Catarina and Rio Grande do Sul) with respect to two axes: (i) the informal economy they trigger; and (ii) the performance publicization they present. Regardless of being based in the local governmental sector, where strict legislation mandates procedures and Constitutional principles rule transparency, these Solidary Pharmacies generate indirect, informal income, but not in a transparent way that is easily available to the citizens. Indeed, they present ill-structured and difficult to access processes which resists objective evaluation. This paper is structured as follows: after this Introduction, a brief literature review is presented (section 2), followed by the Methodological section (3), Results (4), Discussion, Limitations and Final Remarks (5).

2. Literature Review

The main theoretical axes necessary to understand the unexplored roles of the Solidary Pharmacies in Brazil are: (i) informal economy concepts and features; (ii) Constitutional principles that rule the public management activity in the country. It is also debatable whether the CE principles (Alhamad and Donyai, 2020; Alhamad et al., 2020) are fully applied to the case of medicines returns and to what extent there remains random initiatives of circularity for the sake of affordability to the needy people (Viegas et al., 2021).

Informal economy has been studied for long time as a way of alternative economic development, which is in turn considered a force that boosts wealth in society (Feige, 1990). There is a variety of meanings to the informal economy, as "subterranean, hidden, gray, shadow, clandestine, illegal, unobserved, unreported, unrecorded, second, parallel, and black" (Feige, 1990:991). In the case of the Solidary Pharmacies, indirect incomes are generated to the potential beneficiaries every time they receive, for free, medicines assessed as being suitable for recirculation (by having income available that would otherwise have been spent on purchasing the medication). Although such amounts are likely recorded by the pharmacists, citizens that receive such medicines do not usually report and/or record the monetary outcomes. They instead spend the saved amounts on other individual needs (Bertolo et al., 2018). Godfrey (2011) considers the informal economy as an emerging form of poverty alleviation and a complex construct as well. It can be a subservient part of the formal economy running at a small scale (Godfrey, 2011).

Economists and sociologists avoid judgement with respect to categorizing the informal economy as good or bad. According to Worou-Houndekon and Pesqueux (2013: 164), the informal economy "can be defined as a domain where activities are not dictated by an economic legislation." In the context of the Solidary Pharmacies, the local legislative rules usually do not care about economic control records, although the municipal health authorities or the pharmacists are likely to calculate the economic expenses of maintaining their activities and therefore record the monetary amounts redispensed. It is, though, very difficult to standardise, as the accounting reference depends heavily on the medicines' monetary value at the moment of the recording and can vary according to issues such as the brand (branded versus generic medicines) or according to the market context. Besides these intrinsic aspects, Morales et al. (1997) observe that informal and formal processes overlap and are related to the way people behave looking for a better living standard. According to Davidescu et al. (2022: 684), "[i]nformality, as a result of individuals' maximising their payoffs, is a micro phenomenon, but the magnitude and the scale of policies used to address it can make it seem as a macro phenomenon". Given such arguments, it is possible to consider that monetary savings of the Solidary Pharmacies users are the informal income they incorporate to their domestic budget once they become systematic receivers of redispensed medicines. For now, there is no wide study showing the economic and socioeconomic effects of the Solidary Pharmacies activities for their users.

In parallel way, the Solidary Pharmacies provide of the medicines redispensed, and this amount should be easily available for all citizens and stakeholders in order to fulfill the public management principle of publicity stated in the Federal Constitution, article 37 (Brazil, 1988). The same reasoning should be applied to the physical amounts of recirculating medicines. Once the Solidary Pharmacies dispensation outcomes are fully publicized, any stakeholder, citizen or public agent, should have assured the necessary transparency that would enable financial control and subsequent sharper financial planning for medicines public procurement. If well organized, according to the profile of beneficiaries, it would also allow the financial and physical traceability of the returned medicines routes. As a result, the simple application of the Constitutional publicity principle, in this context, could increase the visibility of the redispensation programs and incentivise a better understanding of the socio-economic impacts of the Solidary Pharmacies, a wider adhesion of the supply chain stakeholders to such programs, and a stricter quality control of the products delivered to the needy persons. It would qualify the circularity of ready-to-reuse medicines through the data transparency, which would represent an advancement compared to the current but vague idea of applying the Circular Economy principles to medicines returns.

Once it is assumed that the Circular Economy aims at decoupling the use of natural resources (whether raw material or subproducts) from the economic growth (Kirchherr et al., 2017), circularity, in the case of redispensing medicines, would relate to the association between increasing medicines wastage prevention (with rational purchasing from consumers, rational prescription from physicians) and the degrowth of ignorance that surrounds informal economic outcomes of Solidary Pharmacies work (through organized data in Solidary Pharmacies, in terms of quantity and types of received and redispensed goods). In other words, easily accessible, publicly available data of such redispensation programs would provide powerful tools for better health public management, mainly for improving the medicines public procurement systems in the municipalities.

3. Methodological Procedures

During six months (September 2021-March 2022), questionnaire surveys were sent via telephone and e-mail messages to a list of three Solidary Pharmacies in Sao Paulo (Araraquara, Sertaozinho, Ribeirao Preto municipalities); three in Santa Catarina (Blumenau, Rio do Sul, Criciuma municipalities); and another 15 in Rio Grande do Sul State (Bento Gonçalves, Bom Principio, Canguçu, Caxias do Sul, Charqueadas, Farroupilha, Flores da Cunha, Ivoti, Lagoa Vermelha, Morro Redondo, Nova Petropolis, Rio Grande, Santiago, Osorio, Barra do Rio Azul municipalities). The questionnaire is structured in four sections – the first has 17 questions about the origins, organization, structure and routines of the pharmacies; the second contains 16 questions on the environmental, social and economic impacts of these unities; and the third, 14 questions about the barriers and opportunities to the work of the Solidary Pharmacies. Until April 2022, only one full questionnaire was received with short answers (Barra do Rio Azul municipality), but no quantitative data was available.

Early in April 2022, new phone calls reinforced the invitation to participate in the research. In May 2[nd], 2022, a short video (https://drive.google.com/file/d/1S8o49vmW9ZUBJLf0_XpIS-ImrC_20rr-/view?usp=sharing) was sent to the pharmacists responsible for each Solidary Pharmacy using the WhatsApp social media. This presentation was the last attempt in terms of a call to participate, and no responses were received three weeks after this final communication attempt.
As an alternative, unstructured data on some of the listed Solidary Pharmacies were obtained through a Google Search. Using the expression "Solidary Pharmacy" and the name of each municipality in the Google search engine, and limiting the search to ten pages for each search, recent news releases by some municipal Health Authorities or by the local press were found. At the end of the search, carried out on May 25th 2022, unstructured data on redispensation (either on volumes or financial data) in eight municipalities were found in unstructured way. In order to get a clearer picture about how the available quantitative data could impact the population of each municipality, other searches were performed in the website of the Brazilian Institute of Geography and Statistics (IBGE) (https://cidades.ibge.gov.br/), which keeps a reliable database on Brazilian demographic data including the socioeconomic population profile of the 5,568 Brazilian municipalities.
For the estimation about the socioeconomic impact of the selected Solidary Pharmacies in their respective communities, there were considered both unstructured available data, the total population of each municipality, and the population with income of a half of the minimum Brazilian wage. Some of the Solidary Pharmacies establish a minimum income of one or 1.5 times the Brazilian minimum wage as a requirement to deliver medicines to beneficiaries, or state as beneficiaries the people that cannot afford medicines in their municipalities. At the same time, the IBGE's databases (a reliable source of socioeconomic information in Brazil) provide relative income data only for the range of population with a half of the Brazilian minimum wage. Given the reliability and the wide range of historical data offered by IBGE, this reference was employed to calculate the potential indirect/informal income produced by the municipal pharmacies programs, in physical, monetary or both types of data, when the municipalities themselves do not make available such type of data. The currency conversion followed the value of the American dollar (USD) considering the average rate in May 2022 (1 USD = BRL 4,71).

4. Results

The results are organized according to data availability. The municipalities of Ribeirao Preto (Sao Paulo State), Blumenau (Santa Catarina State), Bom Princípio, Canguçu and Ivoti (all in Rio Grande do Sul State) provided only physical data (packages, units redispensed, or kilograms). In this case, an estimate of the number of beneficiaries can be outlined with IBGE data. Bom Principio and Canguçu also provided the number of beneficiaries along with physical data, which make the results more realistic. Rio do Sul (Santa Catarina State) and Lagoa Vermelha (Rio Grande do Sul State) provided monetary data and numbers of beneficiaries, enabling a clearer picture of the socioeconomic benefits. However, Santiago (Rio Grande do Sul State) provided physical and corresponding monetary data, but not the number of beneficiaries, which required the employment of IBGE data.

Given the unstructured nature of all but the IBGE data, the type and the temporal range of the data are very uneven. For instance, while Ribeirao Preto provided a whole balance of 20 years of their program, Santiago and Rio do Sul offered information from one month only, and the other municipalities disseminated data from an average of 12 months.

From the available information, it is possible to find that Lagoa Vermelha enabled an indirect income of USD 28.41 per capita in redispensed medicines from December 2019 to December 2020, and Rio do Sul, USD 5.41 per capita in one single month (August 2021). In Santiago, this amount was USD 4.05 in January 2022 only. If an extrapolation could be carried out for a whole year, in a steady situation, the indirect informal income enabled by the Solidary Pharmacy of Rio do Sul would be USD 64.92 per capita, and the corresponding value for Santiago citizens of low income would reach USD 48.59 per capita.

The majority of the municipal laws do not limit the access to the medicines in recirculation under a special condition unless to claim the requirement of a low-income person (Canguçu, Lagoa Vermelha, Santiago). Others expressly address the benefit to people that cannot pay for medicines, regardless of their income (Ribeirao Preto, Ivoti), and to citizens registered in the National Health System (SUS), aged above 14 years old (Rio do Sul). The Blumenau program was created to face a humanitarian emergency in 2008 (due to floods and landslides), and it does not impose restrictions for receivers. Only the Bom Principio municipal program limits the access to persons with a maximum income of 1.5 Brazilian minimum wage. In Figure 1, a summary of the data from each selected Solidary Pharmacy is presented, with the original source of the information and the corresponding municipal law that created the pharmacy.

Municipality	**Law/ year of pharmacy creation**	**Physical unities dispensed**	**Monetary values dispensed**	**Number of beneficiaries (*)**	**Range of time considered**	**Original data source**
Blumenau	7,223/2008	2,000 kg	Not informed	(*) At least 15,851 persons	January-September 2021	https://www.blumenau.sc.gov.br/secretarias/secretaria-de-saude/semus/farmaacia-solidaaria-jaa-recebeu-duas-toneladas-de-medicamentos-este-ano81
Bom Principio	2784/2019	840 physical unities	Not informed	458 persons	April 2020-April 2021	https://www.bomprincipio.rs.gov.br/noticia/view/4870/farmacia-solidaria-fez-mais-de-840-dispensacoes-de-medicamentos-em-seu-primeiro-ano-de-atividades
Canguçu	4,631/2018	3,144 physical unities	Not informed	59 persons (53 unities/person)	Feb 2020-Aug 2021	http://revistas.cff.org.br/?journal=experienciasexitosas&page=article&op=download&path%5B%5D=2917&path%5B%5D=1850
Municipality	**Law/ year of pharmacy creation**	**Physical unities dispensed**	**Monetary values dispensed**	**Number of beneficiaries (*)**	**Range of time considered**	**Original data source**
Ivoti	3,300/2020	40,000 physical	Not informed	(*) At least 4,813 persons	January-April 2021	https://www.camaraivoti.rs.gov.br/assets

		unities (10,000 per month)		(2.1 units per capita per month)		/files/atas/Ata_n%C2%BA_1865_09-08-20211.pdf
Lagoa Vermelha	7,612/2019	Not informed	USD 12,019.74	423 persons (USD 28.41 per capita)	December 2020-December 2021	https://lagoavermelha.atende.net/cidadao/noticia/em-um-ano-de-atendimento-a-farmacia-solidaria-doou-mais-de-r-56-mil-em-medicamentos
Ribeirao Preto	9,498/2002	115,000 packages	Not informed	29,218 persons/year	Full year 2002-2022	https://www.ribeiraopreto.sp.gov.br/portal/noticia/farmacia-da-gente-completa-20-anos-de-funcionamento-em-ribeirao-preto
Rio do Sul	5,725/2016	Not informed	USD 6,454.35	1,192 persons (USD 5.41 per capita)	August 2021	https://riodosul.atende.net/cidadao/noticia/farmacia-solidaria-beneficia-pacientes-com-medicamentos-gratuitos-provenientes-de-doacao/
Santiago	315/2021	200 physical unities	USD 6,095	(*) At leas 1,503 persons (USD 4.05 per capita)	January 2022	https://www.santiago.rs.gov.br/noticia/7142/06-01-2022/farmacia-solidaria-confira-a-lista-de-medicamentos-disponiveis-gratuitamente

(*) For the "per capita" estimation, there was considered the percentage of each municipal population with income of a half of minimum Brazilian wage in the respective municipality, according to IBGE data (https://cidades.ibge.gov.br/).

Fig. 1. – Summary of unstructured data of the Solidary Pharmacies available in recent Internet news

5 Discussion, limitation, and final remarks

Access to medicines is a pivotal condition for keeping a healthy living standard for many persons, mainly those with chronic diseases, that rely on medication, but have low income. In Brazil, the Solidary Pharmacies are helping many persons to achieve a socioeconomic balance in their domestic health budget. In this sense, such establishments provide forms of poverty alleviation as defined by Godfrey (2011) with respect to the role of the informal economy. However, these initiatives are running also as sources of indirect income under the structure of the municipal public authorities. This association – the informal running side by side with the formal (governmental) raises several questions. If the informal economy happens outside the legislation, as claimed by Worou-Houndekon and Pesqueux (2013), how can the phenomenon of the Solidary Pharmacies be framed, once they enable indirect, informal income, and are settled in formal, local protective legislation? What is the proper accountability structure for the Solidary Pharmacies considering the effects they bring to the beneficiaries, to the local economy, and, at the same time, to the local public planning of medicines procurement? What are the costs of these municipal units for the public managers regarding their structure and staff? How do the Solidary Pharmacies pharmacists deal with the processes of inspection (quality assessment), redispensation and accounting, considering that these pharmacies take part in the reverse flows of medicines instead of the regular flow in which the commercial pharmacies are active? To what extent does the recirculation of medicines undertaken by the Solidary Pharmacies take into account the warnings about the risks entailed in the use of medicines? These are questions yet to be answered.

The present research was based on the three main purposes that tried to address the dichotomy of informality within the public sector: the understanding of the origins, organization, structure and functioning of the Solidary Pharmacies; the unveiling of socioeconomic and environmental impacts of these establishments; and the hurdles and opportunities they embed. While trying to explore these aspects, two relevant issues was identifed: the informal economy triggered by the Solidary Pharmacies and the transparency gap they incur. Under the Brazilian Constitutional transparency principle in public management, the Solidary Pharmacies should made public their accounts in terms of physical amounts, types, and monetary amounts of received, redispensed and discharged medicines. Regardless of this orientation, during more than six months and using different strategies to gather data, the present research did not succeed to obtain such data from 28 Solidary Pharmacies in Rio Grande do Sul, Sao Paulo, and Santa Catarina States. This is the main limitation faced in the study, that has alternatively looked for unstructured data of some of these pharmacies, released on the Internet with random information.

For future research, a stringent research design is recommended in terms of procedures, with support from the Law of Information Access, with the aim of assuring (Brazil, 2011) the right of data transparency in the public sector. It was observed, in many attempts to obtain interviews, that pharmacists lack both time and the autonomy to dedicate themselves to the public dissemination of their work. Many pharmacists avoided to release information with the argument that this is a role of the local public managers, and others claimed themselves too busy, with no time to provide information. These returns light a red sign with respect to the need for a better management of the Solidary Pharmacies.

Acknowledgement

We acknowledge CNPq (Brazilian National Council for Scientific and Technological Development) financial support, process 404551-2021-1.

We acknowledge the ACPN network for the knowledge exchange that enabled this research.

References

Alhamad, H., Donyai, P. 2020. Intentions to "Reuse" Medication in the Future Modelled and Measured Using the Theory of Planned Behavior. **Pharmacy** 2020, 8, 213; doi:10.3390/pharmacy8040213.

Alhamad, H., Patel, N., Donyai, P. 2020. Towards Medicines Reuse: A Narrative Review of the Dif ferent Therapeutic Classes and Dosage Forms of Medication Waste in Dif erent Countries. **Pharmacy** 2020, 8, 230; doi:10.3390/pharmacy8040230.

Alshemari, A., Breen, L., Quinn, G., Sivarajah, U. 2020. Can We Create a Circular Pharmaceutical Supply Chain (CPSC) to Reduce Medicines Waste? Pharmacy 2020, 8, 221; doi:10.3390/pharmacy8040221.

Anvisa, 2018. Brazilian National Health Surveillance Authority. **Collegiate Resolution (RDC) 222**, Available mat:< https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2018/rdc0222_28_03_2018.pdf>. Last access: May 15th 2022.

Bertolo, R.J., Viegas, C.V., Bond, A., Borchardt, M., Pereira, G.M. 2018. Social Reverse Logistics of Used, Non-Expired Medicines (UNEM) with Public Economic Burden? An Impact Appraisal from a Municipal Program. In: In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 7th International Workshop, Barranquilla, Colombia, June 21th-21nd.

Brazil, 1988. **Federal Constitution**. Available at:<http://www.planalto.gov.br/ccivil_03/constituicao/constituicao.htm>. Last access: May 4th 2022.

Brazil, 2011. **Federal Law 12,527**. Rules the information access. Available at: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2011/lei/l12527.htm. Last aceess: May 15th 2022.

Brazil, 2020. **Federal Decree 10,388**. Regulament on Brazilian Reverse Logistics System. Available at: https://www.in.gov.br/en/web/dou/-/decreto-n-10.388-de-5-de-junho-de-2020-260391756. Last access: May 15th 2022.

Davidescu, A.A.M., Petcu, M.A., Curea, S.C., Manta, E.M. 2022. Two faces of the same coin: Exploring the multilateral perspective of informality in relation to Sustainable Development Goals based on bibliometric analysis. **Economic Analysis and Policy** 73: 683–705, https://doi.org/10.1016/j.eap.2021.12.016.

de Vries, H., Jahre, M., Selviaridis, K., van Oorschot, K.E. and Van Wassenhove, L.N. 2021. "Short of drugs? Call upon operations and supply chain management". **International Journal of Operations & Production Management**, Vol. 41 No. 10: 1569-1578. https://doi.org/10.1108/IJOPM-03-2021-0175.

Feige, E.L. Defining and Estimating Underground and Informal Economies: The New Institutional Economics Approach. **World Development**, V 19, N 7: 989-1002.

Godfrey P.C. 2011. Toward a Theory of the Informal Economy. **The Academy of Management Annals**, 5:1, 231-277, http://dx.doi.org/10.1080/19416520.2011.585818.

Grasso, C., Galvin, D. 2009-2010. The Medicine Return Project in Washington State. **Generations** – Journal of the American Society on Ageing, Vol. 3, N 4:92.

Hui, T.K.L., Mohammed, B., Donyai, P., McCrindle, R. 2020. Enhancing Pharmaceutical Packaging through a Technology Ecosystem to Facilitate the Reuse of Medicines and Reduce Medicinal Waste. **Pharmacy**, 8, 58; doi:10.3390/pharmacy8020058.

Kirchherr, J., Reike, D., Hekkert, M. 2017. Conceptualizing the circular economy: An analysis of 114 definitions**. Resources, Conservation & Recycling** 127: 221–232, http://dx.doi.org/10.1016/j.resconrec.2017.09.005.

Mariacher G.G., Rota M., Hersberger K.E. 1998. Rücklauf ungenutzter Medikamente in Apotheken [Return of unused drugs to pharmacies]. **Praxis** (Bern 1994). 1998 Oct 21;87(43):1441-3. German. PMID: 9844489.

Mackridge, A.J.; Marriott, J.F., Langley, C.A. 2007. Unused medicines with potential for misuse or abuse in primary care. **The International Journal of Pharmacy Practice**, 15: 229–233, DOI 10.1211/ijpp.15.3.0010.

Mangla, S.K., Luthra, S., Mishra, N., Singh, A. Rana, N.P., Dora, M., Dwivedi, Y. 2018. Barriers to effective circular supply chain management in a developing country context. **Production Planning & Control**, 29:6, 551-569, DOI: 10.1080/09537287.2018.1449265.

Martínez-Alcalá, I., Pellicer-Martínez, F., Fernández-López, C. 2018. Pharmaceutical grey water footprint: Accounting, influence of wastewater treatment plants and implications of the reuse. **Water Research,** doi: 10.1016/j.watres.2018.02.033.

Morales, A. 1997.Epistemic Reflections on the "Informal Economy".**International Journal of Sociology and Social Policy**, Vol. 17 Iss 3-4,:1-17, http://dx.doi.org/10.1108/eb013298.

Patil, A., Madaan, J., Shardeo, V., Charan, P., Dwivedi, A. 2021. Material convergence issue in the pharmaceutical supply chain during a disease outbreak. **The International Journal of Logistics Management**, https://www.emerald.com/insight/0957-4093.htm .

Rio Grande do Sul. 2019. **Law 15,339**. Establishes the Solidary Program Pharmacy in Rio Grande do Sul Sate. Available at:< https://leisestaduais.com.br/rs/lei-ordinaria-n-15339-2019-rio-grande-do-sul-institui-o-programa-solidare-farmacia-solidaria-conscientizacao-doacao-reaproveitamento-dispensacaopara-a-populacao-e-descarte-de-medicamentos-no-ambito-do-estado-do-rio-grande-do-sul-e-da-outras-providencias>. Last access: May 15th 2022.

Viegas, C.V., Bond, A., Vaz, C.R., Bertolo, R.J. (2019). Reverse flows within the pharmaceutical supply chain: A classificatory review from the perspective of end-of-use and end-of-life medicines. **Journal of Cleaner Production** 117719, 2019, https://doi.org/10.1016/j.jclepro.2019.117719.

Viegas, C.V., Bond, A., Pedrozo, E., Silva, T.N., Bertolo, R.J. 2021. Beyond circularity: the reverse flows of medicines in Brazilian solidary pharmacies as collaborative consumption. In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): **Advances in Cleaner Production**, **Proceedings of the 10h International Workshop**, Ferrara, Italy. November 11th.

Ze-hua, M., Na, B., Li, D., Wen-bo, S. 2011. Exploring Execution of Ecological Engineering and Cleaner Production in Pharmaceutical Industry. **Energy Procedia** 5: 679–683, doi:10.1016/j.egypro.2011.03.120 .

Worou-Houndekon, R.D., Pesqueux, Y. 2013. Informal economy as a "good" "bad practice"? Informal sale of medicines in Lomé". **Society and Business Review**, Vol. 8 Iss 2:160 – 178, https://dx.doi.org/10.1108/SBR-02-2013-0021.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Identification of Cleaner Production Opportunities in a Corporate Environment

OLIVEIRA, A. V.; PIMENTA, S. M.; LÉLIS, F. R.; MURO JR., A.

a. Instituto Federal de Goiás, Goiânia
b. Instituto Federal de Goiás, Goiânia
c. Instituto Federal de Goiás, Goiânia
d. Instituto Federal de Goiás, Goiânia
**Corresponding author, aldo.muro@ifg.edu.br*

Abstract

Together with Environmental, Social, and Governance (ESG) premises, cleaner production is no longer a luxury for companies but a decisive requirement for investors. Looking forward to promoting sustainable development and good production practices, this paper presents a case study about identifying cleaner production opportunities in a corporate environment of a financial and housing market company located in Goiânia, in the state of Goiás, in the Brazilian Midwest. A systematic literature review was done about cleaner production implementation in corporate environments, demonstrating scarce literature production in this thematic and the importance of doing more research in this area. Based on the structure suggested by the National Center of Clean Technologies, a methodology was developed to be applied to the company's object of study, considering its particularities. Opportunities for cleaner production implementation to the corporate environment company were identified, representing environmental, social, and financial gains to the company and its real estate ventures; and opportunities to mitigate energy consumption and waste disposal in the environment.

Keywords: ASG, cleaner production, sustainability.

1. Introduction

The corporate world's concern with environmental issues has increased due to the perception that each emission, whether of waste, effluent, or atmospheric pollutants, represents an ecological liability that negatively impacts the company's image, resulting in the search for optimization of production processes and business routines. In the financial market, this trend is no different.

The financial area for granting financing and the inclusion of projects in the market needs to minimize the environmental impact arising from emissions and energy consumption, turning its efforts to the implementation of cleaner production and the use of the Environmental, Social, and Governance tripod (ESG).

In his book "How to Avoid a Climate Disaster, " Bill Gates posed five questions: How do we plug things into the socket? How do we manufacture items? How do we grow things? How do we transport things? How do we cool and heat things? These questions serve the reader to question what a means of production with a low negative impact on the environment would be like and how the government could encourage technological innovations and introduce mitigating measures so that consumption and carbon emissions could be significantly reduced. In addition, the author reinforces that the gaze of current large investors is focused on companies with ESG organizational profiles (GATES, 2021).

ESG is a set of parameters and criteria that will guide the creation of new products, new services, and decision-making. In addition, ESG must be part of the company's culture, thus encouraging all employees and the community to think and take more sustainable actions. The letter "A" of the acronym covers all environmental issues and their mitigating measures, such as solid waste, quality, air quality management, carbon emissions, ecological management, and quality and management of water resources, among other matters concerning the environment. The letter "S" in the acronym refers to social issues, such as respect for human rights and labor laws, community relations, data protection, employee engagement, team diversity, and customer satisfaction. The letter "G" of the acronym alludes to the management of a company, as in the composition of the board, committee structures, corporate conduct, executive compensation, and relationship with government entities and politicians.

For the alignment of the ESG premises and aiming to obtain the ISO 14001 and System B certification, the implementation of cleaner production is necessary to insert the culture of reduction of natural resources, community awareness, and decrease in expenses for the company in question that was the object of study of the present work.

Cleaner Production has as its agenda several items to be observed and mitigated, such as water consumption, electricity consumption, and CO2 emissions. Environmental education was used as an awareness tool for the company's employees to perpetuate the culture of cleaner production in the company.

Each author approaches a different methodology regarding the implementation of cleaner production, considering the singularities of the object of study. An example of this is the steps that the National Center for Clean Technologies (CNTL, 2003) developed and the steps that Diógenes (2011) designed for a case study of the implementation of cleaner production in a hotel.

In a cost-benefit analysis of the application of cleaner production, Molinari et al. (2011) demonstrate that the benefits outweigh the costs, and the Payback Time can be less than a year. According to Giannetti et al. (2008), studies in Brazil indicated that cleaner production could generate promising results in reducing pollution and minimizing expenses with raw materials and materials during the production process.

In this sense, the present work aimed to identify the opportunities for cleaner production in a company in the financial sector aimed at civil construction, which has multidisciplinary sectors that operate from the financial market itself, to the consolidation of engineering projects, designing, thus, the best form of implementation according to the particularities of the enterprise and, later, through the indicators adopted in the research, analyze and compare the results after the performance of the project to quantify the improvements achieved.

2. Methods

Given the growth of sound environmental practices, aligned with the benefits brought by cleaner production and the international moves to adopt the system, it was realized the importance of investigating and mitigating the significant environmental impacts arising from the production process of office waste in a corporate environment, which are the generation of solid waste, especially paper and plastics and high energy consumption (Junior et al., 2015). Thus, these two items are the main focus of the mitigation resulting from implementing Cleaner Production. Regarding companies in the corporate environment, there is little literature on the application of Cleaner Production. On the other hand, it is known that it is a growing market for the alignment of corporate culture with the premises of ESG, in which there is considerable speculation on tools and practices in environmental management.

Thus, as a suggestion, the CNTL (2003) brings five phases of implementing cleaner production techniques: Phase 1 – Planning and Organization; Phase 2 – Pre-assessment and Diagnosis; Phase 3 – Assessment; Phase 4 – Feasibility Study; Phase 5 – Implementation. This cleaner production implementation strategy aims to avoid the generation of waste and emissions, reintegrate waste that could not be avoided in the chain and recycle waste that could not be avoided or reintegrated. However, the suggested techniques are independent of the area and particularities in the contemplated company.

Due to its unique characteristics and a more satisfactory application of cleaner production opportunities, a specific methodology was elaborated (Figure 1) to contemplate the cultural, economic, and environmental particularities of the Company that is the object of study. Then, fourteen steps were designed to be followed to implement Cleaner Production in the company.

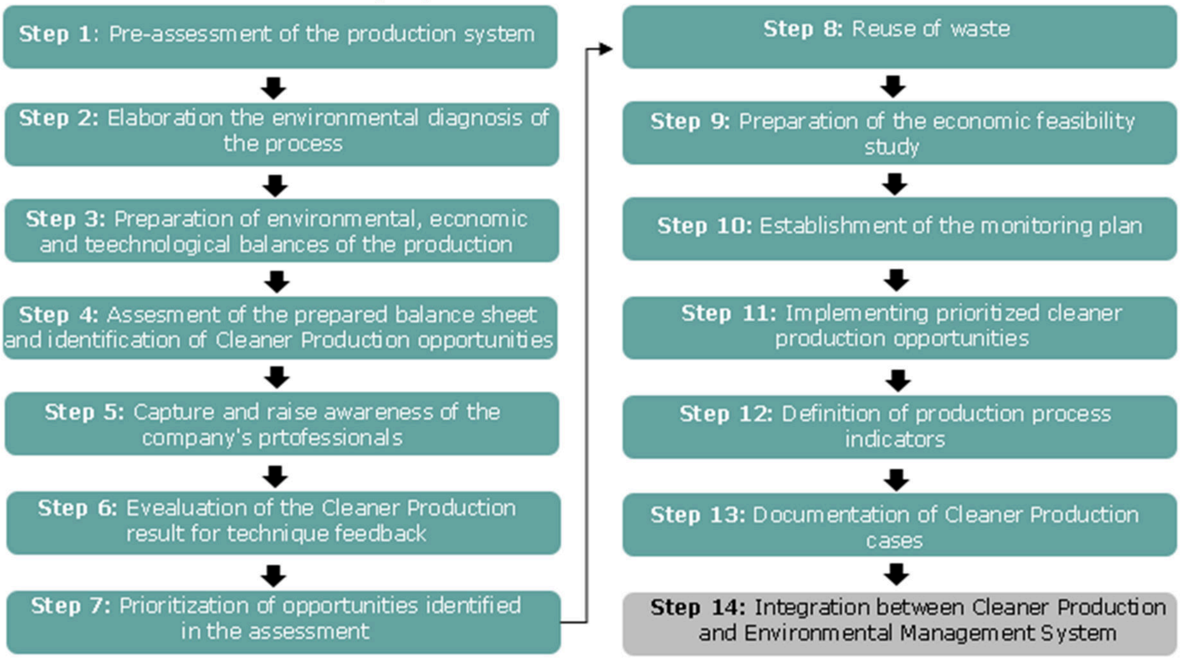


Fig. 1. The authors developed the methodology for implementing Cleaner Production in a company with reduced structure.

The application procedure of the Cleaner Production tool consisted of: first, an evaluation of the company's production process was made, in which the possibilities of implementing Cleaner Production could be identified. From this analysis, the environmental diagnosis of the process was developed, which was the basis for the whole project.

After that, all inputs and outputs of ecological resources of the production chain were identified, and the company's layout and area occupied were analyzed, as well as the amount of water used, energy consumption, and the luminotechnical analysis of the company.

The elaboration of the environmental balance aimed to survey the most critical points. Thus, a qualitative analysis of waste indicators, ecological education, and CO2 emissions was carried out. The economic balance was carried out by calculating expenses related to waste, water and energy consumption from the production chain, and the accounts referring to these items were analyzed with the financial department. For the technological balance, the level of technology adopted by the company was verified. Thus, together with the IT (Information Technology) team, the company performed a quantitative and qualitative analysis of the computers and printers made available. The company's total energy consumption, the company's total water consumption, and energy and water consumption in the condominium were raised through the documentary analysis authorized by the company.

The evaluation of the balances consisted of a description of the problems encountered and the opportunities to solve them. A strategy was outlined, and the actions to be implemented were described. The main obstacles to implementing Cleaner Production are described in this phase. The company's energy balance and CO2 emissions were calculated to obtain factual data. In the fifth step, to raise awareness among the company's professionals, a training program was scheduled with the employees about good environmental practices and the collection of suggestions for mitigating emissions in the company. In the sixth step of the Cleaner Production implementation, the results obtained were evaluated, and feedback on the technique was done. The seventh step consisted of recovering the previously analyzed critical points and prioritizing the opportunities identified in front of these problems.

The eighth step indicates the reuse of waste. This step was carried out in two scopes: in the first, some of the waste generated would be inserted into the production process, such as the possibility of recycling paper for the creation of notebooks for employees. In the second scope, the intention is to expand this project to the construction site of the developments in which the company is a partner, thus destining the civil construction waste to be reused.

The elaboration of the economic feasibility study is the ninth step of the methodology, which consists of comparing the alternatives of Cleaner Production through methods such as Payback, Net Present Value (NPV), and Internal Rate of Return (IRR) to identify which option is more viable from an economic point of view.

To establish a monitoring plan, step ten consisted of naming measurement points to analyze the efficiency and eco-efficiency of the production process. The 11th step consisted of implementing the opportunities previously identified and prioritized by the board and eco-team. Thus, according to CNTL (2003), this stage comprises the execution of support services and anticipating problems that may occur during the implementation. The 12th step of the methodology consisted of defining the efficiency indicators of the production process. In the company, solid waste generated, water consumption, and energy consumption used in the production process will be considered indicators, thus seeking a more accurate environmental analysis. There is also the possibility of converting these environmental indicators into financial indicators aimed at quantifying the amount saved by the company with the implementation of the project, especially for the mitigation of environmental liabilities. From the definition of indicators, it is also possible to analyze in which part of the process there are more significant losses and waste.

The integration between cleaner production and the environmental management system, indicated in the 14th step of the methodology, consists of aligning all actions carried out with the NBR ISO 14001 (ABNT, 2015) so that the implementation of Cleaner Production results at the beginning of the performance Environmental Management System, to bring to the company, the principle of continuous improvement and national and international certifications.

3. Results

3.1. Diagnosis and identified opportunities

The company occupies five floors in a vertical condominium, three covering the entire floor area and the other two covering only half of the floor area. Thus, a systematic analysis of all variables that cause an environmental impact on the company was carried out (Table 1).

ENVIRONMENTAL DIAGNOSTIC - 2020 and 2021	
Variable	Diagnosis
Energy Consumption	A total of 1,571,425 kWh were consumed in the company, corresponding, according to the Carbonfootprint website, to the emission of 142.48 tons of CO2 into the atmosphere. According to the same site, to mitigate all this impact it would be necessary to plant 1017 trees.
Electronic Devices	There were 312 LED lamps throughout the company and 341 dichroic lamps. In addition, a high number of air conditioners was noted, with 66 units throughout the company.
Water Consumption	Water consumption is not individualized, that is, there is no water bill for each office. Therefore, there is an apportionment among the joint owners and the amount is divided equally among them. Thus, it is not possible to quantify the real consumption of the water supplied by the concessionaire to the company.
Solid Waste	Currently, the company does not have a correct destination for the solid waste produced there, so there is no quantification of waste generated by employees and customers. To identify opportunities for Cleaner Production, the number of dumpsters was observed. There are 152 office waste garbage cans distributed over 5 floors, 12 garbage cans for organic waste, 6 garbage cans for recyclable materials, 3 garbage cans for non-recyclable materials, 1 garbage can for the disposal of batteries, and 1 garbage can for PET bottle caps.

Table 1. Environmental diagnosis of the company executed by authors

Aiming to reduce energy consumption and gain environmental comfort, it is suggested to standardize the power of light bulbs and the use of LED bulbs throughout the company. In addition, it is recommended to install motion sensors for the corridors and bathrooms of the company. Another opportunity found regarding the reduction of electricity consumption would be the investment in the awareness of employees through an environmental education initiative so that they do not forget to turn on the computer, since, in conversation with members of the ESG of the company, this problem was identified.

To reduce water consumption, the following opportunities were identified: the installation of flush water-saving devices in the bathrooms on the 12th floor, timer taps in the pantries on all floors, and educational signs regarding water saving during dishwashing.

As for the solid waste generated, the first measure to be implemented is hiring a recycling cooperative to manage and treat all the waste produced in the company. More office waste garbage cans should also be placed, besides creating and maintaining compost garbage cans inside the company. Environmental education should be conducted to make employees aware of the need for the correct disposal of solid waste, as shown in Table 2.

Environmental Variable	Suggested Actions	Environmental Gain	Social Gain	Economic Gain
Energy	Lighting Standardization	Minimization of atmospheric emissions and reduction of natural resource consumption	Maximization of the use of natural resources and gain with the awareness of employees who can disseminate this culture in other places	Improved image, increased company visibility, reduced consumption and operating expense
	Installation of sensors in hallways and bathrooms			
	Installation of photovoltaic panels			
Water	Installation of water-saving devices in all bathrooms			
	Installation of time-controlled faucets in all sinks			
Solid Waste	Deployment of more garbage cans	Reduction of waste going to landfills, use of organic waste and promotion of soil protection	Increased employment and job opportunities	
	Hiring of a cooperative			
	Making and maintaining the compost bin			
Environmental Education	Educational courses on: energy consumption, water consumption and **proper waste separation**	Decrease in environmental impacts caused by lack of awareness	Spreading the ESG Culture	More responsible consumption, satisfied employees, thus increasing productivity
	Distribution of booklets			
	Eco-team dedicated to composting			
	Awareness and dissemination of good environmental practices through gamefication.			

Table 2. Opportunities identified for the implementation of Cleaner Production adapted from Diogenes (2011)

In regard to the environmental education variable, it was suggested that the execution of educational courses aimed at making employees aware of energy consumption, water consumption, and the adequate separation of waste, in addition to the distribution of handouts, the setting up of an eco-team dedicated to the compost bin, and the insertion of green end marketing in the company.

4. Conclusions

The present study indicated that the various techniques to be implemented, mainly with a certain ease, will mitigate emissions and reduce energy consumption.

The cleaner production practices seek to mitigate environmental, social, and financial impacts, reducing pollution from production processes and providing the company with sustainable production, seeking ISO 14001:2015 certification with the implementation of the Environmental Management System and System B Certification with the company's alignment to the ESG premises.

This project demonstrated the need for the board and other departments' engagement to implement cleaner production. Another essential factor is environmental education for employees' awareness because the workforce is fundamental to achieving continuous improvement.

Moreover, the identification of Cleaner Production techniques to be implemented in a corporate environment brought the opportunity to continue the project with the implementation itself, the monitoring of improvements, and the determination of production process indicators.

Applying the Cleaner Production techniques will change the company's routine, bringing more environmental benefits and reducing the fixed bills for energy and water consumption.

The alignment of the company with the premises of Cleaner Production will represent an opportunity for direct gain as to the financial aspects of the Company, besides bringing training through environmental education and the wellbeing of its employees.

As far as its image in the financial market is concerned, implementing cleaner production will be concrete proof that the Company is investing in its ESG indicators, thus attracting more investors to the real estate fund.

Another fact that should be highlighted is that aiming at improving cleaner production, the program should be extended to the construction sites and real estate ventures under the company's responsibility.

During this work, the supervisor responsible for the company's environmental area was dismissed. All the work done by the professionals involved in this project was deconstructed, demonstrating at the very least that the culture of mitigating emissions and reducing energy consumption for environmental improvement and the search for green certification, despite having simple and plausible academic and technical resources, is still an area to be pioneered in the Brazilian market.

References

ABNT - Associação Brasileira de Normas Técnicas. ABNT NBR ISO 14001:2015. Sistemas da gestão ambiental Requisitos com orientação para uso. Rio de Janeiro: ABNT, 2004. 27 p.

AGOSTINO, J. S. UMA ANÁLISE DOS FATORES QUE PODEM CONTRIBUIR PARA UM MAIOR GRAU DE ADOÇÃO DA ANÁLISE ASG PELOS GESTORES DE RECURSOS NO MERCADO BRASILEIRO. Orientador: Prof. Dra. Annelise Vendramini Felsberg. 2021. 148 p. Tese (Mestrado em Gestão para Competitividade) - Fundação Getúlio Vargas, São Paulo, 2021. Disponível em: https://bibliotecadigital.fgv.br/dspace/bitstream/handle/10438/30941/Trabalho%20Aplicado%20-%20Juliana%20S%20de%20Agostino%20-%20v.final.pdf?sequence=5&isAllowed=y. Acesso em: 29 out. 2021.

BARBIERI, J. C. Gestão Ambiental Empresarial: Conceitos, Modelos e Instrumentos. 2 ed. São Paulo: Saraiva, 2007.

BARCARJI, Alencar Garcia et al. Produção Mais Limpa: Conceitos e Definições Metodológicas. INGEPRO - Inovação, Gestão e Produção, Cuiabá, MT, v. 03, ed. 2, p. 46-58, fev 2011. Disponível em: https://www.aedb.br/seget/arquivos/artigos09/306_306_PMaisL_Conceitos_e_Definicoes_Metodologicas.pdf. Acesso em: 7 nov. 2021.

BRASIL. Decreto nº 10.240, de 12 de fevereiro de 2020. Regulamenta o inciso VI do caput do art. 33 e o art. 56 da Lei nº 12.305, de 2 de agosto de 2010, e complementa o Decreto nº 9.177, de 23 de outubro de 2017. Diário Oficial da União: Seção 1, edição 31, página 1, Brasília, DF, 12 fev. 2020.

BRASIL. Decreto nº 10.388, de 5 de junho de 2020. Regulamenta o § 1º docaputdo art. 33 da Lei nº 12.305, de 2 de agosto de 2010, e institui o sistema de logística reversa de medicamentos domiciliares vencidos ou em desuso, de uso humano, industrializados e manipulados, e de suas embalagens após o descarte pelos consumidores. Diário Oficial da União: seção 1 - Extra, edição 107-A, página 1, Brasília, DF, 05 jun. 2020.

BRASIL. Resolução nº 491, de 19 de novembro de 2018. Dispõe sobre padrões de qualidade do ar. Diário Oficial da União: Seção 1, edição 223, página 155, Brasília, DF, 21 nov. 2018.

CETESB - Compahia de Tecnologia de Saneamento Ambiental. A Produção Mais Limpa e o Consumo Sustentável na

América Latina e Caribe: CETESB, 2005, 20 p. Disponível em: https://cetesb.sp.gov.br/consumosustentavel/wp-content/uploads/sites/20/2013/11/pl_portugues.pdf. Acesso em: 28 jun. 2021.

DIÓGENES, V. H., Aplicação de Produção Mais Limpa no setor de turismo: um estudo de caso em hotel de Natal/RN. GEPROS - Gestão da Produção, Operações e Sistemas. Natal, ano 7, p 141-156, n 1, jan/mar 2012, p 141-156.

FILHO, Moacir Godinho et al. Princípios e ferramentas da Produção Mais Limpa: um estudo exploratório em empresas brasileiras. Gestão e Produção, São Carlos, v. 22, ed. 2, p. 326-344, 2015. Disponível em: https://www.scielo.br/j/gp/a/KNLTDMxnJNyvBxrjS9kDCvD/abstract/?lang=pt. Acesso em: 19 nov. 2021

GATES, Bill. Como evitar um desastre climático: As soluções que temos e as inovações necessárias. [S. l.]: Editora Schwarcz S.A., 2021. 299 p.

SLAVIC, P. et al. Review of sustainability terms and their definitions. Journal of Cleaner production, Slovenia, ed. 15, 2007. Disponível em: 10.1016/j.jclepro.2006.12.006. Acesso em: 29 out. 2021

GIANNETTI, B.F.; BONILLA, S.H.; SILVA, I.R.; ALMEIDA, C.M.V.B. Cleaner production practices in a medium-sized gold-plated jewelry company in Brazil: when little changes make the difference. Journal of Cleaner Production, v. 16, pp. 1106-1117, 2008.

GOIÁS. Decreto nº 1,745, de 6 de dezembro de 1979. Aprova o regulamento da Lei nº 8544, de 17 de outubro de 1978, que dispõe sobre a prevenção e o controle da poluição do meio ambiente. Governo do Estado de Goiás, Goiânia, GO, 06 dez. 1979.

HENS, L. et al. On the evolution of "CLEANER PRODUCTION" as a concept and a practice. Journal of Cleaner production, [s. l.], ed. JCLP 11221, 29 Jan. 2022. DOI: 10.1016/j.jclepro.2017.11.082. Acesso em: 29 out. 2021.

KANNO, R., et al. Produção Mais Limpa: Conceito, Panorama atual no Brasil e Análise de Casos de Sucesso. in: Seminário sobre Tecnologias Limpas. 2017, Porto Alegre. Anais [...]. Porto Alegre: VII Seminário Sobre Tecnologias Limpas, 2017. Disponível em: http://www.abes-rs.uni5.net/centraldeeventos/_arqTrabalhos/trab_2_5389_20171113232939.pdf. Acesso em: 28 jun. 2021.

LAURENT, Jose Guillermo Cadeño, et al. Associations between acute exposures to PM2.5 and carbon dioxide indoors and cognitive function in office workers: a multicountry longitudinal prospective observational study. Environmental Research, Boston, USA, ed. 15, 2021. Disponível em: https://iopscience.iop.org/article/10.1088/1748-9326/ac1bd8/pdf. Acesso em: 2 nov. 2021.

MOLINARI, Marcelo Alessandro et al. Avaliação de oportunidades de Produção Mais Limpa para a redução de resíduos sólidos na fabricação de tintas. Produção, Niterói, RJ, v. 23, ed. 2, p. 364-374, abr/jun 2013. Disponível em: http://dx.doi.org/10.1590/S0103-65132012005000074. Acesso em: 4 nov. 2021.

MEDINA, Flávio. Análise da gestão de resíduos industriais e pós consumo gerados na fábrica de medicamento da fiocruz. Orientador: Prof. Sérgio Luiz Braga França, D.Sc. 2015. 124 p. Dissertação (Mestrado em Sistemas de Gestão. Área de concentração: Organizações e Estratégia.) - UNIVERSIDADE FEDERAL FLUMINENS, Recife, PE, 2015. Disponível em: https://app.uff.br/riuff/bitstream/handle/1/4386/Dissert%20Flavio%20Medina.pdf?sequence=1&isAllowed=y. Acesso em: 16 nov. 2021.

MUNIZ, D. C et al. Produção Mais Limpa como princípio para a gestão ambiental em farmácias de manipulação. IX Congresso Brasileiro de Engenharia de Produção: APREPRO, Ponta Grossa, PR, dez 2019. Disponível em: http://aprepro.org.br/conbrepro/2019/anais/arquivos/10202019_201039_5dacec7b153a1.pdf. Acesso em: 7 nov. 2021.

NAUM, Cristiane Maria. Motivações para a adoção dos fatores ambientais, sociais e de governança (ASG) às análises de investimento pelos gestores de ativos. Orientador: Prof. Dr. Eduardo de Rezende Francisco. 2018. 122 p. Tese (Mestrado em Administração com ênfase em comportamento do consumidor) - Escola Superior de Propaganda e Marketing, São Paulo, 2018. Disponível em: https://tede2.espm.br/bitstream/tede/318/2/Dissertacao_MPCC%20-%20Cristine_%20Marian_Naum_2018%20V.%20FINAL%2027-4.pdf. Acesso em: 29 out. 2021.

PENTEADO, José Carlos; MAGALHÃES, Dulce Magalhães; MASINI, Jorge. Experimento didático sobre cromatografia gasosa: uma abordagem analítica E ambiental. Química Nova, São Carlos, v. 31, ed. 8, p. 2190-2193, 2008.

Disponível em: http://quimicanova.sbq.org.br/detalhe_artigo.asp?id=1384. Acesso em: 19 nov. 2021.

PEREIRA, G. R., SANT'ANNA, F. Uma análise da Produção Mais Limpa no Brasil. Revista Brasileira de Ciências Ambientais. Rio de Janeiro, n. 24, p 17-46. jun. 2012.

OLIVEIRA, José Augusto, et al. Cleaner Production practices, motivators and performance in the Brazilian industrial companies. Journal of Cleaner Production, Brasil, v. 231, p. 359-369, 10 sets. 2019. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0959652619315239. Acesso em: 23 nov. 2021.

SILVA, Gisele Cristina et al. Metodologia de checkland aplicada à implementação da Produção Mais Limpa em serviços. Gestão e Produção, Recife, PE, v. 13, ed. 3, p. 411-422, set-dez 2005. Disponível em: https://www.scielo.br/j/gp/a/nwdybj9VWb9fpMFTvmsyRzj/abstract/?lang=pt#:~:text=Essa%20metodologia%20objetiva%20a%20compara%C3%A7%C3%A3o,ou%20n%C3%A3o%20adotar%20este%20programa. Acesso em: 15 nov. 2021.

TOMBONI, Melina Cé et al. Implementação do programa de Produção Mais Limpa em um escritório de advocacia: Uma avaliação econômica e ambiental. III Simpósio sobre Sistemas Sustentáveis , [s. l.], 2017. Disponível em: https://www.researchgate.net/publication/314320346_Implementacao_do_programa_de_Producao_Mais_Limpa_em_um_escritorio_de_advocacia. Acesso em: 19 nov. 2021.

TUCCI, Henrricco Nieves et al. Aplicação de práticas de Produção Mais Limpa em uma empresa do setor metal mecânico: Uma avaliação econômica e ambiental. Simpósio de excelência em gestão e tecnologia, [s. l.], p. 1-8, 2020. Disponível em: https://www.aedb.br/seget/arquivos/artigos19/16828120.pdf. Acesso em: 18 nov. 2021.

VICKERS, Ian. Cleaner production: organizational learning or business as usual? An example from the domestic appliance industry. Business Strategy and the Environment, Recife, PE, v. 9, ed. 4, p. 255-268, 29 Jan. 2022. Disponível em: https://onlinelibrary.wiley.com/doi/10.1002/1099-0836(200007/08)9:4%3C255::AID-BSE252%3E3.0.CO;2-A. Acesso em: 17 nov. 2021.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Life Cycle Assessment: A Contribution for Environmental Indicators in Slaughterhouse

DENES, Q.R.F, KIPPER, L.M., MACHADO, E. L., SCHNEIDER, R.C.S.*

Universidade de Santa Cruz do Sul, Santa Cruz do Sul, Rio Grande do Sul, Brazil
**Corresponding author, rosana@unisc.br*

Abstract
Meat consumption plays an important role in humanity's evolution until today. This demand generates the need for more sustainable and globally competitive processes. Aligned with sustainability, Industry 4.0 expands the possibilities of using smart sensors, artificial intelligence (AI), big data, and creating intelligent factories. It enables the development of environmental-friendly products and processes, facilitating the production of higher-quality food products in less time and at a lower cost. For the changes, it is necessary to monitor indicators, which allow coherent decision-making according to the process needs. Therefore, this study carried out a Life Cycle Assessment (LCA) of the pig meat production process of an industry in southern Brazil. The LCA was carried out using the CML-IA method to observe the most relevant environmental impact categories in the short and medium-term, enabling the identification of environmental indicators. The results of the CML-IA allowed us to identify the Abiotic Depletion (fossil fuels), Global Warming, Marine Ecotoxicity, Acidification, and Eutrophication as the most relevant impact categories. The detected impacts supported the definition of critical KPIs and PPIs on environmental aspects beyond the indicators already controlled by the company, establishing a cause-and-effect relationship with the organization's strategic objectives.

Keywords: pig meat, life cycle analysis, environmental indicators

1. Introduction

Meat consumption plays a vital role in humanity's evolution until the present day regarding life expectancy because it is an excellent source of energy and nutrients for the human body, making it an indispensable item in the diet (You et al., 2022). Its consumption is expected to grow 14% by 2030, and pig meat is considered the second most produced and consumed protein worldwide (OECD/FAO, 2020). Therefore, meat production has significant impacts, and the consumption of this product will unlikely decrease (Putnik and Kovačević, 2021). Furthermore, the demand for meat generates the need for production at competitive and more sustainable prices, minimizing environmental impacts (Andretta et al., 2021).

For this reason, the evaluation of the aspects related to the impacts of the meat chain is essential to support innovative solutions. It is necessary to look at the current technologies and develop sustainable production systems to meet this latent need (Hartmann et al., 2022). The search for high performance is possible with positive results regarding environmental practice, economic, and operational performances (Fang and Zhang, 2018). Implementing practices and tools that assist in sustainability management aims to increase stakeholders' trust in an organization, improve communication, and serve as a basis for decision-making (Corsi and Arru, 2020).

Furthermore, there is a trend to use information in food marketing to bring a competitive advantage in the market, thus making it essential to also communicate sustainability practices as part of the organization's strategy (Petit et al., 2018). It is considered that there is room for business development aimed at meeting the global demand for pig meat. As much as part of consumers may be looking for alternatives for meat substitution, studies suggest that the environmental benefits of such alternatives may be overestimated (Hartmann et al., 2022). It is assumed that there will be a 5% increase in greenhouse gas emissions from the meat sector by 2030. However, this increase is much smaller than the predicted increase in meat production (OECD/FAO, 2020). Reducing the volume of pig meat production could be a strategy for reducing greenhouse gas emissions; however, this option counteracts the balance of supply and demand, destabilizing the market and changing the price dynamics of pig meat (Utnik-Banas et al., 2022).

New sustainability policies related to Corporate Social Responsibility, allied with technologies, have been implemented in food production (Bollani et al., 2019). They improve the production systems regarding the use of technologies to reduce consumption of natural resources and waste management and bring to the core of the discussions the social and economic aspects (Assiri et al., 2021). They ground the concept of sustainability through practices that balance the business's existence with nature and society (Horton and Horton, 2019). Sustainable Development has been discussed for the past 30 years and added social responsibility and sustainability into the focus of discussions (Buckley and Casson, 2021). The United Nations Agenda 2030 for Sustainable Development corroborates the sustainable development debate by establishing goals that represent environmental, social, and economic aspirations (Bandari et al., 2022). One of the ways to leverage operational performance is to adopt quality management practices but to sustain its competitiveness, it is essential to identify the relationships that influence the environmental, social, and economic areas (Alsawafi et al., 2021). Furthermore, prioritizing the meeting of stakeholders' needs concerning people and the planet also leads to the achievement of profit, reinforcing that it is possible to maintain a balance in the three dimensions of the Triple Botton Line (TBL) (Isaksson, 2018). Thus, it is plausible to use tools such as Life Cycle Assessment (LCA) in organizations as a support to establish the causal relationship between process parameters and environmental impacts generated (along the process and at the end of the production line). Its use can assist in constructing environmental policies, marketing, product and process design, and communication strategies (Spreafico, 2022).

Hence, the main objective of this work was to create a model to monitor and control environmental indicators through the LCA in a pig meat processing plant, where the indicators should have a causal relationship with the sustainability strategies of the organization. The advent of Industry 4.0 was added to this discussion, rendering manufacturing highly flexible (Kenett and Bortman, 2022) and fully connected, where data can be digitized and accessed anytime and anywhere, making decision-making more adherent to the needs of its value chain. It is assumed that the use of Industry 4.0 enabling technologies can benefit communication and information flow, sharing of knowledge, and increasing efficiency and productivity through collaboration (Tripathi et al., 2022), embodiment of production, and waste reduction (Letchumanan et al., 2022). However, it is essential to look at the possibility of increasing resource consumption (Fonseca et al., 2021).

2. Methodology

A systematic approach was conducted to assess the life cycle environmental impacts of the pig meat production process (ISO, 2006; Mahmud et al., 2021). The functional unit to assess resource use was 1,000 kg of meat products at the slaughterhouse's shipping door. The industrial plant in Southern Brazil, which made the study feasible, has an average slaughter of 4,000 pigs per day, representing 500 tons, equivalent to 350 tons of finished products after manufacturing. According to data presented by the company, these products are allocated in the following way: around 50% for Raw Materials for the production of industrialized products: 20% for the products for the Internal Market, and 30% for Exportation to several markets, among them: Vietnam, Russia, Hong Kong, Singapore, Georgia, China, and Africa.
The studied process (Fig. 1) begins with receiving the swine from the field in the pen area. The animals rest in the stalls before entering the slaughterhouse. Then, they are cleaned and taken to the stunning and bleeding area, after which they are scalded to facilitate the removal of hair and hooves. The carcasses go through the cooling and maturation process to be quartered and standardized in commercial chilled or frozen cuts when they are ready to be shipped to customers or consumers. The CML-IA baseline v3.05 method was used for the LCA from a short-term perspective. The data was analyzed in the dimension of each category and/or normalized.

3. Life-Cycle Inventory

The data collected to compose the inventory were identified as annual process inputs and outputs for three years of pig slaughtering and processing (Table 1). The data were collected from records and observation of the industrial unit studied, using the monthly/year average for inputs and outputs. For the Liquefied Petroleum Gas (LPG) consumption data records, the conversion of measurement units was used, where each kg of LPG is equivalent to 50.23 MJ (Li et al., 2022). Similarly, for recording energy

consumption, a conversion rate of 3.6 MJ for every 1 kWh was considered (He, 2017). The installed capacities of the equipment in each sector were considered to estimate the energy, steam, and water consumed. The steam inputs in the pig slaughtering process were prorated according to the installed capacity of the equipment per processing step. An average relative boiler working pressure of 7 bar was considered, which generates a heat of 660,800 kcal ton^{-1} of steam used, due to the loss of efficiency of the steam line caused by the layout of the steam pipes.
To quantify the amount of Personal Protective Equipment (PPE) used per process phase, only disposable PPE was considered, such as nitrile gloves, aprons, and sleeves. The total quantity in the accounting write-off records in the company's system was divided by the number of employees in each sector.

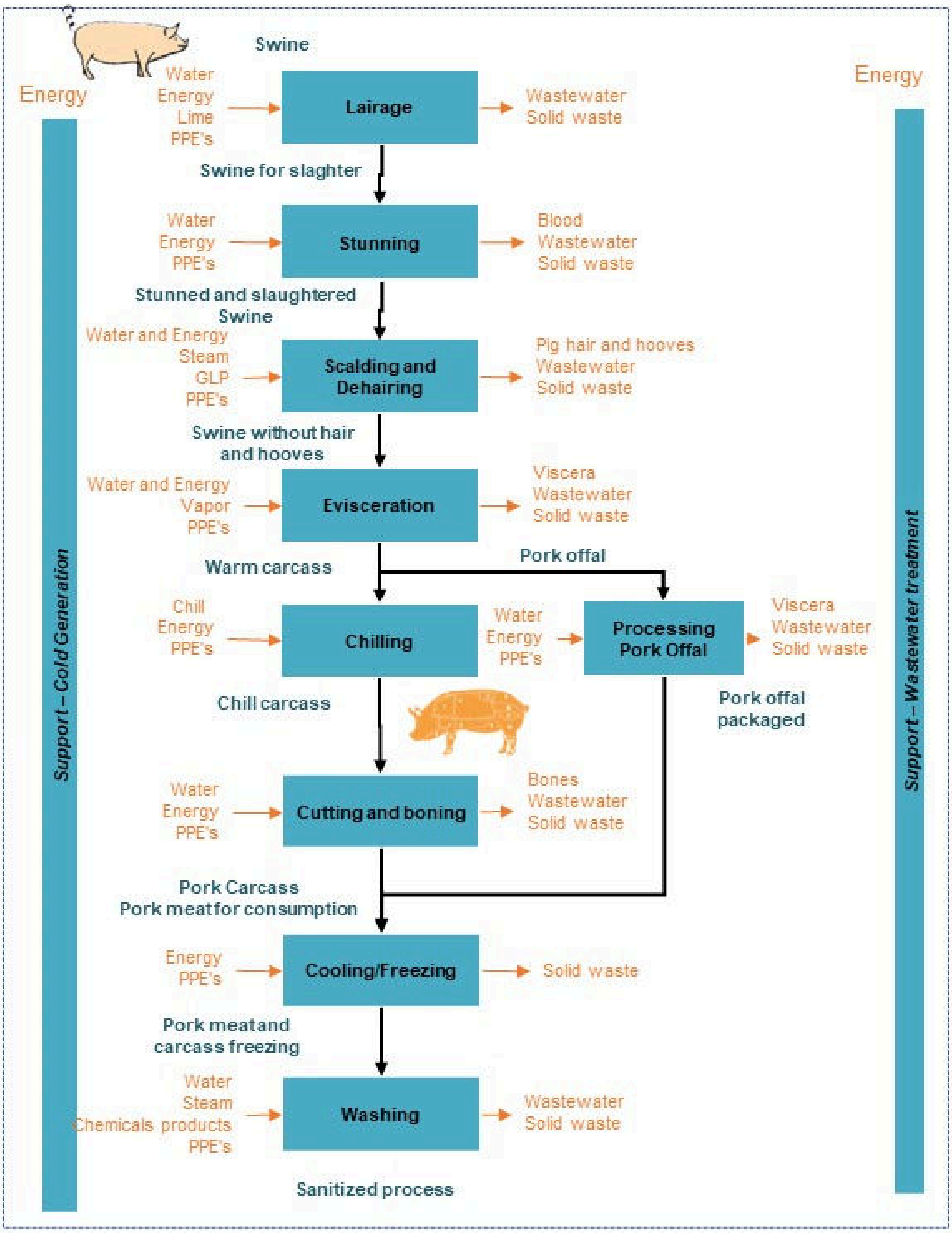


Fig. 1. Boundaries of the pig meat agribusiness system evaluated, with the primary inputs and outputs per stage.

For the chemicals used in sanitizing and disinfecting the process, a survey was conducted of the composition of each product, according to its percentage of composition registered on the Material Safety Data Sheet (MSDS) and registration with the Chemical Abstracts Service (CAS). The sanitizing and disinfecting products inventoried and grouped by chemical function are presented in Table 1. Organic and process waste adjuvants for meat production were identified in the process monitoring and analysis of environmental reports, considering the monthly and annual averages.

Table 1 - Annual resource inputs collected in all stages of the pig meat production process in the industrial unit studied.

Resource	Year 1	Year 2	Year 3	Average
Energy and Process Inputs				
Energy (MJ)	1,350,056	1,712,789	1,484,261	1,515,702
Water (m³)	74,780	83,079	82,359	80,073
Personal Protective Equipment (PPE) (disposable) (Kg)	580.72	430.15	430.59	480.49
Steam (kcal)	1,232,986,610	975,995,879	803,578,603	1,004,187,031
Liquefied Petroleum Gas (LPG) (MJ)	1,520,960	1,654,785	1,915,019	1,696,921
Label (Kg)	2,204.61	2,194.29	2,434.73	2,277.88
Film/Sheet/Flow/Tap (Kg)	18,950.08	17,577.09	19,362.12	18,629.76
Cardboard (Kg)	88,329.27	78,551.40	94,324.54	87,068.40
Bags (Kg)	18,795.24	23,477.11	24,865.67	22,379.34
Pallet (un)	1,288	953	1,437	1,226
Sanitation inputs				
Inorganic acid	212.54	233.54	300.22	248.77
Alcohol	6.20	3.93	9.58	6.57
Polyglycosidase alkyl	-	-	4.80	1.60
Amide	65.56	99.17	71.25	78.66
Amines	30.70	21.96	58.35	37.00
Aryl sulfonates	306.05	387.63	251.30	314.99
Aryl sulfonates and amines	-	-	11.96	3.98
Organic chlorine	69.69	109.59	160.18	113.15
Acrylic thickener	22.27	35.03	51.43	36.243
Ethanol	250.52	233.74	193.27	225.84
Glycols	72.28	91.86	71.25	78.46
Sodium hydroxide	2.483.72	3,164.99	2,801.83	2,816.85
Nonyl phenol	17.14	31.39	36.85	28.46
Anti-corrosion oil	0.17	-	0.042	0.07
Peracid	4.62	7.32	8.47	6.80
Hydrogen peroxide	17.78	28.15	34.85	26.93
Inorganic salt	113.28	108.50	118.92	113.56
Inorganic salt - hypochlorite	1.033.67	10,299.58	11,267.69	7,533.65
Effluent and Waste Output				
Swine manure (Kg)	15,558	28,982	30,749	25.096
Hair and hoof waste (Kg)	82,268	96,675	99,137	92.693
Guts and discarded parts (Kg)	271,500	328,190	343,532	314,407
Solid waste (Kg)	5,740	7,925	7,814.43	7,160
Plastic waste (Kg)	13,852	13.419.66	12,270.88	13,181
Centrifuged sludge disposal (Kg)	481,136.98	520.150.68	562,002.95	521,097
Clean ash waste (Kg)	8,384.49	10.166.57	9,035.91	9,196
Restaurant waste (Kg)	6,464.95	7.092.66	8,141.78	7,233
Biological sludge waste (Kg)	365,237.30	542.840.43	428,949.07	445,676

Health service waste (Kg)	2.13	26.33	22.45	17
Disposable pallet waste (Kg)	1,080.98	1.300.56	1,295.36	1,226
Cardboard waste (Kg)	5,746.76	7.576.09	8,777.02	7,367
Aluminum waste (Kg)	115.24	7.37	57.24	60
Copper waste (Kg)	263.55	55.12	51.63	123
Iron and stainless-steel waste (Kg)	4,162.37	5.658.39	4,447.81	4,756
Cooking oil waste (Kg)	7.47	69.17	118.59	65
Burnt oil	94.96	171.34	120.84	129.05

Additionally, the ecoinvent database was used as a data source in an attributional approach in the SimaPro® program. The ecoinvent provided data regarding the origin of the process inputs, selected according to the production geographical location.

4. Life cycle impact assessment (LCIA)

Among all categories assessed with the CML-IA, besides the highest representativeness in the five categories Abiotic Depletion (fossil fuels), Global Warming, Marine Ecotoxicity, Acidification and Eutrophication, it was observed that during the 3 years of study, the impacts in the different categories varied less than 10%. Therefore, despite the incidence of the COVID19 pandemic in 2020, stability is seen in the management of the process. The impacts were representative of inputs and outputs inventoried in a process where changes in suppliers, composition, and procedures did not cause significant differences in the environmental impact.
Since these values represent the whole dimension of the slaughtering and processing of pigs, the standardization of the operating activities for each industrial process stage and the processes that mitigate environmental impacts are recognized as stable, demanding a disruptive innovation to add value to the sustainability of the process. Figure 2 compares the impact categories potentiated by the meat processing activities with support activities, effluent treatment, and sanitization. It was observed in each step which activity could potentially have impacts attributed. These observations aided in evaluating management actions for monitoring to minimize these impacts. The main environmental impact at the Swine Reception was related to assigning the pigs from the field to be slaughtered. The remaining portion of the impact is due to energy consumption. In the Bleeding of the pigs, the employees' energy consumption for equipment operation and PPE use are added.

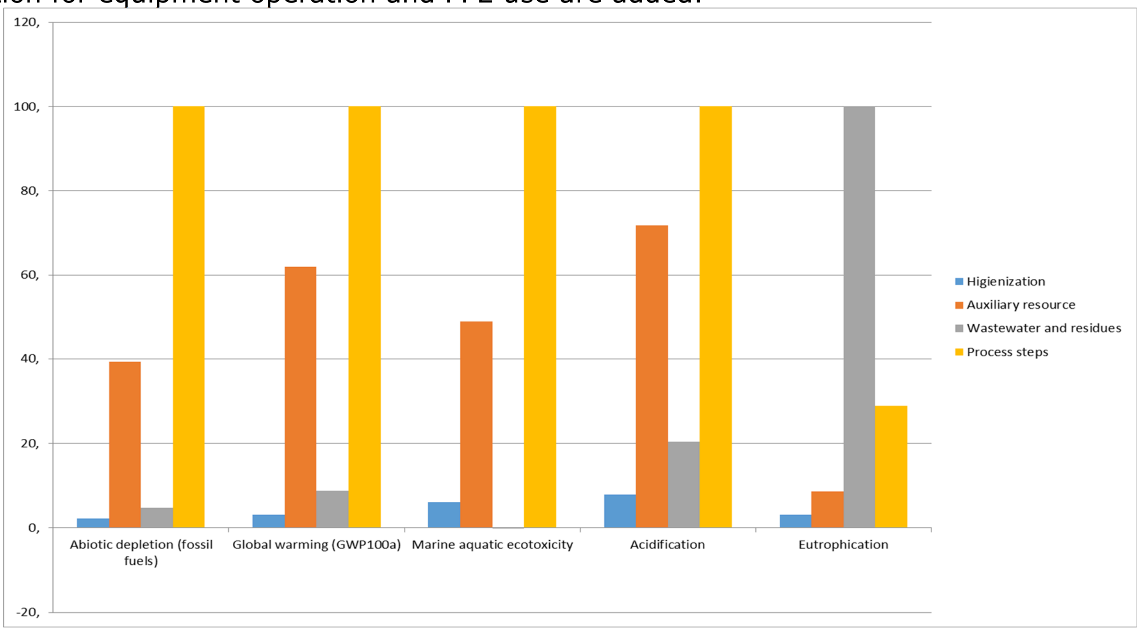


Figure 2. Comparison between the production process and the supporting activities in the contribution to environmental impacts analyzed using the most relevant categories for the CML-IA methods.

The most significant impacts in the Scalding and Depilation refer to (1) the destination of the hair and hoof waste to a third-party Flour and Fat Factory; (2) the electricity consumption to operate the depilator and polishing machines; (3) the LPG consumption to torch the pigs; and (4) the steam consumption to heat the water for the pigs' depilation. In Evisceration, the impact is associated with the destination of the entrails for processing and transformation into Flour and Oil and the energy to operate the rectum extractor, carcass sawing, and lard extractor, among other processes. Cooling, in several stages, adds energy consumption to conserve the cooled carcasses. Boning and Meat Packing contribute to the overall process impact due to packaging consumption (cardboard and plastic). Furthermore, besides the process, there is a need for hygiene and sanitization in all factory sectors, effluent treatment, and steam generation. The graphic representation of the impacts by category and by the main items inventoried is in Figure 3.

Marine ecotoxicity is an impact category that varied over the years; in year 1, the impact was 25,328.94 kg 1.4-DB eq. In year 2, the impact was 29,790.10 kg 1.4-DB eq. In year 3, the impact was 28,830.29 kg 1.4-DB eq, avoiding part of the impacts of energy consumption added in the previous year. The most impactful process step for Marine Ecotoxicity was Swine Butchering and Packing with 11,479.435 kg 1.4-DB eq., which contributed 45.51% to the potential harm to marine life. The process inputs that bring the most of these impacts to the analyzed life cycle were cardboard packaging for product accommodation (7,797.192 kg 1.4-DB eq.) and plastic packaging (2,992.901 kg 1.4-DB eq.), as shown in Figure 3. The Support Resources area accounts for 6,901.521 kg 1.4-DB eq, contributing 27.36% to the process due to the high-energy consumption to control the environment and product temperatures. The next step is the Evisceration of the pigs with 3,173.848 kg 1.4-DB eq. These three process steps together account for 85.46% of the total impact in this category.

In the *Acidification* impact category, the results for year 1 were 0.456 kg SO_2 eq. For year 2, the impact was 0.492 kg SO_2 eq., reflecting an increase of 7.88%. However, year 3 had 0.470 kg SO_2 eq, 3.04% higher than year 1 and 4.49% lower than year 2. The most representative impact along the process was related to Support Resources (31.49%), and again the pig spaying and packing activity stands out (26.61%): the Effluent Treatment and waste destination (13.81%) were relevant for this category. The input resource with the highest contribution to the process is electricity with 0.217 kg SO_2 eq. Furthermore, these impacts are again related to energy consumption by the Support Resources, packaging, disposal of viscera waste, and generation of an effluent that requires treatment.

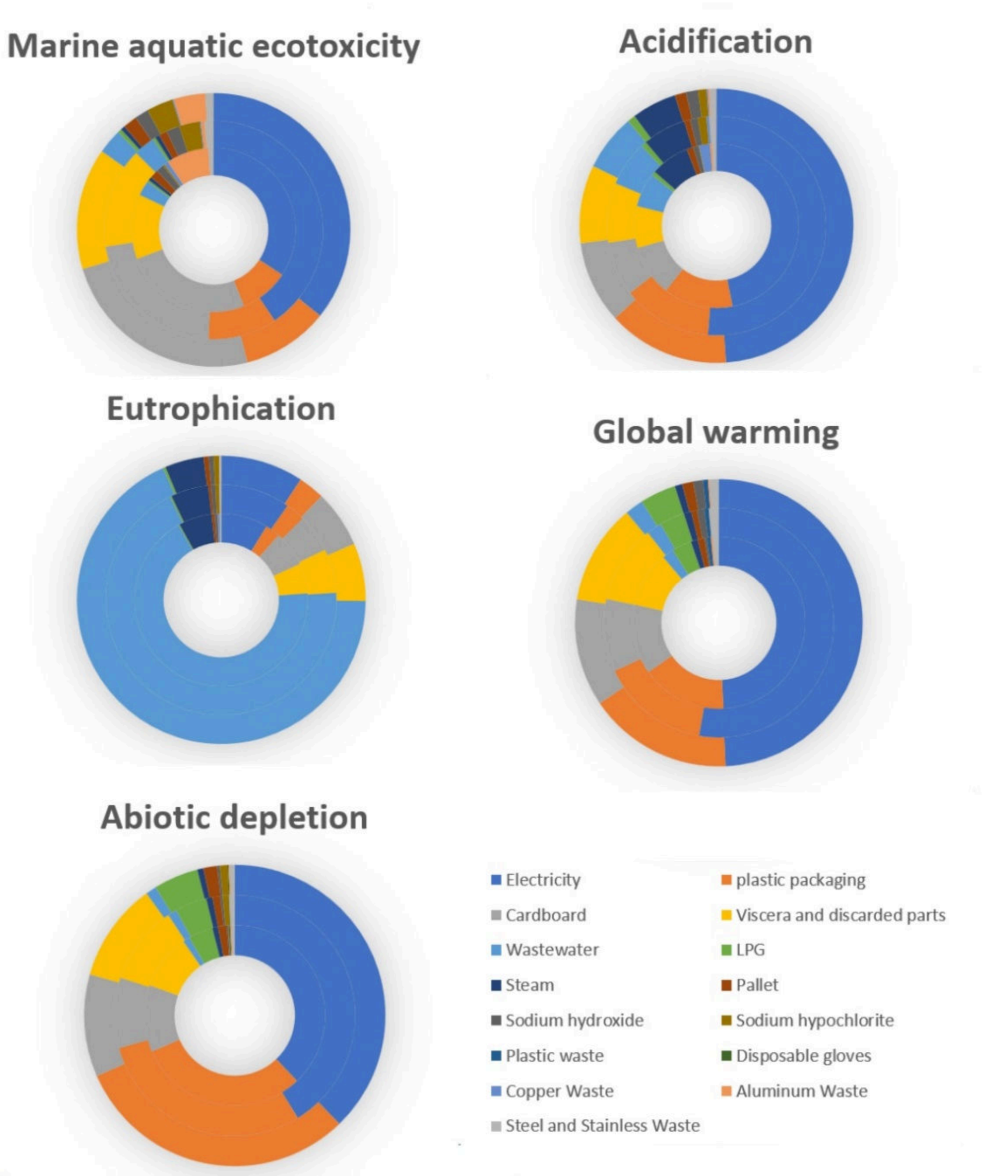


Figure 3: Contribution of process inputs and outputs to the selected impact categories.

For *Eutrophication*, the results obtained were 0.184, 0.195, and 0.186 kg PO_4^{3-} eq. for the 3 years. The Effluent Treatment and Waste Disposal stage represented 69.4% of the total impact, with 68.11% associated with effluent treatment. The *Global Warming* category emissions were 99.354 kg CO_2 eq. in year 1, which increased in year 2 (109.240 kg CO_2 eq.) by 9.95% and decreased in the following year (106.558 kg CO_2 eq.) by 2.46%. The global warming potential of the studied process was mainly related to the energy use by the Support Resources (33.14%). The use of packaging for the meat cuts was also relevant since the commercialization of meat according to parameters established by legislation requires special care with meat conservation. *Abiotic Depletion* caused by fossil fuels was equivalent to 1,338.45 MJ, increasing 8.23% in the following period (1,448.578 MJ) and consecutively maintaining almost the same impact in year 3 (1,436.931 MJ). The system inputs and outputs responsible for a potential impact in this category were the same as those already identified in the other categories (energy, packaging, and waste), plus the impact of LPG use (4.48%).

To assist the management of sustainable development, the company uses quality tools to promote the company's sustainability and provide opportunities to improve the economic and environmental aspects through practices such as optimizing the use of resources, minimizing impacts (Siva et al., 2016), and reducing waste. One of the tools used by the company to measure its degree of process performance improvement against the company's strategic objectives is the Key Performance Indicators (KPIs) (Wang and Cheng, 2011), commonly used by Lean Production to measure business efficiency (Salvadorinho and Teixeira, 2021). Mean indicators can also be used, defined as results of the process operation indicators (Process Performance Indicators - PPIs). Thus, the environmental indicators (resulting from the LCA) that are suggested in addition to what the company already monitored were: Energy Consumption (KPI, Kwh/ton, daily, automatic), Energy Consumption by sector (PPI, kWh), Equipment Efficiency (PPI, %), Refrigeration Efficiency (PPI, %) Heat leakage points (PPI, nº), LPG Consumption (KPI and PPI, Kg of LPG/Slaughtered pig and Time/Slaughtered pig), Pressure (PPI, bar), Steam consumption (KPI, ton/ton), Steam consumption by sector (PPI/ton). All parameters were registered daily and automatically.

5. Conclusions

It is concluded that it was possible to apply the LCA to the process of pig meat to identify the main environmental impacts and which parameters are relevant and can be monitored in the organization. Additionally, we presented the indicators (KPI and PPI) that could be added to the monitoring already existing in the company. KPI and PPI can be registered and analyzed automatically and daily. They could be defined based on the environmental aspects identified in the LCIA of the pig meat production process. From this monitoring, the company could establish a cause-and-effect relationship according to the organization's strategic objectives.

Acknowledgment – CNPq (303934/2019-0, 311531/2021-0 and 310228/2019-0)

References

Alsawafi, A., Lemke, F., Yang, Y., 2021. The impacts of internal quality management relations on the triple bottom line: A dynamic capability perspective. International Journal of Production Economics. 232, 107927.

Andretta, I., Hickmann, F.M.W., Remus, A., Franceschi, C.H., Mariani, A.B., Orso, C., Kipper, M., Letourneau-Montminy, M.P., Pomar, C., 2021. Environmental Impacts of Pig and Poultry Production: Insights From a Systematic Review. Front Vet Sci. 8, 750733.

Assiri, M., Barone, V., Silvestri, F., Tassinari, M., 2021. Planning sustainable development of local productive systems: A methodological approach for the analytical identification of Ecoregions. Journal of Cleaner Production. 287, 125006.

Bandari, R., Moallemi, E.A., Lester, R.E., Downie, D., Bryan, B.A., 2022. Prioritising Sustainable Development Goals, characterising interactions, and identifying solutions for local sustainability. Environmental Science & Policy. 127, 325-336.

Bollani, L., Bonadonna, A., Peira, G., 2019. The millennials' concept of sustainability in the food sector. Sustainability. 11(10), 2984.

Buckley, P.J., Casson, M., 2021. Thirty years of International Business Review and International Business Research. International Business Review. 30(2), 101795.

Corsi, K., Arru, B., 2020. Role and implementation of sustainability management control tools: critical aspects in the Italian context. Accounting, Auditing & Accountability Journal. 34(9), 29-56.

Fang, C., Zhang, J., 2018. Performance of green supply chain management: A systematic review and meta analysis. Journal of Cleaner Production. 183, 1064-1081.

Fonseca, L., Amaral, A., Oliveira, J., 2021. Quality 4.0: the EFQM 2020 model and industry 4.0 relationships and implications. Sustainability. 13(6), 3107.

Hartmann, C., Furtwaengler, P., Siegrist, M., 2022. Consumers' evaluation of the environmental friendliness, healthiness and naturalness of meat, meat substitutes, and other protein-rich foods. Food Quality and Preference. 97, 104486.

He, Z., 2017. Development of Microbial Fuel Cells Needs To Go beyond "Power Density". ACS energy letters. 2, 700-702.

Horton, P., Horton, B.P., 2019. Re-defining Sustainability: Living in Harmony with Life on Earth. One Earth. 1(1), 86-94.

Isaksson, R., 2018. Revisiting the triple bottom line, in: Passerini, G., Marchettini, N. (Eds.), Sustainable development and planning 2018. WITpress, Boston, pp. 425-436.

ISO, 2006. Environmental management: life cycle assessment; Principles and Framework. ISO, International Organization for Standardization.

Kenett, R.S., Bortman, J., 2022. The digital twin in Industry 4.0: A wide-angle perspective. Quality and Reliability Engineering International. 38(3), 1357-1366.

Letchumanan, L.T., Gholami, H., Yusof, N.M., Ngadiman, N.H.A.B., Salameh, A.A., Štreimikienė, D., Cavallaro, F., 2022. Analyzing the Factors Enabling Green Lean Six Sigma Implementation in the Industry 4.0 Era. Sustainability. 14(6), 3450.

Li, H., Ai, X., Wang, L., Zhang, R., 2022. Substitution strategies for cooking energy: To use gas or electricity? Journal of Environmental Management. 303, 114135.

Mahmud, R., Moni, S.M., High, K., Carbajales-Dale, M., 2021. Integration of techno-economic analysis and life cycle assessment for sustainable process design–A review. Journal of Cleaner Production. 317, 128247.

OECD/FAO, 2020. OCDE-FAO Perspectivas Agrícolas 2020-2029.

Petit, G., Sablayrolles, C., Yannou-Le Bris, G., 2018. Combining eco-social and environmental indicators to assess the sustainability performance of a food value chain: A case study. Journal of Cleaner Production. 191, 135-143.

Putnik, P., Kovačević, D.B., 2021. Meat consumption: Theory, practice and future prospects. Теория и практика переработки мяса. 6(4), 335-342.

Salvadorinho, J., Teixeira, L., 2021. Stories Told by Publications about the Relationship between Industry 4.0 and Lean: Systematic Literature Review and Future Research Agenda. Publications. 9(3), 29.

Siva, V., Gremyr, I., Bergquist, B., Garvare, R., Zobel, T., Isaksson, R., 2016. The support of Quality Management to sustainable development: A literature review. Journal of cleaner production. 138, 148-157.

Spreafico, C., 2022. An analysis of design strategies for circular economy through life cycle assessment. Environmental Monitoring and Assessment. 194(3), 1-33.

Tripathi, V., Chattopadhyaya, S., Mukhopadhyay, A.K., Sharma, S., Li, C., Di Bona, G., 2022. A Sustainable Methodology Using Lean and Smart Manufacturing for the Cleaner Production of Shop Floor Management in Industry 4.0. Mathematics. 10(3), 347.

Utnik-Banas, K., Schwarz, T., Szymanska, E.J., Bartlewski, P.M., Satola, L., 2022. Scrutinizing Pork Price Volatility in the European Union over the Last Decade. Animals (Basel). 12(1), 100.

Wang, J.W., Cheng, C.H., 2011. Extracting the rules of KPIs for equipment management based on rough set theory, Advanced Materials Research. Trans Tech Publ, pp. 2358-2361.

You, W., Henneberg, R., Saniotis, A., Ge, Y., Henneberg, M., 2022. Total Meat Intake is Associated with Life Expectancy: A Cross-Sectional Data Analysis of 175 Contemporary Populations. Int J Gen Med. 15, 1833-1851.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Life Cycle Assessment of the Manufacture of Abrasive Discs

BALDERAS-LOPEZ, S. M. [a,b*], AGUILAR-VIRGEN, Q.[b], TABOADA-GONZALEZ, P.[b], VARGAS-GURROLA, L.[a], TEON-VEGA, A.[a], MONTAÑO-SOTO, M.T.[a]

a. Universidad Tecnológica de Tijuana, Tijuana, México

b. Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Tijuana, México

**Corresponding author, silvia.balderas@uttijuana.edu.mx*

Abstract

The life cycle assessment (LCA) has applications in the energy sector, chemical processes, construction sector, waste management, aerospace industry, manufacturing sector, and products manufactured using abrasive processes. However, there is a lack of a life cycle perspective in researching abrasive products necessary for industrial sectors such as automotive, aerospace, steel, hardware, metalworking, construction, and lumber to complete their production cycles. Due to the above, the objective of this study was to evaluate the potential environmental impacts in the manufacture of abrasive discs of aluminum oxide, zirconia, and ceramic gel in the "cradle to grave" mode through the application of an LCA. The assessment follows the methodology of ISO 14040 and 14044. The functional unit was an abrasive sheet of 0.29 m^2, 180 discs per sheet, and 10 minutes of average use per disc. SimaPro 8.2 software, the ReCiPe midpoint method, and the Ecoinvent 3.7 database were used to estimate the life cycle impact assessment. The categories with the greatest impact on the three discs are ecotoxicity and human toxicity. In the first case, marine ecotoxicity represents 49.9% (0.67 to 0.74 kg 1,4-DCB eq), for freshwater ecotoxicity there is 32.8% (0.52 to 0.58 kg 1,4-DCBeq), in terms of the terrestrial ecotoxicity is 2.04% (27.35 to 32.66 kg 1,4-DCBeq). Regarding human toxicity, carcinogenic toxicity represents 10.4% (0.37 to 0.44 kg 1,4-DCBeq) and non-carcinogenic toxicity represents 3.57% (6.88 to 7.85 kg 1,4-DCBeq). These categories are mainly due to the demand for electrical energy in the manufacturing stages of raw materials with 17.6% and use with 74.9%. The category of global warming only represents 0.11%. It is necessary to know the categories that cause an impact to develop proposals to reduce these impacts. This situation is especially critical if they are not within your control area. Strategies with suppliers to promote sustainable actions improve the production systems and minimize the impacts in the manufacturing stage of raw materials. Regarding its influence in the stage of use, it is necessary to raise awareness and socialize the efficient use of the product through marketing strategies.

Keywords: Life cycle assessment, Abrasive discs, Environmental footprint

1. Introduction

Global environmental impacts such as climate change, loss of biodiversity, scarcity of raw materials, and overexploitation of resources are increasingly severe. These chronic problems are a consequence of the increase in the demand for products that satisfy the fundamental needs of human beings. Businesses are responding to the demand for such products but undoubtedly face impending resource and energy shortages, leading to the growing importance of sustainability in manufacturing. For this reason, business development strategies should be proposed that allow economic development with social and environmental responsibility. In this sense, Atia et al. (2020) state that companies recognize that the life cycle perspective can positively affect the entire value chain of products and services, reflecting improving productivity and environmental performance.

1.1 Case study

The case study is developed in an abrasives industry in northern Mexico, dedicated to the assembly and manufacture of abrasive discs mainly from coated abrasives. The company is committed to sustainability and has led it to propose different policies and operating practices. Among its main points is the "Environmental Footprint," which seeks to minimize the environmental impact of its operations in five priorities: 1) Increase the energy efficiency of production; 2) Increase the use of recycled raw material in plants; 3) Reduce CO_2 emissions; 4) Optimize hydraulic resources; 5) Strict waste separation policy. However, these practices are generalized and do not have indicators or particular environmental evaluations of the processes. The impact of the changes that promote these sustainable actions is not measured.

The product under evaluation is an abrasive disc and is in the quick-change product classification. These discs are made of the abrasive or sandpaper surface, velcro (a printed and pigmented polyester film internally called lantuck), and a button. Coated abrasives or sandpaper are made of flexible backings or support such as paper, cloth, cloth-paper combination, and vulcanized fiber. They also have abrasive grains such as aluminum oxide, garnet, silicon carbide, and zirconium. Although however, there are still some applications with natural materials; most abrasive grains are made from synthesized materials. They are used in portable tools and are ideal for intermediate, refined, and micro-finishing operations. Larger diameters are typically utilized on stationary sanders to size and finish metal and wood parts.

2. Literature review

Life cycle assessment (LCA) has been a widely used systematic approach to assessing the environmental impacts of products, processes, and services (Mah et al., 2018; Lourenço and Carvalho, 2020; Toniolo et al., 2020). The wide application of LCA is due to the credibility, scientific recognition, and precise application guidance of ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b).

The literature shows that LCA has a wide application in sectors such as chemical industry, construction and adaptation of buildings, generation and use of energy, agro-industrial products, agricultural products (large-scale and urban orchards), food, processes manufacturing (such as glass, steel, plastics, floors), wastewater treatment and the management of hazardous and special handling waste, among others. Some studies are as follows:

- In the energy sector, LCA is used alongside exergy methodologies, which allows the development of thermodynamic models that interpret equipment and fuel consumption operation and are integrated into the evaluation of environmental impacts with less uncertainty. (Lourenço and Carvalho, 2020).
- In processes of greater specialization, such as the chemical sector (Fernandez-Dacosta, Posada and Ramirez, 2016; Mangili *et al.*, 2018) or in the aerospace industry(Al-Lami, Hilmer and Sinapius, 2018), the LCA serves as the basis for the selection of impact assessment methodologies and characterization factors, mainly focused on the carbon footprint category. This information is processed in its platforms such as eeam-python to generate indicators that can be environmental, economic, and eco-efficiency.
- The construction sector focuses on implementing LCA by making comparisons of different scenarios to identify those that generate less impact on the systems (Allacker and De Troyer, 2013; Mah, Fujiwara and Ho, 2018). Likewise, they focus on the analysis of the energy performance of the constructive solutions for the thermal envelope of the building because it is the outer part and, therefore, it is the one that has the most significant influence on the energy consumption of the building (Ferrandez-Garcia, Ibanez-Fores and Bovea, 2016).
- In waste management, those focused on energy use are extremely important to reducing global emissions of greenhouse gases (GHG) since extensive efforts have been made to promote the evaluation of greenhouse gas emissions. GHG of the sector and LCA is one of the tools used (Zhao, Huppes and van der Voet, 2011).
- In the manufacturing sector, LCA aims to assess environmental loads through the identification and quantification of energy and materials consumed and the waste produced. The information it provides shows the effects of an activity on the environment and identifies opportunities to make changes and reduce impacts at various points in the life cycle of products, processes, and activities (Toniolo *et al.*, 2020). These environmental loads are intensified when natural resources such as non-ferrous metals are used; they are considered one of the relevant raw materials for industrial development since they have a wide range of applications and a high degree of industrial relevance. These materials play an essential role in the economy, national defense, social development, and other aspects (Chen and Lin, 2020). These metals are also the raw material for

the manufacture of abrasives; however, their smelting and processing are accompanied by high energy consumption and increased greenhouse gas emissions.

From this perspective, and assuming that the industrial sectors are interrelated, any finished product not only generates environmental pressures on the process but also on the industries of the value chain suppliers: the packaging plants, packaging, energy, logistics, companies of other materials or inputs such as abrasives, chemical products, among others. Therefore, the environmental pressure emitted by industry must cover all related production processes, and the exhaustive evaluation is carried out through LCA (Chen and Wu, 2018).

3. Methods

As mentioned above, the life cycle analysis is based on the framework proposed by the ISO 14040 and 14044 standards. These standards establish the stages and guidelines for conducting the examination. Life Cycle Analysis (LCA) will be integrated into the study as the tool to calculate the environmental footprint of quick-change abrasive disc manufacturing.

3.1 Goal and scope definition

The objective of this study was to analyze the environmental footprint of quick-change abrasive discs and identify critical points from the ecological point of view throughout the product's life cycle.

3.2 Determination of functional unit and boundaries

The product under evaluation is an abrasive disc and is in the quick-change product classification. These discs are made of the abrasive or sandpaper surface, velcro (a printed and pigmented polyester film internally called lantuck), and a button.

An abrasive sheet of aluminum oxide, zirconia, and ceramic gel with a surface of 0.29 m^2 was selected as a functional unit. It should be noted that 180 abrasive discs are manufactured from each sheet, and they have an average use time of 10 minutes.

An LCA from the cradle to the grave was proposed. The stages considered are manufacturing and transportation of raw materials, conditioning of raw materials, manufacturing of the disk and its packaging, distribution, use, and end of life. (**Erro! Fonte de referência não encontrada.**).

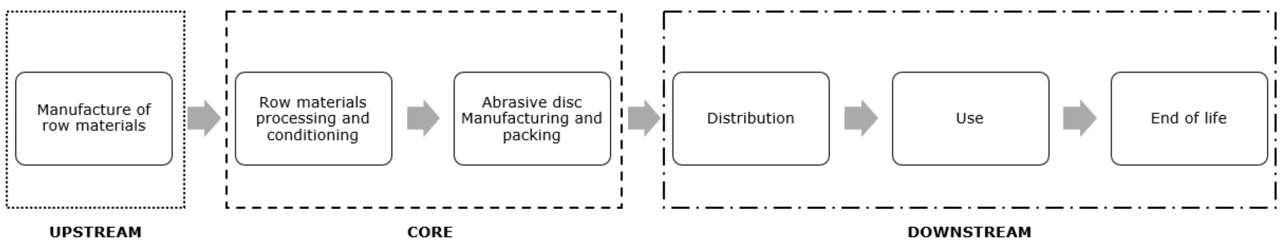


Fig. 1 System boundaries of the abrasive discs manufacturing

3.2 Analysis inventory

The inventory (Table 1), includes values related to the consumption of raw materials, the demand for electrical energy for the conditioning and production of the disc, and the stage of use of the product for the functional unit (FU). The company provided the primary data for the upstream and core steps. The information corresponding to the downstream, that is, the distribution, use, and end of life, was proposed considering that the product moves to the center of the country, where it is used and disposed of.

Table 1 LCI data of the baseline scenario of abrasive discs (1 sandpaper sheet, 180 discs)

		Sandpaper type			
	Input/output	**Al_2O_3**	**ZrO_2**	**Ceramic gel**	**Unit**
Manufacture of row materials	Sandpaper	0.3666	0.5984	0.4321	kg
	Chemicals	0.2683	0.2723	0.3006	kg
	Pigments	0.0050	0.0052	0.0044	kg
	Lantuck	0.0507	0.0507	0.1015	kg
	Metallic button	0.2065	0.2065	0.2065	kg
	Transportation of raw materials	3.8822	4.2371	3.9966	tkm
Row materials processing and conditioning	Electricity	1.8103	1.8103	1.8103	kWh
	Tap water	0.0345	0.0344	0.0344	kg
	Hazardous waste	0.1513	0.1513	0.1513	kg
	Scrap (sandpaper waste)	0.0209	0.0113	0.0082	kg
	Gas emission	0.5322	0.5322	0.5322	kg
	Particulates	2.08E-05	2.08E-05	2.08E-05	kg
	Volatic organic compounds	0.0322	0.0322	0.0322	kg
	Fuels	0.0003	0.0003	0.0003	kg
Abrasive disc Manufacturing and packing	Electricity	1.7392	1.7392	1.7392	kWh
	Cardboard box	0.1120	0.1185	0.0411	kg
	Labels	0.0003	0.0011	0.0010	kg
	Packaging transport	0.0034	0.0034	0.0034	tkm
	Hazardous waste	0.0037	0.0037	0.0037	kg
	Scrap (sandpaper waste)	0.1827	0.2309	0.2100	kg
Distribution	Distribution transport	2.0952	2.4603	2.0541	tkm
Use	Electricity	9.0000	9.0000	9.0000	kWh
	Particulates	0.0804	0.2456	0.1248	kg
End of life	Transport (end of life)	0.0353	0.0537	0.0294	kg
	Cardboard box waste	0.1122	0.1196	0.0421	kg
	Scrap used disc	0.3126	0.5274	0.3126	kg

Note: Mean values refer to 2019. Refer to FU (functional unit)

3.3 Life cycle impact assessment results of mid-point indicators

Life Cycle Impact Assessment (LCIA) tries to convert the raw materials used and the substances emitted by a specific product during its life cycle into potential environmental loads, identifying the causes and effects of said loads. In this context, the ReCiPe method was used for midpoint categories (Huijbregts *et al.*, 2017), which comprises 18 categories of potential impact: global warming (GWP), stratospheric ozone depletion (ODP), ionizing radiation (IRP), ozone formation, human health (HOFP), fine particulate matter formation (PMFP), Ozone formation, terrestrial ecosystems (EOFP), terrestrial acidification (TAP), freshwater eutrophication (FEP), marine eutrophication (MEP), terrestrial ecotoxicity (TETP), freshwater ecotoxicity (FETP), marine ecotoxicity (METP), human carcinogenic toxicity (HTPc), human non-carcinogenic toxicity (HTPCnc), land use (LOP), mineral resource scarcity (SOP) and fossil resource scarcity (FFP). The impact evaluation was carried out in the SimaPro 8.2 software, and the Ecoinvent 3.7 databases were used.

It is essential to point out that data sets such as the jumbo, pigments, and adhesives were created to calculate the environmental footprint. In particular, a dataset corresponding to electrical energy was created for Baja California, Mexico, since the energy matrix differs from the matrix for the rest of the country. In addition, a contribution analysis was applied, and the relevant processes were evaluated through a sensitivity analysis.

4. Results

Chart 1 presents the normalized impact categories. The indicators show that the greatest impacts in the three disks are ecotoxicity (in its variants: marine, terrestrial and freshwater) and human toxicity (carcinogenic and non-carcinogenic). Regarding marine ecotoxicity, it represents 49.9% (0.67 to 0.74 kg 1,4-DCB eq), for freshwater ecotoxicity there is 32.8% (0.52 to 0.58 kg 1,4-DCBeq), in terms of the terrestrial ecotoxicity is 2.04% (27.35 to 32.66 kg 1,4-DCBeq). Regarding human toxicity, carcinogenic toxicity represents 10.4% (0.37 to 0.44 kg 1,4-DCBeq) and non-carcinogenic toxicity represents 3.57% (6.88 to 7.85 kg 1,4-DCBeq). These impacts are particularly due to the demand for electrical energy in the manufacturing stages of raw materials with 17.6% and in the disk use stage with 74.9%. Although the category of global warming only represents 0.11, it is shown in the results since it is a requested indicator for the fulfillment of goals in the company.

Graphs 2, 3, and 4 shows the results of the normalized indicators of the environmental footprint of each of the quick-change abrasive discs evaluated. The impact categories are similar in the three discs. The most significant contribution is reflected in the manufacturing processes of raw materials (upstream) and the disc's use (downstream). These processes are part of the company's area of influence. Regarding the disc manufacturing processes, which are part of the control area, the impacts generated are due to the consumption of electrical energy during the conditioning of the raw materials.

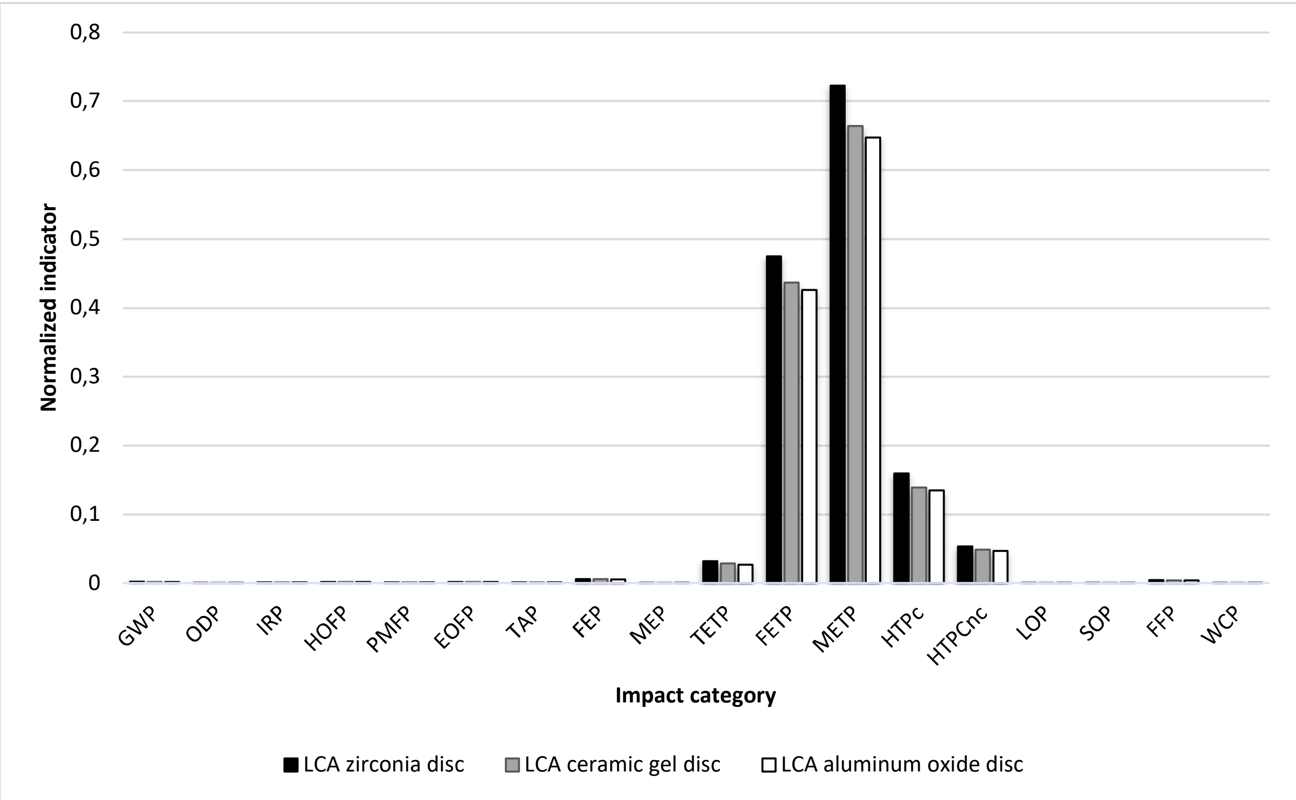


Chart 1 Standardized impact categories of abrasive discs manufacture

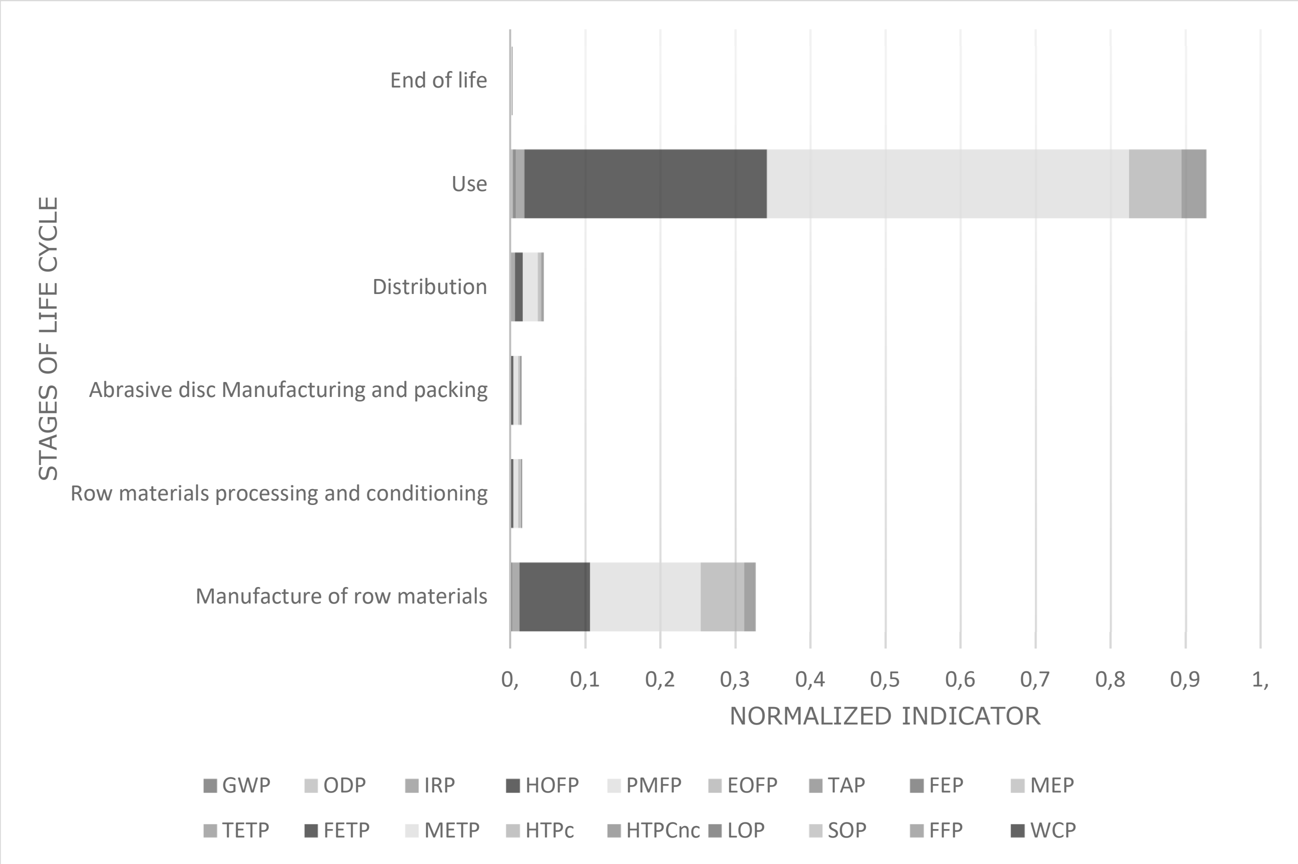


Chart 2 Normalized impact categories of ceramic gel abrasive disc

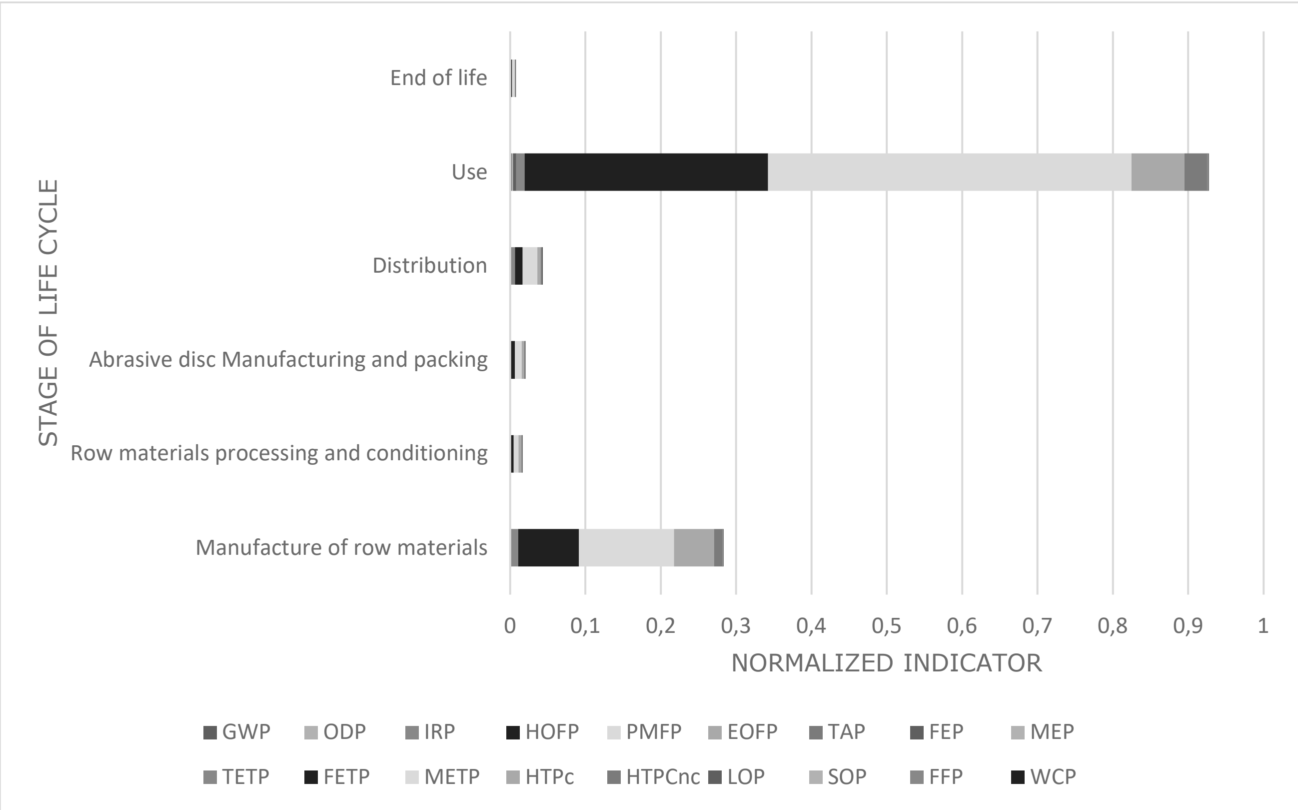


Chart 3 Normalized impact categories of aluminum oxide abrasive disc

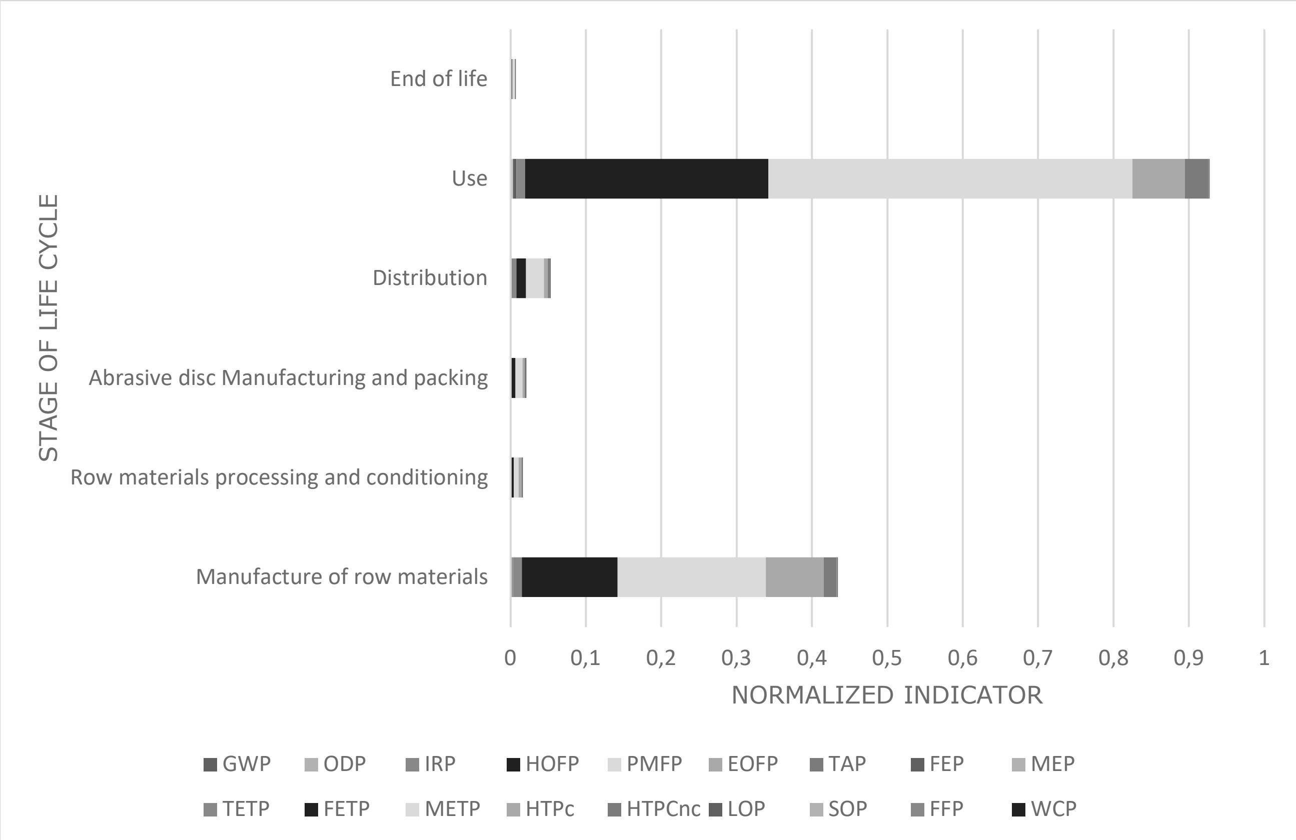


Chart 4 Normalized impact categories of zirconia abrasive disc

5. Conclusions

It is observed that the environmental profile is dominated by the manufacturing phase of the raw materials and the use of the abrasive disc. These stages correspond to the area of influence by the company, which represents a challenge to develop proposals aimed at raising awareness and socializing alternatives that make the use of the product more efficient.

In the case of the control area (where the production of the disk is carried out), although it is not the critical area, strategies can also be proposed to improve energy efficiency. A first step would be to increase production with the same machinery and, in the medium term, replace it with more efficient equipment for processing raw materials that generate less environmental impact.

It is still pending to develop and analyze the economic and social impacts of abrasive discs, considering that they are single-use products widely used in the market.

6. References

Allacker, K. and De Troyer, F., 2013. Moving towards a more sustainable belgian dwelling stock: the passive standard as the next step?. Journal of Green Building. 8, 112–132.

Al-Lami, A., Hilmer, P., Sinapius, M., 2018. Eco-efficiency assessment of manufacturing carbon fiber reinforced polymers (CFRP) in aerospace industry. Aerospace Science and Technology. 79, 669–678.

Atia, N.G., Bassily, M.A. and Elamer, A.A., 2020. Do life-cycle costing and assessment integration support decision-making towards sustainable development?. Journal of Cleaner Production. 267, 122056.

Chen, S. and Wu, D., 2018. A revealed damage cost method to evaluate environmental performance of production: Evaluating treatment efficiency of emissions and scaling treatment cost bounds. Journal Of Cleaner Production. 194, 101–111.

Chen, X., Lin, B.,2020. Assessment of eco-efficiency change considering energy and environment: A study of China's non-ferrous metals industry. Journal of Cleaner Production. 277, p. 123388.

Fernandez-Dacosta, C., Posada, J.A., Ramirez, A., 2016. Techno-economic and carbon footprint assessment of methyl crotonate and methyl acrylate production from wastewater-based polyhydroxybutyrate (PHB). Journal Of Cleaner Production. 137, 942–952.

Ferrandez-Garcia, A., Ibanez-Fores, V., Bovea, M.D., 2016. 'Eco-efficiency analysis of the life cycle of interior partition walls: a comparison of alternative solutions. Journal Of Cleaner Production. THE BOULEVARD, LANGFORD LANE, KIDLINGTON, OXFORD OX5 1GB, OXON, ENGLAND: ELSEVIER SCI LTD.

Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F, Stam, G., Verones, F., Vieira, M.D.M., Hollander, A., Zijp, M., Van Zelm. R., 2017. ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. The International Journal of Life Cycle Assessment, 22, 138–147.

ISO 14040:2006. Gestión ambiental — Análisis del ciclo de vida — Principios y marco de referencia. https://www.iso.org/obp/ui#iso:std:iso:14040:ed-2:v1:es. Last accessed: May 2021.

ISO 14044:2006(es), Gestión ambiental — Análisis del ciclo de vida — Requisitos y directrices. https://www.iso.org/obp/ui#iso:std:iso:14044:ed-1:v1:es. Last accessed: May 2021.

Lourenço, A.B. and Carvalho, M., 2020. Exergoeconomic and exergoenvironmental analyses of an off-grid reverse osmosis system with internal combustion engine and waste heat recovery. Chemical Engineering Journal Advances. 4, 100056.

Mah, C.M., Fujiwara, T., Ho, C.S., 2018. Life cycle assessment and life cycle costing toward eco-efficiency concrete waste management in Malaysia. Journal of Cleaner Production, 172, 3415–3427.

Mangili, P. V., Souza, Y. P., de Menezes, D. Q., Santos, L. S., & Prata, D. M., 2018. Eco-efficiency evaluation of acetone-methanol separation processes using computational simulation, Chemical Engineering And Processing-Process Intensification. 123, 100–110.

Toniolo, S.,Tosato, R.C., Gambaro, F., Ren, J., 2020. Chapter 3 - Life cycle thinking tools: Life cycle assessment, life cycle costing and social life cycle assessment. In Ren, J. and Toniolo, S. (eds) Life Cycle Sustainability Assessment for Decision-Making. Elsevier, 39–56.

Zhao, W., Huppes, G. and van der Voet, E., 2011. Eco-efficiency for greenhouse gas emissions mitigation of municipal solid waste management: A case study of Tianjin, China. Waste Management, 31, 1407–1415.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Life Cycle Assessment of Plastic Packaging Film in Flexographic Printing

BARDINI, M., COLARES, G. S., LUTTERBECK, C. A., SCHNEIDER, R. C. S., BECKER JUNIOR, A. M., RODRIGUEZ, A. L., MORAES, J. R., MACHADO, Ê. L.*

Universidade de Santa Cruz do Sul-UNISC, Rio Grande do Sul, RS, Brazil

**Corresponding author, enio@unisc.br*

Abstract

In order to contribute to further study plastic film life cycle, this study aimed to analyze and diagnose the flexographic printing process through life cycle assessment tool. The research was conducted in a plastic packaging industry in Brazil. The data needed was inventoried and applied on SimaPRO v. 7.3.3 software. ReCIPe and Impact 2002+ methods were used. This study was done in accordance with International Standards ISO 14.040 and 14.044, and the functional unit was defined as 1077 m² of plastic packaging impression, resulting in a reference flow of 1000 kg of material. The results infer that printing process has the highest contributions for all categories of environmental impacts used among the evaluated elementary processes. This is due to the plastic films production's chain and due the consumption of solvent base products. The recovering Volatile Organic Compounds (VOCs) is the one of possible scenario that could be evaluated in the elementary process of printing.

Keywords: Plastic Packaging, Flexographic Printing, Life Cycle Assessment, Environmental Impact, Environmental Management

1 Introduction

It is estimated that 80% of costumer purchasing decisions for food stuffs are made based on the packaging [1]. Consumers are closer to the sustainability issues, and often made decisions about the best product to be purchased, such as those derived from fossil or renewable source [2]. Therefore, it is important to inform consumers about the environmental implications of the entire product life cycle, including its packaging and processes related to the final product, such as plastic films printing process. [3,4]. Among the techniques used for plastic films printing stands out the flexography. In this process water-based liquid ink, solvent or cured by UV light are used [5]. This type of printing is based on high speed rotation, which is widely used in the graphic arts and packaging materials printing, such as cardboard, paper or foil [6]. A package design must be carried out considering cost, shelf-life, safety and practicality, and also the environmental sustainability. The packaging industry should improve their production processes and minimize the use of material to provide packages whose functionality helps reduce other significant impact, such as unnecessary losses when the product is being used [7-9].

Large groups in the food industry have applied the LCA technique in their processes in order to identify and evaluate their environmental sustainability, for example, Nestlé group sustainability actions. Since the launch of Nescafé Dolce Gusto in 2006, the product carbon footprint was reduced by 32%; the amount of non-renewable energy was decreased by 41%; and the overall water consumption was reduced by 25% (http:/www.nestle.com/asset-library/Documents/Library/Documents/Corporate_Social_Responsability/2011). Another group, Dupont, has also developed studies with LCA for rotogravure and flexography, but focused on the product without detailing the process in its publication acessed in 2017 (http://www2.dupont.com/Packaging_Graphics/en_GB/assets/downloads/AdvancingSustainability.pdf). The academic community has also shown interest in evaluating the life cycle of plastic bags, especially packages and trays. These studies range from inventories analysis, as well as complete product life cycle analysis [10-16].

Toniolo et al. [17] and Siracusa et al. [4] evaluated the life cycle of a tray and a plastic film, respectively. In the first case was evaluated an innovative recyclable plastic packaging is more environmentally friendly compared to others that are not recyclable. They compared two plastic films: monolayer and multilayer.

The functional unit adopted was a tray with 0,54L capacity. The study showed that the monolayer film with additives to enable their recycling has lower environmental impact values for all evaluated categories. For example, for the climate change category, the monolayer film had a value of 7.83 10^2 kg of CO_2-eq., while the multilayer film has contributed an amount of 8.24e2kg of CO_2-eq. Siracusa et al. [4] evaluated a plastic film life cycle containing a polyamide and a low density polyethylene layer. The functional unit adopted was 1 m² of plastic film. The results showed a greater environmental impact in the production of polyamide and low density polyethylene, due to consumption of natural resources, including natural gas and crude oil, as well as other air emissions. The categories with major damage were Resources, followed by climate change, Human Health and Ecosystem Quality. In order to reduce the environmental impacts the film thickness and the use of recycled polyamide granules were regarded, providing environmental damage reductions between 15 and 25%, respectively.

However, the plastic industry has a lack of studies focusing at the process of plastic packaging film printing life cycle. Piluso et al. [18] conducted one of the few studies found. The eco efficiency of flexographic printing process was evaluated by three different inks and associated techniques, which are: solvent-based ink; water-based ink and; Ink cured by UV. The results were expressed in terms of environmental impacts categories such as climate change, primary energy, ozone depletion and human toxicity. The functional unit was defined as 1000 m² printed of low-density polyethylene plastic film. The results showed that for all categories evaluated the water-based ink present lower contribution then cured UV ink base. Furthermore, the solvent-based ink showed the highest values for the environmental impacts categories. Other research example was conducted by Navajas et al. [19]. The research evaluated the life cycle of polyvinyl chloride printed tapes. To conduct the assessment, the authors considered eleven categories of environmental impacts. The results showed that the processing step had the highest environmental impacts in the product life cycle. Given the above scenario and to contribute with future studies, this study aimed to evaluate, through a case study, the life cycle of plastic packaging produced through flexography process on an industrial unit located in southern Brazil.

This environmental assessment differs from the others by considering and discussing the contribution of each elementary process in the product footprint, thus facilitating the visualization of critical and improvement targets points.

2 Methodology

This study was done in accordance with International Standards Methodologies, which were ISO 14.040 [20] and ISO 14.044 [21].

2.1 Objective and scope

This study selected gate-to-gate as cutoff criteria for data collection (Fig. 1). The objective was to apply the LCA methodology to identify and evaluate the main environmental impacts associated with the plastic packaging fabricated by flexographic printing process. In addition, it sought to contribute with process data regarding the printing of plastic packaging. The environmental impacts categories and the method selected in this study were based on Toniolo et al. [17]. The methods Impact 2002+ 2.10 and Recipe midpoint (H) were used in SimaPro v. 7.3.3 software. The functional unit is 1077 m² of plastic packaging impression, which lead us to the material flow of 1000 kg. Each package has an area of 0.07 m² and mass 0.065 kg. The evaluation was carried out conducted taking into consideration the mandatory elements of classification and characterization, such as the optional normalization factor as applied by Siracusa et al. [4]. The categories of impacts selected for discussion were based on the normalization method mentioned above. Climate change impact is considered as exception due to its relevance for previous researches and importance for carbon footprint studies.

2.2 Study boundaries and Inventory Life Cycle

Figure 1 show the boundaries of the study.

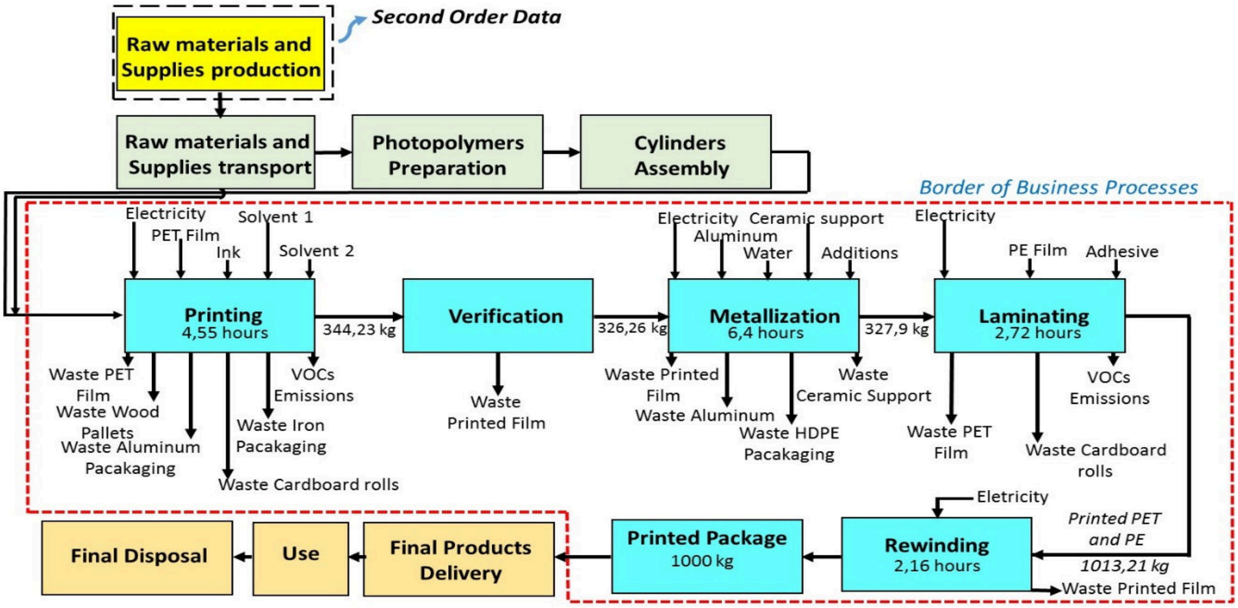


Figure 1. Borders of the study for Plastic Packaging Film in Flexographic Printing

Input and output data of the elementary processes is assessed on the border of the study. The following elementary processes were considered in the boundary of the study: printing; check; metallization; laminating and rewinding. The data collected were from the first-rate. Second order data was acquired for system expansion. In this case, the data was collected mostly from Ecoinvent library v. 2.1. Questionnaires were applied in order to obtain primary data information. Measurement, observation of activities, research on data sheets and equipment manuals, consultations to the plant system were also collected. Volatile Organic Compounds (VOCs) values were obtained considering the losses post-processing solvent. Some process steps was not included in the scope of the study, such as raw materials and supplies transportation, products used and the final disposal of them. It was also not included in the study the elementary processes responsible for recording and assembling the photopolymer.

3 Results and Discussion

3.1 Life Cycle Inventory (LCI)

Among the environmental aspects involved in the flexographic printing process, it was observed the potential consumption of impacting agents, such as plastic film, inks and solvents (Table 1). Furthermore, all elementary processes has shown considerable electricity consumption and waste generation. Due the use of alcohols, ketones, ether and ester, this process present release of VOCs. The further details of the composition of the chemicals was made through the chemicals data sheets - Material Safety Data Sheet/2017 – MSDS (https://www.msdsonline.com/). The printing process is followed by the verification step, and this is considered an extension of the printing process. The purpose of verification is to analyze and detect flaws in printed material, by quality control. In this case, it was observed the waste generation of 17.97 kg of PET film.

The next elementary process is metallization, which aims to create a protective barrier on the plastic film by adding an aluminum layer. According to Suguiuti et al. [23], metallization increases the barrier properties of the material by 20 to 100 times. Aluminum and ceramic material, which support aluminum, are consumed within this stage. In this process, there is basically the consumption of aluminum and a ceramic material, which serves to support that aluminum, can be evaporated under vacuum condition. After the metallization, there is the lamination's elementary process, and this aims to add a layer of polyethylene (PE) to the metallized film, aiming to add mechanical or barrier properties to the material. Adhesives are applied in this step to assemble the plastic films. Lastly, rewinding is the last elementary process. Table 1 presents the inventory data as well the chosen data from SimaPRO v. 7.3.3 software. Most of the chosen data was derived from the Ecoinvent library v. 2.1. Solid wastes are observed as being potentially recyclable through the evaluated process, avoiding hazardous waste as well. Another important aspect is the maximum percentage generated in all elementary processes does not exceed 4% in all elementary processes, regarding the percentage of solid waste generated in relation to the inputs of raw materials and additives.

Furthermore, it was observed that 37.38% of paints and solvents were incorporated into the plastic film. .The remaining portion is mainly solvents, provided the source of emission of VOCs. This emission is released directly into the stratosphere, where there is no gases treatment system. According to Almeida [23], control the VOCs emissions is important because they are a major component to the chemical and physical reactions that form ozone and other photochemical oxidants in the atmosphere.

3.2 Life Cycle Impact Assessment (LCIA)

Some chemical compounds were not found in the SimaPRO database, including boron nitride, titanium diborate and aluminum nitride. For these cases were taken the chemical reactions of synthesis thereof. Due to generalities specified in the technical sheets of the additives used in the elementary process of metallization, were used databases from "Dummy_biocide_at plant / S" and "Dummy Solution corrosion inhibitor, at plant / US". These include a general inventory for these types of compounds.

Normalization is an optional element cited by the ISO 14.040 [20]. By using this tool, comparing the results of reference values, the most important impact categories can be identifying. The ReCiPe midpoint (H) adopts values referenced by Sleeswijk [24]. Figure 2 presents the results for the normalized environmental impacts categories. The following abbreviation was applied: Climate Change (CC); Ozone Depletion (OD); Human Toxicity (HT); Photochemical Oxidant Formation (FOF); Freshwater Eutrofization (FE); Terrestrial Ecotoxicity (TE); Freshwater Ecotoxicity (FEc); Water Depletion (WD); Metal Depletion (MD); Non Renewable Energy (NRE) and; Fossil Depletion (FD). It is noted that the highest impact category is the Photochemical Oxidant Formation. This amounted a total of 1.66 points, of which 95.77% is due to the release of VOCs during the packaging printing.

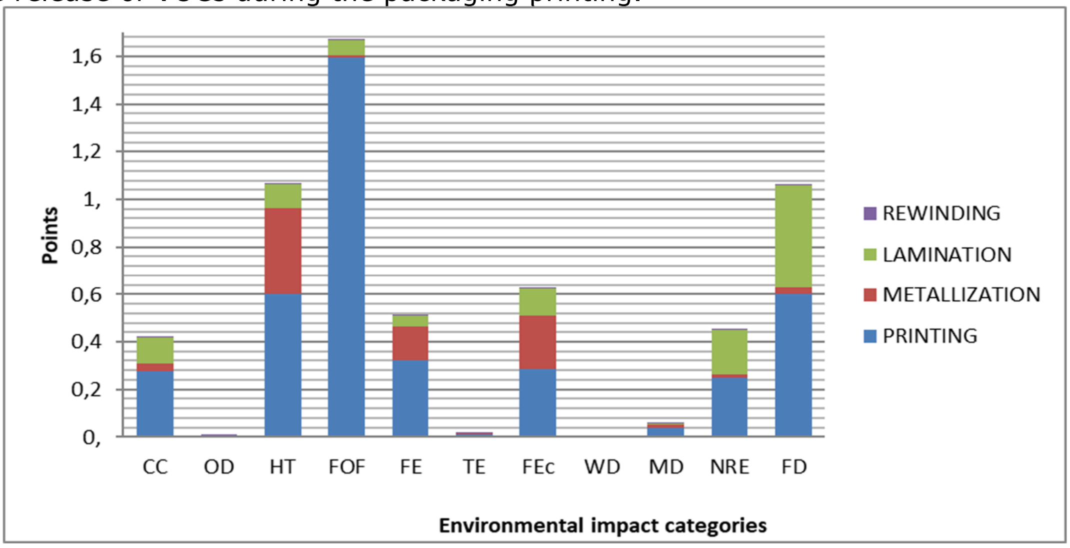


Figure 2. Normalized environmental impact categories according to ReCiPE 2008 midpoint (H) and Impact 2002+ methods.

All normalized impact categories totaled 5.87 points. Table 2 presents the significance of each category of environmental impact, compared to the value of 5.87 points.

Table 2. Impact categories representativeness.

Impactcategories	Points	% when compared to the 5.87 points
Climatechange	0.417	7.10
Ozone depletion	0.006	0.10
HumanToxicity	1.06	18.12
Photochemical oxidant formation	1.66	28.40
Freshwatereutrofization	0.51	8.6
Terrestrialecotoxicity	0.016	0.28
Freshwaterecotoxicity	0.62	10.67
Waterdepletion	0.0	0.0
Metal depletion	0.095	0.93
Non renewableenergy	0.45	7.67
Fossildepletion	1.06	18.03

Based on the results presented in Table 2 it can be seen that the most significant categories are: Photochemical oxidant formation, human toxicity, ecotoxicity (freshwater) and fossil depletion. The printing process has showed as the largest contribution for all impact categories. In addition, it was noted that the lamination process contributed to fossil depletion due the high plastic consumption. On the other hand, Vidal et al. [12] explained that the global warming category was the most significant impact with respect to normalized values, and the freshwater eutrofization impact had the lowest normalized value. These results are different of those presented in Table 2. The researchers used other methods to character and normalize and the difference founded could be associated with this.

Figure 3 presents the impact categories (in %) characterized. Table 3 presents the impact categories characterized with its equivalent units. It is noted that the printing process contributes the largest share to all impacts, and much of this characteristic is due to PET film production chain. When the life cycle of a multilayer plastic package is evaluated through Impact 2002+ method, the results obtained by Siracusa et al. [4] also indicated this characteristic. According to the researchers, in these pellets production processes are consumed primary resources, such as natural gas and oil, which results in major environmental impacts in the plastics life cycle.

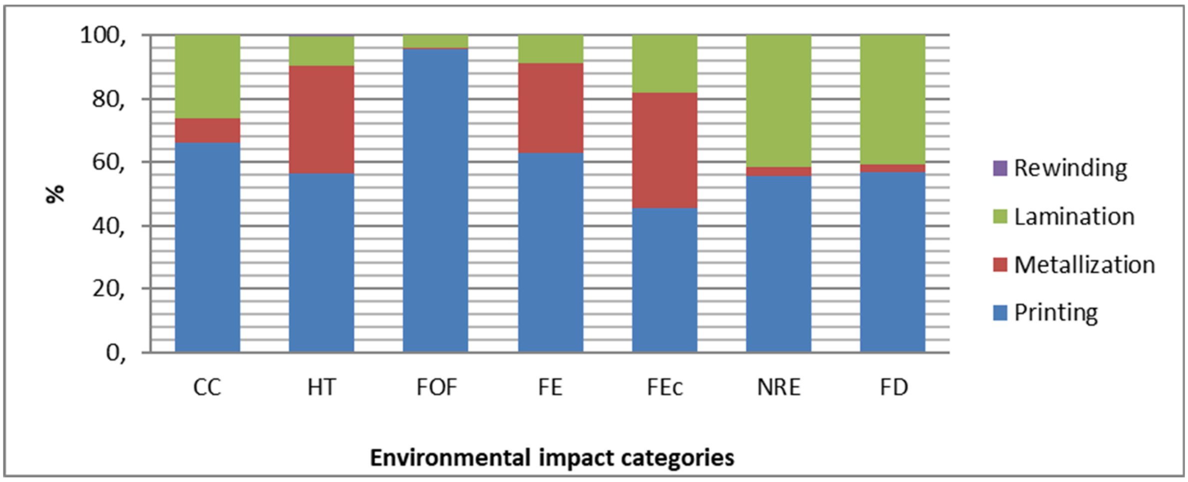


Figure 3. Characterized (in %) environmental impact categories according to ReCiPE 2008 midpoint (H) and Impact 2002+ methods.

When looking at Table 3 it can be seen that the fabrication of 1000 kg of film packaging contributed with 2,875.09 kg of CO_2 equivalent. This leads to a ratio of 2.875 kg of CO_2 eq. for each kg of printed packaging. Figure 4 presents each elementary process contributions on climate change category.

Table 3 Characterized environmental impact categories in accordance to ReCiPE 2008 midpoint (H) and Impact 2002+ methods

Environmental impact categorie	Unit	Printing	Metallization	Lamination	Rewinding	Total
Climatechange	kg CO_2 eq.	1,896.80	224.77	751.04	2.48	2,875.09
Humantoxicity	kg 1,4 DB-eq	70.59	42.22	11.86	0.21	124.88
Photochemical oxidant formation	kg of NMVOC	78.18	0.36	3.08	2.93 e^{-3}	81.62
Freshwatereutrofization	kg P eq	9.28 e^{-2}	4.18 e^{-2}	1.30 e^{-2}	1.78 e^{-4}	0.14
Freshwaterecotoxicity	kg 1,4 DB-eq	1.23	0.98	0.49	3.68 e^{-3}	2.70
Non renewableenergy	MJ	37,991.52	1,967.19	28,438.51	16.67	68,413.89
Fossildepletion	kg ofoil eq.	828.69	36.36	589.09	0.30	1,454.44

Printing process accounted for 65.97% (1896.8 kg CO_2 eq.) of the total. From this point of view, 1398.9 kg CO2 eq. are from the PET film production chain. The electricity consumption accounted for only 13.04% of the total (247.44 kg of CO2 equivalent). Lamination process contributed with 26.12% on climate change category, and it can be seen that 91.59% is associated with the PE film production chain. From these results it is noticed that most of the contributions is indirect, associated with operations outside the direct control of the company. As found by Siracusa et al. [4] the substances that cause the significant impact are carbon dioxide (with 1177 kg CO2eq) and methane (267.8 kg CO2eq).

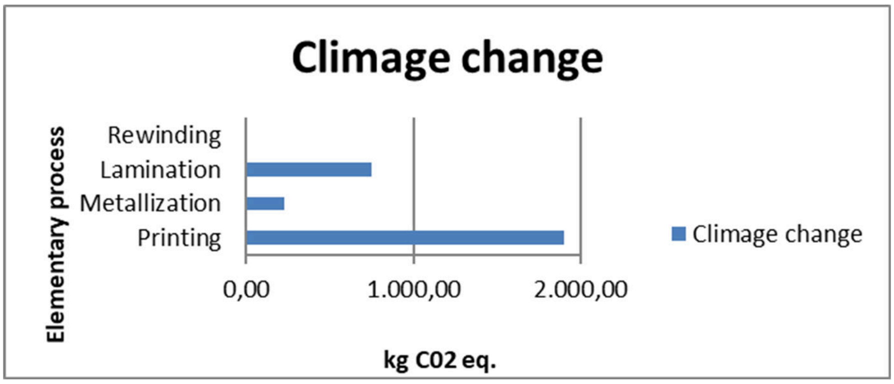


Figure 4. Contribution of each elementary process for the climate change impact category.

Figure 5 presents a comparison with other studies on the climate change impact category. In order to standardize the discussion to the selected impact categories, the functional units were extrapolated in accordance with the functional unit of this research. Toniolo et al. [17] evaluated the impacts associated with two types of packaging, one of these was multilayer. The results showed a value of 2746.6 kg CO_2 eq., which is close to those found in this study. On the other hand, the research conducted by Siracusa et al. [9] found a value of 508.34 kg CO_2 eq. As the material evaluated had not been sent to the print plant, the inventory did not consider all the processes linked to it, justifying the lower values. It is noteworthy that the researchers considered the entire product life cycle, including transport of raw materials and final disposal. The results showed that large amount of the contribution is related to the production chain of plastic film, being similar to the results founded on this work.

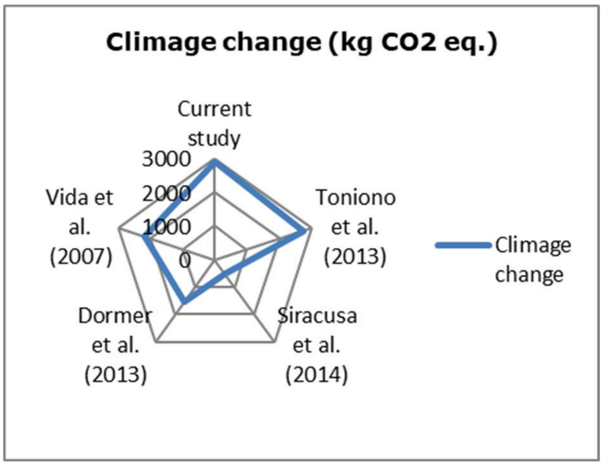


Figure 5. Comparison chart with other researchers for the climate change's impact category

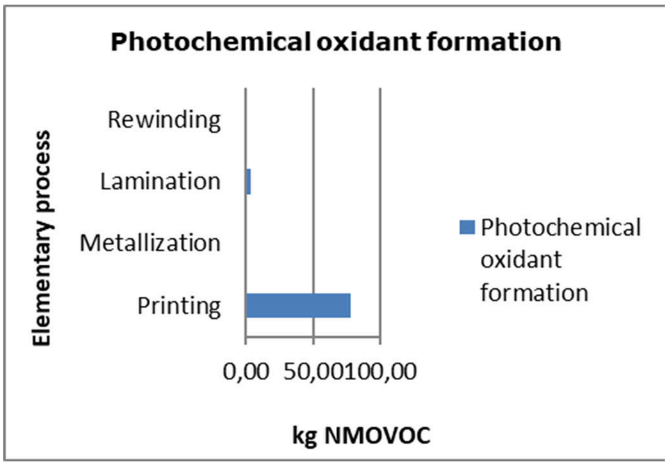


Figure 6. Contribution of each elementary process for the photochemical oxidant formation's impact category.

Dormer et al. [26] assessed the carbon footprint of PET manufacturing. The results showed the production of raw materials represented 45% of this total, which confirmed the characteristics obtained in this research. Vidal et al. [13] evaluated two types of plastic films. The results indicated a value of 2197.08 kg CO2 eq. for the propylene film, close to the value obtained in this research. Regarding to the human toxicity, the printing of 1000 kg of packages showed a total contribution of 124.88 kg 1.4 DB-eq. Due to the energy matrix and ethyl acetates consumption in printing and the aluminum production chain used on metallization, these processes together account for 90% of the total contribution. The substances causing the most impact are manganese (with 62.12kg 1.4-DB eq) and arsenic (with 17,73 kg 1,4-DB eq). The same characteristic is observed on freshwater ecotoxicity impact category (Figure 7). However, in this impact category the substances with the most influences are nickel (with 0.94kg 1.4-DB eq) and vanadium (with 0.43 kg 1.4-DB eq). Toniolo et al. [17] reported a value of 600 kg 1.4-DB eq. for human toxicity's impact category. The contribution was 81.62 kg of NMVOC and 95.7% to the photochemical oxidant formation impact, due to the release of VOCs during the printing operation. Figure 6 shows the contribution of each elementary process evaluated for this impact category.

Toniolo et al. [17] reported a value of 6.43 kg NMVOC. As already mentioned, researchers do not consider the inventory associated with the plastic film printing process, which explains the difference between the results founded from each one. The results for freshwater eutrophication indicated a total of 0.14 kg P eq., where the printing processes (due to ethanol consumption in paints and solvents) and metallization (due to aluminum production's chain) are the largest contributors

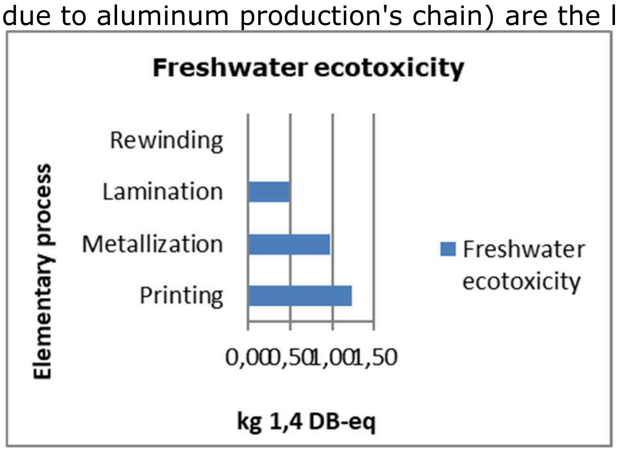


Figure 7. Contribution of each elementary process for freshwater ecotoxicity's impact category.

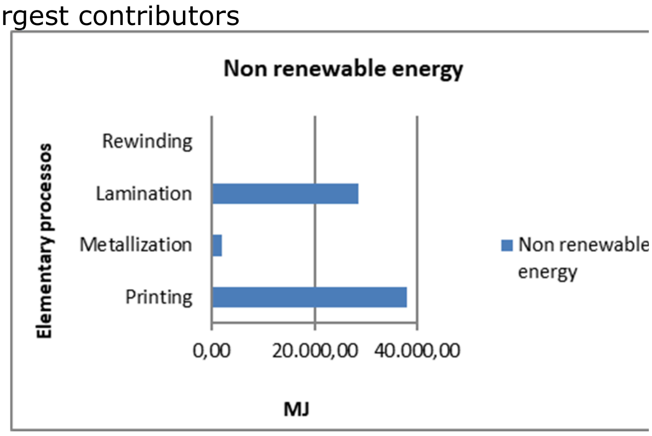


Figure 8. Contribution of each elementary process for non-renewables energy's impact category.

For the non-renewables energy impact, it was observed a contribution of 68.413,89 MJ. The elementary processes of printing and lamination were responsible for the largest shares, which are 55.53% and 41.56%, respectively. The most impacting substances are coal and natural gas, as found by Siracusa et al., [9]. Figure 8 presents the contribution of each elementary process for this impact category. According to Barlow and Morgan [1] an intense power demand is required for the polymers manufacture (comparable to metals). In addition, most of it is derived from fossil fuels, which makes the environmental impact significant. In this context, as was expected, the elementary processes of printing and laminating showed the highest contribution on fossil depletion impact, corresponding to 56.97and 40.50% of the total, respectively. This is due the high consumption of plastics and chemicals. As found by Siracusa et al. [4], the most impacting substances are crude oil and natural gas. The printing of 1000 kg of plastic packaging has led to a total of 1,454.44 kg oil equivalent. These values are similar to those found by Toniolo et al. [17].

Based on the Normalized and Characterized impacts categories, the results indicate that actions/improvements should be applied in the printing process, mainly focusing on reducing consumption of polymers and solvent-based products. Other studies has evaluated the impact of reducing the thickness of the packaging; using alternative energy sources; reducing the transportation distance of inputs and raw materials; reducing fuel consumption; using a portion of recycled plastic; among others [4; 17; 25; 26]. These alternatives are relevant but impractical in the studied company. A potential proposal for improvement for packaging printing segment that was not studied would be VOCs recovery in the flexographic print process. According to the inventory data presented in this study, approximately 65 % of the mass of paints and solvents applied in printing is lost during the process. This portion is dropped into the stratosphere due to the absence of a gas treatment system, besides have caused environmental impacts throughout their life cycle, from the extraction, production and transportation. A systematic recovery of VOCs can reduce the amount of solvent acquired by the company. Only in 2014 the company studied consumed 48.600 liters of solvents to clean parts, equivalent to the total cost of U$ 10.000,00.

However, this situation needs to be assessed in a broader perspective, since the possible techniques for VOCs recovery generate new environmental aspects such as consumption and disposal of other materials, both of the systems installation phase and in its operations. Among the possible techniques, adsorption on activated carbon could be assessed for this scenario.

Conclusion

This study aimed to perform an environmental assessment of plastic packaging manufactured by the flexographic printing process on a plastic packaging industry, based in the countryside of Rio Grande do Sul state, in Brazil. This analysis was performed by the LCA tool. The access and transparency of the company with respect to process data were essential to the execution of the study. It is hoped that this study serve with a guideline for the company improve its products chain under the environmental point of view, and can also contribute to the researched in the future associated with this studied. The results showed that the printing process had the highest contributions to the seven categories studied. Most of this impact is associated with PET film production network, energy matrix used and the production chain of the components of the paints and solvents.

The lamination and metallization processes had lower environmental impacts, though not negligible. In the first case, the PE film production chain and the adhesive are shown as critical points. In the case of metallization, all contributions are linked to the aluminum production chain. Among the categories of environmental impacts are considered significant by normalization method. The highlight was the formation of particles photo-oxidants, representing 28.40% of the total points to eleven categories of tested environmental impacts. This profile is due to the release of VOCs during operation. It is recommended for future research to environmental assessment of VOCs recovery scenario in the flexographic printing process. Adsorption on activated charcoal technique could be evaluated for this scenario. However, this situation needs to be assessed in a broader perspective, since the possible techniques for VOCs recovery generate new environmental aspects such as consumption and disposal of other materials, both of the systems installation phase and in its operations. This proposition does not rule out the possibility of other process improvements, such as other energy alternatives to replace the energy matrix studied.

References

[1] C. Y. Barlow, D. C. Morgan, Polymer film packaging for food: An environmental assessment. Resources, Conservation and Recycling 2013, 78, 74 – 80.

[2] M.Traverso, M. Finkbeiner, A. Jørgensen, and L. Schneider, Life Cycle Sustainability Dashboard. Journal of Industrial Ecology 2012, 16(5), 680–688.

[3] J. Pasqualino, M. Meneses and F. Castells, The carbon footprint and energy consumption of beverage packaging selection and disposal. Journal of Food Engineering 2011, 103, 357–365.

[4] V. Siracusa, C. Ingraob, A. L. Giudicec, C. Mbohwac, and M. Dalla Rosa, Environmental assessment of a multilayer polymer bag for food packaging and preservation: An LCA approach, Food Research International 2014, 62, 151–161.

[5] Associação Brasileiro de Tecnologia Gráfica, [Brazilian Association of Graphic Technology], Manual de impressão flexográfica, (ABTG), São Paulo 2013.

[6] A. Lorenza, A. Senneb, J. Rohdec, S. Kroha, M. Wittenberga, K. Krügera, F. Clementa, D. Biroa, Evaluation of Flexographic Printing Technology for Multi-Busbar Solar Cells, Energy Procedia 2015, 67, 126 – 137.

[7] Büsser, S., N. Jungbluth. 2009. The role of flexible packaging in the life cycle of coffee and butter.Int J Life Cycle Assess 14 (Suppl 1):S80–S91.

[8] M. Meneses, J. Pasqualino, and F. Castells, Environmental assessment of the milk life cycle: The effect of packaging selection and the variability of milk production data. Journal of Environmental Management 2012,107, 76-83.

[9] D. Raheem, Application of plastics and paper as food packaging materials – An overview, Emir. J. Food Agric. 2012, 177-188.

[10] M. De Monte, E. Padoano, D. Pozzetto, Alternative coffee packaging: an analysis from a life cycle point of view. Journal of Food Engineering 2005, 66, 405–411.

[11] A. Zabaniatou, E. Kassidi, Life cycle assessment applied to egg packaging made from polystyrene and recycled paper, Journal of Cleaner Production 2003, 549–559.

[12] R.Vidal, P. Martínez, E. Mulet, R. González, B. López-Mesa, P. Fowler, and J. M.. Fang, Environmental assessment of biodegradable multilayer film derived from carbohydrate polymers, J Polym Environ 2007,15,159–168.

[13] S. Büsser and N. Jungbluth, The role of flexible packaging in the life cycle of coffee and butter, The International Journal of Life Cycle Assessment 2009, May (14), 80–91

[14] R. Zhao, Y. Xu , X. Wen , N. Zhang , J. Cai, Carbon footprint assessment for a local branded pure milk product: a life cycle based approach, Food Science and Technology 2017, ISSN 0101-2061. DOI: 10.1590/1678-457X.02717

[15] L. Zampori, G. Dotelli, Design of a sustainable packaging in the food sector by applying LCA. Int J Life Cycle Assess 2014, 19, 206–217.

[16] M. Banar and Z. Çokaygil, A Life Cycle Comparison of Alternative Cheese Packages, Clean 2009, 37 (2), 136 – 141.

[17] S. Toniolo, A. Mazzi, M. Niero, F. Zuliani, and A. Scipioni, Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging. Resources, Conservation and Recycling 2013, 77, 61– 68.

[18] C. Piluso, J. Serafano, L. M. Kloock, R. Grandke, and C. A. Bradlee, Eco-Efficiency Analysis Demonstrates the Environmental and Economic Benefits of Flexographic Printing Inks in Film Applications, BASF Corporation, Product Stewardship, Sustainability Programs 2009.

[19] A. Navajas, A. Bernarte, G. Arzamendi, and L. M. Gandía, Ecodesign of PVC packing tape using life cycle assessment. Int J Life Cycle Assess 2014, 19, 218–230.

[20] NBR ISO 14040: Gestão ambiental: avaliação do ciclo de vida- princípios e estrutura.[In English: Environmental management: evaluation of life-cycle principles and structure]. Rio de Janeiro, 2009.

[21] NBR ISO 14044: Gestão ambiental: avaliação do ciclo de vida: requisitos e orientações. [In English: Environmental management: evaluation of lifecycle: requirements and guidelines], Rio de Janeiro, 2009.

[22] P. A. Suguiuti, L. M. Oliveira and F. G., Teixeira, Determinação da força de adesão da metalização com alumínio em filmes plásticos utilizados em embalagens flexíveis: desenvolvimento e validação de metodologia. 2º Congresso Interinstitucional de Iniciação Científica. Instituto de Tecnologia de Alimentos. In English: Determination of the strength of adhesion of metallization with aluminum in plastic films used in flexible packaging: development and validation of methodology [2nd Inter Congress of Scientific Initiation. Institute of Food Technology],2008.

[23] C. M. V. B Almeida, Ecologia industrial: Conceitos, ferramentas, e aplicações. In English: Industrial Ecology: Concepts, Tools, and Applications São Paulo: Edgard Blücher, 2006.

[24] A. Sleeswijk, L.Oers, J. Guinee, J. Struijs, A. Huijbregts, Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000 Science of the Total Environment 2007, 227- 240.

[25] H. Khoo, H., R. B. H. Tan, and K.W. L. Chng. Environmental impacts of conventional plastic and bio-based carrier bags. Int J Life Cycle Assess 2010, 15, 284–293.

[26] M. Manfredi and G. Vignali.. Life cycle assessment of a packaged tomato puree: a comparison of environmental impacts produced by different life cycle phases. Journal of Cleaner Production 2014, 73, 275 – 284.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Life Cycle Assessment Used for Product Development: A Comparative Study Between Fossil and Vegetal products

LACERDA M. T. [a*], MACENO, M. M. C. [a] , SPIER, M. R. [a], JOAO, S. [a]

a. Universidade Federal do Paraná, Curitiba/Paraná

**Corresponding author, matheus_mtl@hotmail.com*

Abstract

The use of plastic bags has become quite common in today's society, but its exacerbated use and, in some cases, incorrect disposal have resulted in increased environmental impact. Thus, it became necessary to search for new materials that could be used in its manufacture that could reduce its environmental impact. One alternative was substituting the petrochemical matrix with a biological matrix. On this assumption, in order to compare the environmental impacts between these two matrices, three polymers were used, two of a petrochemical matrix, high-density polyethylene (HDPE) and low-density polyethylene (LDPE), and one of a renewable biological matrix, thermoplastic starch (TPS). The Life Cycle Assessment (LCA) tool was used for the environmental comparison, which compares the processes from the extraction of raw materials to their final disposal using the ReCiPe 2016 and IMPACT World+ environmental impact methodologies. After the simulations, sensitivity analysis and Monte Carlo simulation were performed between the impact categories of most significant influence on the environmental impact of plastic bags to ascertain the convergence of results between the methodologies. Applying the described procedures made it possible to ascertain which polymer has the lower environmental impact. The results obtained between the polymers showed that TPS has a high impact in all impact categories evaluated. Through sensitivity analysis and Monte Carlo simulation, the category that most impacts the life cycle of single-use plastic bags, freshwater ecotoxicity, is very sensitive between the methods, and the Monte Carlo simulation shows no correlation among the methods.

Keywords: Life Cycle Assessment. Plastic bags. Biodegradable polymer. Sensitivity analysis. Monte Carlo simulation.

1. Introduction

Plastic bags have become a product present in everyone's life for their practicality and because they are offered free at the end of the shopping trip. However, these plastic bags are not only used to help transport the purchased goods to the home. In most cases, they are used later to accumulate household waste (LIU et al., 2020; MACINTOSH et al., 2020).

When the single-use plastic bag is used to accumulate household waste, recycling proves to be economically unviable due to the high cost associated with decontaminating the material; thus, the use of virgin raw material for the manufacture of plastic bags proves to be more economically viable (FERNÁNDEZ-BRAÑA; FEIJOO-COSTA; DIAS-FERREIRA, 2019; ZAMBRANO-MONSERRATE; ALEJANDRA RUANO, 2020)

Another point that should be emphasized is that using plastic bags to accumulate household waste contradicts the United Nations Environment Program (UNEP), which promotes the use of plastic bags as many times as possible to reduce their impact (UNEP, 2021). However, plastic bags in household garbage cans is a cultural practice in Brazil and trying to mitigate the impact of this use, and this paper aims to present a new biodegradable biological polymer as a substitute for petrochemical polymers.

The difference between biodegradable biological materials and petrochemicals is that biological materials have a short life span until decomposition, ranging from six months to two years. However, their main advantage is that when they decompose, they become nutrients due to the biological cycle of the material and do not become toxic microplastics like the petrochemical material. The production of plastic bags shares the same production process, with differences in some operational settings in the extrusion (MENICAGLI et al., 2019; ZHANG et al., 2020).

An effective measurement must be performed from raw material extraction to final disposal to make a statement regarding a lower environmental impact of the polymer. For this measurement of environmental impacts, the life cycle assessment (LCA) method is the most widespread globally (HU; MILNER, 2020).

LCA emerges as a method to analyze the environmental impacts on the most diverse aspects. Covering all the production processes, showing itself as one of the most complete and integrated tools for measuring an environmental impact, formally is defined by ISO 14040 (2006) and ISO 14044 (2006). For an LCA study, the following phases are required: definition of the Goal and the Scope, the Life Cycle Inventory (LCI), the Life Cycle Impact Assessment (LCIA), and interpretation of the results (ISO 14044, 2006) so in this study, the LCA was used to answer the question: what is the environmental impact caused by plastic bags produced from different polymers?

2. Methods

According to ISO 14044 (2006), to perform the LCA analysis, the following steps should be followed: objective and scope, life cycle inventory, life cycle impact, and interpretation of results.

Thus, the objective of this study is to compare the environmental impacts of the single-use plastic bag produced from a new recipe of thermoplastic starch (TPS) developed at the Federal University of Paraná (UFPR) in partnership with the State University of Londrina (UEL) with two most used polymers to produce single-use plastic bag, high-density polyethylene (HDPE) and low-density polyethylene (LDPE).

In the scope defined the function, the first function is to carry goods from the supermarket to the home, and the second function is to use the plastic bags in the garbage cans for accumulating household waste. The functional unit is to carry 4.5 kg (kilograms) of groceries once in the plastic bags.

The reference flow was one plastic bag of TPS and 0.9 plastic bags of HDPE and LDPE. The cradle to grave boundary was used because the boundary assesses raw material extraction to final landfill disposal. However, the impacts associated with the transportation of plastic bags after production were not measured.

To assemble the life cycle inventory (LCI) was used data from the development process of the biodegradable polymer carried out by the UFPR/UEL partnership and data collected in the literature for the petrochemical polymers. Some adaptations were necessarily using the Ecoinvent library version 3.8 to perform the LCA study using SimaPro software, and the life cycle inventory is shown in table 1.

Table 2 - Life Cycle Inventory (LCI)

Process		**Production**			**Use**	**End of life**
		Extrusion	**Cut and welding**		**-**	**Sanitary landfill**
Material		Granule	Plastic film	Film cuts	Plastic bag	Plastic bag
Quantity - HDPE	**Input**	6.43g	6.11g	-	5.50g	5.50g
	Output	6.11g	5.50g	0.610g	5.50g	-
	Electrical Consumption	0.0063KWh	0.000014KWh	-	-	-
Quantity - LDPE	**Input**	19.30g	18.33g	-	16.50g	16.50g
	Output	18.33g	16.50g	1.500g	16.50g	-
	Electrical Consumption	0.0188KWh	0.000041KWh	-	-	-
Quantity - TPS	**Input**	39.51g	37.53g	-	33.78g	33.78g
	Output	37.53g	33.78g	3.753g	33.78g	-
	Electrical Consumption	0.0384KWh	0.000084KWh	-	-	-

The Normalization of the environmental impact assessment methodologies ReCiPe 2016 and IMPACT 2002+ were used in the evaluation of environmental impacts, and the categories of most significant influence on environmental impact in the LCA study than a sensitivity analysis and a Monte Carlo simulation were performed using the characterization value do compare the category that has a significant influence in the LCA of single-use plastic bags.

After identifying the impact categories, it was necessary to harmonize the metric units between the LCA methodologies to compare their results. The methodological sequence presented by Owsianiak et al. (2014) was adapted for the analysis following the steps: 1 - Simulate the LCA study through the SimaPro software; 2 - Use the Characterization results in a Microsoft Excel® spreadsheet for each LCA methodology; 3 - Define the environmental impact categories to be used; 4 - Define the reference for the conversion unit; 5 - Analyze the substances contained in the category to verify the possibility of comparison; 6 - Search for the characterization factor of the impact category substance to perform the unit conversion; 7 - Calculate the harmonized impact of the category (H) through Equation 1:

$$H = \frac{\text{the potential impact of the reference method}}{\text{characterization factor of the method to be converted}} \quad (1)$$

Then calculate the harmonized impact for the category ($\check{h}$) using Equation 2:

$$\check{h} = \frac{\text{harmonized impact}}{\text{characterization value obtained in the LCA simulation}} \quad (2)$$

After harmonizing the impact category, it is possible to calculate the sensitivity of the harmonized impacts between the LCIA methodologies using Equation 3, which shows the percentage difference between the methods (% LCIA) to see how much they differ from each other.

$$\%\, LCIA = \frac{\text{harmonized impact} - \text{the impact of the reference method}}{\text{the impact of the reference method}} * 100 \quad (3)$$

After harmonizing the environmental impact categories between the LCA methodologies, it is possible comparing the environmental impact category through a sensitivity analysis to identify variations between the results of the methodologies.

The harmonized Characterization values used in the sensitivity analysis were also used for the Monte Carlo uncertainty simulation, so this data was transported to a Microsoft Excel® spreadsheet and allocated in two columns corresponding to the LCIA methodology. Then the minimum and maximum values were defined to generate a triangular random number. According to Sabará (2020) and Baldoni et al. (2021), the triangular distribution is one of the options for generating random numbers that can be used in Monte Carlo simulation. Equation 4 generated the random numbers following the triangular distribution (NADT).

$$NADT = \text{Max value} + (\text{Minimum value} - \text{Max value}) * (\text{RANDON()} + \text{RANDON()})/2 \quad (4)$$

The triangular random number was used as input for the Monte Carlo simulation. Barreto and Howland (2010) developed the plug-in for Microsoft Excel® was used for the analysis. For the simulation, 10,000 iterations were simulated, corresponding to the satisfactory amount for determining the object's behavior under study, according to Cherubini et al. (2018) and Igos et al. (2019).

Based on the previous data, it was possible to evaluate the environmental impact of polymers through the life cycle assessment using the ReCiPe and IMPACT World+ methodologies to verify the polymer with the lowest environmental impact. The sensitivity analysis between the impact category of more significant influence was performed to verify how distant their results were among the LCIA methods then the Monte Carlo simulation was performed to verify if there was a convergence of the results between the methodologies.

3. Results and discussion

A comparison was made between the three polymers regarding the environmental impacts between the renewable and non-renewable bases, using the ReCiPe 2016 and IMPACT World+ assessment methods. The environmental impacts are demonstrated with the Normalization of the environmental impact in Fig. 1 for ReCiPE 2016 and Fig. 2 for IMPACT World+, showing the impact categories' scores.

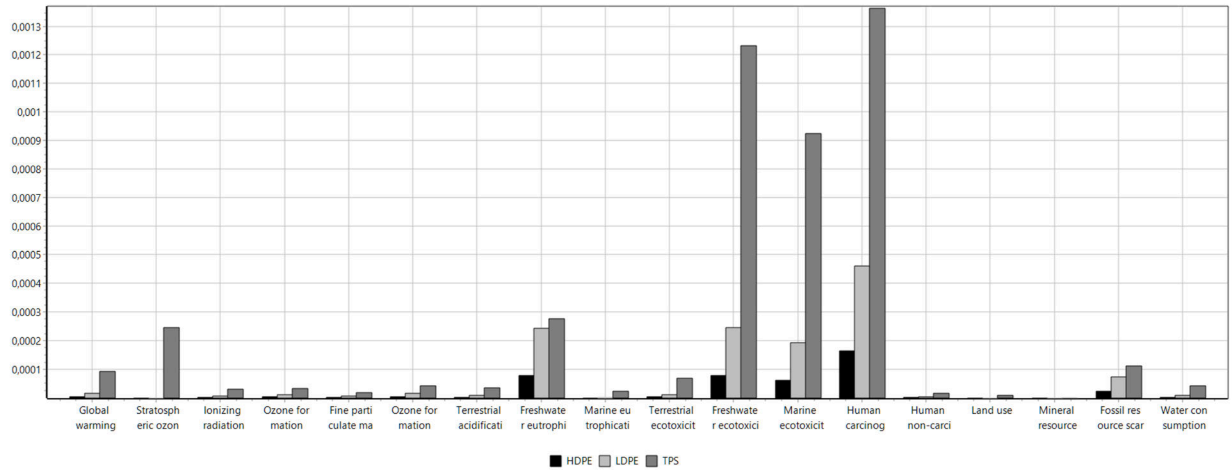


Fig. 1. Environmental impact by Normalization (ReCiPe 2016)

Through the Normalization of impact categories for the ReCiPe 2016 environmental assessment method, three impact categories show the most significant influence on the life cycle of plastic bags of the evaluated polymers: freshwater ecotoxicity, marine ecotoxicity, and human carcinogenic toxicity.

The freshwater ecotoxicity category, TPS, HDPE, and LDPE, had the following scores: 5.54E-04, 4.09E-05, and 1.32E-04. The following scores were obtained for the marine ecotoxicity category for TPS, HDPE, and LDPE, 4.09E-04, 3.15E-05, and 1.01E-04, respectively. The last category with the most significant life cycle influence, human carcinogenic toxicity, showed the same scoring pattern, with TPS scoring the highest, HDPE the lowest, and LDPE scoring in between, respectively 1.30E-03, 1.83E-04 and 5.08E-04.

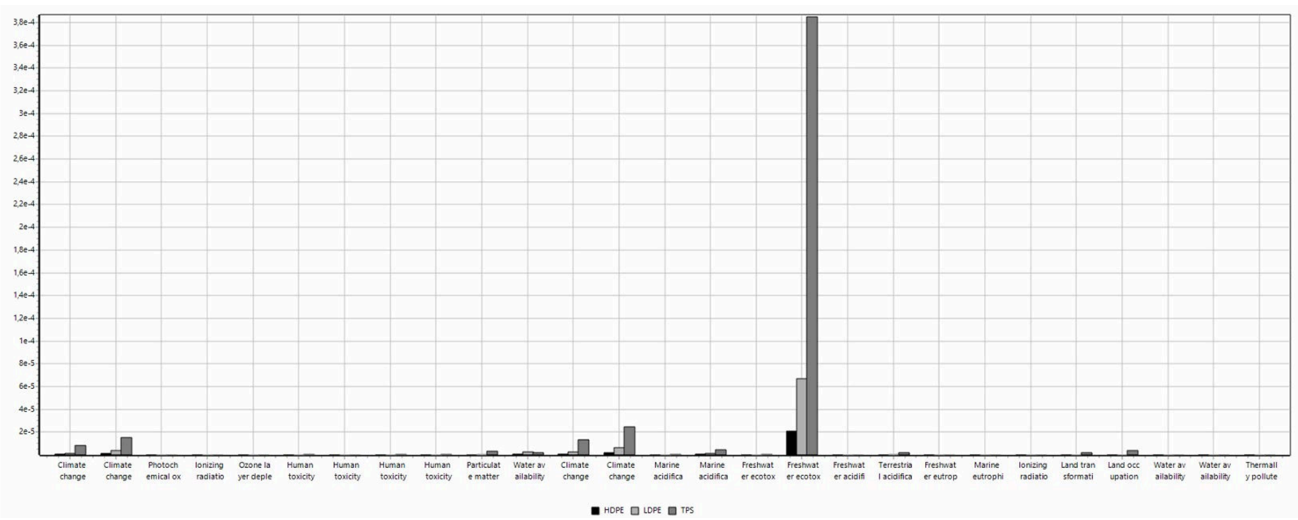


Fig. 2. Environmental impact by Normalization (IMPACT World+)

Through the Normalization of impact categories for the IMPACT World+ environmental assessment methodology, there is one impact category of most significant influence on the life cycle assessment of plastic bags of the evaluated polymers the freshwater ecotoxicity, long term.

TPS showed a score of 2.39E-04, LDPE showed 7.26E-05, and HDPE showed a score of 2.28E-05. The scores obtained show the same pattern as the ReCiPe 2016 methodology presented. TPS with the highest score, HDPE with the lowest score, and LDPE with the intermediate score.

The freshwater ecotoxicity category is the most influential in the life cycle assessment of plastic bags in both LCIA methodologies, and for this reason, the sensitivity analysis and Monte Carlo uncertainty simulation were applied. The ReCiPe 2016 LCA methodology units were used for the conversion between the units. In this way, the Characterization results were harmonized between the methodologies.

In the freshwater ecotoxicity category, the unit conversion from the IMPACT World+ method to the unit of the reference method was performed using the Benzene, 1,4-dichloro factor of the ReCiPe method Characterization.

The freshwater ecotoxicity category for the IMPACT World+ method is a junction of the marine and terrestrial ecotoxicity categories as it features substances that can be toxic regardless of the receiving ecosystem (BULLE et al., 2019). For this reason, to harmonize and compare the freshwater ecotoxicity category, the marine and terrestrial ecotoxicity categories of the ReCiPe 2016 method were considered. Table 2 demonstrates the conversion factors between the methodologies.

TABLE 2 - conversion factors between LCIA methods

Impact categories with the reference unit	ReCiPe 2016	IMPACT World+
Freshwater Ecotoxicity - kg 1,4-DCB	1	1,02E-03
Marine Ecotoxicity - kg 1,4-DCB	1	-
Terrestrial Ecotoxicity - kg 1,4-DCB	1	-

Table 3 demonstrates the harmonized results between the ReCiPe 2016 and IMPACT World+ methodology for the characterization values obtained in the LCA study using the conversion factor shown in table 2.

TABLE 3 - Sensitivity analysis between the 2016 ReCiPe and IMPACT World+ methodologies for the most influential indicators in the LCA

	ReCiPe 2016			IMPACT World+		
	PEBD	**PEAD**	**ATP**	**PEBD**	**PEAD**	**ATP**
Freshwater Ecotoxicity (kg 1,4-DCB)	1,81E-01	6,12E-02	1,15E+00	1,05E+00	3,32E-01	7,33E+00
% ReCiPe 2016	-	-	-	478,9	441,71	540,19

The freshwater ecotoxicity category shows higher impact values for the IMPACT World+ method than the ReCiPe 2016 methodology, ranging from 441.71 to 540.19%, with the lowest variation for HDPE and the highest for TPS.

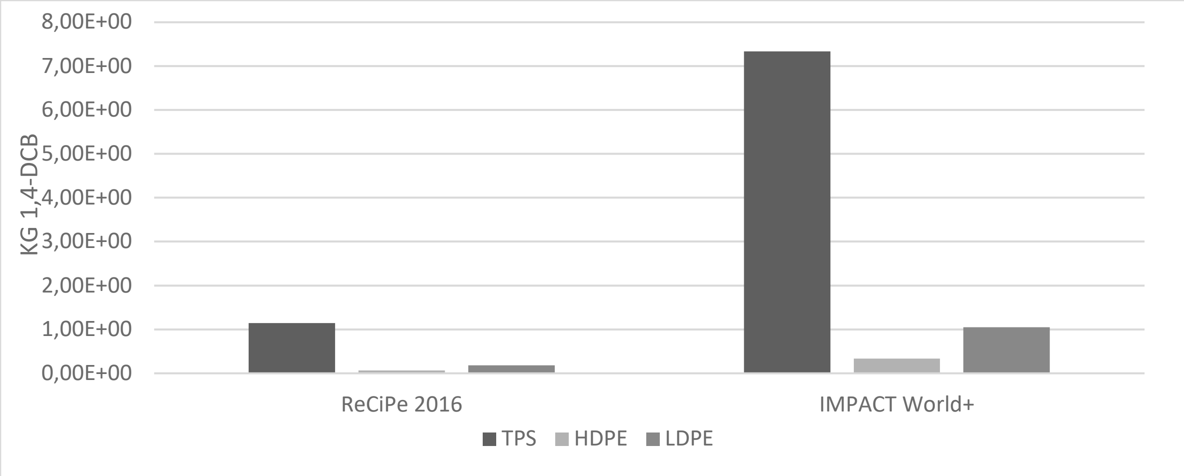


Fig. 3. Harmonized impact freshwater ecotoxicity (KG 1,4-DCB)

After the sensitivity analysis for the freshwater ecotoxicity impact category, the Monte Carlo uncertainty simulation was performed for the category. Table 4 demonstrates the triangular random value obtained between the harmonized Characterization results for each polymer between the LCA simulations for the methodologies.

TABLE 4 - Random value of characterization between methodologies (freshwater ecotoxicity)

Polymer	ReCiPe 2016	IMPACT World+	Random value
LDPE	1.81E-01	1.05E+00	3.49E+01
HDPE	6.12E-02	3.32E-01	1.36E+01
TPS	1.15E+00	7.33E+00	1.40E+02

The LDPE presented: a mean of 1,03E+02; a standard deviation of 4.21E+01, and maximum and minimum values, respectively, 2.05E+02 and 2.03E+00. The HDPE presented: a mean of 3.27E+01, a standard deviation of 1.33E+01, and maximum and minimum values, respectively, 6.54E+01 and 4.74E-01. The TPS presented: an average of 1.61E+02, the standard deviation of 6.52E+01, and maximum and minimum values, respectively, 3.20E+02 and 5.24E+00. Fig. 4 shows the polymer's histogram distribution for the Monte Carlo simulation.

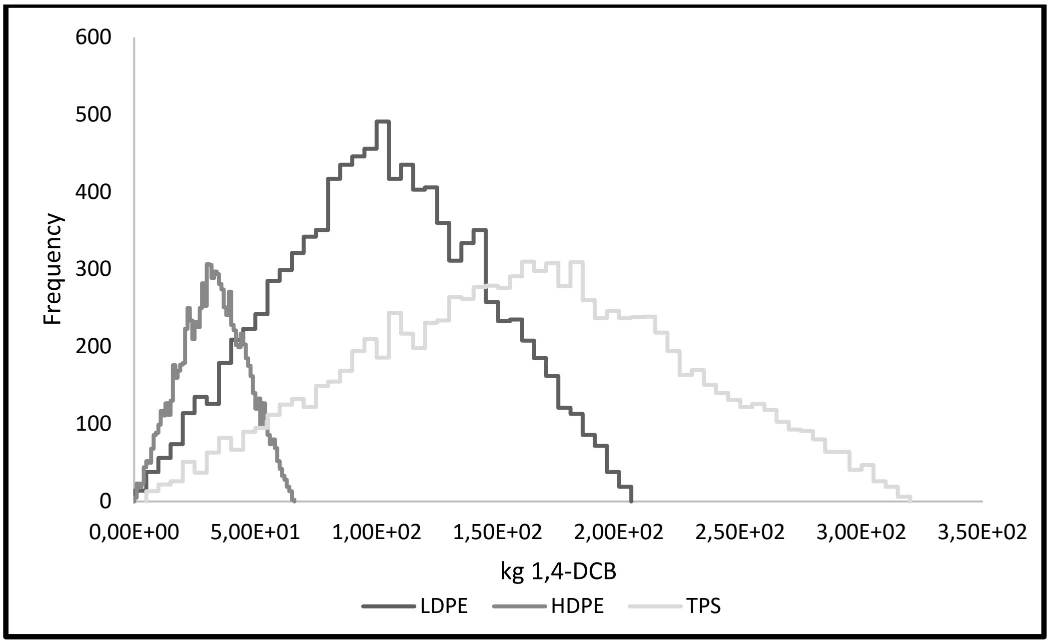


Fig. 4. Polymers histogram - freshwater ecotoxicity

Analyzing the values obtained after the Monte Carlo simulation for each polymer, LDPE had a coefficient of 40.87%, HDPE a coefficient of variation of 40.67%, and ATP a coefficient of 40.50%, showing a high dispersion between the impacts characterized by the methodologies.

In fig. 4, a partial overlap of the values between the polymers was shown. The impact obtained by the HDPE is almost entirely within the range of impact of LDPE that is almost entirely within the range of values obtained by the TPS.

The HDPE overlaps LDPE values between 2.03E+00 and 6.54E+01, corresponding to 97.60% of its range. HDPE overlaps TPS between the values 5.24E+00 2.05E+02, corresponding to 92.66% of its range. LDPE shows overlap with TPS between 5.24E+00 and 2.05E+02, corresponding to 98.42% of its range. Thus, it is impossible to differentiate the polymer between these lower and higher environmental impact ranges.

The results presented above confirm the results obtained in the studies of Gómez and Escobar (2021), which demonstrated that the single-used plastic bags produced from the petrochemical matrix have a lower environmental impact than biodegradable biological single-used plastic bags, even with the different components of the TPS recipe of this study and the previous studies.

The sensitivity analysis and uncertainty analysis using Monte Carlo simulation showed that for single-use plastic bags, the freshwater ecotoxicity impact category is the category with de significant impact on the LCA of the bags and presents a high sensibility between the methodologies showing a considerable difference between the results, and Monte Carlo uncertain simulation has shown that there is no correction between the methodologies and it is hard to say the polymers that have a lower or high impact category in the results of the methodologies.

4. Conclusion

This study presented the comparison of the environmental impact through the LCA of three different polymers, thermoplastic starch (TPS), high-density polyethylene (HDPE), and low-density polyethylene (LDPE), used to produce single-use plastic bags.

The production process included raw material acquisition, bag production process (extrusion and cutting and welding processes), the primary use for carrying groceries and the secondary use for accumulating household waste, and final disposal in landfills, classifying the study as a cradle to grave approach, using ReCiPe 2016 and IMPACT World+ through the software SimaPro v 9.3.0.3 for the analysis.

After performing the simulations between the environmental impact methodologies using the Normalization to demonstrate the environmental impact score in each category, it was possible to identify which category has the most significant influence on the life cycle impact of single-use plastic bags.

The impact category of freshwater ecotoxicity is the most influential on the LCA of the single-use plastic bag among the methods. Presenting TPS for both methodologies as the polymer with the highest environmental impact means that TPS has the worst environmental performance of the polymers used to produce single-use plastic bags. This study demonstrated that the TPS recipe is not an option for the single-used petrochemical plastic bag.

References

BALDONI, Edoardo; CODERONI, Silvia; GIUSEPPE, Elisa Di; D'ORAZIO, Marco; ESPOSTI, Roberto; MARACCHINI, Gianluca. A Software Tool for a Stochastic Life Cycle Assessment and Costing of Buildings' Energy Efficiency Measures. *[S. l.]*, 2021. DOI: 10.3390/su13147975. Disponível em: https://doi.org/10.3390/su13147975.

BARRETO, Humberto; HOWLAND, Frank M. **Excel Add-In: Monte Carlo Simulation**. 2010. Disponível em: http://www3.wabash.edu/econometrics/EconometricsBook/Basic Tools/ExcelAddIns/MCSim.htm. Acesso em: 16 jan. 2022.

BULLE, Cécile et al. IMPACT World+: a globally regionalized life cycle impact assessment method. **International Journal of Life Cycle Assessment**, *[S. l.]*, v. 24, n. 9, p. 1653–1674, 2019. DOI: 10.1007/s11367-019-01583-0.

CHERUBINI, Edivan; FRANCO, Davide; GUILHERME, &.; ZANGHELINI, Marcelo; SOARES, Sebastião Roberto. Uncertainty in LCA case study due to allocation approaches and life cycle impact assessment methods. **The International Journal of Life Cycle Assessment**, *[S. l.]*, v. 23, p. 2055–2070, 2018. DOI: 10.1007/s11367-017-1432-6. Disponível em: https://doi.org/10.1007/s11367-017-1432-6.

DONG, Yahong; HOSSAIN, Md Uzzal; LI, Hongyang; LIU, Peng. Developing conversion factors of lcia methods for comparison of lca results in the construction sector. **Sustainability (Switzerland)**, *[S. l.]*, v. 13, n. 16, 2021. DOI: 10.3390/su13169016. Disponível em: https://doi.org/10.3390/su13169016.

FERNÁNDEZ-BRAÑA, Álvaro; FEIJOO-COSTA, Gumersindo; DIAS-FERREIRA, Célia. Looking beyond the banning of lightweight bags: analysing the role of plastic (and fuel) impacts in waste collection at a Portuguese city. **Environmental Science and Pollution Research**, *[S. l.]*, v. 26, n. 35, p. 35629–35647, 2019. DOI: 10.1007/s11356-019-05938-w. Disponível em: https://link.springer.com/article/10.1007/s11356-019-05938-w. Acesso em: 25 ago. 2020.

HU, Ming; MILNER, David. Visualizing the research of embodied energy and environmental impact research in the building and construction field: A bibliometric analysis. **Developments in the Built Environment**, *[S. l.]*, v. 3, n. April, p. 100010, 2020. DOI: 10.1016/j.dibe.2020.100010.

IGOS, Elorri; BENETTO, Enrico; MEYER, Rodolphe; BAUSTERT, Paul; OTHONIEL, Benoit. How to treat uncertainties in life cycle assessment studies? **The International Journal of Life Cycle Assessment**, *[S. l.]*,

2019. DOI: 10.1007/s11367-018-1477-1. Disponível em: https://doi.org/10.1007/s11367-018-1477-1.

ISO 14040. **Environmental management—life cycle assessment—principles and framework**. Geneva, Switzerland.

ISO 14044. **Environmental management—life cycle assessment—requirements and guidelines**. Geneva, Switzerland.

LIMA, André Luiz Pereira De; LIMA, Taísa Maria Gomes De. A CONCEPÇÃO DA VANTAGEM COMPETITIVA POR MEIO DA ANÁLISE DE CUSTOS. **Revista Ibero-Americana de Humanidades, Ciências e Educação** , *[S. l.]*, v. 7, n. 3, p. 182–187, 2021. DOI: 10.51891/rease.v7i3.767. Disponível em: https://www.periodicorease.pro.br/rease/article/view/767. Acesso em: 11 ago. 2021.

LIU, Gengyuan; AGOSTINHO, Feni; DUAN, Huabo; SONG, Guanghan; WANG, Xueqi; GIANNETTI, Biagio F.; SANTAGATA, Remo; CASAZZA, Marco; LEGA, Massimiliano. Environmental impacts characterization of packaging waste generated by urban food delivery services. A big-data analysis in Jing-Jin-Ji region (China). **Waste Management**, *[S. l.]*, v. 117, p. 157–169, 2020. DOI: 10.1016/j.wasman.2020.07.028. Disponível em: https://doi.org/10.1016/j.wasman.2020.07.028.

MACINTOSH, Andrew; SIMPSON, Amelia; NEEMAN, Teresa; DICKSON, Kirilly. Plastic bag bans: Lessons from the Australian Capital Territory. **Resources, Conservation and Recycling**, *[S. l.]*, v. 154, p. 104638, 2020. DOI: 10.1016/j.resconrec.2019.104638.

MENICAGLI, Virginia; BALESTRI, Elena; VALLERINI, Flavia; CASTELLI, Alberto; LARDICCI, Claudio. Adverse effects of non-biodegradable and compostable plastic bags on the establishment of coastal dune vegetation: First experimental evidences. **Environmental Pollution**, *[S. l.]*, v. 252, p. 188–195, 2019. DOI: 10.1016/j.envpol.2019.05.108. Disponível em: https://doi.org/10.1016/j.envpol.2019.05.108.

OWSIANIAK, Mikołaj; LAURENT, Alexis; BJØRN, Anders; HAUSCHILD, Michael Z. IMPACT 2002+, ReCiPe 2008 and ILCD's recommended practice for characterization modelling in life cycle impact assessment: a case study-based comparison. **International Journal of Life Cycle Assessment**, *[S. l.]*, 2014. DOI: 10.1007/s11367-014-0708-3.

SABARÁ, Marco Antônio. Uncertainties in Life Cycle Inventories: Monte Carlo and Fuzzy Sets Treatments. **Lecture Notes in Mechanical Engineering**, *[S. l.]*, p. 177–197, 2020. DOI: 10.1007/978-3-030-53669-5_14. Disponível em: https://link.springer.com/chapter/10.1007/978-3-030-53669-5_14. Acesso em: 12 jan. 2022.

UNEP. Addressing single-use plastic products pollution using a life cycle approach. Nairobi, 2021.

ZAMBRANO-MONSERRATE, Manuel A.; ALEJANDRA RUANO, Maria. Do you need a bag? Analyzing the consumption behavior of plastic bags of households in Ecuador. **Resources, Conservation and Recycling**, *[S. l.]*, v. 152, 2020. DOI: 10.1016/j.resconrec.2019.104489.

ZHANG, Tong; LIU, Yuanyuan; ZHONG, Shan; ZHANG, Lishan. **AOPs-based remediation of petroleum hydrocarbons-contaminated soils: Efficiency, influencing factors and environmental impactsChemosphere**Elsevier Ltd, , 2020. DOI: 10.1016/j.chemosphere.2019.125726. Disponível em: https://linkinghub.elsevier.com/retrieve/pii/S0045653519329674. Acesso em: 25 ago. 2020.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Methodological Development for Climate Change Research: The Case of the RCGI Advocacy Group

LEMOS, G. L. de [a,c*], PAES, R. F. [a], SANTOS, J. F. dos[a], COSTA, H. K.M.[a], FAGÁ, M. F.[a], MOUTINHO, E. S.[a]

the. University of São Paulo, São Paulo

**Corresponding author, geraldolavigne@usp.br*

Abstract

Many researchers have addressed the problem pertinent to climate change, mechanisms to mitigate its effects and Padapt society. This article aims to describe the development of the methodology consisting of the preparation and application of a preliminary form, submitted only to the members of the advocacy group of the Research Centre for Greenhouse Gas Innovation (RCGI). This methodology aims to test the effectiveness of the form to obtain quantitative and qualitative data and, thus, support the preparation of the final form. The results indicated improvements in the preliminary form through feedback from the research participants. It is concluded that the preliminary research has achieved its objective and is adequate to be applied to other RCGI target audiences.

Keywords: climate changes, research methodology, questionnaire application.

1. Introduction

Numerous studies have been carried out to address climate change, mitigate its effects and adapt society (IPCC, 2018; IEA, 2016; Humphreys, 2009; Interministerial Committee On Climate Change, 2008). Among the alternatives currently being the agenda are topics such as NBS, CCU, BECCS and GHG. These themes are intensely reviewed in short periods since they include promising strategies for solving climate issues (Silveira et al., 2022). Studies such as Bellamy and Healey (2018) come to probe the future of the development of climate engineering ideas.

To achieve the goals of the Paris Agreement, we need to improve the socio-technical models used in decarbonization planning (Bellamy; Healey, 2018). It is believed that the multisectoral and polysemic contribution involving researchers from various areas of knowledge may provide more robust data to support crucial decisions. Given this scenario, the present research aimed to develop a methodology for the collection of quantitative and qualitative data on the themes highlighted and that are in the daily lives of researchers, such as institutional link, related research group, study theme, normative bases, regulatory gaps and stakeholders of the studied area.

The application of the methodology developed contributed to aggregating sparse data and obtaining crucial information for the performance of strategies in policies to cope with climate change. In addition, the methodology developed allows identifying stakeholders from the researched area, summarizing the long-term experiences of other researchers. To Bellamy et al. (2021), stakeholders' interests have relationships with socioeconomic specificities and local political contexts. This circumstance requires refined data collection to be faithful to the researched territory, allowing for multifaceted and heterogeneous planning discussion.

2. Methodology

The Paris Agreement on climate change has sought through established commitments to keep the planet's temperature under control, where the increase should be kept below 2°C. However, some modeling studies have shown it to be almost impossible without implementing Negative Emissions Methods and Technologies (NETs), aimed at large-scale greenhouse gas (GHG) removal (Gasser et al., 2015; Brazil 2015; Brazil 2020; Brazil 2022). There are arduous struggles that state and non-state climate policy actors are less recognized. In one of these struggles, we can highlight studies related to public opinions on using new technologies such as BECCS, CCU, NBS and GHG. Since their use dominates energy generation and climate policy regimes, despite the challenges in seeking to bring support from institutions and incentives to this area, it requires priority to continue the development of these technologies.

Given this scenario, the development of the methodology object of the present study started with the elaboration of a preliminary form, submitted only to the members of the advocacy group of the Research Center for Greenhouse Gas Innovation (RCGI), in order to test the effectiveness of the form for obtaining quantitative and qualitative data and, thus, supporting the preparation of the final form. In this context, the application of the preliminary form gave rise to the assessment of the clarity of the questions and the usefulness of the answers, considering that they are data that need to be categorized, systematized and analyzed from a scientific point of view. After the application of the preliminary form, the members of the advocacy group were invited to participate in a meeting to present their critical analysis of the form as respondents. Such measures allowed for the improvement of the preliminary form requirements with a view to preparing the final form.

The developed methodology aims to collect quantitative and qualitative data. Quantitative data will be obtained from the questions on the form submitted to researchers, with slight chances for obtaining qualitative data, even though the questions have an open-ended option. This fact occurs because, after processing the data obtained in the responses, it is expected to organize them into categories that can be expressed in graphs and tables. On the other hand, as qualitative data are essential, it is intended to combine the final form with the development of workshops in order to collect qualitative data from respondents specialized in the studied subjects.

2.1 Google forms search: preliminary form

The preliminary questionnaire developed in "Google Forms" was designed as a research tool in order to test it, firstly for a restricted group of 18 people who have an academic relationship within the 69 Project. The following objectives guided the preliminary questionnaire: i) Identify, prioritize and detail topics potentially covered by national and international agreements, conventions and other legal documents associated with the NBS, CCU, BECCS and GHG programs; (ii) identify interested parties and interact with them to prepare comments and participate on laws and decisions within legal possibilities; (iii) establish structures for periodic compilation (access), monitoring and feeding of the development of the set of conventions, agreements, international protocols, decisions of international courts (jurisdiction and arbitration), as well as national laws and resolutions on the topics NBS, CCU, BECCS and GHG; (iv) identify and analyze gaps in national legislation on the subject - topics of nationally determined contribution (NDCs), particularly applications associated with NBS, CCU, BECCS and GHG.

In this sense, the first set of questions consisted of 4 questions, 3 of which were mandatory answers so that the research participant could be known, opening a communication channel (e-mail) with the respondent and taking his area of research as a reference, given that this answer will guide the questions of the next block, as seen in Table 1.

Table 1 – Project 69 preliminary form

Question	Type of answer
Section 1 Study on proposals for international standardization and advocacy services for the implementation and consolidation of legal, regulatory and standards frameworks to contribute to Brazilian commitments linked to NDCs (Nationally Determined Contributions).	
E-mail	Written

What is your name?	Written
What is your institution and the link with it?	Written
Wich research group do you participate?	Written
In which study area do you research? (NBS) (BECCS) (CCU) (GHG)	Multiple mark

Source: Own Development

The second section has specific questions related to the participant's research area. In this form, the questions were elaborated favoring open answers to allow a greater flow of information, as shown in Table 2.

Table 2 – Project 69 preliminary form

Question	Type of answer
Section 2 The following questions are specific to the respondent's area of research. Please consider only the research area(s) marked in the previous section (NBS, BECCS, CCU, GHG).	
In your opinion, what are the priorities in the topics of the NDCs, particularly the applications associated with your area of research.	Written
Do you know or attend national forums and other important public participation groups, including those on social media, on NDC topics, particularly those related to your area of research? Which one(s)?	Written
In your opinion, who are the main stakeholders in your area of research? If possible, list names and contact details.	Written
What topics do you consider potentially covered by national and international agreements, conventions and other legal documents related to your area of research?	Written
Of the topics indicated in the previous answer, which one do you consider most relevant? Why?	Written
In your opinion, what are the gaps in national legislation related to NDCs in your area of research?	Written
Which database(s) do you access when you need to search for agreements, conventions and other national and international legal documents related to your area of research?	Written
Gostaria de acrescentar sugestões ou considerações?	Written

Source: Own Development

Thus, the results obtained were satisfactory for preliminary research since they allowed a significant amount of information answered by the respondents, so that, especially, the open questions have the potential to receive important and desired information, according to the aforementioned guide items. However, attempts to group or synthesize them into graphs and tables proved impractical by the volume and diversity of data obtained, even though it was a restricted group of participants.

2.2 Feedback meeting

The feedback meeting was essential to adjust the questions of the preliminary form and prepare the final form from the critical analyses of the respondents. In the case of *expert respondents in* the studied areas, the feedback meeting (i) clarified obstacles of open questions in counterpoint with the definition of answers by alternatives, with express recommendation for the restriction of open or descriptive answers, transforming the answers into alternative options to mark; (ii) emphasized the importance of including an item for the collection of the main objective of the respondent's study; and (iii) pointed to the need for a question about the chain of activity of the area studied by the respondent, open with description of all stages of the process. The restriction of open responses in certain items indicated in item (i) had the purpose of standardizing the answers that, when opened, although they indicated the same result, needed to be treated in order to be standardized and categorized. Thus, the options of alternatives to mark, in these cases, give better quality data, already categorized and systematized. The inclusion of an item for the collection of the main objective of the respondent's study indicated in item (ii) aimed to provide the deduction of the bases and normative gaps of the theme studied. Thus, it is possible to understand or at least deduce whether the themes have immediate applicability or if they require some modification or normative insertion that makes their application feasible. The addition of a question on the activity chain of the studied area indicated in item (iii) allows the respondent's study to be situated within this chain, understand how the study relates to the other components of the chain and identify opportunities and obstacles crossed. For example, the respondent can describe the chain from carbon capture to final use, in the case of CC, by situating their study in capture sector, with the identification of obstacles in carbon transport and opportunities in its use.

2.3 Google forms search: final form

The preliminary form was revised (Table 3) considering the quality of the data obtained with its application and the manifestations of the feedbeck meeting. After revision, the final form started to have five sections, i.e.: Introductory section; Specific issues of the study area, Legal standards, NDCs and study area; Technical standards, NDCs and study area; Suggestions and final considerations. The final form was then resubmitted to the respondents of the previous form and to the participants of the feedback meeting, who expressed agreement with the final writing of the form. All those involved concluded that the definitive form satisfied the interests of the research.

Table 3 – Project 69 final form

Question	Type of answer
Section 1	
Study on proposals for international standardization and advocacy services for the implementation and consolidation of legal, regulatory and standards frameworks to contribute to Brazilian commitments linked to NDCs (Nationally Determined Contributions).	
E-mail	Written
What is your name?	Written
What is your institution and the link with it?	Written

Among the alternatives below, what is the main study area that you research? (BECCS) (CCS) (CCU) (GHG) (NbS)	Single mark
What is the main object of your research in your area of study?	Written
Could you describe the chain of action in your area of study with a description of all the stages of the process and indicate at which point in the chain your research is located? (Example: for a research on reforestation such as NbS, there is the creation of the project, the identification of the area destined for the project, the estimation of the results, identification of the stakeholders, the gathering of the necessary resources, the execution of the project, the monitoring of the area, the final destination of the area and the quantification of the results; and the research can be situated in the gathering of the necessary resources through the study of the carbon market) (Attention: if the interviewee does not know the chain of action, please answer "I do not have enough string data".)	Written
Section 2	
The following questions are specific to the respondent's area of study. When answering the following questions, please consider only the study area marked in the first section (BECCS, CCS, CCU, GHG or NbS, as the case may be) and the Brazilian Nationally Determined Contributions (NDCs).	
What are the priorities in the topics of the NDCs, particularly with applications associated with your area of study?	Written
What national and international forums and other important public participation groups do you know about or attend (including those in the regulatory, legislative, executive, standards and social media environment) on NDC topics, particularly related to your area of study?	Written
Who are the main stakeholders in your area of study? If possible, in addition to names, provide contact details.	Written
Which other researchers could you indicate from your area of study to answer this questionnaire? If possible, in addition to names, provide contact details.	Written
Section 3	
The following questions are specific to the respondent's area of study. When answering the following questions, please consider only the study area marked in the first section (BECCS, CCS, CCU, GHG or NbS, as the case may be), the Brazilian Nationally Determined Contributions (NDCs) and the general notion of legal norms (Laws, decrees, ordinances, resolutions, etc., including regulatory agencies).	
What topics do you consider potentially covered by national and international agreements, conventions and other legal documents related to your field of study? If possible, cite the associated legal norms forums.	Written
About the topics indicated in the previous answer, which one do you consider most relevant? Why?	Written

In your opinion, what are the gaps in Brazilian legal norms related to the development of technologies or mitigation mechanisms linked to NDCs in your study area?	Written
What other topics do you consider relevant for the development of legal norms to support the establishment and use of mitigation mechanisms linked to your study area? (regulatory, legislative and executive environment)	Written
Which database(s) do you access when you need to search for agreements, conventions and other national and international legal documents related to your study area? Please indicate the name and access method (Database name and electronic address or physical address).	Written
Section 4	
The following questions are specific to the respondent's area of study. When answering the following questions, please consider only the study area marked in the first section (BECCS, CCS, CCU, GHG or NbS, as the case may be), the Brazilian Nationally Determined Contributions (NDCs) and the general notion of technical standards (ABNT, ISO etc.).	
What topics do you consider potentially covered by national and international technical standards related to your area of study? If possible, cite the associated technical standards forums.	Written
About the topics indicated in the previous answer, which one do you consider most relevant? Why?	Written
In your opinion, what are the gaps in technical standards related to the development of technologies or mitigation mechanisms linked to NDCs in your study area?	Written
What other topics do you consider relevant for the development of technical standards to support the establishment and use of mitigation mechanisms linked to your study area? (product standards, technology standards, GHG accounting, process management, etc.)	Written
Which database(s) do you access when you need to search for national and international technical standards related to your study area? Please indicate the name and access method (Database name and electronic address or physical address).	Written
Section 5	
Would you like to add suggestions or considerations?	Written

Source: Own Development

3. Results and Discussion

The steps addressed with the preliminary form were fundamental to improve the quality of obtaining the data by the final form, since researchers from several areas participated critically analyzed the advantages and disadvantages of the questions still in the preliminary form, as well as shared their previous experiences with the matter.

In addition, the methodology was successful in obtaining quantitative and qualitative data. Such results can be expressed in graphs and tables for current diagnostic analysis, evolution and projections. In particular, qualitative data contribute to the discussion and formulation of more assertive proposals in the final recommendations of this research.

The answers to the first set of questions allowed the generation of graphics, enabling the visualization of the participants' data regarding the institution of bonds and the groups and research areas of the participants. Thus, Figure 4 presents the institutional link of the respondents, totalizing 18 responses, which is the number of participants; in Figure 5 the graphic shows the answers of the research groups frequented by the participants, with a sum greater than 18, since a respondent may attend and cite more than one research group. Similarly, the graphic of Figure 6 represents the number of times that the respondents' research areas were mentioned in the form, with a total greater than 18.

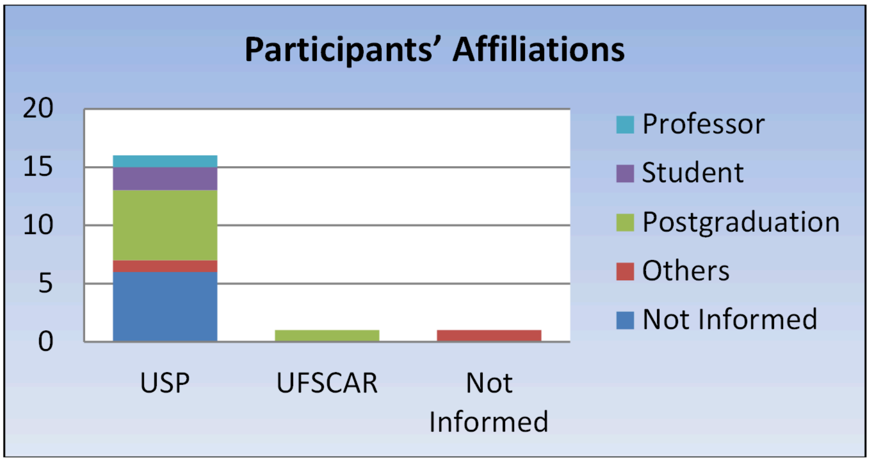


Figure 4: Respondent's affiliations
Source: Own Development

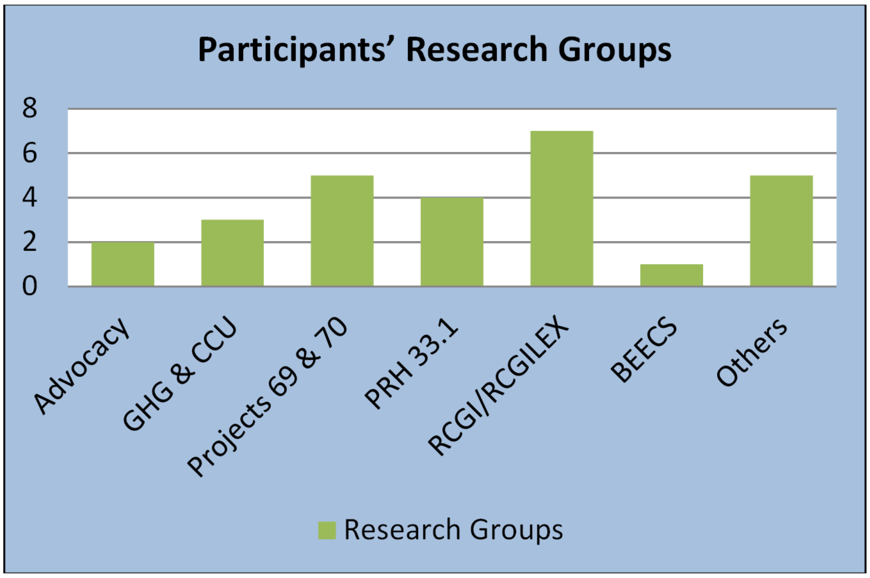


Figure 5: Respondents' research groups
Source: Own Development

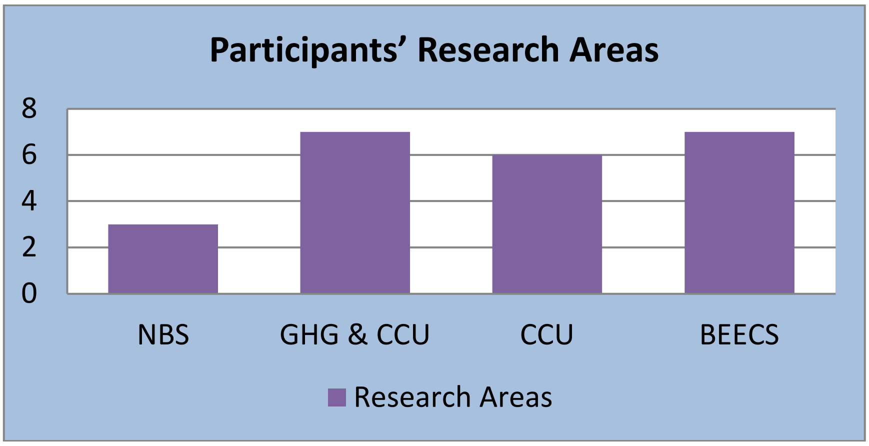


Figure 4: Respondents' research areas
Source: Own Development

However, the second set obtained broader answers, providing a large quantity of information, but with a demand for individual analysis of the answers provided by each participant, thus, a limiting factor in the case of a much larger number of interviewees since such varied information becomes difficult even to be organized in tables and makes it impossible to synthesize in graphs by an essentially qualitative nature, on the other hand, this information qualifies quantitative data and provides information on other forums for more information, even if it requires individualized attention.

4. Conclusion

The methodological development presented proved successful for creating a form to obtain quantitative and qualitative data in the areas of NBS, CCU, BECCS and GHG. The preliminary results show that the application of the preliminary form contributes to the collection of important and sparse data or typical information of the experiences of researchers and respondents. In this context, it is possible to attribute special usefulness to the application of questionnaires in research areas with developing themes on the frontier of knowledge. As such data are not usually cataloged, systematized or published in scientific sources, the questionnaire favors obtaining such data directly from researchers or institutions where such research is ongoing.

In the present case, following the steps of methodological development was fundamental to improve the previous form and reach the final form. The next stage of methodological development involves the application of the final form and the preparation of workshop rounds with researchers and respondents. It is expected that the application of the final form will present new quantitative and qualitative data, better grouped and specialized content. The workshop rounds will be useful to deepen qualitative data, strengthening the dialogue between researchers and the exchange of specific knowledge. The methodological model may be replicated in similar cases of other research.

Acknowledgements

We thank the support from the National Agency for Petroleum, Natural Gas and Bio-fuels Human Resources Program (PRH-ANP), funded by resources from the investment of oil companies qualified in the R,D&I clauses from ANP Resolution number 50/2015 (PRH 33.1 – Related to Call number 1/2018/PRH-ANP; Grant FINEP/FUSP/USP Ref. 0443/19).

We are also grateful to the "Research Center for Gas Innovation - RCGI" (Fapesp Proc. 2020/15230-5), supported by FAPESP and Shell, organized by the University of São Paulo, and the strategic importance of the support granted by the ANP (National Agency of Petroleum, Natural Gas and Biofuels of Brazil) through the R&D clause.

Funding

This research was funded by ANP/FINEP/FUSP/USP, grant number 0443/19, and by RCGI/FAPESP, grant number 2020/15230-5.

References

Bellamy, R.; Healey, P., 2018. 'Slippery slope' or 'uphill struggle'? Broadening out expert scenarios of climate engineering research and development. Environmental Science & Policy. 83, 1-10.

Bellamy, R.; et al., 2021. Incentivising bioenergy with carbon capture and storage (BECCS) responsibly: Comparing stakeholder policy preferences in the United Kingdom and Sweden. Environmental Science & Policy. 116, 47-55.

Brazil, 2022. Brazil Frist NDC - Second update [WWW Document]. UNFCCC. URL https://www4.unfccc.int/sites/NDCStaging/Pages/Party.aspx?party=BRA (accessed 5.27.22).

Brazil, 2020. Paris Agreement Brazil's Nationally Determined Contribution (NDC) (Updated submission) [WWW Document]. SECR UNFCCC. URL https://www4.unfccc.int/sites/NDCStaging/Pages/Party.aspx?party=BRA (accessed 3.2.22).

Brazil, 2015. Intended Nationally Determined Contribution: Towards achieving the objective of the United Nations Framework Convention on Climate Change [WWW Document]. SECR UNFCCC. URL http://www4.unfccc.int/Submissions/INDC/Published Documents/Brazil/1/BRAZIL iNDC english FINAL.pdf

Gasser, T., Guivarch, K., Tachiiri, C., Jones, C., Ciais, P., 2015. Negative emissions physically needed to keep global warming below 2°C. Nat. Commun. 6, 7958.

Humphreys, S, 2019. Human rights and climate change. New York: Cambridge University Press. Available at: https://www.cambridge.org/core/books/humanrights-and-climate-change/introduction-human-rights-and-climate-change/B89D34682C9C05FF50914706A342A275. Accessed on: 30 Mar. 2022.

IEA, 2016. 20 Years of Carbon Capture and Storage - Accelerating future deployment. Paris: OECD, 2016. Available at: https://www.oecd-ilibrary.org/energy/20-years-of-carbon-capture-and-storage_9789264267800-en. Accessed on: 30 Mar. 2022.

Interministerial Committee On Climate Change, 2008. National Plan on Climate Change. Available at: https://www.mma.gov.br/estruturas/smcq_climaticas/arquivos/plano_nacional_mudanca_clima.pdf. Accessed on: 30 Mar. 2022.

IPCC, 2018. Intergovernmental Panel on Climate Change. Global Warming of 1.5°C (Summary for Policymakers). Geneva: World Meteorological Organization.

Silveira, B.H.M., Costa, H.K. de M., Santos, E.M. dos, 2022. Analysis of CBio as an initial step to the development of BECCS in Brazil, in: ANAIS DO 3the INTERDISCIPLINARY SYMPOSIUM OF ENVIRONMENTAL SCIENCE. IEE-USP, São Paulo, pp. 291–304.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Natural Disaster Risk Perception, How to Assess? Questionnaire Suggestion for Evaluation

MAGNAGO, R. F.[a*], MEDEIROS, P.[a], COSTA, S. C.[b], PANCERI, R.[b], LAWALL, I. T[c].

a. Universidade do Sul de Santa Catarina, Palhoça

b. Defesa Civil, Estado de Santa Catarina

c. Universidade do Estado de Santa Catarina, Joinville

**rachelfaverzanimagnago@gmail.com*

Abstract

Natural disasters are disasters caused by natural processes or phenomena that may result in human losses or other impacts on health, damage to the environment and property, interruption of services and social and economic disturbances. The level of a community risk perception is essential to reduce human loss and material damage caused by natural disasters, and formal education has an interventionist role in the culture of a community. In Santa Catarina, actions aimed at continuing education for disaster risk perception have been developed mainly by the State and Municipal Civil Defense. Empirical evaluations support the hypothesis that the education program enhances the risk perception of those involved and support the demand for public investments in this area. Therefore, a questioning instrument is required that effectively evaluate the education process and that allows continuous improvements. This study developed a questionnaire as an assessment tool to be used in education courses on natural disasters risk reduction in the state of Santa Catarina (Brazil). The survey used qualitative and quantitative methods to gather data on the pedagogical effectiveness of adapting the questionnaire to the reality of local disasters. The questionnaire was applied before and after a 2-hour presentation to 50 students from the Civil Defense Continuing Education Course in the Municipalities of Mariana, Barra Longa, Santa Cruz do Escalvado and Rio Doce, in Minas Gerais, Brazil. The review of the answers demonstrates that the use of the questionnaire evidenced that the presentation increased the students' awareness in relation to the topics addressed, thus contributing to enhance the risk perception of the group. It was concluded that the questionnaire was able to detect an increase in the participants' perception of risk. The instrument also helped identifying the presentation's participants' profile and resulted in an important tool for the evaluation of the Disaster Risk Reduction program.

Keywords: Education, Natural Disasters, Risk Perception, Questionnaire.

1. Introduction

Natural disasters have become more intense due to inappropriate land use, urbanization, global climate change, among others; therefore, the enhancement of dwellings resilience to natural disasters should be one of the aims of society, through the development for example, of community risk perception. Oktari et al. (2015) highlighted a decrease in the perception of risk over time and the familiarity that the individual acquired with untoward events made risks normal, minimizing them, thus increasing the probability of life hazards and material damage.

Risk perception analysis can be considered a risk reduction strategy as well as a risk adaptation measure (Oktari et al., 2015). Risk perception varies from person to person and is directly associated to the level of risk (Pazzi et al., 2016), the individuals' previous experiences, beliefs, social and cultural values (Bandecchi et al., 2019).

The actions to develop risk perception have included mainly presentations given by civil defense agents to community members and the training of teachers to pass on the information to their students. Although Civil Defense is structured to operate in community disaster education, in particular, in schools, it still ought to improve the process of evaluating the actions taken. Subjects' learning verifications are still subjective, and it is necessary to upgrade the evaluation process of these presentations/courses for continuous improvement of these programs.

Whereas in South America, the configuration of the Andes Mountain chain favors the channeling of the low-altitude jetstreams to the South and Southeast of Brazil often causing extreme rainfall events in these regions, like in the States of Santa Catarina and Minas Gerais (Reis et al., 2018). One of such catastrophes occurred in the Vale do Itajaí in 2008, which caused significant economic and social losses due to heavy rains, floods and multiple landslides, which resulted in 135 deaths and thousands of affected people in 60 municipalities (Herrmann, 2014). The floods of January 2022 left 39 dead in the State of Minas Gerais and affected the water basins of the Doce and Paraopeba rivers, still under the impact of socio-environmental crimes associated with the failure of ore tailings dams that occurred in Mariana, in 2015, and in Brumadinho, in 2019 (Armada, 2019). Since those events, formal and continuous educational actions on disaster risk reduction have been intensified in the State of Minas Gerais.

Raising risk perception through education automatically generates a culture of prevention and increases community resilience to natural disasters. This is because, when realizing the risks, the population acts consciously (Bandecchi, 2019).

Schmidt (2018) adopted the use of questionnaires and found from the responses of students, their families, teachers, managers and employees of eleven schools in southern Israel that the teachers' knowledge slightly exceeded the students' knowledge but in both cases knowledge was shallow. They also found that the school staff was not prepared to act correctly in guiding students regarding natural disasters. It was detected that, contrary to the objective of the program, students were not replicating the information with their families; it was found, among other deficiencies, the distribution of outdated material that did not hold the attention of students and teachers, the latter being overloaded with the fulfillment of the annual students' program.

Rahman (2019) found that residents of the city of Dakha (Bangladesh) did not have enough knowledge about the correct actions to be taken during an earthquake. Therefore, it is necessary to continue education at all levels and to evaluate these programs to promote a continuous improvement of the teaching techniques adopted and effectively qualify the community.

In this connection, this article aimed to identify the perception of risk through the results obtained from the application of a questionnaire to an audience (mostly students) who attended a presentation on the subject and who attend the Civil Defense Continuing Education Course of the Municipalities of Mariana, Barra Longa, Cruz do Escalvado and Rio Doce, in the State of Minas Gerais.

2. Methods

This was an applied research combining a qualitative and quantitative method. The project was approved by the ethics committee of the Universidade do Sul de Santa Catarina and had a descriptive objective on the operational aspects and effectiveness of adapting the questionnaire to the reality of disasters in Brazil (Günther, 2006).

For this purpose, a questionnaire validated by Schmidt (2018) adapted to the reality of the State of Minas Gerais was used. For the questionnaire adaptations, the main natural hydrological and geological disasters with the highest occurrence in Brazil were taken into account, such as floods, drought, windstorms, hail and landslides, based on the records from the Santa Catarina Civil Defense.

The questionnaire was divided into three parts: I - Demographic factors (such as age, gender and housing area); II - Perception of risk to floods, landslides and other hazards; III - Analysis of behavior in case of disaster; and a section comprising 14 multiple-choice questions and one descriptive question where participants were asked to comment on how they would tell their family members about how to prepare for a natural disaster. The pre-test of the adapted questionnaire was carried out with professors and volunteer students of the Graduate Program in Environmental Sciences with the Santa Catarina Civil Defense Risk Manager.

The questionnaire was applied to 50 students of the Civil Defense Continuing Education Course in the Municipalities of Mariana, Barra Longa, Santa Cruz do Escalvado and Rio Doce, in the State of Minas

Gerais, Brazil.

The questionnaires were applied twice: 48 hours before and immediately after a two-hour lecture on natural disasters given by the team; the surveyors further compared the results obtained. The lecture was prepared based on the material developed by the Civil Defense of the State of Santa Catarina (Margarida et al., 2019). To examine the multiple-choice questionnaire responses, the investigators performed statistics on the responses of the Google Forms questionnaires considering only the responses from the individuals who participated both before and after the presentation, to allow comparison of the responses.

The answers were reviewed according to the question categories (e.g., prior knowledge vs. knowledge acquired in class) on an individual basis. To assess the answers in the descriptive question, it was decided to build a word cloud using the AtlasTi® program. The words identified were the ones that were repeated the most, with at least six occurrences.

3. Results and discussion

I - Demographic factors

The survey participants were mostly male (58.3%); 69.4% went through high school and 30.6% had higher education. The participants' age was distributed as follows: from 30 to 39 years of age (75%), 40 to 49 years (22.2%) and 18 to 29 years (2.8%). The data reflect the World Economic Forum information about the existence of a gap between work opportunities and female workers (Machado; Ribeiro, 2021). However, in this specific case, it is necessary to reach the female audience, as women are considered more vulnerable when compared to men and face challenges during a disaster (Wisner, 2006); they are usually with children and family members in different risk situations. Therefore, it can be suggested that the university environment is a suitable place to approach disaster education, as colleges enroll a significant number of women

The survey participants were residents of the State of Minas Gerais (Brazil) in the municipalities of Mariana (69.4%), Rio Doce (13.9%), Santa Cruz do Escalvado (11.1%), Acaiaca (5.6%). Out of these, 75% lived in urban areas and 25% in rural areas. Among the participants, 47.2% lived in a one-story house, 50% in a two-story house and 2.8% in an apartment.

II - Perception of risk to floods, landslides and other hazards

The percentage of responses on the perception of risk concerning floods, landslides and other disasters are described in **Tables 1** and **2**. **Table 1** presents the percentage of responses to the first question, indicating whether the participant had attended a lecture, a movie or a lesson on natural disasters during the last two years and if he/she participated in an exercise on how to proceed in the event of a natural disaster.

Table 1. Question 1 of the questionnaire applied to the participants before and after the lecture on natural disasters.

About natural disasters (floods, landslides, hail, drought or gale),		**Yes %**	**No %**	**I don't remember %**
1.1 Have you ever attended a lecture, a movie, or a lesson on natural disasters?	Before	92	8	0
	After	97	0	3
1.2 Have you participated in an exercise on how to proceed in the event of natural disasters in the last two years?	Before	78	22	0
	After	86	14	0

Table 1 demonstrates that even before the lecture, the participants had already attended a lecture, a movie or a lesson on natural disasters (question 1.1) with 92% positive responses. After the presentation,

positive responses increased by 5%. Before the lecture, 8% had answered "no" and after the lecture no participant answered "no". The alternative "I don't remember" was not ticked before the lecture, with 3% of the participants ticking that answer after the lecture.

In addition, in **Table 1**, for question 1.2, before the lecture 78% of the participants answered "yes", 22% answered "no". After the lecture the percentage of "yes" increased to 86% and "no" decreased to 14%. The option "I don't remember" was not checked by any participant before or after the lecture.

Table 2 presents the response rate for question 2 that asked the participants' opinion about the risk of a natural disaster occurring in their region and whether they believe it is possible to receive advance notice from the official communication networks before a natural disaster occurs.

Table 2. Question 2 of the questionnaire applied to the participants before and after the lecture on natural disasters.

2- In your opinion...		Yes %	No %	I don't know %
2.1 Is there a great risk of a natural disaster occurring in your region?	Before	91.7	5.6	2.8
	After	100	0	0
2.2 Is it possible to receive advance notice from official communication networks before a natural disaster occurs?	Before	75	19.4	5.6
	After	66.7	27.8	5.6

Question 2.1 in **Table 2**indicates that before the lecture 91.7% of the participants answered yes to the possibility of a disaster, 5.6% answered "no" and 2.8% answered "I don't know". After the lecture, everyone answered yes to this question.

Also in **Table 2**, in question 2.2, "It is possible to receive advance notice from the communication networks before a natural disaster occurs", before the lecture, 75% of the participants answered yes, 19.4% answered "no" and 5.6% replied "I don't know". After the lecture, the percentage of positive responses dropped to 66.7%, negative responses increased to 27.8% and the percentage of "I don't know" remained unchanged.

Table 3 reports the responses rate to question 2 for the participants for the options ranging from "strongly disagree" to "strongly agree".

Table 3. Question 3 applied through the questionnaire to the participants before and after the lecture on natural disasters.

Questions	**Moment**	**Fully agree %**	**I agree %**	**Neither agree nor disagree %**	**I disagree %**	**Strongly disagree%**
3.1 Are you concerned about the possibility of a natural disaster occurring in your region?	Before	63.9	30.6	2.8	0	2.8
	After	61.1	36.1	0	0	2.8
3.2 Are estimates of the occurrence of natural disasters important?	Before	69.4	27.8	0	0	2.8
	After	77.8	19.4	0	0	2.8
3.3 Does your family prepare for the possibility of a natural disaster in your area?	Before	22.2	33.3	19.4	19.4	5.6
	After	13.9	52.8	22.2	2.8	8.3
	Before	72.2	19.4	2.8	2.8	2.8

3.4 Do you consider that climate change is increasing the occurrence of natural disasters?	After	86.1	8.3	2.8	2.8	0

The percentages presented in Table 3 for the question "Are you concerned about the possibility of a natural disaster occurring in your region?" showed that before the lecture 2.8% of the participants "strongly disagreed", no participant "disagreed", 2.8 % "neither agreed nor disagreed", 30.6% "agreed" and the majority, 63.9%, "fully agreed". After the lecture, the rates of "strongly disagree" and "disagree" remained the same, none of the participants "neither agreed nor disagreed", those who "agreed" increased to 36% and those who "strongly agreed" to 61.1%. When adding the percentages of positive responses, they represented 94.5% before and 97.2% after the lecture. Respondents seemed well-prepared in terms of risk perception, being some of them, members of the Civil Defense of the State of Minas Gerais. This result is in line with the fact that there is an increase in the perception of risk with the continuous training of individuals, reducing the probability of risk to life and material damage (Pazzi et al., 2016; Okitari et al., 2015).

Also in **Table 3**, now regarding the question "estimates of the occurrence of natural disasters are important", 2.8% responded that they "totally disagree" before and after the lecture; the items "disagree" and "neither agree nor disagree" were not marked by anyone before or after the lecture; before the lecture, 27.8% "agreed" and after the lecture 19.4% and finally, "totally agreed" rose from 69.4 to 77.8%, maintaining a high rate of positive responses.

In addition, in **Table 3**, when asked about the "preparation of the family for the possibility of a natural disaster", 22.2% "strongly agreed" and after the lecture this figure dropped to 13.9%; among those who agreed, the values rose from 33.3 to 52.8%; "neither agreed nor disagreed" increased from 19.4 to 22.2%; the number of participants who "disagreed" dropped from 19.4 to 2.8% and "strongly disagreed" increased from 5.6% to 8.3%. A family's preparedness for a natural disaster says a lot about their perception of disasters and reflects in a more adequate response to an emergency situation, avoiding human and material losses (Antronico et al., 2017). The participants' families are prepared to face a disaster.

Finally, **Table 3** presents the answers to the question about how much the participant agrees or not that "climate change is causing an increase in the occurrence of natural disasters". Before the lecture, 72.2% "completely agreed" and after the lecture 86.1% said there was no doubt about the influence of climate change on the number of disasters. Also "agreed" with this statement 19.4% before the lecture and 8.3% after the lecture, clearly demonstrating a migration to "I totally agree", since the options "neither agree nor disagree" and "disagree" remained unchanged with 2.8% of respondents both before and after the lecture and the percentage of people who "strongly disagreed" dropping from 2.8% to zero response. Climate change is a great global challenge. It is frequently associated with an increase in the frequency and intensity of natural disasters, impacting especially the developing countries.

Table 4 shows the percentage of response for when the participant believes that one of the following events described in the first column will occur (Flood, Drought, Windstorm, Hail and Landslide) responding before and after the lecture between: a) This can occur at any time; b) Next year; c) Five years from now; d) Ten years from now or e) I don't know.

Table 4. Question about the perception of disaster occurrence, a) This can happen at any time; b) Next year; c) Five years from now; d) Ten years from now or e) I don't know.

When do you think the following natural disaster might occur?										
Event	Flood		Draught		Gale		Hail		Landslide	
Before or after the lecture	Before	After	Before	After	Before	After	Before	After	Before	After

a) This can happen at any time %	88.9	94.4	52.8	55.6	88.9	94.4	91.7	94.4	91.7	94.4
b) Next year %	2.8	0	30.6	30.6	0	0	2.8	0	0	2.8
c) In five years %	0	0	0	2.8	0	0	0	0	0	0
d) In ten years %	0	0	2.8	0	0	0	0	0	0	0
e) I don't know %	8.3	5.6	13.9	11.1	11.1	5.6	5.6	5.6	8.3	2.8

Table 4 shows that for most participants, even before the lecture, the disasters described can occur at any time with the response rates increasing after the lecture. With the exception of the Drought event, which presented percentages 52.8 and 55.6% before and after the lecture, all others had 94.4% responses after the lecture. The drought event received 30.6% of responses both before and after the lecture for the option "Next year". Further, in this option, the flood and hail events received 2.8% responses before the lecture, and the Landslide event 2.8% after the lecture. The answers clearly showed a lower perception of the drought risk, in line with the reality of the region that has a low occurrence of the event (Reis et al., 2018). To conclude **Table 4**, the option "I don't know" remained at 5.6% before and after the lecture and in all other events the rates diminished after the lecture with the greatest reduction for the event "landslide".

In **Fig.1**, **Fig. 2** and **Fig. 3** we have the answers on how to act before **(Fig. 1)**, during **(Fig. 2)** and after **(Fig. 3)** the occurrence of disaster events, before and after the lecture. **Fig. 1**shows the opinion of the participants on how to act before the occurrence of natural disasters.

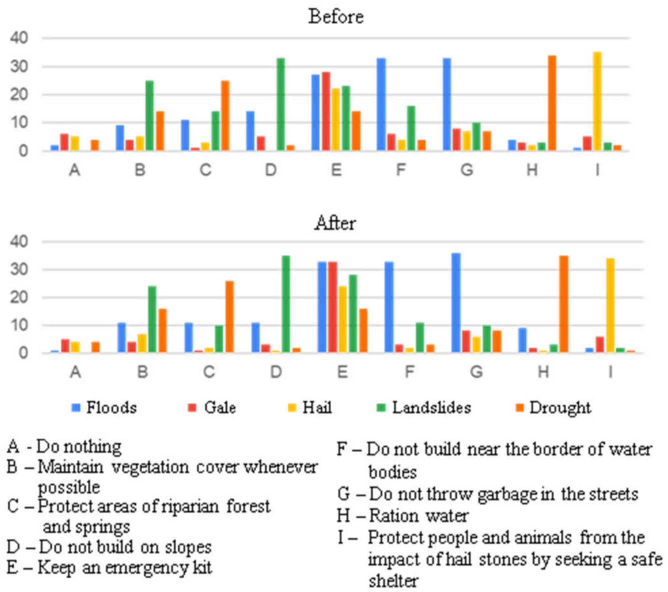


Fig. 1. Question - How to act BEFORE the following disasters occur? Before and After the Lecture.

As seen in **Fig. 1** the responses before and after the presentation held a common pattern across all types of disasters. For item A - "Do nothing" - the highest number of responses was 5 for the gale disaster. As for items B - "Maintain vegetation cover whenever possible" - and D - "Do not build on slopes" -, the emphasis was given to Landslides. The Drought event stood out in items C - "Protect areas of riparian forest and springs" - and H - "Ration water" -, with 26 and 35 responses, respectively. Item E - "Keep an emergency kit" - was the one that presented a significant number of responses for all events, resulting in 33 responses to Floods and Gale after the lecture. In items F - "Do not build near the border of water bodies" - and H - "Ration water" - the Flood event received greater emphasis, with 32 and 36 responses, in that order, after the lecture.

Fig. 2 gathers the opinion of the participants on how to act during the occurrence of natural disasters.

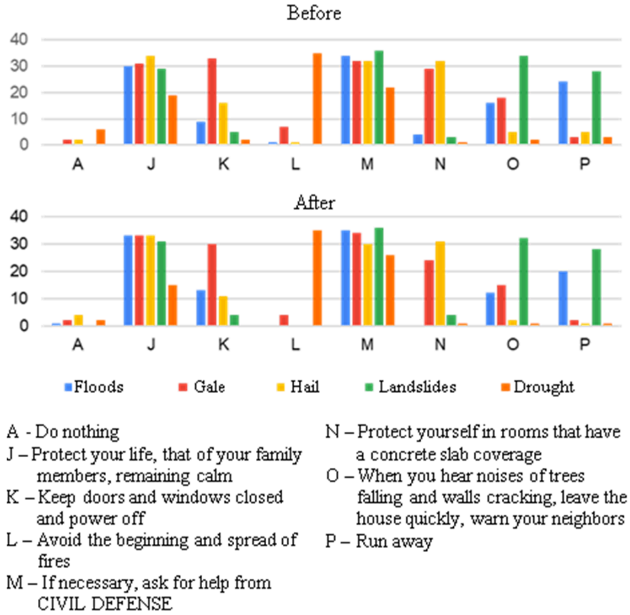


Fig. 2. Question - How to act during the occurrence of the following disasters? Before and After the lecture.

Fig. 2 demonstrates that the pattern of responses before and after the lecture was similar and showed few changes. For item A - "Do nothing" - the events received little or no response, with responses lower than 3 after the lecture. For items J - "Protect your life" - and M - "If necessary, ask for help from Civil Defense and Protection" -, all events were mentioned more frequently after the lecture. For option K - "Keep doors and windows closed and power off" - the event Gale was highlighted. Option L - "Avoid the setting and spread of fires" - was chosen by the vast majority of participants in the drought event. The Hail event received the greatest number of responses for item N - "Protect yourself in rooms that have concrete slab coverage". At the end of Chart 8, items O - "When you hear noises of trees falling and walls cracking, leave the house quickly, warn your neighbors" - and P - "Run away" - received the highest number of responses for the Landslide event.

Fig. 3 presents the opinion of respondents on how to act after the occurrence of natural disasters.

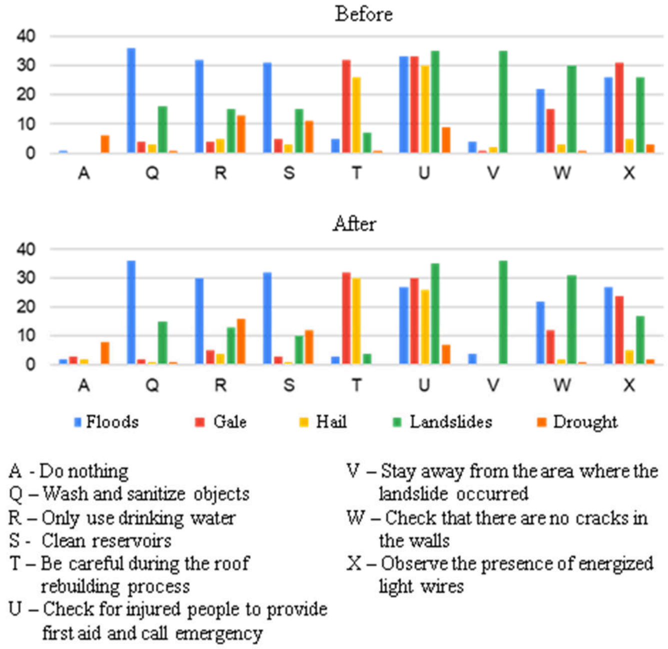


Fig. 3. Question - How to act after the occurrence of the following disasters? Before and After the lecture.

According to **Fig. 3**, the participants' responses showed similar behavior before and after the lecture on natural disasters. Item A - "Do nothing" - received few responses. The Flood event was the most cited in items Q - "Wash and sanitize objects" -, R - "Only use drinking water" - and S - "Clean reservoirs" - with responses equal to or greater than 30. The events Gale and Hail received the most responses, both before and after the lecture, in item T - "Be careful during the roof rebuilding process". The events Floods, Gale, Hail and Landslides obtained results above 25 with the highest number of responses for Landslides. The Landslide event also stood out among items V - "Stay away from the area where the landslide occurred" - and W - "Check that there are no cracks in the walls" - with responses higher than 30. Finally, item X - "Observe the presence of energized light wires" - the Floods event stands out, followed by Gale.

Regarding how much your family prepares for the possibility of a natural disaster in your region, word clouds were generated (**Fig. 4)** when asked to list three activities to prepare for a natural disaster.

Fig.4. Word clouds generated from individual participant responses (a) before and (b) after the lecture.

Fig. 4a before attending the lecture, participants repeated the words "maintain" and "safe", related to a safe place or personal safety. After attending the lecture Fig. 4b, a greater number of participants cited the words "maintain", "kit" and "aid". It is worth mentioning the emergence of the words "calmness", "defense" and "civil". There is evidence of an increase in the intention to maintain an emergency kit at home and the need to remain calm, in addition of course to the indication of the Civil Defense to deal with disaster situations. The population is expected to be active and to act consciously to impose attitudes that preserve their physical integrity, that of their families, as well as the community's. It should be considered that human behavior is determined by many influential factors, such as target population, communication channels, training, attitudinal and behavioral trends (Kim; Madison, 2020).

4. Conclusion

The development of community's resilience goes through the subjects' perception of risk that can be improved with formal education. In this study, a questionnaire that provides data on the perception of risk to the most common disasters in the State of Santa Catarina was adapted to the Brazilian reality.

Through the application of the questionnaire in two phases, it was possible to verify that the participants demonstrated an awareness from a lecture on natural disasters. In addition to defining the profile of the participants, it is noteworthy that the participants had already attended or participated in a presentation related to a disaster, but few had already participated in a practical exercise on how to act during the occurrence of a natural disaster. It was also confirmed that respondents consider that climate change has contributed to the increase in the frequency of natural disasters and that they trust existing disaster communication networks.

The use of this questionnaire can be explored in the future to extract information about the risk perception of respondents, their profile, in addition to being able to identify attitudinal actions.

Acknowledgment

We are grateful to the Instituto Anima and CAPES for the Research Fellowship and Master's Degree Scholarship respectively granted to the authors and to the partnership with the Santa Catarina Civil Defense.

References

Armada, C.A.S., 2019. The Environmental Disasters of Mariana and Brumadinho and the Brazilian Social Environmental Law State. Available at SSRN:http://dx.doi.org/10.2139/ssrn.3442624

Antronico, L., Coscarelli, R., Pascale, F., Muto, F., 2017. Geo-hydrological risk perception: A case study in Calabria (Southern Italy). International Journal of Disaster Risk Reduction, 25, 301–311.https://doi.org/10.1016/j.ijdrr.2017.09.022

Bandecchi, A.E., Pazzi, V., Morelli, S., Valori, L., Casagli., N., 2019. Geo-hydrological and seismic risk awareness at school: Emergency preparedness and risk perception evaluation. International Journal of Disaster Risk Reduction, 40, 101280.https://doi.org/10.1016/j.ijdrr.2019.101280

Günther, H., 2006.Pesquisa Qualitativa Versus Pesquisa Quantitativa: Esta É a Questão? Psicologia: Teoria e Pesquisa, 22, 201-210.

Herrmann, M.L.P., 2014. Atlas de desastres naturais do estado de Santa Catarina: período de 1980 a 2010 [Atlas of natural disasters in the state of Santa Catarina, period from 1980 to 2010].

Kim, D.K.D., Madison, T.P., 2020. Public Risk Perception Attitude and Information-Seeking Efficacy on

Floods: A Formative Study for Disaster Preparation Campaigns and Policies. Int J Disaster Risk Sci. 11, 592–601. https://doi.org/10.1007/s13753-020-00307-5

Machado, W., Ribeiro, C.C., 2021. The association between spouses' earnings and trends in income inequality in Brazil (1993–2015). Advances in Life Course Research, 49, 100413. https://doi.org/10.1016/j.alcr.2021.100413

Oktari, R.S.,Shiwaku, K.,Munadi, K.,Syamsidik, Shaw, R.,2015. A conceptual model of a school-community collaborative network in enhancing coastal community resilience in Banda Aceh, Indonesia. International Journal of Disaster Risk Reduction, 12, 300–310.https://doi.org/10.1016/j.ijdrr.2015.02.006

Pazzi, V., Morelli, S.,Pratesi, F.,Sodi, T.,Valori, L.,Gambacciani, L.,Casagli, N. 2016. Assessing the safety of schools affected by geo-hydrologic hazards: The geohazard safety classification (GSC). International Journal of Disaster Risk Reduction, 15, 80–93.https://doi.org/10.1016/j.ijdrr.2015.11.006

Rahman, M.L., 2020. Risk perception and awareness of earthquake: the case of Dhaka. International Journal of Disaster Resilience in the Built Environment, 10, 65–82.https://doi.org/10.1108/IJDRBE-04-2018-0020

Reis, A.L., Silva, M.S., Regis, M.V., Silveira, W.W., Souza, A.C., Reboita, M.S., Carvalho, V.S.B., 2018. Climatologia e eventos extremos de precipitação no estado de Minas Gerais. Revista Brasileira de Geografia Física, 11, 652-660. https://doi.org/10.26848/rbgf.v11.2.p652-660

Schmidt, J., 2018. Notes on national earthquake education programs in Israel. Procedia Engineering, 212, 1265–1272.https://doi.org/10.1016/j.proeng.2018.01.163

Wisner, B., 2006. Let our children teach us!: a review of the role of education and knowledge in disaster risk reduction. https://www.undrr.org/publication/let-our-children-teach-us-review-role-education-and-knowledge-disaster-risk-reduction

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Production of Charcoal by Pyrolysis Process for the Treatment of Liabilities of Industrial Landfills: Bibliometric and Life Cycle Analysis

WEISS, F.[a], COLARES, G. S. MACHADO[a], Ê., L., LÓPEZ, D. A. R., RODRIGUEZ[a], A. L., HAUSCHILD, T., LUTTERBECK[b], C. A., BERGMANN, C. P[b], BASEGIO, T.[b], SCHNEIDER, R. C. S[a]. TROTHMANN,A[a].

a. *Universidade de Santa Cruz do Sul-UNISC, Rio Grande do Sul, RS, Brazil*

b. *Universidade Federal do Rio Grande do Sul-UFRGS, Rio Grande do Sul, RS, Brazil*

**Corresponding author, enio@unisc.br*

Abstract

Pyrolysis studies were investigated with waste from a unit that manages liabilities from numerous industries in different sectors in order to recover energy. This study evaluated pyrolysis for non-hazardous reactive waste, according to ISO 10004/2004. These are wastes with considerable calorific value, with 40% m/m of plastic, 25% m/m of paper/cardboard, 25% m/m of foam and synthetic rubbers and 10% m/m of cotton fabric and cellulose casings. We opted for pyrolysis at low temperature (350ºC) with a heating rate of 2.75ºC per minute; with 120 minutes as the time necessary to reach the level of 350 ºC, remaining for another 30 minutes at this temperature. In each test, the calorific value was determined. 10 grams of each of the segregated materials were used, following the above-mentioned composition. A bed-type retainer was used, with a resistance compliance zone of 1800W, 220 V - 26.89 Ohms, 8.18 A and 2.59 W cm^{-1}. The values of the Useful Calorific Power (UCP) of the samples of crude residues, and of the char were determined. The analysis of the Life Cycle considering the procedures studied was performed. Normalization, Characterization and Single Score from SimaPro 8.0.1 and Impact 2002+ method were considered. Scenarios of reduction of environmental impacts, as well as positive environmental impacts were observed, considering the depletion of the ozone layer, extraction of mineral resources, greenhouse effect and aquatic ecotoxicity. In these cases, the electrical energy of 1.8kWh to operate the reactor on a bench scale would be generated from coal and the gaseous fraction of the pyrolysis and catalytic pyrolysis processes, both with 4,227 cal g^{-1} for the char without catalyst and 5,473 cal g^{-1} having the catalyst in the process.

Keywords: industrial residues, management centers. Integrated management, LCA

1 Introduction

Waste treatment by pyrolysis processes can no longer be considered just an environmental management path to reduce environmental liabilities and/or recover energy by obtaining synthesis gas, bio-oil, char and biochar. It should also be considered that obtaining the char or biochar establishes the potential creation of scenarios of various mechanisms for circular economy. In these cases improving soil quality, purifying water, immobilizing toxic substances in the soil, control the excess of nutrients, both in the soil and in filtering gardens, supporting air and water purifiers and supporting nutrients to improve the production of methane in anaerobic processes (Draper, 2019; Saletnik, 2019; Song et al., 2021).

Biochar or charcoal, is produced at different temperature ranges, which, for example, considering the decomposition of cellulose from 240-350 °C, has a production of more expressive quantities of synthesis gas, bio-oil and a smaller fraction of biochar/charcoal. If lignin decomposition is considered, with temperature ranges between 280-500 °C, the biochar can yield up to 35-40%, with values even higher if temperatures are maintained between 375-400 °C (SAGADEVAN et al., 2017)

Nevertheless, when the solid fraction of the reduced product is obtained from synthetic materials, such as plastics, paper, cardboard, cotton, the most used term is only "coal from the pyrolysis process". An example is HDPE, which pyrolyzed between 400-450 °C, produces coal with 51.40% (w/w) of volatile material, 46.03% (w/w) of fixed carbon, a fixed fraction of 2.41% (w/w) and, with ashes of only 0.16% (w/w). The BET (Brunauer, Emmett, Teller method) surface, the pore volume, the density, the PCU value of this same material presents 16.77 m^2 g^{-1}, 0.2080 cm^3 g^{-1}, 1.59 g cm^{-3} and 4.5 kcal g^{-1}, respectively (Jamradloedluk and Lertsatitthanakorn, 2014).

Considering then, the importance of biochar/charcoal and pyrolysis for energy recovery, environment and agriculture, the legal references for the use of these products must be known, as well as the effective sustainability. More specifically for biochar, which could also be a reference for pyrolysis coal, there are references from the International Biochar Initiative, Biochar Quality Mandate, European Biochar Certificate and Refertil Biochar (Yrjälä, Ramakrishnan, Salo, 2022).

It must be clear that the effective sustainability of the biochar/charcoal production processes has references to recover energy from waste, as well as fix carbon in the soil. Dong et al. 2019, assessed the sustainability by life cycle analysis (LCA), using the software Gabi 8.0 and considering the processes of incineration, pyrolysis in a rotary kiln, gasification of a rotating fluidized bed and gasification with a rotary kiln with burning of synthesis gas and fusion of ashes in the production of metal alloys. Specifically, in the pyrolysis process, for 1 ton of solid urban waste, 319.1 kg of coal are generated, being immediately used in the combustion process for power generation.

Smebey et al. 2017 evaluated the LCA of biochar production for different technologies, including pyrolysis, considering the sequestered carbon and the avoided production of electrical energy. The authors used wood waste with no value as raw material and considered endpoint indicators adopting a hierarchical perspective, associating normalization and weighting in different impact categories.

Specific impact categories received special attention: GWP, ecosystems and human health emissions of particulate matter and their effects on human health through inhalation, land transfer and occupation. The cost of extracting minerals and fossil fuels for influential impact categories, such as ecotoxicity and eutrophication, were grouped into "remaining categories". It is important to point out that the generation of biochar alone does not result in significant positive impacts on the life cycle and, therefore, additional environmental benefits, such as the treatment of wastewater and increased soil fertility, are necessary.

Therefore, it becomes evident the importance of effectively evaluate the environmental benefits of the pyrolysis method. So, the present study aimed to investigate the passive treatment of class IIA (NBR 10.004 - ABNT, 2004**)** landfill waste located in an environmental protection foundation in southern Brazil, which treats waste from 13 cooperative companies, involving sectors such as tobacco, food and electroplating, among others. LCA was applied for the pyrolysis method using a bench reactor in order to evaluate the yield and behavior of pyrolysis methods for landfill residues predominantly containing plastics, paper and cotton, potentiating recovering energy and releasing the studied landfill cell liabilities.

2 Methodology

2.1 Sampling and sample preparation

The samples for the pyrolysis assays were collected along a class II A deactivated landfill cell (according to the classification of NBR 10.004 - ABNT, 2004), located in an area belonging to an Environmental Protection Foundation in Southern Brazil. This unit has 6,300 m³ of waste coming from companies of the tobacco, food, metal-mechanical and plastic and polymeric materials sectors. From 10 points uniformly distributed on the surface cell, aliquots of 5 kg of residues were removed, considering all types in the heterogeneous mixture, including: plastics, paper, cardboard, tailings, foams and synthetic rubbers, as well as cotton fabrics and casings. cellulose.

After mixing the fractions of the collected samples, aliquots of each type of material were removed from the heterogeneous mixture in rates of 40% plastic, 25% paper/cardboard, 25% synthetic foam and rubber and 10% cotton fabric and cellulose casings. These aliquots constituted an individual sample of each type of waste, with prior crushing (De Leo) for a fraction of 5mm, with drying at 60 ° C for seven days, until constant weight was obtained.

2.2 Non-Catalytic and Catalytic Pyrolysis Assays

The tests were performed in a pyrolizer with a fixed bed type reactor, Sanchis, with the following specifications: heating zone with 1800W resistance, 220 V - 26.89 Ohms, 8.18 A and 2.59 W cm^{-1}, involving the entire quartz tube, in which the sample was packaged for pyrolysis treatment. The pyrolysis assays were carried out with a maximum temperature of 350ºC, with heating rates of 2.75ºC per minute, with 120 minutes as necessary time to reach a level of 350 °C, remaining for another 30 minutes at this temperature, totaling then 150 minutes. Cooling down to room temperature (25 ° C) was done in a natural, i.e., with the quartz tube outside the oven.

2.3 Life Cycle Analysis of Pyrolysis Methods

The study was developed in four stages, considering the standards NBR ISO 14,040 and NBR 14,044, considering the development of goals and scopes; data collection; inventory analysis and impact assessment and interpretation. The creation of prognosis scenarios using clean technologies was carried out based on the interpretation of the main causes of environmental impacts of the study case. The inventory of the method referenced in Fig. 1 is presented in Table 01. These data were estimated and determined according to the procedures adopted for the experimentation of pyrolysis.

Table 1. Inventory for the development of the studied pyrolysis methods.

	Methods	
Parameters	**Pyrolysis**	**Catalytic Pyrolysis**
Wastes (g)	10	10
Nitrogen (purge mL min^{-1})	250	250
Energy Consumption (kWh)	1.8	1.8
Catalyst (red clay)	-	10
Pyrolysis Time (min)	150	150
Quantity of generated coal (g)	7.1	6.6

Life cycle assessments were developed using a 100-year baseline model and applied to the extent of damage on the hierarchical scale. Special consideration was given to the contribution of chemical inputs and the Brazilian energy matrix.

From the SimaPro 8.0.4 software, the Impact 2002+ method was applied, mainly exploring the database with reference to the (S) systems taking into account the study process illustrated in Figure 1. The exceptions were electricity and heat, where the unit (U) was used. The broader coverage of the data profiles also considered the options of RoW, RER and GLO. The Impact 2002+ was chosen to provide a more balanced coverage of the environmental impact determination response.

2.4 Bibliometric Analysis

Bibliometric analysis was performed using the Web of Science database (Clarivate Analytics, 2021). This platform was selected because of the quality control database of peer-reviewed research material related to the study subject. The search terms used for the database information obtained were: Life Cycle Assessment, Pyrolysis and Biochar. From the information accessed on the database, a bibliometric mapping was carried out using the VOSviewer software (version 1.6.12), considering records from all periods and applying a methodology similar to that recommended by De Souza et al. (2019). The main steps of the *VOSviewer* application consisted of feeding the software with the downloaded database to create a map of co-occurrence terms based on text data, considering the words present in the title and summary fields. The terms were extracted by the software using "binary count", a method in which only the presence or absence of a term is important, while the number of occurrences of a term in a document is not taken into account. The minimum number of occurrences of a term was defined as 10, as the default software recommendation.

3 Results and Discussion

3.1 Bibliometric Mapping

Considering the 121 articles found by the search terms "Life Cycle Assessment Pyrolysis Char/Biochar", processing was performed with the VosViewer software, using binary counting (not counting an item repeated in the same article). The minimum occurrence value was defined as 10 (software standard) and the terms were extracted from the titles and abstracts of the articles, generating the network visualization map shown in Figure 3. For the network presentation, the items obtained are represented by a label that, in some cases, is not placed in order so that there is no overlap in a circle, and each circle size is proportional to the occurrence of the item.

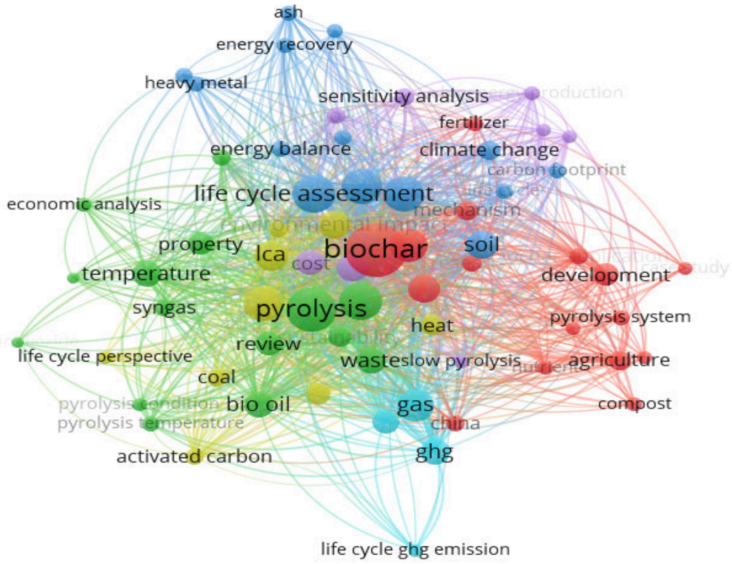


Figure 1. Network visualization map generated by VOSviewer Software from Life Cycle Assessment Pyrolysis Biochar material. The colors represent clusters of extracted terms, grouped by the software according to the item relationships.

The color defines to which cluster an item is inserted and the lines represent the links between the items, and the distance between two items indicates the strength of the relationship, that is, closer items are more related than more distant items (Eck and Waltman, 2019).

Based on Fig. 1, three large groups can be distinguished. The red cluster focused on factors related to the production of biochar, especially from vegetable residues and sludge from effluent treatment plants, in addition to operational factors for application of the solid pyrolysis product to the soil. In the green cluster, review articles on pyrolysis, bio-oil production, synthesis gas and temperature ranges and detention times for carrying out the processes are highlighted. The blue cluster is directly related to life cycle analysis, mainly considering energy recovery and climate change associated with the greenhouse effect. Sensitivity analysis, operating costs, life cycle analysis (LCA) concerning production of activated carbon are also referenced, but with less intensity in the clusters.

3.3 Life Cycle Analysis, Development of Clean Technologies and Sustainability

In LCA studies on biochar, impact methods such as ReCipe (Munoz et al. 2017) and the Eco 99 indicator (Homagain et al. 2015) appear as the most used, as well as the CML-baseline and Impact 2002+. Moreover, the use of SimaPro software from version 8.3 (Hong et al., 2010; Jolliet 2003) is also very frequent. Therefore, in the present work, the Impact 2002+ method was chosen. The inventory associated with SimaPro 8.03 can be seen in Table 2.

Table 2. Inventory with data from the EcoInvent 3.1 database

	Investigated class II-A landfill liability	**Pyrolysis**	**Catalytic Pyrolysis**
Parameters/SAMPLES	10 g	10 g	10 g
Polyethylene, high density, granulate {GLO}| market for | Alloc Rec, S	4 g	4 g	4 g
Waste paperboard, sorted {GLO}| market for | Alloc Def, S	2.5 g	2.5 g	2.5 g
Polymer foaming {GLO}| market for | Alloc Rec, S	1.25 g	1.25 g	1.25 g
Synthetic rubber {RER}| production | Alloc Rec, S	1.25 g	1.25 g	1.25 g
Cotton fibre {GLO}| market for | Alloc Rec, S	1.25 g	1.25 g	1.25 g
Cellulose fibre, inclusive blowing in {GLO}| market for | Alloc Rec, S	1.25 g	1.25 g	1.25 g
Clay {GLO}| market for | Alloc Rec, S	-	-	7.5 g
Known Entries of the Technological Sphere - Electricity Heat			
Electricity, low voltage {BR}| market for | Alloc Rec, S	-	1.8 kwh	1.8 kWh
Known Technology Sphere Entries - Avoided Products	-		
Carbon black {GLO}| market for | Alloc Rec, S	-	7.1 g	6.6

The consideration for the use of electric energy could be disregarded if the system were already operated on a pilot scale, since the return of the gas fraction and some fraction of bio-oil generated would be attenuating or totally substituting electric energy. Thus, data from two different scenarios are presented for the LCA of this work: with and without consumption of electricity.

Hamedani et al. (2019) discussed the ability of the synthesis gas generated in the treatment of animal (pig) manure to recompose the energy demand for the operation of the pyrolizer. This taking into account that the yield of biochar, synthesis gas and bio-oil were 33.5%, 31.9% and 34.6%, respectively. The values of synthesis gas and bio-oil can be 11 and 16 MJ kg-1. The Normalization tests, on the other hand, demonstrate the main impacting parameters of the Class II A landfill liability, as well as for the Pyrolysis process with and without the catalyst. The results can be visualized in Figures 2A (test scenario) and 2B (scenario of a pyrolysis plant with energy use).

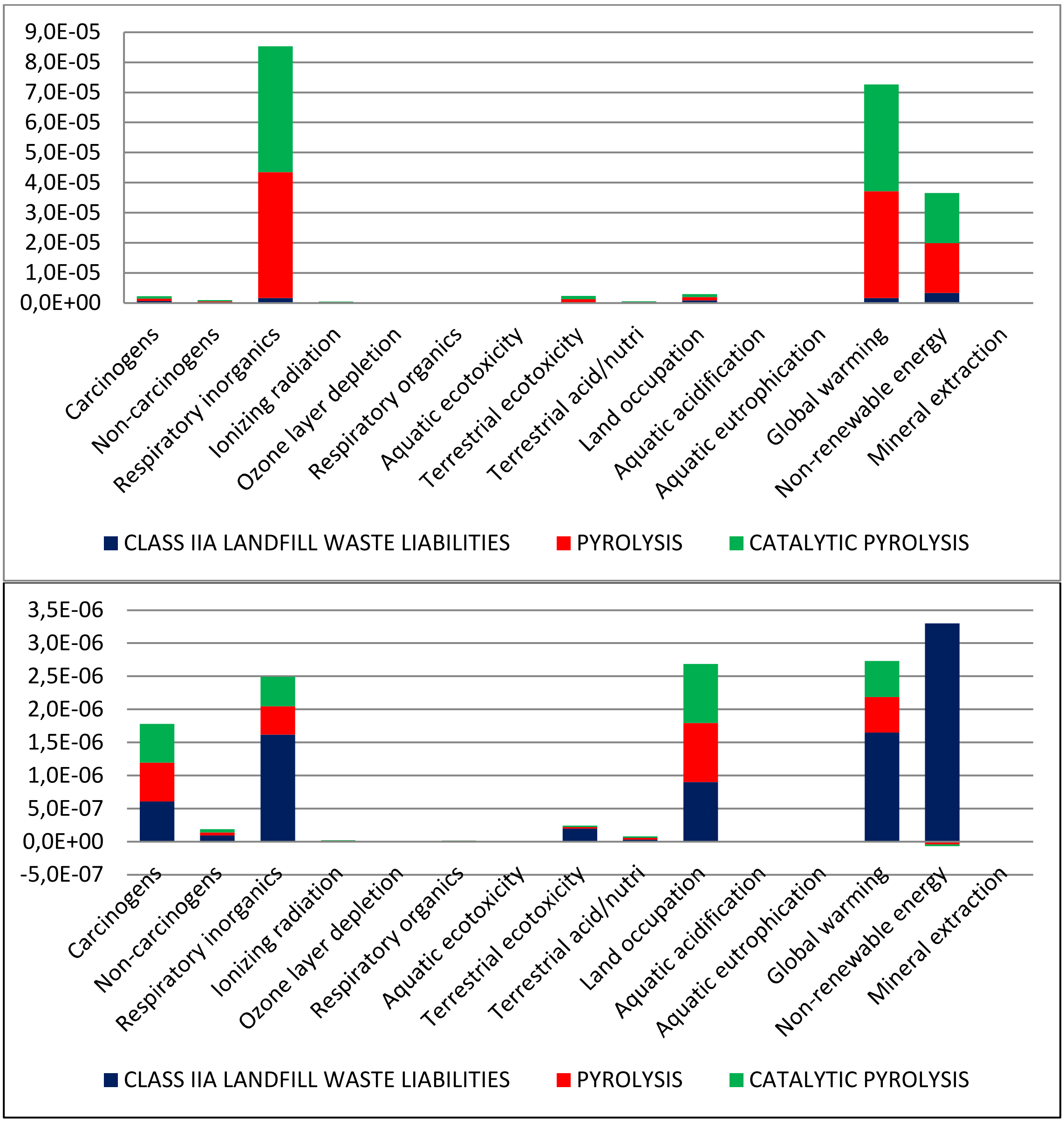


Figure 2. (A) Normalization for the environmental liability regarding the studied pyrolysis methods, test scenario, and functional unit of 10 g of Class II A waste. (B) Normalization for the environmental liability regarding the studied pyrolysis methods, scenario of a pyrolysis plant with energy use, and functional unit of 10 g of Class II A waste.

In the same way as in the Normalization, the Characterization also demonstrates the difference in sustainability and clean technologies of pyrolysis methods without using biochar by-products to replenish the system, as shown in Figure 3A (test scenario) and Figure 3B (scenario of a pyrolysis plant with the energy use). No difference regarding environmental impacts when considering both pyrolysis with or without catalyst was observed, as well as the production of biochar is even lower than expected, with 66% against 71% of the method without clay. Dou and Goldfarb (2017) referenced the use of clay in their study. However, these researchers used bentonite clay, having uniformity of spreading with the sample by placing pineapple peels and mango peels/kernel with 500 solution mg of bentonite in 100 mL of deionized water, and after that, adding 2 g of the dry samples with a 250 µm granulometry to disperse the catalyst in the samples.

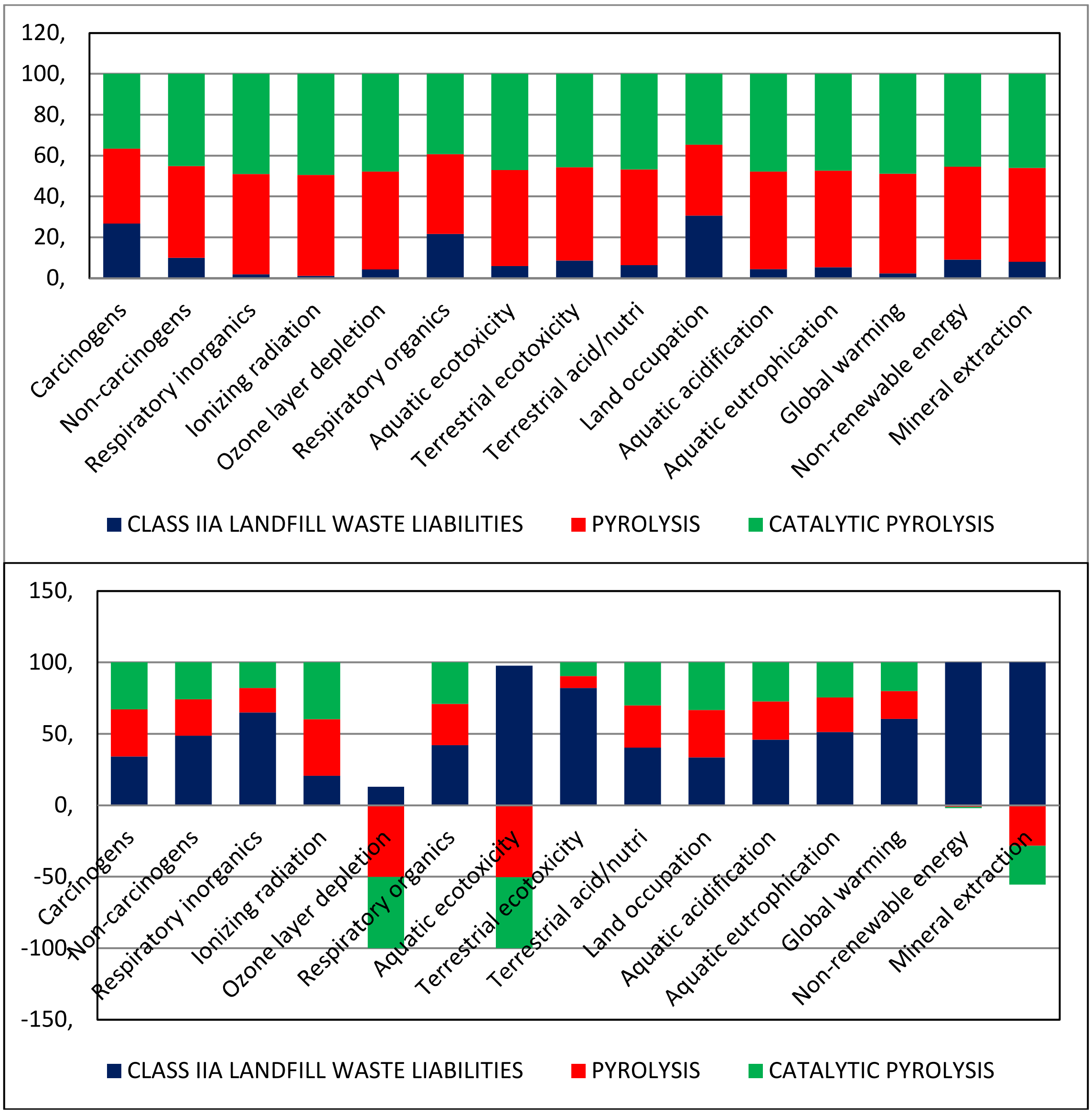


Figure 3. (A) Characterization for the environmental liability considering the studied pyrolysis methods, test scenario, and functional unit of 10 g of Class II A waste. (B) Characterization for the environmental liability for the studied pyrolysis methods, scenario of a pyrolysis plant with energy use, and functional unit of 10 g of Class II A waste.

Add taking into account the reference of the environmental multifunctionality, biochar and/or pyrolysis coal can be considered as sustainable and clean technology, since pyrolysis can decompress areas of environmental liabilities, to the soil to control leaching, prevent aspects of global warming, and reduce of waste pathogens, among others. However, the analytical part of process and product control has to be improved with online control of pyrolizers, both for atmospheric emissions and for bio-oil and biochar (Saletnik et al., 2019).
In this sense, the effectiveness of pyrolysis processes for the clean technologies can be observed by the Weighting analysis. However, an effective control of the energy balance should be done, since otherwise, the effect of environmental gains may not be of positive environmental impacts, as demonstrated in Figure 4A (test scenario) and Figure 4B (scenario of a pyrolysis plant with energy use).

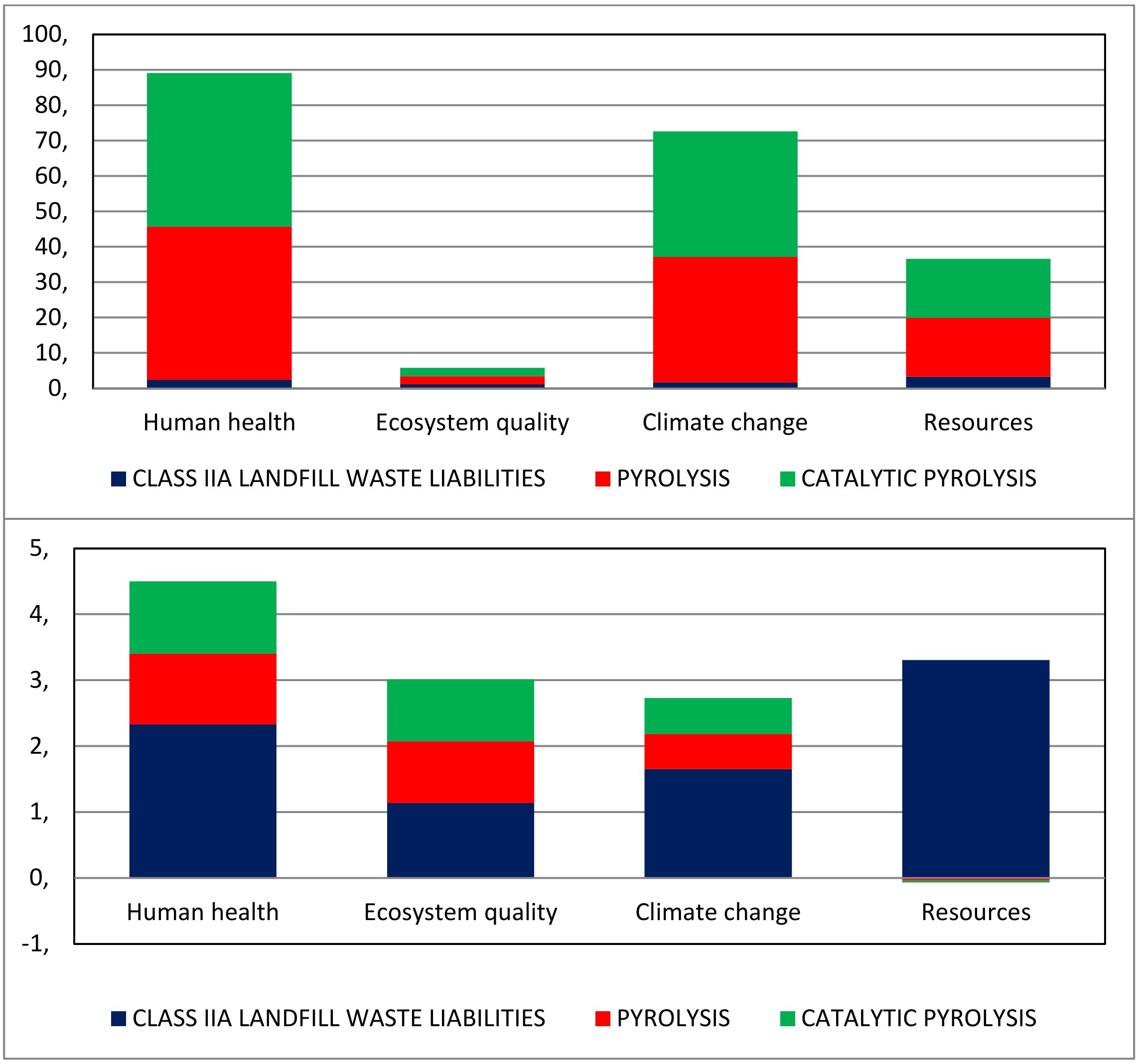


Figure 4. (A) Weighting for the environmental liability for the studied pyrolysis methods, test scenario, and functional unit of 10 g of Class II A waste. (B) Weighting for the environmental liability for the studied pyrolysis methods, scenario of a pyrolysis plant with energy use, and functional unit of 10 g of Class II A waste.

As one can observe in Figures 4A and 4B, climate change and resources may be the main environmental gains for the pyrolysis processes aimed at producing coal from pyrolysis. Likewise, through studies to recover areas contaminated with heavy metals and organic pollutants, as well as or degraded with erosion, human health, the quality of ecosystems and the supply of raw materials will also be significantly improved (Moreno et al. 2020).

Conclusion

As demonstrated with the LCA, pyrolysis will be effectively sustainable with effective control of the energy balance, formulation and development of biochar products that improve the quality of ecosystems and, indirectly, increase the quality of human health. In the present work we found that the use of red clay, being applied only as powdered powder on the environmental liability of the class IIA waste area does not produce additions to improve the pyrolysis condition

The heterogeneity and impregnation in the residues were not efficient, since a yield below 5% was verified for the production of pyrolyzed coal. The clay has no impact on the assessments made by LCA, and can then be improved for future assays with a cleaner production profile. The pyrolysis reactor must also be improved, as the lack of pyrolysis uniformities was observed when the coal is removed. On alternative to improve the performance of the prototype for bench assays might be the insertion of a centralized boat.

References

ABEJON, R., BALA, A., VAZQUEZ-ROWE, I., ALDACO, R., FULLANA-I-PALMER, P., 2020. When plastic packaging should be preferred: Life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. Resources Conservation and Recycling. 155.

AGARSKI, B., NIKOLIĆ, V., KAMBEROVIĆ, Ž., ANĐIĆ, Z., KOSEC, B., BUDAK, I., 2017. Comparative life cycle assessment of Ni-based catalyst synthesis processes. Journal of Cleaner Production. 162, 7-15.

AGARSKI, B., VUKELIC, D., MICUNOVIC, M.I., BUDAK, I., 2019. Evaluation of the environmental impact of plastic cap production, packaging, and disposal. J. Environ. Manage. 245, 55-65.

CAMPION, N., THIEL, C.L., WOODS, N.C., SWANZY, L., LANDIS, A.E., BILEC, M.M., 2015. Sustainable healthcare and environmental life-cycle impacts of disposable supplies: a focus on disposable custom packs. J. Clean. Prod. 94, 46-55.

CIVANCIK-USLU, D., PUIG, R., VOIGT, S., WALTER, D., FULLANA-I-PALMER, P., 2019. Improving the production chain with LCA and eco-design: application to cosmetic packaging. Resour. Conserv. Recycl. 151.

FOOLMAUN, R.K., RAMJEEAWON, T., 2012. Comparative life cycle assessment and life cycle costing of four disposal scenarios for used polyethylene terephthalate bottles in Mauritius. Environmental Technology (United Kingdom). 33(17), 2007-2018.

GUINÉE, J.B., LINDEIJER, E., 2002. Handbook on life cycle assessment: operational guide to the ISO standards. Springer Science & Business Media.

JOLLIET, O., MARGNI, M., CHARLES, R., HUMBERT, S., PAYET, J., REBITZER, G., ROSENBAUM, R., 2003. IMPACT 2002+: a new life cycle impact assessment methodology. The international journal of life cycle assessment. 8(6), 324-330.

KALBAR, P.P., KARMAKAR, S., ASOLEKAR, S.R., 2016. Life cycle-based decision support tool for selection of wastewater treatment alternatives. J. Clean. Prod. 117, 64-72.

MENDES, N.C., BUENO, C., OMETTO, A.R., 2016. Avaliação de Impacto do Ciclo de Vida: revisão dos principais métodos. Production. 26(1), 160-175.

SANGWAN, K.S., BHAKAR, V., 2017. Life cycle analysis of HDPE pipe manufacturing–a case study from an Indian industry. Procedia CIRP. 61, 738-743.

TONIOLO, S., MAZZI, A., NIERO, M., ZULIANI, F., SCIPIONI, A., 2013. Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging. Resour. Conserv. Recycl. 77, 61-68.

VAN EYGEN, E., LANER, D., FELLNER, J., 2018. Integrating High-Resolution Material Flow Data into the Environmental Assessment of Waste Management System Scenarios: The Case of Plastic Packaging in Austria. Environ. Sci. Technol. 52(19), 10934-10945.

XIE, M.H., LI, L., QIAO, Q., SUN, Q.H., SUN, T.C., 2011. A comparative study on milk packaging using life cycle assessment: from PA-PE-Al laminate and polyethylene in China. J. Clean. Prod. 19(17-18), 2100-21 Biochar Quality Mandate (BQM) v.1.0. Disponível em : http://www.britishbiocharfoundation.org/wpcontent/uploads/BQM-V1.0.pdf. Acessado em 21 de janeiro de 2020.

DE SOUZA, M. P.; HOELTZ, M.; BRITTES BENITEZ, L.; MACHADO, Ê. L. et al. Microalgae and Clean Technologies: A Review. CLEAN–Soil, Air, Water, 47, n. 11, p. 1800380, 2019.

DONG, J.; TANG, Y.; NZIHOU, A.; CHI, Y. Key factors influencing the environmental performance of pyrolysis, gasification and incineration Waste-to-Energy technologies. Energy conversion and management, 196, p. 497-512, 2019.

DOU, G.; GOLDFARB, J. L. In situ upgrading of pyrolysis biofuels by bentonite clay with simultaneous production of heterogeneous adsorbents for water treatment. Fuel, 195, p. 273-283, 2017.

DRAPER,K. Biochar: If you make it, will they come? Biomass Magazine, Setember, 2019. Disponível em: http://biomassmagazine.com/articles/16427/biochar-if-you-make-it-will-they-come. Acessado em 20 de janeiro de 2020

EBC. European Biochar Certificate. Guidelines for Sustainable Production of Biochar; Version 6.2E; European Biochar Foundation (EBC): Arbraz, Switzerland, 2012.

ECK, N. J. V.; WALTMAN, L. Manual for VOSviewer version 1.6.10. Uninversiteit Leiden, CWTS Meaningful metrics, 10 de janeiro de 2019

GLASER, B.; HAUMAIER, L.; GUGGENBERGER, G.; ZECH, W. The'Terra Preta'phenomenon: a model for sustainable agriculture in the humid tropics. Naturwissenschaften, 88, n. 1, p. 37-41, 2001.

HOMAGAIN, K.; SHAHI, C.; LUCKAI, N.; SHARMA, M. Life cycle environmental impact assessment of biochar-based bioenergy production and utilization in Northwestern Ontario, Canada. Journal of Forestry Research, 26, n. 4, p. 799-809, 2015.

HONG, J.; LI, X.; ZHAOJIE, C. Life cycle assessment of four municipal solid waste management scenarios in China. Waste management, 30, n. 11, p. 2362-2369, 2010.

JAMRADLOEDLUK, J.; LERTSATITTHANAKORN, C., Characterization and utilization of char derived from fast pyrolysis of plastic wastes. Trans Tech Publ. 849-83.

JOLLIET, O.; MARGNI, M.; CHARLES, R.; HUMBERT, S. et al. IMPACT 2002+: a new life cycle impact assessment methodology. The international journal of life cycle assessment, 8, n. 6, p. 324, 2003.

MOHAMMADI, A.; SANDBERG, M.; VENKATESH, G.; ESKANDARI, S. et al. Environmental analysis of producing biochar and energy recovery from pulp and paper mill biosludge. Journal of Industrial Ecology, 23, n. 5, p. 1039-1051, 2019.

MORENO, V. C.; IERVOLINO, G.; TUGNOLI, A.; COZZANI, V. Techno-economic and environmental sustainability of biomass waste conversion based on thermocatalytic reforming. Waste Management, 101, p. 106-115, 2020.

MUÑOZ, E.; CURAQUEO, G.; CEA, M.; VERA, L. et al. Environmental hotspots in the life cycle of a biochar-soil system. Journal of Cleaner Production, 158, p. 1-7, 2017.

RAJABI HAMEDANI, S.; KUPPENS, T.; MALINA, R.; BOCCI, E. et al. Life Cycle Assessment and Environmental Valuation of Biochar Production: Two Case Studies in Belgium. Energies, 12, n. 11, p. 2166, 2019.

SALETNIK, B.; ZAGUŁA, G.; BAJCAR, M.; TARAPATSKYY, M. et al. Biochar as a Multifunctional Component of the Environment—A Review. Applied Sciences, 9, n. 6, p. 1139, 2019.

ZAMAN, C. Z.; PAL, K.; YEHYE, W. A.; SAGADEVAN, S. et al. Pyrolysis: A Sustainable Way to Generate Energy from Waste. In: Pyrolysis: BoD–Books on Demand, 2017. p. 1.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11[h] International Workshop, Florence, Italy. July 15[th], 2022

Proposal for the Integration of Circular Practices into the Product Development Process Focused on Packaging

JOÃO, S. [a*], MACENO, M.M.C. [a], ANTONELO, A.K [a], LACERDA M. T.[a]

a. Universidade Federal do Paraná, Curitiba

**Corresponding author, samuel.joao@hotmail.com*

Abstract

Organizations worldwide have been exploring ways to operationalize circular economy (CE) practices. One strategy is to integrate these circular practices through the Product Development Process (PDP). This paper identifies, analyzes, and proposes integrating circular practices, for initial phases and steps of PDP, from planning to product launch, focusing on physical products, such as packaging. This objective is based on the fact that the literature presents studies on adopting circular practices and initiatives during product development but addresses isolated phases and stages of PDP. That is, focusing on planning, conceptual design, or project detailing, for example, without presenting a complete view of adopting practices and initiatives throughout the product development process. Thus, a systematic literature review (RSL) was conducted to identify circular practices and models for physical product development, emphasizing the packaging, in addition to a qualitative analysis of documents related to the topic, such as the Circ It Nord Guide for Product Design and Development, the European Action Plan for Circular Economy, and the ABNT ISO/TR14062 standard. Next, the phases and stages of product development models (PDM) proposed by Ulrich and Eppinger (2008) and Rozenfeld et al. (2006) were used to analyze and integrate circular practices into them. Thus, 23 circular practices are presented and distributed in the Pre-development and Development, from the organizational management to the operational level. In this sense, this study contributes to and facilitates the adoption of circular practices for each phase and stage of PDP, should encourage the application of circular practices in PDP, inspire product development practitioners and developer companies, and leverage product circularity and the inherent CE benefits.

Keywords: *Circular Economy, Product development model, Package*

1. Introduction

Linear economics emerged from the Industrial Revolution, based on the extraction, manufacture, use, disposal, and dependence on large amounts of finite resources. Since then, it has been understood that natural resources may become depleted, compromising future generations and requiring efforts towards a more sustainable economic transition. (ELLEN MACARTHUR FOUNDATION, 2021; PINHEIRO et al., 2019).

In this sense, the Circular Economy (CE) emerges, which is restorative and regenerative by the concept. It aims to decouple economic growth from the use of finite resources, keep products, components, and materials at their highest utility and value, and regenerate ecosystems, relying on reuse, remanufacturing, and recycling practices. (ELLEN MACARTHUR FOUNDATION, 2021).

Organizations worldwide have been exploring ways to operationalize these practices and initiatives through systemic processes that enable such sustainable goals and circular practices (SELVEFORS et al., 2019).

These initiatives can lead to cultural and organizational change and essential benefits such as stimulating cost savings, fostering innovation, new market opportunities, improving quality, health and safety, market acceptance, and meeting legal requirements. (ABNT, 2004; GIORGI et al., 2022; GUERRA et al., 2021; MEGLIN; KYTZIA; HABERT, 2022).

One strategy widely used to take advantage of the substantial benefits existing in adopting CE strategies is to integrate organizations through the Product Development Process (PDP) (ALBÆK et al., 2020; FRANCO, 2019).

Industries have directed CE practices to PDP to raise environmental performance and harness the benefits of the transition. These are efforts to adopt methods that enable the integration of circularity strategies, tools, and indicators for their products. Thus, current PDP models have been adapted to integrate CE strategies (LUGNET; ERICSON; LARSSON, 2020; PAIANO et al., 2021; VAN DAM; SLEESWIJK VISSER; BAKKER, 2021).

PDP is a systematic tool applied to meet customer needs, considering technological constraints and fundamental importance to move toward a circular economy. But it requires a degree of customization to adapt circular practices and specificities of organizations and their products (PINHEIRO et al., 2019; SHAHBAZI; JÖNBRINK, 2020).

Products are intended to meet the needs of the market. However, they are complex and constantly evolve. Thus, the most relevant environmental solutions for product design and development also have specificities and dynamism because they continuously develop (ABNT, 2004) On the other hand, all products, goods, and services cause some impact on the environment, which can be resource consumption and emissions that cause air, water, and soil pollution and climate change.

Given the topic's relevance and aiming to help operationalize the integration of CE practices in organizations, this paper aims to identify, analyze and propose the integration of circular practices for the initial phases of PDP, from planning to product launch.

2. Methods

This study presents a methodology divided into three stages: 1-Analysis of the circular practices extracted from the articles resulting from the RSL and documents related to CE, 2- Grouping of circular practices according to the phases of the product development models (PDM) proposed by Ulrich and Eppinger (2008) and Rozenfeld et al. (2006), namely Pre-development and, development and, finally, 3- Presentation of circular practices for each phase of development.

The adoption of the PDMs is justified because they are models widely used in the literature, comprehensive, present in studies related to the theme of this research (OLIVEIRA; FRANÇA; RANGEL, 2019a; SHAHBAZI et al., 2020) present strong similarity between them and with the development phases of the model addressed by the ABNT ISO/TR 14062/2012 standard.

The Systematic Literature Review (SLR), based on the review proposal of Conforto and Amaral (2011), was employed to identify the phases and stages of development, practices, and initiatives circular.

Were considered the largest possible number of combinations of strings related to the theme CE, product development models, and packaging. The strings used were product development, product development model, new product development process, circular economy, circular design, circular product, ecodesign, and sustainability design.

It included articles published in English between 2000 and 2021, available and published in the Scopus database in open access or subscription journals. Articles were excluded in which CE and Product Development (PD) was not the central themes, i.e., it was only one among several topics addressed, in addition to unavailable or duplicate articles.

The initial search resulted in 1134 articles. After full reading and exclusion of duplicate or unavailable articles, 81 articles were listed (Fig. 1).

Additionally, the RSL was expanded to Google Scholar to explore other documents such as guides and standards related to the topic (Table 1).

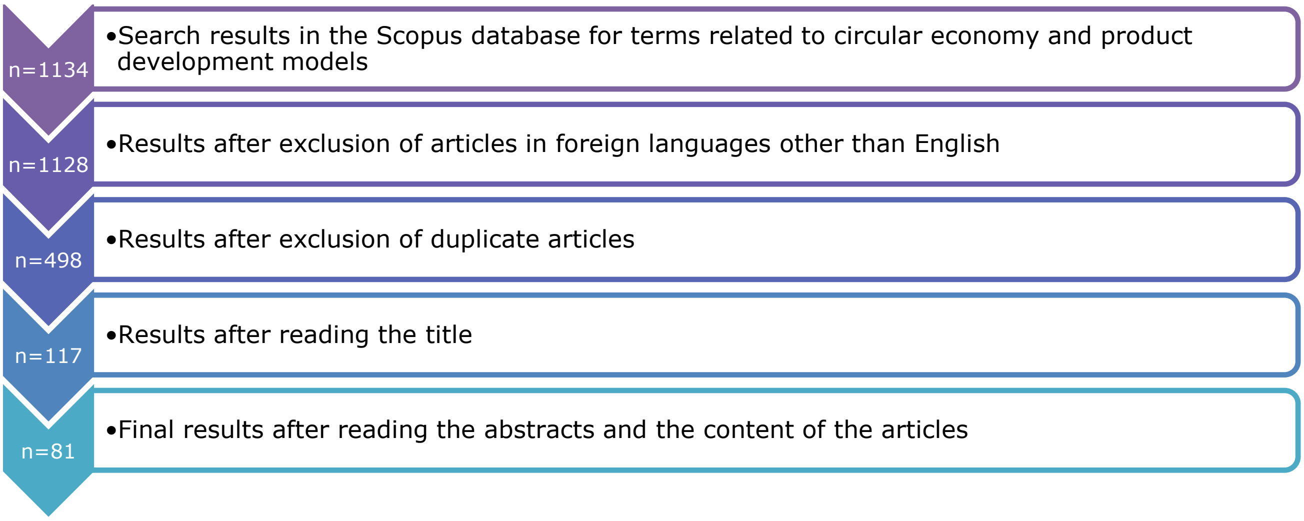


Fig. 1. Filters for article selection in the scopus journal base

Table 1: List of search results in google scholar database

N°	Documents	Type	Objective
1	Article de Oliveira, França e Rangel (2019).	Article	Propose environmental and circular practices for product development.
2	Guide CIRCit Nord Project and product development.	Guide	Propose strategies, guidelines and circular practices for product development
3	ABNT ISO-TR 14062 - Gestão Ambiental - Integração de Aspectos Ambientais no Projeto e Desenvolvimento do Produto.	Standard	Addressing the integration of environmental aspects into traditional product development processes.
4	European Action Plan for the CE.	Document	Address guidelines, strategies, and initiatives for CE adoption.
5	ISO/TC 323 e ISO WD 59004 Standard	Standard	Set of principles, terminology, definitions, and a standard management system structure for CE.

3. Results

After reading the 81 articles, it was concluded that predominantly, authors have researched, in isolation and independently, some of the phases and early stages of product development, focusing on design. The focus of these approaches is justified because the initial stages of PDP can define up to 80% of all environmental impact, and as the process progresses and technical solutions are established, it becomes more difficult to include circular practices an sustainable solutions. Another factor is that CE has a strong connection with Design (ABNT, 2004; Ellen MacArthur Foundation, 2021; Shahbazi et al., 2020).

4.1 Circular practices for the pre-development macro-phase

The pre-development phase refers to the strategic planning of the product and project. It includes activities such as the definition of the scope and description of what will be obtained, restrictions that surround the product, definition of deadlines, activities, and resources needed during planning and development, project duration, budget, market analysis, such as the existence of new competitors, development of suppliers and emerging technologies that may replace those currently used. (ROZENFELD, 2006;ULRICH AND EPPINGER, 2008)

The following circular practices for the pre-development phase are presented (Table 2):

Table 2: Circular practices for project and product planning phases (Pre-development phase)

Circular practices for the Pre-development phase	Stages PDM						
	1.1	**1.3**	**1.5**	**1.6**	**1.7**	**2.2**	**2.3**
Cascater: Industrial Symbiosis	X	X					
Reuse: Exchange-based sharing and product life extension (Remanufacture, Reuse, Upgrade, Repair/maintain)	X	X					
Analysis of the viability of the function strategy through the Product Service System (PSS): Product as a service	X	X	X	X			
Examination of legislations and certifications	X						
Functionality aspects for circularity of products						X	
Examination of circular strategies and guidelines						X	
Identification of trade-offs in the adoption of circular strategies and practices							X
Analysis of economic viability of circular products					X		X
Adopt and specify drivers to increase product circularity						X	

Caption: 1.1 Define scope of Strategic Business Plan review;1.3 Consolidate technology and market information;1.5 Analyze company's product portfolio;1.6 Propose changes to product portfolio;1.7 Verify/decide feasibility of product portfolio;2.2 Define product scope;2.3 Assess risks

Industrial symbiosis: The practice of using waste as a resource or industrial symbiosis belongs to the Cascade strategy (SHAHBAZI; JÖNBRINK, 2020; UE, 2020). The practice of using waste as a resource is one of the principles of Circular Economy being addressed in the literature within the planning phase(OLIVEIRA; FRANÇA; RANGEL, 2019b) (UE, 2020), (ELLEN MACARTHUR FOUNDATION; SUN 2015). The practice of industrial symbiosis requires a study of the feasibility of using by-products, defining which wastes can be used as resources, and defining their characteristics and requirements (OLIVEIRA; FRANÇA; RANGEL, 2019b). The waste can come from internal processes to the company or capture from the development of partnerships with external companies that, preferably, are geographically close and interested in the use or supply of the by-products or waste.

Product-Service System (PSS): Three forms of PSS can be adopted, namely: (i) when traditionally the product is sold, and additional services are offered to the customer to ensure product functionality, (ii) when the product is delivered, and the customer pays for availability or use and still (iii) when, in mutual agreement, the customer pays for the solution and results obtained (FERNANDES et al., 2020). The adoption of PSS systems contributes to product design to extend the useful life and encourage the adoption of other circular strategies.

Sharing: Belonging to the reuse strategy, the practice of sharing is based on exchanges, in which the user can purchase a used product instead of buying a new one, preventing the item from being discarded as waste, thus maximizing its us (SELVEFORS et al., 2019). However, these practices related to the reuse and sharing strategy cause changes in the consumption profile and, for this reason, need to be considered still in the planning stages (SELVEFORS et al., 2019).

Examination of legislation and certifications: Refers to investigating current and future environmental laws, regulations, policies, and certifications. The importance of environmental regulations and legislation is widespread in the literature, guiding producers and consumers, aiming at environmental protection during the life cycle of the product and its process, protection of health, and safety of those involved(ABNT, 2004). They consist of good practices, obligations, and duties for the correct treatment of waste and disposal of products.

A Functionality aspects for circularity of products: Some products are discarded before they are physically worn out because the design is inappropriate or prevents circumstantial changes. It is necessary to evaluate the adequacy of the product in relation to its function, i.e., to what it proposes to do, under aspects of usability, useful life, appearance, and others. For example, directing the project towards a long-lasting aesthetic or foreseeing different functions of use can prolong its durability, raise the level of circularity and reduce the environmental impact (ABNT, 2004).

Examination of circular strategies and guidelines: Without losing focus of product function, quality, and purpose, it is essential to simultaneously employ several circular strategies in design (NORD, 2020). For example, a product may be designed to feature ease of assembly and disassembly of its components for repair (remanufacturing strategy), just as its defective parts may be highly recyclable (recycle strategy)(NORD, 2020).

Identification of trade-offs: The definition and adoption of circular strategies and practices may be subject to trade-offs. These deal with the analysis of the impacts of one choice over another. It consists of pre-identifying compensatory trade-offs and contradictions that need to be considered for decision-making (ABNT, 2004). For example, applying durable materials and reuse strategy may affect recycling and make the cost of the product unviable.

Economic feasibility analysis of circular products: refers to the control and monitoring of costs related to the product, defining its price. It contributes to the decision of the portfolio implementation, allowing the market's willingness to acquire the circular product to be analyzed, a factor considered to influence the acceptance of the product (BOYER et al., 2021;STEENIS et al., 2018). In other words, one should monitor the costs of the object in a way that ensures the same budget throughout the process. Monitoring starts in the planning stages and occurs in all phases. It can include methods and tools of technical-economic evaluations, internal company data and market research, marketing service agencies, surveys, and depth research.

Drivers to increase circularity: Adopting and specifying drivers during planning helps increase the product's circularity. This includes discussing and analyzing (i) product and market-related aspects; (ii) managerial aspects (iii) sustainability aspects; (iv) among other general aspects, such as stimulating creativity and improving moral culture(URBINATI; CHIARONI; TOLETTI, 2019), (NORD, 2020).

4.2 Detailing the circular practices for the development macro-phase

The development phase refers to the informational, conceptual design, including the development of the product's target specifications and the proposition and selection of the best concept, detailing of its systems and components, the definition of processes and resources, including equipment, materials, people and support structures, preparation for production, such as testing activities and pilot lot production, in addition to activities related to the product launch (ROZENFELD, 2006;ULRICH AND EPPINGER, 2008).

Thus, the following circular practices for the development phase are presented (Table 2): **Definition of circular goals and objectives:** They must be identified and related to the strategies adopted (NORD, 2020). The distribution of circularity goals occurs in the phases and stages of the PDP model through the company's official documents, such as work instructions and procedures. (SHAHBAZI et al., 2020).

Life Cycle Assessment (LCA) and Circularity: Widely addressed in the literature, the use of tools for techno-economic assessments, circularity, and life cycle aassessment provides an environmental comparison, support decision making, and assist in the management of life cycle information. (ACERBI; TAISCH, 2020);(MARIANO et al., 2022) (ALBÆK et al., 2020); (LONGO et al., 2021); (POLVERINI; MIRETTI, 2019) (TALENS PEIRÓ et al., 2020); (RIO et al., 2020); (SCHULZ et al., 2021); (SHOAIB-UL-HASAN et al., 2021); (VIMAL; KANDASAMY; GITE, 2021); (WAGNER; BOLOGNA PAVLIK, 2020). The joining of LCA and circularity indicators can present an important analysis because LCA provides a broader approach, considering the impacts on Human Health and Ecosystem Quality, while the circularity indicator can contribute to improvements in resource use at a smaller process and product scale (LONCA et al., 2018)

Table 3: Circular practices for the Development macro-phase

Circular practices for the Development phase	Stages PDM												
	3.5	**3.6**	**4.2**	**4.3**	**4.5**	**4.9**	**5.2**	**5.9**	**5.13**	**6.2**	**6.4**	**7.3**	**7.5**
Definition of circular goals and objectives	X	X											

Life cycle assessment (LCA)					X								
Circularity assessment					X								
Design for Reuse			X	X									
Design for Recycling			X	X									
Define sustainable processes						X							
Design for Remanufacturing, Repair/Maintenance, Reuse, and Reconditioning				X									
Use durable and robust components and materials							X						
Use circular,biodegradable and compostable materials and resources from renewable energy source.							X						
Develop manuals and documentation								X					
Test and homologate the product									X				
Use of circular materials and sustainable technologies for pilot lot production										X	X		
Technical assistance services for circular products													X
Circular aspects for distribution and transportation												X	

Caption: 3.5 Define product requirements, 3.6 Define product target specifications, 4.2 Functionally model the product;4.3 Develop solution alternatives for the product;4.5 Analyze systems, subsystems and components (SSC);4.9 Plan macro manufacturing process/define macro process plan, 5.2 Create and detail SSCs, documentation and configuration,5.9 Create product support material,5.12 Test and homologate product,6.2 Plan pilot production; 6.4 Produce pilot lot, 7.3 Develop distribution process;7.5 Develop technical assistance process

Design for Reuse: Considers the product and components easy to clean and provides for support activities during product use. The reuse strategy precedes others such as remanufacturing, repair/maintenance, reconditioning, recycling, recovering, updating, as well as sharing practices such as the use of durable and robust components and materials.

Design for Recycling: This refers to the adoption of reprocessing practices. Some examples are the selection of recyclable and secondary (recycled) materials; packaging materials that are easy to recycle; considering their recycling rate, using economically recyclable materials; foresee packaging in which only one recycling process is necessary, avoiding compound and incompatible materials, that is, avoid mixing materials to increase homogeneity; use materials that are easy to separate; use packaging materials that already have recycling technology and market and use more efficient recycling technologies; evaluate the toxicity and other environmental aspects of the materials, design for modularization, facilitating the separation and disassembly of the product in a non-destructive way, identify the materials and relevant information besides providing manuals and documentation.

Define sustainable processes: Processes should be defined using efficient technologies. For example, using the efficiency of sensing and automation systems used in packaging processes and internal logistics helps reduce the amount of plastic in product development. Industry 4.0 technologies, such as Artificial Intelligence (AI), Internet of Things (IoT), Big Data, and Virtualization, can support the optimization and efficiency of the operation, as well as assist in the guidance and correct use of products, provide preventive maintenance to understand which and when components will fail.

Design for remanufacturing, repair/maintenance, and reconditioning strategies: Aims to put products, systems, and components in equal or better operating condition compared to new and original ones, also reduces obsolescence, facilitates disassembly and cleaning activities, reassembly and testing.

Other circular aspects: Computer simulations and digital mock-ups should be preferred to produce prototypes and physical mock-ups.

Specify circular materials (biodegradable, compostable, and resources from renewable energy source: Considers new materials to adopt natural composites, biodegradable of total and rapid decomposition, in addition to the use of waste identified as resources, recyclable materials, recycled and from renewable energy sources)(ALBÆK et al., 2020; EMF, 2015; OLIVEIRA; FRANÇA; RANGEL, 2018; SHAHBAZI; JÖNBRINK, 2020). One should eliminate the use of scarce, toxic, and hazardous materials to people and the environment and evaluate other environmental aspects of the materials

Other practices for material specification: Avoid using different and incompatible materials, i.e., avoid using composite materials or mixtures of these materials. The fewer mixtures the material has, the better it will be to reuse it, facilitating strategies of ratcheting and recycling, for example. However, when this is not possible, identifying the materials is necessary.

Other circular practices for packaging development: Avoiding the use of surface coatings and paints, reducing material consumption in packaging, such as over-packaging, amount of mass, and adopting alternative reusable systems where technical and biological cycle consumer goods can be handled safely without packaging. And when packaging is necessary, instead of packaging products for branding purposes, use high-quality products and eliminate packaging waste.

Developing manuals and documentation: Consists of creating instruction manuals for operation, training, product discontinuation, making a statement of life extension and performance optimization, and guidance on the correct use and handling. In addition to creating and providing the link to an electronic file containing information about the product and spare parts and how they can be found. You can also provide other data about the content of the materials, how to dismantle them, and which segments and fractions of the materials should be destined for recycling.

Product tests and approvals: Refers to the product quality tests and trials, the mechanical analysis of tension, breaks, wear, corrosion and stains. For example, the resistance and rigidity of packaging to verify if the requirements were met, thus allowing the planned useful life to be reached. In addition, it involves verifying that the requirements of regulations, environmental legislations, and certifications foreseen in the previous phases of development have been met.

Technical support services for circular products: As with the product function, the main value proposition lies in the availability and offering of services. In addition to the supply of spare parts, one should think about offering maintenance services, repair, post-use control, a support structure and customer service for the continuous use and increased value of the products.

Circular aspects for distribution and transportation: You should optimize the use of transportation, minimize the weight of components, reduce freight volumes, consider transporting products in compact modules, e.g., the assembly of the final product may take place at the customer or the distributor, select suppliers based on location, transport larger quantities at once, encourage efficient and environmentally friendly driving and transportation that reduces transport emissions, e.g., shipping and rail are preferable to road transport.

4. Final considerations

The integration proposal was based on the CE practices recommended by the European Union Action Plan for the Circular Economy, the Circ it Nord guide for project and product development, integrative aspects addressed by the ABNT ISO/TR 14062/2004 (ABNT, 2004) standard and CE practices deduced from the articles resulting from the systematic literature review.

CE practices were integrated into the Pre-development and Development phases of the reference models for the product development process proposed by Ulrich and Eppinger (2008) and Rozenfeld et al. (2006) and serve as a model for the circular development of physical products in general.

As a suggestion for future work, we recommend the application of these practices in a real case of product development to evaluate the proposal and create new propositions more directed to a particular market segment.

5. Referênces

ABNT. **ABNT ISO_TR 14062 - Gestão ambiental - Integração de aspectos ambientais no projeto e desenvolvimento do produto**. 2004. Available in: https://kupdf.net/download/abnt-iso-tr-14062-gest-atilde-o-ambiental-integra-ccedil-atilde-o-de-aspectos-ambientais-no-projeto-e-desenvolvimento-do-produto_5afa584ee2b6f5e25b596c28_pdf. Accessed in: 27 maio. 2021.

ACERBI, F.; TAISCH, M. **Towards a Data Classification Model for Circular Product Life Cycle Management**. [s.l: s.n.]. v. 594 DOI: 10.1007/978-3-030-62807-9_38.

ALBÆK, J. K.; SHAHBAZI, S.; MCALOONE, T. C.; PIGOSSO, D. C. A. Circularity evaluation of alternative concepts during early product design and development. **Sustainability (Switzerland)**, *[S. l.]*, v. 12, n. 22, p. 1–25, 2020. DOI: 10.3390/su12229353.

BOYER, R. H. W.; HUNKA, A. D.; LINDER, M.; WHALEN, K. A.; HABIBI, S. Product Labels for the Circular Economy: Are Customers Willing to Pay for Circular? **Sustainable Production and Consumption**, *[S. l.]*, v. 27, p. 61–71, 2021. DOI: 10.1016/j.spc.2020.10.010.

ELLEN MACARTHUR FOUNDATION. **What Is the circular economy?** 2021. Available in: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy. Accessed in: 4 jun. 2021.

ELLEN MACARTHUR FUNDAÇÃO; (SUN), Stiftungsfonds für Umweltökonomie und Nachhaltigkeit. **GROWTH WITHIN: A CIRCULAR ECONOMY VISION FOR A COMPETITIVE EUROPE**. [s.l: s.n.].

EMF. **Circularity indicators: An Approach to Measuring Circularity Metodology**. 2015.

FERNANDES, S. D. C.; PIGOSSO, D. C. A.; MCALOONE, T. C.; ROZENFELD, H. Towards product-service system oriented to circular economy: A systematic review of value proposition design approaches. **Journal of Cleaner Production**, *[S. l.]*, v. 257, 2020. DOI: 10.1016/j.jclepro.2020.120507.

FRANCO, M. A. A system dynamics approach to product design and business model strategies for the circular economy. **Journal of Cleaner Production**, *[S. l.]*, v. 241, 2019. DOI: 10.1016/j.jclepro.2019.118327.

GIORGI, Serena; LAVAGNA, Monica; WANG, Ke; OSMANI, Mohamed; LIU, Gang; CAMPIOLI, Andrea. Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices. **Journal of Cleaner Production**, *[S. l.]*, v. 336, p. 130395, 2022. DOI: 10.1016/J.JCLEPRO.2022.130395. Disponível em: https://linkinghub.elsevier.com/retrieve/pii/S0959652622000415. Acesso em: 24 jan. 2022.

GUERRA, Beatriz C.; SHAHI, Sheida; MOLLEAI, Aida; SKAF, Nathalie; WEBER, Olaf; LEITE, Fernanda; HAAS, Carl. Circular economy applications in the construction industry: A global scan of trends and opportunities. **Journal of Cleaner Production**, *[S. l.]*, v. 324, p. 129125, 2021. DOI: 10.1016/J.JCLEPRO.2021.129125.

LONCA, Geoffrey; MUGGÉO, Romain; IMBEAULT-TÉTREAULT, Hugues; BERNARD, Sophie; MARGNI, Manuele. Does material circularity rhyme with environmental ef fi ciency ? Case studies on used tires. **Journal of Cleaner Production**, *[S. l.]*, v. 183, p. 424–435, 2018. DOI: 10.1016/j.jclepro.2018.02.108.

LONGO, S. et al. Life cycle assessment for supporting eco-design: The case study of sodium–nickel chloride cells. **Energies**, *[S. l.]*, v. 14, n. 7, 2021. DOI: 10.3390/en14071897.

LUGNET, J.; ERICSON, Å.; LARSSON, T. Design of product–service systems: Toward an updated discourse. **Systems**, *[S. l.]*, v. 8, n. 4, p. 1–14, 2020. DOI: 10.3390/systems8040045.

MARIANO, Marcell; MACENO, Corrêa; JOÃO, Samuel; RAPHAELA, Danielle; ZATTAR, Izabel Cristina. Life cycle assessment and circularity evaluation of the non - medical masks in the Covid - 19 pandemic : a Brazilian case. **Environment, Development and Sustainability**, *[S. l.]*, n. 0123456789, 2022. DOI: 10.1007/s10668-022-02388-2. Disponível em: https://doi.org/10.1007/s10668-022-02388-2.

MEGLIN, Ronny; KYTZIA, Susanne; HABERT, Guillaume. Uncertainty, variability, price changes and their implications on a regional building materials industry: The case of Swiss canton Argovia. **Journal of Cleaner Production**, *[S. l.]*, v. 330, p. 129944, 2022. DOI: 10.1016/J.JCLEPRO.2021.129944.

NORD, CIRCit. **Guidelines for circular product design and development Table of Content**. [s.l: s.n.].

OLIVEIRA, Fábio Ribeiro De; FRANÇA, Sergio Luiz Braga; RANGEL, Luís Alberto Duncan. Princípios de economia circular para o desenvolvimento de produtos em arranjos produtivos locais. **Interações (Campo Grande)**, *[S. l.]*, v. 20, p. 1179–1193, 2019. a. DOI: 10.20435/inter.v20i4.1921. Available in http://dx.doi.org/10.20435/inter.v20i4.1921. Accessed in: 26 maio. 2021.

OLIVEIRA, Fábio Ribeiro De; FRANÇA, Sergio Luiz Braga; RANGEL, Luís Alberto Duncan. Princípios de economia circular para o desenvolvimento de produtos em arranjos produtivos locais. **Interações (Campo Grande)**, *[S. l.]*, v. 20, p. 1179–1193, 2019. b. DOI: 10.20435/inter.v20i4.1921. Available in: http://dx.doi.org/10.20435/inter.v20i4.1921. Accssed in: 16 jun. 2021.

OLIVEIRA, F. R. D.; FRANÇA, S. L. B.; RANGEL, L. A. D. Challenges and opportunities in a circular economy for a local productive arrangement of furniture in Brazil. **Resources, Conservation and Recycling**, *[S. l.]*, v. 135, p. 202–209, 2018. DOI: 10.1016/j.resconrec.2017.10.031.

PAIANO, A.; GALLUCCI, T.; PONTRANDOLFO, A.; LAGIOIA, G.; PICCINNO, P.; LACALAMITA, A. Sustainable options for paints through a life cycle assessment method. **Journal of Cleaner Production**, *[S. l.]*, v. 295, 2021. DOI: 10.1016/j.jclepro.2021.126464.

PINHEIRO, Marco Antonio Paula; SELES, Bruno Michel Roman Pais; DE CAMARGO FIORINI, Paula; JUGEND, Daniel; LOPES DE SOUSA JABBOUR, Ana Beatriz; DA SILVA, Hermes Moretti Ribeiro; LATAN, Hengky. **The role of new product development in underpinning the circular economy: A systematic review and integrative frameworkManagement Decision**Emerald Group Publishing Ltd., , 2019. DOI: 10.1108/MD-07-2018-0782.

POLVERINI, D.; MIRETTI, U. An approach for the techno-economic assessment of circular economy requirements under the Ecodesign Directive. **Resources, Conservation and Recycling**, *[S. l.]*, v. 150, 2019. DOI: 10.1016/j.resconrec.2019.104425.

RIO, M.; KHANNOUSSI, K.; CREBIER, J. C.; LEMBEYE, Y. Addressing Circularity to Product Designers: Application to a Multi-Cell Power Electronics Converter. *In*: PROCEDIA CIRP 2020, **Anais** [...]. [s.l: s.n.] p. 134–139. DOI: 10.1016/j.procir.2020.02.158.

ROZENFELD, Henrique; DANIEL CAPALDO AMARAL, DÁRIO HENRIQUE ALLIPRANDINI, FERNANDO ANTÔNIO FORCELLINI, JOSÉ CARLOS DE TOLEDO, RÉGIS KOVACS SCALICE, Sergio Luis da Silva. **GESTÃO DE DESENVOLVIMENTO DE PRODUTOS - Google Books**. 2006. Available in: https://www.google.com.br/books/edition/GESTÃO_DE_DESENVOLVIMENTO_DE_PRODUTOS/JyprDwAAQBAJ?hl=pt-BR&gbpv=1&dq=rozenfeld+2006+desenvolvimento+de+produtos&printsec=frontcover. Accessed in em: 9 jul. 2021.

SCHULZ, M.; NIERO, M.; REHMANN, L. M.; GEORG, S. Exploration of decision-contexts for circular economy in automotive industry. *In*: PROCEDIA CIRP 2021, **Anais** [...]. [s.l: s.n.] p. 19–24. DOI: 10.1016/j.procir.2020.11.005.

SELVEFORS, A.; REXFELT, O.; RENSTRÖM, S.; STRÖMBERG, H. Use to use – A user perspective on product circularity. **Journal of Cleaner Production**, *[S. l.]*, v. 223, p. 1014–1028, 2019. DOI: 10.1016/j.jclepro.2019.03.117.

SHAHBAZI, S. ;.; JÖNBRINK, A. K. ;.; JENSEN, T.; HJORT, ; PIGOSSO, D. C. A. ;.; MCALOONE, T. C. **General rights Circular Product Design and Development: CIRCit Workbook 3**. [s.l: s.n.].

SHAHBAZI, S.; JÖNBRINK, A. K. Design guidelines to develop circular products: Action research on nordic industry. **Sustainability (Switzerland)**, *[S. l.]*, v. 12, n. 9, 2020. DOI: 10.3390/su12093679.

SHOAIB-UL-HASAN, S.; ROCI, M.; ASIF, F. M. A.; SALEHI, N.; RASHID, A. Analyzing temporal variability in inventory data for life cycle assessment: Implications in the context of circular economy. **Sustainability (Switzerland)**, *[S. l.]*, v. 13, n. 1, p. 1–12, 2021. DOI: 10.3390/su13010344.

STEENIS, N. D.; VAN DER LANS, I. A.; VAN HERPEN, E.; VAN TRIJP, H. C. M. Effects of sustainable design strategies on consumer preferences for redesigned packaging. **Journal of Cleaner Production**, *[S. l.]*, v. 205, p. 854–865, 2018. DOI: 10.1016/j.jclepro.2018.09.137.

TALENS PEIRÓ, L.; POLVERINI, D.; ARDENTE, F.; MATHIEUX, F. Advances towards circular economy policies in the EU: The new Ecodesign regulation of enterprise servers. **Resources, Conservation and Recycling**, *[S. l.]*, v. 154, 2020. DOI: 10.1016/j.resconrec.2019.104426.

UE. **Circular Economy | EPRS | European Parliament**. 2020. Disponível em: https://www.europarl.europa.eu/thinktank/infographics/circulareconomy/public/index.html. Acesso em: 24 jun. 2021.

URBINATI, A.; CHIARONI, D.; TOLETTI, G. Managing the introduction of circular products: Evidence from the beverage industry. **Sustainability (Switzerland)**, *[S. l.]*, v. 11, n. 13, 2019. DOI: 10.3390/su11133650.

VAN DAM, S.; SLEESWIJK VISSER, F.; BAKKER, C. The Impact of Co-Creation on the Design of Circular Product-Service Systems: Learnings from a Case Study with Washing Machines. **Design Journal**, *[S. l.]*, v. 24, n. 1, p. 25–45, 2021. DOI: 10.1080/14606925.2020.1851427.

VIMAL, K. E. K.; KANDASAMY, J.; GITE, V. A framework to assess circularity across product-life cycle stages-A case study. *In*: PROCEDIA CIRP 2021, **Anais** [...]. [s.l: s.n.] p. 442–447. DOI: 10.1016/j.procir.2021.01.131.

WAGNER, Gary A.; BOLOGNA PAVLIK, Jamie. Patent intensity and concentration: The effect of institutional quality on MSA patent activity. **Papers in Regional Science**, *[S. l.]*, v. 99, n. 4, p. 857–898, 2020. DOI: 10.1111/pirs.12515. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/pirs.12515. Acesso em: 28 fev. 2021.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Proposition of a Model for Healthcare Waste Management: Review of Brazilian Legislation

SANTANA, N. M. [a], ANGELO, G.F[c]., EL-DEIR, S. G. [b,c*]

a. Econosp, Recife – PE (Brazil)

b. Federal Rural University of Pernambuco- UFRPE, Pernambuco (Brazil)

c. Environmental Management Research Group in Pernambuco (Brazil)

**Corresponding autho:, soraya.el-deir@ufrpe.br*

Abstract

In December 2019, the world was surprised by a new disease that had its epicenter in the Chinese city of Wuhan and quickly spread to several Asian countries. The World Health Organization declared the new disease a pandemic in March 2020, calling it novel coronavirus, SARS-CoV-2 or Covid-19. Currently, this has reached more than 200 countries on all continents, causing a strong negative impact on the environment, due to the generation of high-risk contaminating biological waste from hospitals, institutions and homes with a high potential for transmission between humans.Healthcare waste is an important kind of residue due to its pathological risks which cause potential harm to the environment and society. Therefore, it must have specific guidelines to its management. The present mini review aims to propose models of healthcare waste management based in case studies and analyze the legal aspects in each one of them, regarding Brazilian law, by documents and literature review. Six models were proposed, and among them, only one was in complete agreement with Brazilian laws. Yet, it can be improved in order to achieve better sustainability standards.

Keywords: Brazilian Law; Environmental management; Healthcare waste management; Hospitals; Infectious Waste

Introduction

Economic growth made without planning may prejudice the environment since many shareholders still associate environmental protection with the deceleration of economic progress (PINTO et al., 2018). Beyond that, States that face social difficulties tend not to prioritize environmental protection in their agendas neglecting that this is directly related to public health (CANIATO; TUDOR; VACCARI, 2016). Birpinar, Bilgili and Erdogan (2009) comment that though Medicine is a field which is in continuous development throughout the decades, the management of its residues do not attract the same level of attention. According to Makajic-Nikolic et al. (2016), establishing an efficient healthcare waste management model is a relevant environmental issue, not only for healthcare institutions, but also for a wide range of organizations and communities. Also, the implementation of efficient healthcare waste management in hospitals raises their market credibility. But recently, several cases of pneumonia of unknown cause emerged in the city of Wuhan (CHINA, 2020), Hubei province, China, with the first case detected on December 8, 2019. From the analysis of the genetic material isolated from the virus, at the Institute of Virology of Wuhan, it was found that it was a new betacoronavirus, initially named 2019-nCoV by the World Health Organization (WHO), in the English World Health Organization (WHO, 2020a).

The new virus was renamed Severe Acute Respiratory Syndrome Corona virus 2 (SARS-CoV-2 or Corona Virus Disease (Covid-19), which replaces the name 2019-nCoV, used provisionally after the discovery of the respiratory disease (WHO, 2020b). The International Committee on Taxonomy of Viruses (ICTV), the global authority on the designation and naming of these beings, named the new coronavirus as coronavirus 2 or SARS-CoV-2 (ICTV, 2020). The disease spread rapidly across Chinese territory and, later, patients infected with SARS-CoV-2 were identified in other countries, mainly in Europe (with Italy and Spain as epicenters), in the United States, Canada and Brazil (SHEARER et al., 2020; SINGHAL, 2020).

Waste generated in healthcare activities is an important kind of hazardous waste because of its high pathogenicity and, therefore, it must be collected and treated separated from others (HE; LI; FANG, 2016). Healthcare waste is a special category considered the potential for negative effects to the environment and the society by treating infected material, as well as issues such as global warming potential, photochemical oxidant creation potential, acidification potential and human toxicity (KOO; JEONG, 2015). Given the potential impact, providing a safe and reliable healthcare waste management system is a key environmental issue for healthcare providers (AUNG; LUAN; XU, 2019). The correct disposal of this waste aims to reduce potential environmental degradation, improving the quality of life (ROSADO; HEIDRICH, 2016). Proper management of solid waste involves various mechanisms and multiple levels of governance, from shareholders (quota holders) to direct and indirect stakeholders (customers, managers, employees, suppliers), as well as consumers and suppliers (SILVEIRA, 2017). The complexity level of the waste management in Hospitals are even higher than the ones found in other fields, since they are the only type of business that produces all categories of waste, and they also have multiple departments that have different purposes and priorities (ROMERO; CARNERO, 2019).

Volumetric and gravimetric study, in addition to understanding the healthcare waste generation process, are initial steps for the continuous improvement of hospital waste management (XIN, 2015). The volume of waste generated by health services is relevant data for the management of urban centers for the determination of management models. Studying the annual production of health waste in Istanbul divided into dialysis, specialty, educational state university and state hospitals, non-educational state and non-educational private hospitals, Korkut (2018) reported that the total estimated healthcare waste from hospitals has increased from approximately 5,307 tonnes in 2000 to 22,755 tonnes in 2017. This represents an increase in daily healthcare waste per hospital unit from 0.43 kg. bedday^{-1} in 2000 to 1.68 kg.bedday^{-1} in 2017.

The right management of this kind of residue can decrease its quantity, as well as the number of accidents in workplace and the public health costs (KOLIMIS, MAKROLEIVADITIS; NIKOLAKOPOULOU, 2017). Given the presence of infectious agents, if the health waste management system is inadequate, it can render all healthcare waste as infectious and toxic. Thus, if not properly treated, these wastes pose significant potential health and environmental risks (WHO, 2017). This matter is also relevant, since there is no way to stop the production of the pathogenically residues by the healthcare assistance. Thus, this paper aims to propose healthcare waste management models, based on international case studies, analyze them towards the legal compliance and then propose a guide model in order to help the healthcare facilities to achieve the Healthcare waste Management excellence.

Methodology

This study made qualitative research (WELCH; PIEKKARI, 2017) of documental and bibliographic data to analyze the "state of art" of the Brazilian legislation relative to healthcare waste handling, to find indicators of legal compliance. The documentary survey, which is very close to the bibliographic research, is defined as the process that uses techniques and methods for the perception, understanding and observation of documents. It differs from the other method by the source type, that are mainly documentary bases, without no analytical treatment. These research documents are stored in archives of private institutions, scientific associations and public agencies, and also by regulations, laws, decrees, letters, etc. (GIL, 2017), as well as institutional reports and websites.

This paper also surveyed international case studies that regarded the healthcare waste handling in Bangladesh, Gaza Strip, Mauritius Islands, Turkey, Myanmar, India, China, Greece and Serbia, evaluating individually each stage of the handling, since the waste generation until its disposal. These cases were found through bibliographic study, seeking to identify the most different studies in relation to stages of solid waste management of existing studies on the subject (MOHEE, 2005; BIRPINAR; BILGILI; ERDOGAN, 2009; RADHA et al., 2009; PATWARY et al., 2011; GAVRANCIC et al., 2012; MOREIRA; GUNTHER, 2013; AGHAPOUR et al., 2013; AKUM, 2014; SARSOUR et al., 2014; TIPPAT; PACHKHADE, 2015; MUTHONI et al., 2016; CANIATO; TUDOR; VACCARI, 2016; HE; LI; FANG, 2016; KOLIMIS; MAKROLEIVADITIS; NIKOLAKOPOULOU, 2017; CHASSEIGNE et al., 2018; AUNG; LUAN; XU, 2019; FERRONATO et al., 2019; ZAMPARAS et al., 2019, CHINA, 2020). The criterion used was the presentation of the technological route of health waste, with all stages, for comparison purposes.

Starting from theoretical references, different operational models were observed, based on the state of the art (ANSARI; KANT, 2017), by degree of complexity, based on the operational management steps: (i) generation, (ii) segregation; (iii), treatment and (iv) disposition (BOTELL-ÁLVAREZ et al., 2018). Therefore, technological routes were used (DANTAS; LEGEY; MAZZONE, 2013), aiming to be a guide for enterprises that want to adopt the best existing technologies (GALENO et al., 2018). Flow charts were used to better illustrate the waste technological route as done by Aguiar et al. (2019). The international case studies generated four diagrams, that were analyzed and evaluated by its legal compliance with Brazilian law, by a qualitative method of presence or absence of the management parameters. Then, improvements regarding the legislation were recommended so it could fit the Brazilian legislation and have a good cost-benefit. The models were proposed aiming to suit as guides to the healthcare waste management. The radioactive waste route generated on the facilities wasn't analyzes due to its completely distinguish of recommendations and applicable norms.

Brazilian Legislation

Laws and regulation are essential to the development of more efficient environment management systems (SOUZA et al., 2016). To reach these goals, regulatory agencies must create clear policies that focus on long term benefits (PANYA et al., 2018). Aragao, Jacobs and Cliquet (2016) point that it is difficult for laws to be effective once improvements are only felt in the future while costs are present. Moreira and Gunther (2013) reason that despite the lack of clear and specific legislation for healthcare waste being a common problem in developing countries, it doesn't apply to Brazil. Since 1993, this country has issued Federal Resolutions that focus on this kind of material and that cover all phases of the healthcare waste management.

The Law nº 6.938, that declares the Environment National Policy (BRASIL, 1981), proposes to conciliate Brazilian economic growth with the environment preservation having as one of its tools the concept of pollutant-payer, obligating the responsible for the polluting to recover and/or pay when damages happen. Beyond that, the Law establishes the constitution of Environmental Nacional System and makes the Environment National Council - Conama - as the advisory and deliberative agency. It is Conama's responsibility to create the rules and criteria for the control and conservation of environmental quality.

The 9th article of the Environment National Policy (BRASIL, 1981) lists as instruments: (i) the establishment of environmental quality patterns; (ii) the environmental zoning; (iii) the environmental impacts assessment; (iv) active and potential pollutant activities licensing and review; (v) production, equipment use and technology development that aims to improve environmental quality incentive; (vi) the creation of environmental protection zones; (vii) compensatory or disciplinary penalties for not fulfilling the established correcting or preserving measures to prevent environmental degradation. These instruments focus on the identification of potential problems that the enterprise may have related to the natural resources.

Healthcare waste can be defined as "all waste materials generated at health care facilities, such as hospitals, clinics, physician's offices, dental practices, blood banks, and veterinary hospitals/clinics, as well as medical research facilities and laboratories" (US EPA, 2013). For the World Health Organization (WHO, 2013) healthcare waste includes "needles and syringes to soiled dressings, body parts, diagnostic samples, blood, chemicals, pharmaceuticals, medical devices and radioactive materials," which cannot be similarly landfilled, waste from other sources, such as domestic or industrial waste. The Brazilian Resolution Conama nº 358 (CONAMA, 2005), which dispute about the healthcare waste treatment and final disposal classifies these residues in 5 types (Table 1).

Table 5 - Healthcare waste classification according to Conama 358 (CONAMA, 2005)

Group	Description
Group A	Residues that may have biological agents that shall present infection risks
Group B	Residues that may have chemical substances that shall present risks to the environment of public health
Group C	Residues that present radionuclides in quantities that are above the limits established by the Nuclear Energy Nacional Commission and that cannot be reused
Group D	Residues that do not present biological, chemical or radiological risks
Group E	Sharp residues

This Resolution also divides the group A into five subgroups that differ in the minimum treatment they should have (CONAMA, 2005). Incineration can be applied to all subgroups but, due to its high costs, this type of treatment is only used when no other is available (LEE; VACCARI; TUDOR, 2016). The Conama's Resolution also determines that healthcare waste that fits in the group A cannot be recycled, reused or recovered (CONAMA, 2005).

In 2018, the Sanitary Surveillance National Agency - Anvisa - published the Resolution nº 222 (ANVISA, 2018) that regulates the good practices for the healthcare waste management and present other measurements. This Resolution advocates that treatments which have microbial inactivation level III, as autoclave disinfection, can be used for the A1 and A2 subgroups. The A3 and A5 subgroups must be incinerated and the A4 subgroup may be disposed in specialized landfills. This Law is applied for all places that perform services related to the human and animal health assistance

> (...) including domestic assistance services; analytic laboratories for healthcare products; morgues, funerary centers and places where embalming services are performed;–legal medicine services; drugstores and pharmacies, including the manipulation ones; healthcare teaching and research places; zoonoses control centers; distributors of pharmaceutical products, importers, distributors of materials and controls for in vitro diagnostics; mobile healthcare units; acupuncture services; tattoo and piercing services; aesthetics and beauty salons, among others (ANVISA, 2018, p. 1)

The Anvisa's Resolution nº 222 (ANVISA, 2018) forces every healthcare waste generator to have a healthcare waste management plan which must be made in accordance with all local rules and include each step of waste management, since its generation until its final disposal. This law also determines that the healthcare waste handling is composed for: (i) Segregation; (ii) Packaging; (iii) Identification; (iv) Internal hauling; (v) Internal temporary storage; (vi) Treatment; (vii) External storage; (viii) Collection and external transportation; (ix) Final disposal. The treatment can be made in the healthcare facility or outside, however, if the waste is transported without previous disinfection, more security measurements must be applied. Furthermore, healthcare waste treatment systems have a special licensing process, according to Resolution Conama nº 237 (CONAMA, 1997).

Brazilian Law charges the generator to have continuous training for the people that are involved with the healthcare waste handling (ANVISA, 2018). This Resolution also considers that the segregation made in the exact time of the waste generation can reduce the amount of hazardous residue and the incidence of work injuries. Still, this Resolution allows that the group B can be recycled, reused or recovered.

The group C waste is standardized by the Nuclear Energy National Commission's Norm nº 801 (CNEN, 2014). This code states that the radioactive waste must be isolated from the other typologies as soon as it is generated. Its packages have to be identified and solid enough to prevent its leak, its inside and outside storages need to be designed focusing in preventing mixed contamination and that the treatments must be previously accepted by the Commission. This guideline still allows the disposal of some radioactive waste with the household ones if some requirements are obeyed, as its quantity cannot exceed the values stablished in the Table II of the Norm's annex or, in the case of bottles that contained the hazard, after its wash.

The Law nº 12305, that institutes that Solid Waste National Policy - PNRS (BRASIL, 2010), defines rubbish as a type of solid waste that does not have any treatment possibility other than the landfill disposal. This Law defines as solid waste management all phases included in the collection, transportation, hauling, treatment and final disposal. Therefore, the disposal of waste that can be valued is against Brazilian guidelines. The waste's generators must prioritize not generating, reducing, recycling, treating and disposing, in this order. This Law also states that hiring a company for collecting, storing, treating and disposing do not exempt the generator responsibility of the prejudices that these phases may cause, if they are not done correctly. It is forbidden to dispose waste in water bodies, beaches or in nature, as well as burning it in unlicensed places.

The Law nº 9605 (BRASIL, 1998) defends that fighting crimes and impunity is crucial for the environment protection. In its introduction, the Law of Environmental Crimes defends that an offense against nature is a crime against all humanity and that the whole society is responsible for preserving the environment. On the article 54 of this Law, environmental crime is described as "causing pollution of any nature in levels that result or may result in human health damages or provoke death of animals or destruction of the flora". Thus, contaminating the ground the high pathogen waste, as medical ones, is a transgression against the environment. Although laws and regulations are essential to induce people to act in the correct environmental manner, these instruments must be adjusted so as they can better fit the reality of the society they rule So, the including healthcare facilities shareholders in the development of new rules and standards would help its adherence.

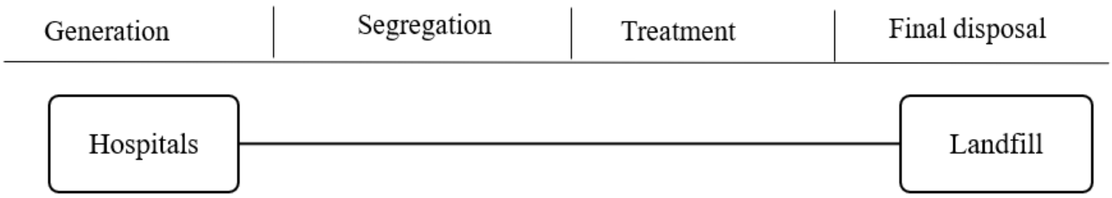
Theoretical Models for Healthcare Waste Management

Before the demographic expansion explosion, it was still possible to remove the waste away from the urban centers without any damage for the society's health (JOUHARA et al., 2017). Makajic-Nikolic et al. (2016) points out that the problem of healthcare waste and its disposal is growing rapidly throughout the world, as a direct result of rapid urbanization and population growth, requiring specialized treatment and management. So, nowadays governments must stimulate the creation and adoption of waste management systems in order to maintain the life quality of the citizens (PANYA et al., 2018).

Many developing countries still have problems with the unsafe reuse and recycling of healthcare waste, this practice made by a marginalized share of the society not only expose them to the hazards, but also the poor citizens that cannot afford to buy new equipments (TIPPAT; PACHADE, 2015; PATWARY et al., 2011). Patwary et al. (2011) wrote a paper that brought to attention the illegal reuse and recycling of hazardous healthcare waste in Bangladesh. Scavengers collected the waste both in the bins located outside of the healthcare facility and in the dumping sites. Then, this waste is cleaned with water and introduced as raw material or resold without any disinfection procedure. They reported that people involved in this area usually don't understand its risks.

Caniato, Tudor and Vaccari (2016) analyzed the healthcare waste management in the Gaza Strip to understand how it was done in places with high social stress and identified that the waste was not segregated correctly. Beyond that, they identified that 75% of the hazardous waste did not have the minimum required treatment. A similar condition was found by Sarsour et al. (2014), that also conducted a study in the Gaza Strip. They reported that the only segregation done in the researched facilities was between sharp materials and the others – both infectious and non-infectious -, and that hazardous waste were collected mixed with the household ones. They attribute these flaws to the absence of clear legislation for the healthcare waste management. They also draw attention to the lack of incinerators for the treatment. This flow chart (Figure 1) is in complete disagreement with legality, once it has the contamination of non-hazardous waste and some of the dangerous ones are left without treatment.

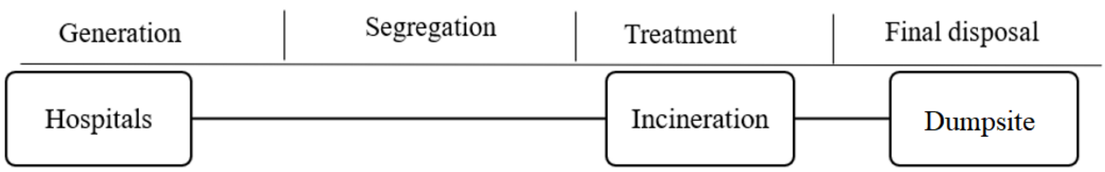
Figure 1 – Flow chart of the waste technological route without any segregation and without any proper treatment



For Makajic-Nikolic et al. (2016), healthcare waste is a special type of waste that, if improperly treated, can cause numerous potential risks to the health and safety of people and the environment. Xin (2015) points out that the rate of healthcare waste generation is not a homogeneous indicator in the health service, varying according to differences in scale, type of treatment performed, medical specialization of care, technical level of attendants, quality and efficiency of the hospital regarding the management processes and characteristics of the materials used in care. Thus, in order to establish the model improvement, data of annual quantity of healthcare waste, number of beds, inpatient occupancy rate, number of diagnosis-related groups, and case-mix index are required.

Caniato, Tudor and Vaccari (2016) described that some of the healthcare facilities developed flows (Figure 2) of management and segregated waste, which was meant to be disposed in landfills from others that should be incinerated. However, both types of waste were often mixed during the collection phase and were taken together to incineration. This flow offers less risk to the environment once all waste, perilous or not, received thermal treatment, but it was economically unavailable due to incineration costs.

Figure 2 – Flow chart of waste handling without any segregation but with treatment of all types of waste but with proper treatment



Mohee (2005) explicit that though the healthcare waste in Mauritius Islands is usually segregated into household and infectious, which the first is disposed into a sanitary landfill and the second is incinerated, there were mixing in the segregation phase causing the contamination of the entire technological route. Similar conditions were found by Birpinar, Bilgili and Erdogan (2009) in Turkey. They attribute the mixing of waste categories to the payment method of waste management in the country, in which hospitals' bills are directly related to the amount of infectious waste weighted.

Aung, Luan and Xu (2019) conducted a study in Myanmar's hospitals, both private and public, and analyzed the healthcare waste technological route. They reported deficiencies in the healthcare waste infrastructure, as the absence of regular training to the staff, and record keeping methods. They also spotted the lack of identification on the waste trolleys and the absence of a special flow to the hazard material. The healthcare facilities considered in the paper segregated the waste into distinct colour-coded bins, into general waste, infectious waste and highly-infectious waste. Waste which presents chemical or sharpen risks aren't the majority, but it cannot be disconsidered.

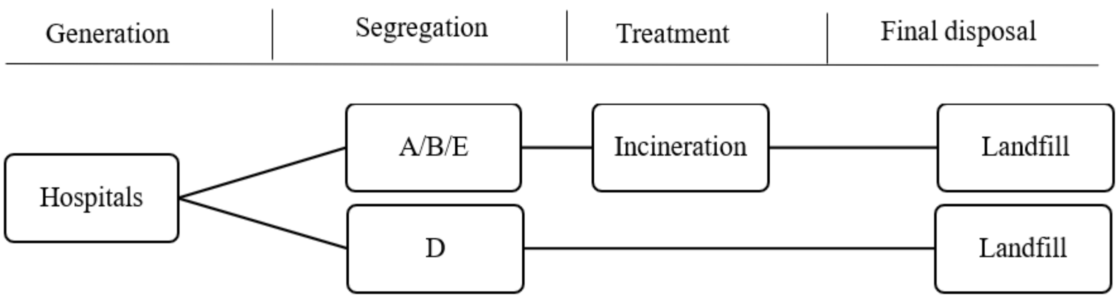
Tippat and Pachkhade (2015) researched the technological route of the healthcare waste in hospitals of the city of Amravati-India and mentioned many failures in their management system. The hospitals had color-coded containers for the different waste typologies inside of the facilities, but the outside storage area had no barriers to prevent the entrance of waste pickers. They also reported that the infectious waste was directed for incineration, while the non-hazardous went through a later segregation to separate the recyclable plastics. They were emphatic that the medical management systems were inefficient the researched city, and that though there were rules, they weren't followed.

There was a lack of suitable healthcare waste treatments in the city of Nanjing-China, once the only treatment available was incineration (CHINA, 2020). They reasoned that more methods should be implemented in China, such as steam sterilization, microwave sanitation and other types of disinfection. Though, the waste generated in the healthcare facilities were segregated between infectious, municipal and sharp, there was only one treatment method for the ones that presents risks to human health. Also, they reported that there were cases when the non-hazard waste was mixed with the infectious ones, causing both the increase of the management cost, as the growth of the risks to the environment and public health.

Liao and Ho (2014) created a classification system for medical institution's risks related to the biohealthcare waste management processes, demonstrating the minimum risk level that requires monitoring. They diagnosed that the segregation is usually ineffective in countries with low income per capita, so the amount of hazardous waste is augmented (WHO, 2013). Makajic-Nikolic et al. (2016) states that healthcare waste can be divided into harmful and harmless. However, the definition of healthcare waste as the potential to be infectious leads to the different interpretation developed by the individual countries, depending on national circumstances, policies and regulations (CANIATO et al., 2015).

The World Health Organization (WHO, 2018) declares that approximately 85% of the weighted waste generated in healthcare facilities are not dangerous. Kolimis, Makroleivaditis and Nikolakopoulou (2017) observed that 75% of the waste produced in microbiology laboratories were categorized as hazardous. He, Li and Fang (2016) identified that 60% of the Chinese healthcare waste were classified as perilous, using the same parameters as the WHO.

Since it is economically unavailable to incinerate every type of waste produced by a healthcare facility, another flow (Figure 3) was proposed that comprehends the minimum segregation between waste that offers risks to human health and environment from others that don't. Even though the economic aspects are more favorable in this flow, it still presents economic and environmental failures.
Figure 3 – Flow chart of the waste handling with the minimum segregation

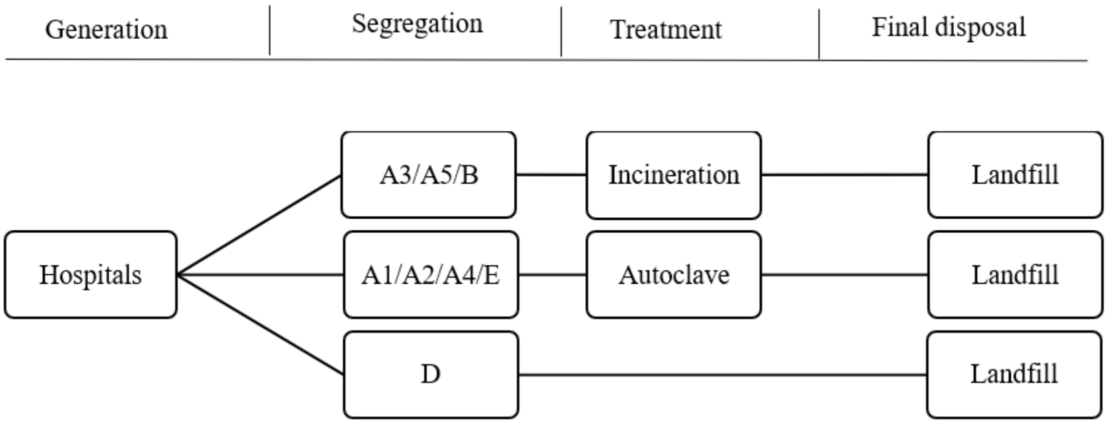


This model is present not only in countries at war, but also in places where there are no laws determining management procedures for this type of waste. Gavrancic et al. (2012) points out that this reality is common in developing countries, as found in the Republic of Serbia, which up to 2009 did not have a healthcare waste management protocol for health institutions. When the population in a developing country expand, the healthcare system to serve them don't grow in the same rate. Even when this growth occurs, it does not have a plan to optimize the healthcare waste management (AUNG; LUAN; XU, 2019). According to Ferronato et al. (2019), the introduction of effective solid waste management strategies in developing countries should be considered as a tool for improving sustainability at global and local level, and many barriers must be overcome, such as environmental policy making, effective investment, social inclusion and public awareness.

For the World Health Organization, poorly managed health waste can "potentially expose healthcare workers, waste handlers, patients and the community to large infections, toxic effects and injuries" (WHO, 2018). That is why this Organization developed technical guidelines for the safe management of healthcare waste, particularly addressing the challenges of developing countries. Zamparas et al. (2019) assessed the healthcare waste management system in a teaching hospital in the Center of Greece. They found that this facility classifies its waste into four categories: (i) municipal, (ii) purely infectious, (iii) sharp and (iv) mixed hazardous; that differs from the treatment and the packaging requirements. Municipal waste is sent to the landfill, infectious and sharp waste are disinfected and the mixed hazardous is directed to incineration. They also encountered shares that are in agreement with the ones issued by the WHO (2018).

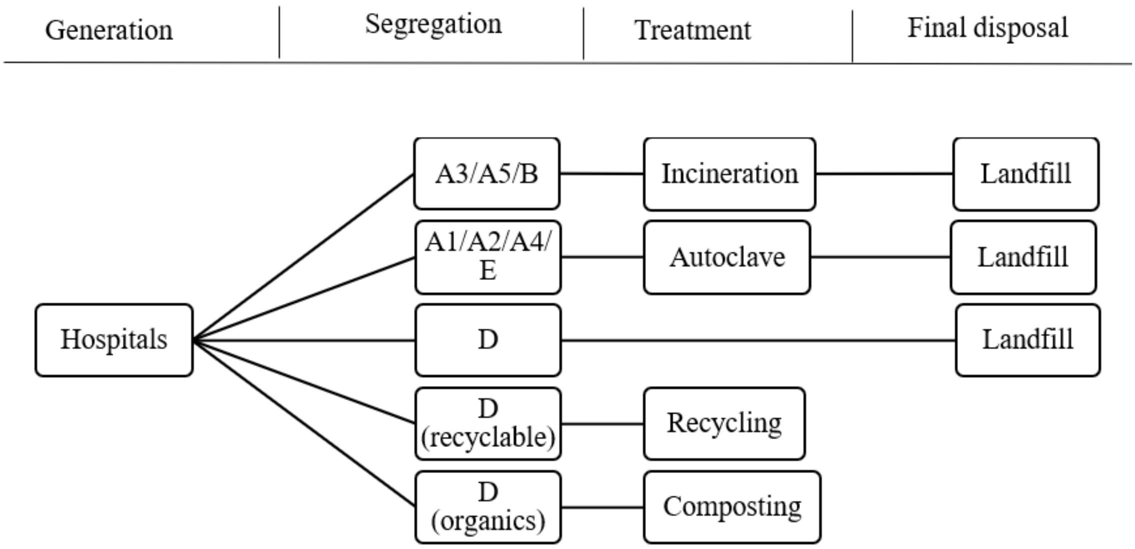
Once the Resolution Anvisa n 222 (ANVISA, 2018) proposes technological routes that are cheaper for some groups of waste, it is suggested an example (Figure 4), that works with a more refined segregation during its generation, aiming to divide it according to the type of treatment that will be used. Though, the flow is still in disagreement with the Solid Waste National Policy guidelines.

Figure 4 – Flow chart of the waste handling with the segregation of the infectious share according to Anvisa's Resolution



Some of the waste generated in hospitals cannot be recycled due its characteristics, but a great fraction of it can easily and safely be reintroduced into the manufacturing chain (VOUDRIAS, 2018). Composting is an efficient technique to return the nutrients to the environment and diminish the costs and externalities of the healthcare waste management system (ZAMPARAS et al., 2019). Though these measures cannot be done with the hazardous part of the waste, they are still relevant once most of the waste produced in a healthcare facility does not present dangerousness. Thus, with this perspective and in order to comply with the Solid Waste National Policy (BRASIL, 2010), it is proposed a flow (Figure 5) in which the waste segregation is made in a manner that values every type that of non-hazardous residue that is possible. Obstacles related to it include the lack of space to place all the necessary containers and the difficulty to properly train the employees on the matter (VIANI; VACCARI; TUDOR, 2016).

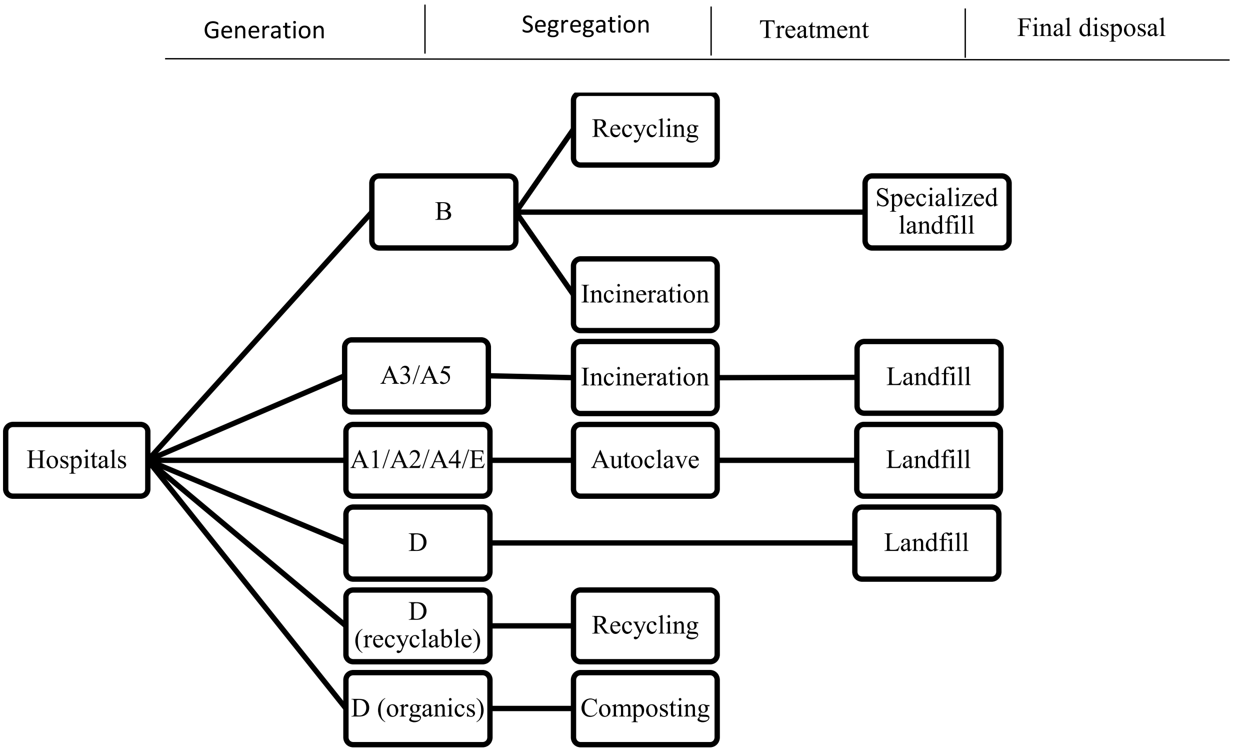
Figure 5 – Flow chart of a waste handling with the segregation of the hazardous and the non-hazardous ones according to the minimum treatment



Voudrias (2018) discuss how important the circular techniques, as safe reuse, recycling and reprocessing, are to the sustainability of the healthcare waste management. But, as he points out, some materials do not have a circular method so far, thus the traditional linear solutions cannot be abandoned.

The flow suggested (Figure 6) exemplifies the greater level that the healthcare waste management can achieve. This flow is in complete agreement with the legal aspects, once every hazardous waste is sent to its suitable treatment and everyone that can be valued is isolated and returned to the productive chain. Beyond that, this model presents the better cost-benefit version of the healthcare waste management, since some waste is generating revenue for the company and recycling the group B makes the amount of waste that is meant to be incinerated decrease. This flow aligns, as much as the Brazilian law allows, with the upcycling definition described by Voudrias (2018), which is the transformation of the waste into something with the same or higher value than the original material.

Figure 6 – Flow chart of the waste handling according to the optimum cost-benefit



Regardless of the flow in which the hospital fits, a more developed or archaic one, the staff awareness always pose as a key factor of the waste management development (MOHEE, 2005; BIRPINAR; BILGILI; ERDOGAN, 2009; PATWARY et al., 2011; GAVRANCIC et al., 2012; LIAO; HO, 2014; SARSOUR et al., 2014 ;TIPPAT; PACHADE, 2015; CANIATO; TUDOR; VACCARI, 2016; HE; LI; FANG, 2016; KOLIMIS; MAKROLEIVADITIS; NIKOLAKOPOULOU, 2017; CHASSEIGNE et al., 2018; AUNG; LUAN; XU, 2019; FERRONATO et al., 2019; ZAMPARAS et al., 2019), since there is no way to implement sustainable practices without the engagement of the people that are directly involved with it (VIANI; VACCARI; TUDOR, 2016). Zamparas et al. (2019) states that the sustainability in the healthcare waste management systems is only achieved with the use of green practices, human resources attitudes, and behaviours oriented to the environmental aspects. They also point out that many developing countries are losing biomass-, recycled-, chemical-, and energy-embodied sources by not reintroducing their waste into a circular economy.

Xin (2015) suggests that the generation rate for medical activities in different departments should be monitored to support a fully-equipped and computerized hospital information system. This results in a better clinical data quality control which helps managers to compare the performance of hospital waste management, favoring the seek legal and technical non-confirmations of installed systems. It is of paramount importance to adapt the healthcare waste management of hospitals to a reality focused on reducing the possible negative impacts caused by mistreatment in the various stages of the technological route, avoiding damage to both people and the environment (CAMPION et al., 2015). Also, there are other measures to diminish the amount of waste that must be treated and sent to the landfill, as (i) the safe reuse of medical and other equipment that can be subjected to sterilization, (ii) the purchase of materials and medical supplies that generates less waste and (iii) the control of the use of some materials (VOUDRIAS, 2018).

Campion et al. (2015) discuss that many disposable custom packs have more tools than the medical assistance needs, and most of it ends in the hazardous technological route even when it wasn't use. Thus, the hospitals can benefit both economically and environmentally by analyzing the items they purchase. These authors also support the laundry and reuse of the cotton towels inside of these packs. Chasseigne et al. (2018) reported that up to 20.1% of the cost of surgical supplies in their researched hospital were due to disposable material that was unused during the procedure. They highlight that it is both an economical and an environmental misuse. Another factor that induces the hospital's procurement team to prefer the single use devices is that they only consider the amount of each equipment cost, neglecting the disposal cost (VIANI; VACCARI; TUDOR, 2016). This can be solved by a higher interaction between the purchase department and the waste management one.

In order to reusing being an option, the healthcare facilities must have the correct equipment for the sterilization the used material (VIANI; VACCARI; TUDOR, 2018). According to the statement by Makajic-Nikolic et al. (2016), it is being common practice in large international health institutions to apply methods and techniques for managing risks. The development of Contingency Plans is also increasing when any procedural non-compliance occurs during the stages of the process. Moreover, for Bouzarour-Amokrane, Tchangani and Peres (2015), institutions should be aware of the concept of sustainability in all processes, especially in waste management. Thus, they will remain in compliance with environmental standards and add value to the institutional image, being better perceived by consumers.

It is important to remind that the waste management is only one aspect of an Environment Assessment System and the adoption of other measures, such as the inspection of the water, energy and materials consumption and the preference for purchasing supplies that have lower environmental impacts, will contribute for the hospital's sustainability (ROMERO; CARNERO, 2019). Though, since waste management is the only regulated aspect of healthcare facilities sustainability, it is an obvious starting point towards the implementation of an Environment Assessment System (ISO 14004). Certainly, the technological evolution present in the different countries will transform the healthcare waste management models, positively influencing the Brazilian legislation, increasing the efficiency of the processes, improving monitoring methods, facilitating the identification of procedural nonconformities and structuring them (FERREIRA, 2017).

Conclusion

Brazilian legislation prioritizes the non-generation of waste and, if produced, its reuse or recycling. To achieve this goal, healthcare waste management systems must prior the segregation phase. It was proposed 6 flows in which only two agree with Brazilian legislation once infecting waste that could be valued is a crime. Though the flow presented in the "Flow chart of a waste handling with the segregation of the hazardous and the non-hazardous ones according to the minimum treatment" is in accordance with the legality, it can be improved in the environmental and economic aspects. On the other hand, the flow proposed in "Flow chart of the waste handling according to the optimum cost-benefit" shows the optimum standards, once it is in complete conformity with the law and has the lower maintenance cost.

Also, the institution that present a waste management flow similar to the one proposed in the one that prioritizes the best sustainable and cost-benefit alternatives for its waste can still improve its environmental and waste management system by controlling the amount of disposables used in the assistance, making environmental-friendly choices in the purchase of supplies and using instruments that can be disinfected and reused.

ACKNOWLEDGEMENTS

To the Government of Brazil, for the financial support through the Coordination for the Improvement of Higher Education Personnel and the National Council for Scientific and Technological Development, of the Ministry of Science, Technology and Innovation. We also thank the Government of the State of Pernambuco for the financial support through the Foundation for the Support of Science and Technology of the State of Pernambuco.

References

Anvisa. (2018). Sanitary Surveillance National Agency. RDC nº 222. Standardizes the good practices for the healthcare waste management and make other arrangements. *Diário Oficial da União.*
Ansari, Z. N., & Kant, R. (2017). A state-of-art literature review reflecting 15 years of focus on sustainable supply chain management. *Journal of Cleaner Production*, *142*, 2524-2543.
Aragão, A., Jacobs, S., & Cliquet, A. (2016). What's law got to do with it? Why environmental justice is essential to ecosystem service valuation. *Ecosystem Services*, 22, 221-227.
Aung, T. S., Luan, S., & Xu, Q. (2019). Application of multi-criteria-decision approach for the analysis of healthcare waste management systems in Myanmar. *Journal of Cleaner Production*, 222, 733-745.
Birpinar, M. E., Bilgili, M. S., & Erdoğan, T. (2009). Healthcare waste management in Turkey: A case study of Istanbul. *Waste Management*, 29(1), 445-448.
Bouzarour-Amokrane, Y., Tchangani, A., & Pérès, F. (2015). Decision evaluation process in end-of-life systems management. *Journal of Manufacturing Systems*, 37, 715-728.
Brasil. (1981). Federal Law no 6938, August 1981. Provides about the Environment National Policy, its goals and the formulation and application methods, and make other arrangements. *Diário Oficial da União.*
Brasil. (2010). Federal Law no 12305, August 2010. Establishes National Policy of Solid Waste. *Diário Oficial da União.*
Brasil. (1998). Federal Law no 9605, February 1998. Provides for criminal and administrative sanctions arising conduct and activities that are harmful to the environment, and other measures. *Diário Oficial da União.*
Campion, N., Thiel, C. L., Woods, N. C., Swanzy, L., Landis, A. E., & Bilec, M. M. (2015). Sustainable healthcare and environmental life-cycle impacts of disposable supplies: a focus on disposable custom packs*. Journal of Cleaner Production,* 94, 46-55.
Caniato, M., Tudor, T. L., & Vaccari, M. (2016). Assessment of health-care waste management in a humanitarian crisis: A case study of the Gaza Strip. *Waste Management*, 58, 386-396.
Chasseigne, V., Leguelinel-Blache, G., Nguyen, T. L., de Tayrac, R., Prudhomme, M., Kinowski, J. M., & Costa, P. (2018). Assessing the costs of disposable and reusable supplies wasted during surgeries. *International Journal of Surgery*, 53, 18-23.
CNEN. (2014). Nuclear Energy National Commission. Resolution no 167. Radioactive waste management of low and medium radiation levels. *Diário Oficial da União.*
Conama. (1997). Nacional Council of the Environment. Resolution no 237, December 1997. Provides for environmental licensing; States and Cities Competences; list of activities that are subjected to licensing; Environmental Studies, Environmental Impact Assessment and Report of Environmental Impact. *Diário Oficial da União.*
Conama. (2005). Nacional Council of the Environment. Resolution no 358, August 2005. Provides for the treatment and final disposal of healthcare waste and make other arrangements. *Diário Oficial da União.*
Dantas, G. A., Legey, L. F., & Mazzone, A. (2013). Energy from sugarcane bagasse in Brazil: An assessment of the productivity and cost of different technological routes. *Renewable and Sustainable Energy Reviews*, 21, 356-364.
Ferronato, N., Rada, E. C., Portillo, M. A. G., Cioca, L. I., Ragazzi, M., & Torretta, V. (2019). Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. *Journal of Environmental Management*, 230, 366-378.
He, Z. G., Li, Q., & Fang, J. (2016). The solutions and recommendations for logistics problems in the collection of healthcare waste in China. *Procedia Environmental Sciences*, 31, 447-456.
Jouhara, H., Czajczyńska, D., Ghazal, H., Krzyżyńska, R., Anguilano, L., Reynolds, A. J., & Spencer, N. (2017). Municipal waste management systems for domestic use. Energy, 139, 485-506.
Koo, J. K., & Jeong, S. I. (2015). Sustainability and shared smart and mutual–green growth (SSaM-GG) in Korean healthcare waste management. *Waste Management & Research*, 33(5), 410-418.
Komilis, D., Makroleivaditis, N., & Nikolakopoulou, E. (2017). Generation and composition of healthcare wastes from private medical microbiology laboratories. *Waste Management*, 61, 539-546.
Korkut, E. N. (2018). Estimations and analysis of healthcare waste amounts in the city of Istanbul and proposing a new approach for the estimation of future healthcare waste amounts. *Waste Management*, 81, 168-176.

Lee, S., Vaccari, M., & Tudor, T. (2016). Considerations for choosing appropriate healthcare waste management treatment technologies: A case study from an East Midlands NHS Trust, in England. *Journal of Cleaner Production*, 135, 139-147.

Liao, Z. (2018). Content analysis of China's environmental policy instruments on promoting firms' environmental innovation. *Environmental Science & Policy*, 88, 46-51.

Makajic-Nikolic, D., Petrovic, N., Belic, A., Rokvic, M., Radakovic, J. A., & Tubic, V. (2016). The fault tree analysis of infectious healthcare waste management. *Journal of Cleaner Production*, 113, 365-373.

Mohee, R. (2005). Healthcare wastes characterisation in healthcare institutions in Mauritius. *Waste Management,* 25(6), 575-581.

Moreira, A. M. M., & Günther, W. M. R. (2013). Assessment of healthcare waste management at a primary health-care center in São Paulo, Brazil. *Waste Management*, 33(1), 162-167.

Panya, N., Poboon, C., Phoochinda, W., & Teungfung, R. (2018). The performance of the environmental management of local governments in Thailand. *Kasetsart Journal of Social Sciences*, 39(1), 33-41.

Patwary, M. A., O'Hare, W. T., & Sarker, M. H. (2011). An illicit economy: Scavenging and recycling of healthcare waste. *Journal of Environmental Management*, 92(11), 2900-2906.

Pinto, G. M. C., Pedroso, B., Moraes, J., Pilatti, L. A., & Picinin, C. T. (2018). Environmental management practices in industries of Brazil, Russia, India, China and South Africa (BRICS) from 2011 to 2015. *Journal of Cleaner Production*, 198, 1251-1261.

Romero, I., & Carnero, M. C. (2019). Environmental assessment in health care organizations. *Environmental Science and Pollution Research*, 26(4), 3196-3207.

Rosado, R. M.; Heidrich, Á. L. (2016). Leituras na esteira do galpão: catadores, território e educação ambiental. Política nacional de resíduos sólidos e suas interfaces com o espaço geográfico: entre conquistas e desafios, 219-233

Sarsour, A., Ayoub, A., Lubbad, I., Omran, A., & Shahrour, I. (2014). Assessment of healthcare waste management within selected hospitals in Gaza Strip Palestine: A pilot study. *International Journal of Scientific Research in Environmental Sciences*, 2(5), 164.

Souza, J. C. R. R.; Pinheiro, S. M. G.; Rodrigues, A. C.; Mello, D. P. de; Silva, R. G. da; Aquino, J. G. de, El-Deir, S. G. (2016) Papel das políticas públicas no gerenciamento dos resíduos sólidos. *In: Forum Internacional de Resíduos Sólidos-Anais*

Tippat, S. K., & Pachkhade, A. U. (2015). Survey of bio-healthcare waste disposal system in some hospitals of amravati city. *IJCPS*, 4, 530-5.

Viani, C., Vaccari, M., & Tudor, T. (2016). Recovering value from used medical instruments: A case study of laryngoscopes in England and Italy. *Resources, Conservation and Recycling*, 111, 1-9.

Voudrias, E. A. (2018). Healthcare waste management from the point of view of circular economy [editorial]. *Waste Management,* 75, 1-2.

Welch, C., & Piekkari, R. (2017). How should we (not) judge the 'quality'of qualitative research? A re-assessment of current evaluative criteria in International Business. *Journal of World Business*, 52(5), 714-725.

WHO-World Health Organization (2018) Available at: http://www.who.int/en/news-room/fact-sheets/detail/health-care-waste (accessed 15 september 2019).

Yong, Z., Gang, X., Guanxing, W., Tao, Z., & Dawei, J. (2009). Healthcare waste management in China: a case study of Nanjing. *Waste management*, 29(4), 1376-1382.

Zamparas, M., Kapsalis, V. C., Kyriakopoulos, G. L., Aravossis, K. G., Kanteraki, A. E., Vantarakis, A., & Kalavrouziotis, I. K. (2019). Healthcare waste management and environmental assessment in the Rio University Hospital, Western Greece. *Sustainable Chemistry and Pharmacy*, 13, 100163.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

Scientiometric Evaluation of Electric Vehicle Battery Recycling

COSTA, B. P. O., MURO, A.

Instituto Federal de Educação, Ciência e Tecnologia de Goiás, Goiânia

**Corresponding author, aldo.muro@ifg.edu.br*

Abstract

The automobile sector represents a significant portion of the pollutants released into the atmosphere. Linked to environmental and social responsibility, electric vehicles - EVs, are a viable alternative mainly because they are more energy-efficient, and have a low maintenance cost. In recent years, environmental concern has become more predominant, especially in developed countries, regarding the electronic waste derived from EVs. Recently, harmful batteries, composed of components such as lead-acid, are being replaced by lithium-ion batteries, given they are more environmentally friendly. With this scenario, the main objective of this work was to carry out international scientometric research on electric vehicle lithium batteries recycling, looking for possible biases and geographic gaps where a more robust investigation can be applied. To achieve this, a search for recent articles was done (2012 - 2021) on the Elsevier Scopus Platform, using the following sequence of keywords and boolean operator: "electric vehicle" AND "battery" AND "recycling" AND "lithium-ion" AND "electronic waste." Applying the necessary filters and selecting them manually, 70 articles were found. The year 2021 presented the highest number of publications. Europe and Asia represented represent the majority of published articles, with 28 and 26 publications, respectively. A significant portion of the articles studies different Li-ion battery recycling techniques, demonstrating a technological advance in this sector.

Keywords: Scopus, VE, E-Waste, Electronic Waste.

Introduction

The automobile sector is responsible for most of the harmful measures directed toward the environment. Vehicles powered by combustion engines are supplied internally, where their driving force is the combustion of fuels released from particles transported daily. This field has been challenged to develop new environmentally friendly technologies - whose solutions are presented to the sustainable movement of vehicles designed with alternative engines to internal change by cars equipped with electric or electric vehicles (EV) (CORREIA; SIMIONI, 2021).

Electric vehicles, in addition to reducing atmospheric emissions, thus contributing to the fight against climate change, play an essential role in mitigating environmental emissions, as they are more energy-efficient, technologically more advanced, and economically more viable in terms of maintenance and use, despite still having a high initial acquisition cost (IEA, 2018; CONSONI *et al.* 2018, VELLOSO, 2010).

EV use brings many benefits to society and, consequently, to the environment. Therefore, a greater understanding of the batteries used in electric vehicles is necessary because the future impact caused by the improper disposal of batteries at the end of their useful life is still little known, especially in developing countries that do not have policies for correct provisions for solid circulars, res, and recycling and reverse logistics, use for cleaner and more economical production (BIESEK, 2019).

Batteries usually have an average residual charge of 50% when reused or discarded (CASTRO; CONSONI, 2020), but the environmental liability arising from storms is high, due to diffuse contamination of the soil and aquifers, by trace metals when incorrectly disposed of, with a tendency to increase the number of discarded batteries, with the increase in production and, consequently, the circulation of electric vehicles.

Li-ion batteries require a more complex recycling process than lead-based batteries, mainly due to their composition. The lithium extraction and recycling process bring numerous benefits, namely: (I) components are separated and used during the process for the use of value-added metal structures; (II) the practice of a sound environmental policy, where the preservation of environmental resources guarantees them for future generations; and (III) dependence on other countries with lithium reserves can be reduced through recycling (KARMAZINOVA; KAZDA; JANDOVA, 2017).

The countries with the largest lithium reserves are Australia and Chile, with annual production values of 14,300 and 12,000 tons, respectively (BARCELOS, 2020).

Through the financing of the Federal Government in the 60s of the 20th century to research, graduate programs, scientific events, and tax incentives that resulted in the participation of the private sector in the scientific development of the country, the need arose to outline a panorama of publications that reflects the "state of the art" on recycling, reuse and reverse logistics policies, cleaner production, and circular economy, involving batteries used in vehicles, both in Brazil and elsewhere (PARRA; COUTINHO; PESSANO, 2019).

Scientometrics, which involves the quantitative study of scientific activities, has as reference some indicators such as: number of works, number of citations, co-authorship, number of patents, number of patent citations and maps of fields and countries (MACIAS-CHAPULA, 1998).

In this work, the evolution of lithium-ion battery recycling in electric vehicles was evaluated, with a time frame of 10 years (2012 - 2021) and in all countries where publications related to the topic occurred, identifying possible biases and geographic gaps where they could be applied to a more robust investigation.

As for scientometric evaluation, it can also produce positive impacts and "do good" for society, playing a role of social marketing through extension projects, in addition to research. There is also the impact factor, caused by experience or personal contact with a project that can sensitize people and public policies (AKERMAN, 2013).

Given the above, and the need to produce works that investigate and analyze the production of studies in several areas, a scientometric evaluation was carried out on the recycling of electric vehicle batteries with the objective of defining information to fill research gaps and recycling strategies.

Methods

The methodology used in this work was the scientometric analysis which, according to Chapula (1998), refers to the study of the quantitative aspects of science, which may help in the assessment of the current state of science itself, as well as in decision making. and research management.

Thus, a quantitative and qualitative approach was taken. The qualitative approach is justified by the fact that after the quantitative approach is carried out, the data will be analyzed, interpreted and, given meanings, to them.

Articles related to the recycling of lithium-ion batteries for electric vehicles were selected using the Elsevier Scopus platform database (https://www.scopus.com/).

The "blank space" was used to fill in combinations linked to the "title, abstract and keywords" when searching for articles. The keywords used to carry out the search were: electric vehicle; battery; recycling; lithium-ion; and electronic waste.

With the help of the Boolean operator "AND", the following final combination was filled in to search for articles: "electric vehicle" AND "battery" AND "recycling" AND "lithium-ion" AND "electronic waste".

Five exclusion criteria were used for the articles: (a) the time frame (2012 - 2021); (b) final publication stage, dismissing articles in the process of publication; (c) type of document-article, disregarding other classifications such as abstracts and book chapters; (d) language of publication - English; and (e) area of knowledge - environmental sciences.

After sorting the articles, they were tabulated and organized in an electronic spreadsheet, in order to classify them according to the aforementioned criteria.

The final date for searching for articles was April 1st, 2022.

Results

Using the proposed tool, 73 articles were found applying the automatic exclusion criteria and 70 articles manually selecting them, in order to discard articles not related to the proposed theme about the recycling of batteries in electric vehicles on the Scopus platform.

The number of published articles has grown significantly in the last two years, which demonstrates a progressive concern with the significant amount of lithium-ion batteries that will come in the coming years, due to the wide adoption and circulation of electric vehicles in the world.

In 2021, there were 27 publications on the topic, approximately triple the number of publications in 2019, which were 10, pre-pandemic period (of the SARS-CoV-2 virus, known as COVID-19), as shown in Figure 01.

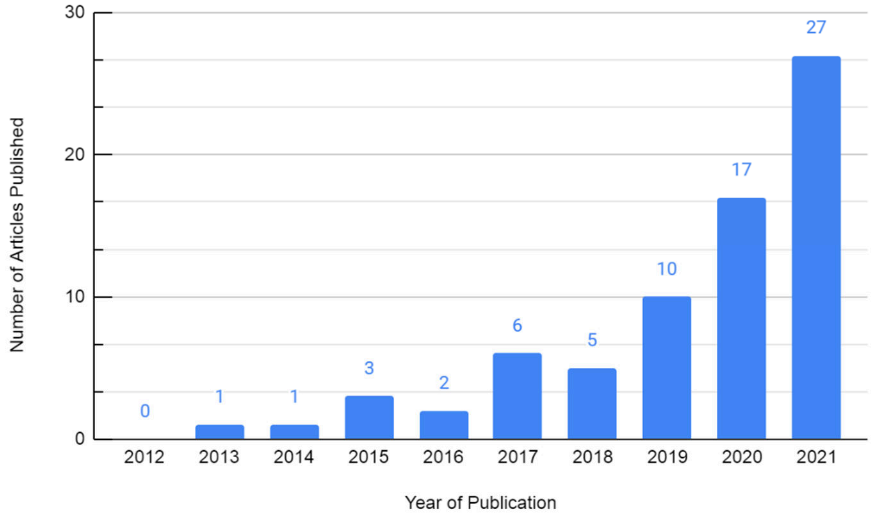


Fig. 1. Number of articles published per year.

Between 2012 and 2016, the number of publications varied between 0 and 3, which showed a low concern with electronic waste from electric vehicle batteries in this period and that, recently, the recycling of these materials has been gaining strength due to the growing incentive to switch from combustion-powered vehicles to electric vehicles within the next few years.

Of the 70 articles that were analyzed, the continents that led in terms of publications of articles relevant to the proposed theme were Asia and Europe, with 26 and 28 publications, respectively.

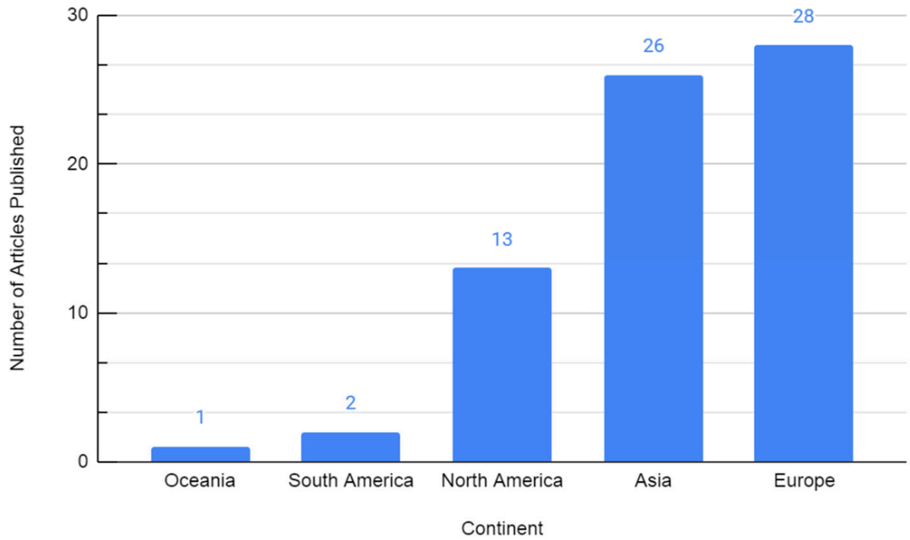


Fig. 2. Number of articles published per continent.

Europe's predominance in the number of articles published is due to the fact that they have ambitious goals to ensure safer, more ecologically sustainable and efficient transport. In Norway, which currently accounts for 50% of all newly sold fleets represented by electric vehicles, the forecast is that by 2025 all passenger cars and new buses will be zero-carbon vehicles (Norway Ministry of Transport, 2021).

There is a disparity in the number of articles published in Asia and Europe when compared to North America, with only 13 publications. The United States, which represents a large part of the articles published on the continent, presents a cultural resistance to EVs.

A report released by the Pew Research Center (2021) exposed that Americans are evenly divided on the idea of eradicating combustion vehicles. A proposal made by twelve US states to the current Joe Biden administration (January 20, 2021 - currently), including California, aimed to phase out the manufacture of new gasoline-powered vehicles by the year 2035. 51% of Americans are opposed to this idea, however the percentage may vary according to party - whether Democrat or Republican - and the age of the respondent.

The Fuels Institute Consumer Behavior Report (2021) showed that in the United States most of the incentives and registrations for electric vehicles are concentrated in the state of California. The state, being one of the most diverse in terms of ethnicity and race, currently represents approximately half of all electric vehicle registrations in the country, the rest being distributed among the other North American states.

The articles found were categorized into 5 different groups, according to the focus of their study, namely: (i) recycling techniques; (ii) demand for materials; (iii) environmental impacts; (iv) policies, regulation and economics; and (v) others. For the "others" category, topics that had a low number of publications were considered, such as, for example, inherent to the transport of lithium-ion batteries and the dangers arising from their dangerousness and design to optimize battery recycling.

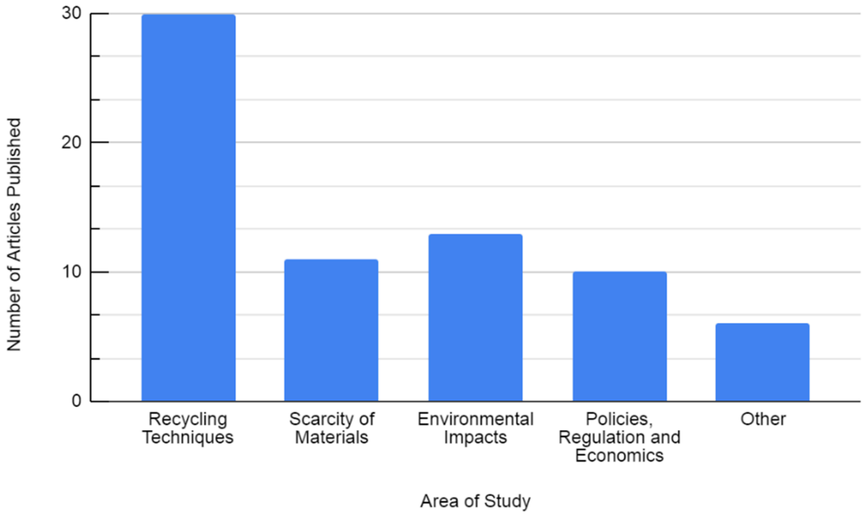


Fig. 3. Number of articles published per continent.

As can be seen in Figure 3, the group that presented the largest number of publications on the proposed theme was "recycling techniques", with 30 articles published (43%). This demonstrates a technological predominance in the articles studied. The main recycling techniques addressed in the articles found can be categorized into three processes, namely hydrometallurgical, pyrometallurgical and direct recycling. The recycling tools and techniques of each of the processes used were not studied in detail, since they are outside the scope of this work.

Thirteen articles were found for the group "environmental impacts", - representing (19%), which concerns the impacts caused by the types of lithium-ion battery recycling processes. From the point of view of hydrometallurgical and pyrometallurgical processes, the environmental impacts caused by the recycling of lithium-ion batteries were categorized in one of the articles into six types: (i) global warming; (ii) water consumption; (iii) non-carcinogenic human toxicity; (iv) scarcity of mineral resources; (v) terrestrial ecotoxicity; and (vi) marine ecotoxicity (REY *et al*., 2021).

The hydrometallurgical process generates large volumes of acidic solutions, producing large amounts in wastewater. Liquid waste and sludge produced by the hydrometallurgical process must be carefully disposed of to avoid secondary pollution in the environment. On the other hand, pyrometallurgical processes use large amounts of inert gases that contribute to eutrophication, ozone layer depletion, human carcinogenic toxicity, non-carcinogenic human toxicity, and ecotoxicity. Despite the large amount of liquid waste generated in the first process, it has more environmental benefits.

An alternative to reducing the environmental impacts resulting from the EV battery recycling processes would be the use of fewer acids and fewer heating steps. In order for battery recycling to be beneficial for the environment, it is also necessary that the emissions generated by recycling and reusing batteries are lower when compared to the emissions generated during the manufacture of a new battery (WILSON *et al*., 2021).

In general, the analyzed articles point out that the environmental impact of the reused components of lithium-ion batteries is relatively low in all impact categories when compared to the manufacturing stage of a new battery or when disposed in the environment without its due. reuse.

Conclusion

Concern about recycling electric vehicle batteries has increased significantly in the last decade, as can be seen by the increasing number of articles published per year, and also by the number of publications regarding the scarcity of materials that make up these batteries - such as the lithium, aluminum, graphite, among others. Since the materials that make up batteries are increasingly scarce, battery recycling could reduce dependence on international demand from material reserves, in addition to reducing the environmental impacts resulting from the manufacture of new batteries or their final disposal. in the environment.

In addition, the adoption of EVs in the coming years would have a mitigating effect on emissions from fossil waste from mobile sources and also presents itself as a solution to the oil shortage. Combustion-powered vehicles represent the majority of atmospheric emissions, especially in large cities. EVs have low or zero-emission of noise and particles suspended in the air, making them great allies to the environment.

South American countries, such as Brazil, still face barriers related to the economic system, available technologies, and an effective governance system. Cultural and monetary differences prevent the development of an adequate infrastructure to support EVs and their circulation. Countries that are a reference when it comes to the implementation of the EV charging structure, such as Norway, offer tax incentives, reduced operating costs, and several charging points throughout the country.

Although the fleet of electric vehicles in Brazil increases every day, according to estimates by the Brazilian Association of Electric Vehicles (ABVE), the country still does not demonstrate the adequate capacity to follow the evolution of mobility in electric vehicles.

About the topics covered in the articles, a large portion of the articles analyzed came from European and Asian countries. The transition from the combustion-powered vehicle to the EV in these countries occurs more quickly, as well as their concern with the disposal of lithium-ion batteries that accompany their adoption. China is currently a significant exporter of electric vehicles, contributing to the country's government incentive for the population to adhere to this type of mobility.

Regarding the area of study of publications, there is a predominance of articles that relate to the recycling processes of lithium-ion batteries, which demonstrates a technological advance in this sector, especially in countries on the Asian continent, where the major EV manufacturing companies. Studies related to environmental impacts show that the consequences arising from recycling processes are significantly lower when compared to conventional methods of extracting ores.

The expectation is that for the following few years, studies on battery recycling in electric vehicles will grow exponentially, as occurred between 2012 and 2021, also due to the War in Ukraine (2022 – currently) that was a trigger for the ban on imports of oil and other materials from Russia in several countries. There is room for the development of studies focused on the impact of the War on urban mobility and how this influences more deeply the adoption of EVs and the need to recycle their batteries.

References

AKERMAN, M. Measures of experience and scientometrics to evaluate the impact of scientific production. Revista de Saude Publica, v. 47, n. 4, p. 824–828, 2013.

BARCELOS, L. P. Estudos sobre reaproveitamento de baterias íon-lítio. 2020. 125 f. TCC (Graduação) - Curso de Engenharia Química, Universidade Federal de Uberlândia, Uberlândia. Available at: https://repositorio.ufu.br/handle/123456789/31032. Last accessed: nov. 10 2021.

BIESEK, A. S. Legislação Ambiental: Logística reversa como ferramenta para mitigar impactos dos resíduos sólidos eletrônicos. Congresso Sul-Americano de Resíduos Sólidos e Sustentabilidade. Foz do Iguaçu. 2019.

CASTRO, C. P.; CONSONI, F. L. Diagnóstico dos cenários de manejo ambiental do uso e disposição final de baterias de lítio de veículos elétricos. E-Locução, Revista Científica da FAEX, v. 9, n. 17, p. 439–457, 2020. Available at: https://periodicos.faex.edu.br/index.php/e-Locucao/article/view/252/196. Last accessed: nov. 10 2021.

CONSONI, F. e. Estudo de Governança e Políticas Públicas para Veículos Elétricos. 2018. LEVE (Laboratório de Estudos do Veículo Elétrico). PROMOB-e. Brasília.

CORREIA, G. M. C.; SIMIONI, C. Políticas ambientais e uma possível mudança na matriz energética da indústria automobilística na Noruega. Caderno da Escola Superior de Gestão Pública, Política, Jurídica e Segurança, v. 4, n. 1, p. 50–64, fevereiro de 2021. Available at: https://www.cadernosuninter.com/index.php/ESGPPJS/article/view/987. Last accessed: nov. 10 2021.

MACIAS-CHAPULA, C. A. O papel da informetria e da cienciometria e sua perspectiva nacional e internacional. Ciência da Informação, Scielo, v. 27, n. 2, 1998.

NORWEGIAN MINISTRY OF TRANSPORT. Reports. National Transport Plan 2022–2033. Noruega, 2021. Disponível em: https://www.regjeringen.no/en/dokumenter/national-transport-plan-2022-2033/id2863430/. Available at: 14 mi. 2022. Last accessed: nov. 11, 2021.

PARRA, M. R.; COUTINHO, R. X.; PESSANO, E. F. C. Um Breve Olhar Sobre a Cienciometria: Origem, Evolução, Tendências E Sua Contribuição Para O Ensino De Ciências. Revista Contexto & Educação, v. 34, n. 107, p. 126–141, 2019. Available at: https://doi.org/10.21527/2179-1309.2019.107.126-141. Last accessed: nov. 10 2021.

PEW RESEARCH CENTER. Gen Z, Millennials Stand Out for Climate Change Activism, Social Media Engagement With Issue. Estados Unidos. 2021. Available at: https://www.pewresearch.org/science/2021/05/26/gen-z-millennials-stand-out-for-climate-change-activism-social-media-engagement-with-issue/. Last accessed: abr. 10 2022.

Recycling – Processes & Technologies. The Electrochemical Society, ECS Transactions, v. 81, n. 1, p. 255–260, 2017.

REY, et al. Environmental Impacts of Graphite Recycling from Spent Lithium-Ion Batteries Based on Life Cycle Assessment. ACS Sustainable Chemistry and Engineering. v. 9, n. 43, p. 14488 – 14501, 2021. Available at: https://doi.org/10.1021/acssuschemeng.1c04938. Last accessed: abr. 17 2022.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

The evolution of Plastic Caps for Bottles of Water and Soda: A LCIA in a Plastic Caps Industry in Brazil

LIMA, T. C. H. C [a], COLARES, G. S. [a], SCHNEIDER, R. C. S.[a*], KIPPER, L. M. [a], MORAES, J. A. R. [a], MACHADO, E. L. [a]

a. Universidade de Santa Cruz do Sul, Rio Grande do Sul, RS, Brazil

**Corresponding author, rosana@unisc.br*

Abstract

The main objective of this study was to evaluate the environmental impacts related to the stage of manufacturing plastic caps during the last years. The method used for this evaluation was the AICV, using the method Impact 2002+ and the software Simapro 8.5, to evaluate a plastic packaging manufacturing industry in Brazil as a case study. Through technological evolution, significant reductions in the damage generated by these products were obtained, around 25% considering the single score, it is the result of dematerialization, of the elimination of the ethylene vinyl acetate (EVA) seal and of the elimination of intermediate processes that generated a significant reduction in the electric energy consumption per thousand of manufactured cap of 2.01E-03 kWh (31%). This path taken so far serves as a framework for future research, and the study shows room for evolution through the use of post-consumer recycled resin (PCR), in the use of biopolymer, and in the change of packaging or in product design that enable greater dematerialization.

Keywords: plastic packaging, life cycle assessment, plastic cap

1 Introduction

According to Ellen Macarthur Foundation (2018) only around 15% of global plastic is recycled, and almost 45% goes to landfills, being the highest demand from the packaging sector (39.9%). Thus, it is necessary for plastic packaging to be increasingly sustainable, so that environmental impacts at a global level can be mitigated. To understand the next steps in the search for better environmental performance, it is necessary to know what path has been taken so far and what has already been done that can still be explored.

To measure environmental impacts on packaging, the most used tool is the Life cycle assessment (LCA). The results of LCA in packaging provide the backdrop for identifying potential optimization opportunities, thanks to the comprehensive assessment of all possible environmental impacts related to these products (Niero et al., 2017). LCA is a process that aims to quantify the environmental impacts associated with a product (energy consumption, materials used, waste and emissions released) throughout its life cycle (Pauer et al., 2019).

The ISO 14.040 and ISO 14.044 standards cite the main rules for conducting a product or process life cycle analysis. According to Mendes et al. (2016), for plastic packaging scenario the most used impact methods are CML and Impact 2002+. The application of environmental management tools, such as LCA, in the production of plastic products allows the determination of the main points of impact and can help a company to improve its environmental profile (Agarski et al., 2017).

Foolmaun and Ramjeeawon (2012), used a LCA method to compare polyethylene terephthalate (PET) bottles in Mauritius and define the best disposal route this material. Different configurations of the waste management system of plastic packaging in Austria was assessed using life cycle inventory data and the results highlight the importance of high-quality single-polymer plastics recycling (Van Eygen et al., 2018). Elduque et al. (2018), evaluated the environmental impacts for the same process (injection molding) for different plastic materials and molding machines', focusing on the electricity consumption.

An LCA was carried out to compare plastic packaging with that of other materials (Abejon et al., 2020). Cosmetic packaging with different raw materials has already been evaluated and possibilities of environmental gains have been found (Civancik-Uslu et al., 2019). A LCA with plastic caps has also been carried out in Europe, comparing 2 models of caps and generating prognoses of scenarios with different mix of electric power generation (Agarski et al., 2019). These works explored the use of the LCA tool for plastic packaging, but there are some important limitations that should be explored, such as the assessment of impacts in the Brazilian scenario of plastic caps. How has the behavior of technological evolution been in relation to the environmental damage generated by these products?

This research aims to evaluate the environmental performance of plastic caps for water and soda bottles over time, understanding which components of the material flow are more significant and generate the greatest impacts. Through the historical data of the environmental evolution of this product, is expected to be able to direct options for future studies in the field of plastic packaging.

2 Methodology

In this study the functional unit is: "Production of a single plastic cap able to seal a bottle of water or soda". The bottles may vary in dimensions, but the plastic cap is always the same for all sizes of soda and water till 3L commercialized in Brazil. The development of the work was done by evaluating and discussing the LCIA results individually and the comparative LCIA between the results to identify the most relevant evolutions through these years. The IMPACT 2002+ and CML-IA method were used. The order of assessment was chronological from oldest to most recent, starting with the plastic cap of generation 1, followed by generation 2, then generation 3 and finally a comparative analysis aiming to identify the main changes in the environmental impacts generated by them. A normalization step is widely exercised in life cycle assessment (LCA) studies in order to better understand the relative significance of impact category results. The second step was the characterization of each cap generation. Another step also performed using SIMAPRO was the single score. The so-called single score is the further normalization and weighting of endpoints in order to obtain overall environmental performance indicators in the form of one dimensionless single indicator (Kalbar et al., 2016). The last analysis developed in the software was the damage assessment. The damage categories, also known as endpoint approach allows for results to be expressed with equivalent numerical parameters and, therefore, the environmental effects of the analyzed system to be represented quantitatively (Ingrao et al., 2014).

2.1 Goal, Scope and Process detailing

The objective of the study is to perform a LCA to assess the evolution of the environmental impacts generated by plastic caps for water and soda used in Brazil, which is basically the same as used all around the world, during the last 25 years. A case study in a plastic caps industry in Brazil was used to reach the results, including 3 scenarios with different generations of caps, evaluating the real impacts in a serial production process. The plastic caps are responsible for sealing of PET bottles of water and soda for many years, according to the company in this case study, there are 3 generations of plastic caps manufactured by them to the Brazilian market in the last 25 years. The first generation began to be commercialized in 1996, it was composed 2.7g of polypropylene (PP) and a seal of 0.4g of ethylene-vinyl acetate (EVA). The second generation entered the cap market around 2011, it has the same sealing mode of the first generation, but the benefit to be produced with just 2.4g, which means a 11% reduction of mass.

Before going throw the generation 3, another detail important to mention is that this kind of plastic caps also need an anti-tamper seal, to ensure that the bottles are not sabotaged, leaving any kind of opening and/or tampering with the cap visible. Registering that, the third generation started on caps market was 2015, and it brings a very different concept, because it is made with polyethylene, it does not use the EVA sealing, and the anti-tamper seal is generated of the injection process. Basically, the cap generation 3 has on its design a sealing system that replace the EVA sealing, that is, the cap does not need to go throw any other process after the injection. The compositions of all the 3 generations are described in the Table 1.

Tab. 1. Composition on the plastic caps.

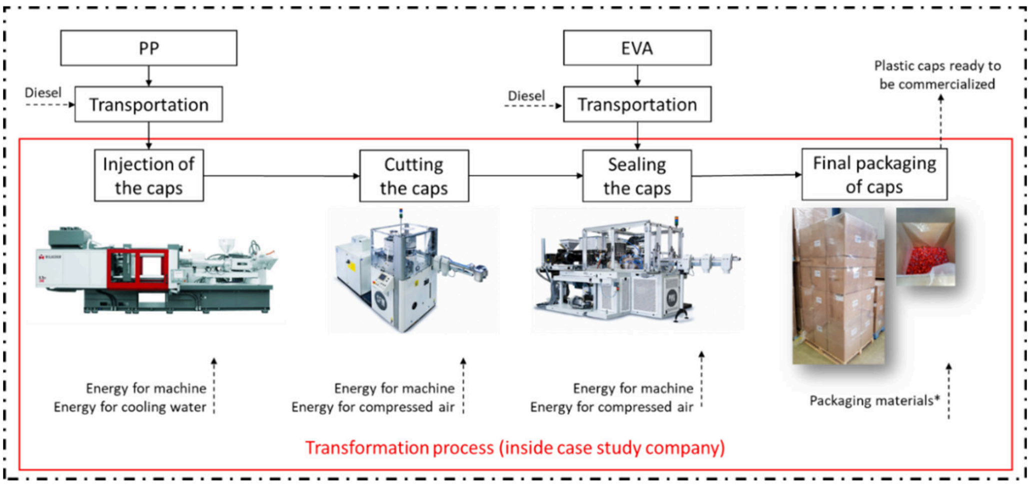
Generation	*Description*	*Weight*	*Material*
1	*Plastic cap yellow with EVA seal*	*2,7g (cap) + 0,4g (seal)*	*Polypropylene (PP) + Ethylene vinyl acetate (EVA)*
2	*Plastic cap blue with EVA seal and less material*	*2,4g (cap) + 0,4g (seal)*	*Polypropylene (PP) + Ethylene vinyl acetate (EVA)*
3	*Plastic cap red without EVA seal and less material*	*2,4g*	*High Density Polyethylene (HDPE)*

All the manufacturing process involving the generation 1 and 2 of the plastic caps are in the Figure 2, which also represents the boundaries for the analysis, and it is possible to see that the process is sequential and where the inputs and outputs are. For both generation 1 and 2, the main raw material is the polypropylene, which is transported to the factory by road. The first transformation process is the injection, where is consumed energy and water for cooling the mold. Even that the water works in a closed loop system, the process has a median consumption of 68m3 per day due to evaporation on the cooling towers, because of that the water is considered in the inventory.

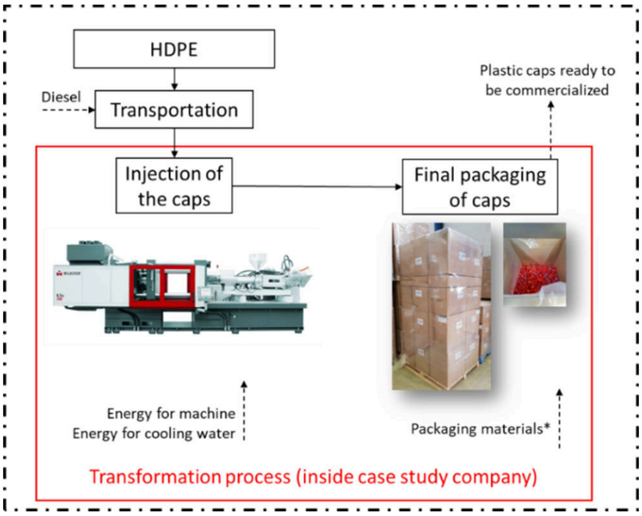
In the injection process, there are also some differences between the mold's sizes and cycle times from generation 1 and 2 caps to generation 3 caps. For the company in this case study, while the molds for generation 1 and 2 can produce 31,130 caps h-1, the generation 3 mold can produce 23,040 caps h^{-1}.

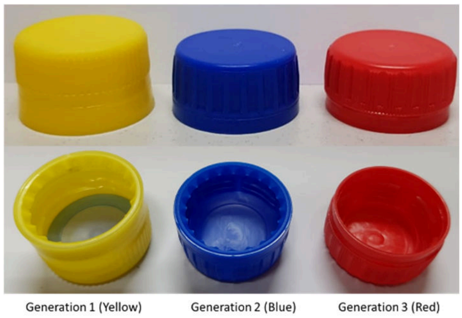
The second process is the cutting using the Slitter machine (SACMI - Italy), which is responsible to cut the cap and create the anti-tamper seal. In this process is consumed energy for the machine and for the compressed air to transport the caps throw the machine and throw the processes. The third process, carried out by the Liner machine (SACMI - Italy), is the sealing step, where there is the consumption of energy for the machine and for compressed air too. The last step is the final packaging, which the packaging materials used are cardboard box, plastic bag, wooden pallet and stretch plastic film.

For the generation 3 plastic cap, as mentioned before, the huge difference is that is no longer necessary the cutting and sealing steps, the plastic cap goes straight from the injection machine to the final packaging. In that way, in addition to the 2 processes, the use of the seal of EVA is also eliminated. A summary of the boundaries and details of the process for the plastic caps from generation 3 can be seen in Figure 1.



Generation 1 and 2





Generation 3

Fig. 1. Boundaries for the plastic cap (Generation 1, 2 and 3)

2.2 Life-cycle inventory

The injection mold and the injection machine manufacture were not considered in the inventory. According to (Agarski et al., 2019), the environmental impacts generated by the injection mold can be neglected when it is considered on a scale of single-cap production. In their study they found that the life cycle of the mold was to produce 19,008,000 plastic caps, however in the case study the mold can produce for up to 5 years and can produce at least 900,000,000 plastic caps, making the tool manufacturing impacts even more insignificant compared to the rest of the process. The main material and energy flow LCI results for the life cycle phases are provided in Tables 2 (caps generation 1, 2 and 3). The data were obtained from the plastic cap manufacturer and from the Ecoinvent database. The measurements of the energy consumed by all stages of the manufacturing processes were carried out using the equipment "Energy analyzer RE6000", which records the average consumption for periods of time and is commonly used in the industry. The equipment was installed inside the power substation at the entrance for each of the equipment that needs to be measured.

As these 3 generations of plastic caps already operate normally for a long time, the caps manufacturer has a history of measurements of several years. The cooling process is measured separately because it is a different entrance and the cooling system (equipment responsible for cooling the water for the process, like chillers, bombs, and cooling towers) is used for all the 23 injection machines in the industrial park equally. The choice items from database were made after a critical analysis of Ecoinvent's options and based on works related to the same research profile of plastic packaging LCA (Abejon et al., 2020; Agarski et al., 2019). For the raw materials, which are globally traded products, a distinction on the level of continental economies is sufficient because these commodities can hardly be traced back on a national or regional level.

Tab. 2. Material and energy flow for caps generation 1, 2 and 3.

Input of material and energy	***Database***	***Amount***	***Note***
		Generation 1 and 2	
PP (1) and PP (2)	*(PP), production mix, at plant RER*	*2.7 and 2.4g*	*The masterbatch represents 0.5% and has the same base as the resin, so it is considered as PP too. The cap gen. 1 is 2.7g and 2.4*
EVA (1 & 2)	*(EVA), at plant/RER S*	*0.4 g*	*There is just the raw material, no pigment.*
	Lubricating oil, at plant/RER S	*1.34E-03 g*	*After 10,000 hours, the oil of the injection machine has to be changed. 480L of oil is used per time. The machine operates 24h*

Lubrification oil for the injection machine (MOBIL DTE 25)			*day^{-1} and produce 23,040 piecesh^{-1}. (480L/10,000h/31,130 caps) = 1.54E-03 mL caps^{-1}. The density of the oil is 0.87 kg. 0.87 kg x 1.54E-03 mL caps^{-1}*
Tool heating, injection machine heating and operating (movements)	*Electricity, medium voltage, production BR, at grid/BR S*	*4,53E-03 kWh*	*The energy consumed by all the steps related to the injection process was carried out through measurements directly at the outlet of the power substation to the case study equipment. The historic data of this measurements is 141 kWh. 141 kWh / 31,130 caps h^{-1}*
Cooling of the tool and the machine	*Electricity, medium voltage, production BR, at grid/BR S*	*1.04E-03 kWh*	*The consumption by the cooling water system (chiller, bombs, cooling towers) has a historic data. The median of 1 h of work for the entire plant is 745 kWh. For 1 machine is 745 kWh/23 = 32,39 kWh. 32,39 kWh / 31,130 caps h^{-1}*
Water for cooling system	*Water, cooling, unspecified natural origin/m3*	*3.96E-06 m^3*	*The historic data of consumption of water due to evaporation in the cooling towers is 68 m^3. 68m^3 / 23 injection machines => 2.96m^3 / 747,120 caps day^{-1}*
Cutting machine (Slitter)	*Electricity, medium voltage, production BR, at grid/BR S*	*1.81E-04 kWh*	*The historic data of measured energy consumption for Slitter is 7,8kWh.*
		Generation 3	
HDPE (3)	*(PE-HD), production mix, at plant RER*	*2.4 g*	*The masterbatch represents 0.5% and has the same base as the resin, so it is considered as HDPE too*
Lubricating oil for the injection machine (MOBIL DTE 25)	*Lubricating oil, at plant/RER S*	*1.81E-03 g*	*After 10,000 h, the oil of the injection machine has to be changed. 480 L of oil is used per time. The machine operates 24h day^{-1} and produce 23,040 pieces h^{-1}. (480 L/10,000 h/23,040 caps) = 2.08E-03 mL caps^{-1}. The density of the oil is 0.87 kg. 0.87 kg x 2.08E-03 mL caps^{-1}.*
Tool heating, injection machine heating and operating (movements)	*Electricity, medium voltage, production BR, at grid/BR S*	*2.99E-03 kWh*	*The energy consumed by all the steps related to the injection process was carried out through measurements directly at the outlet of the power substation to the case study equipment. The historic data of this measurements is 69 kWh. 69 kWh / 23,040 caps h^{-1}*
Cooling of the tool and the machine	*Electricity, medium voltage, production BR, at grid/BR S*	*1.41E-03 kWh*	*The consumption by the cooling water system (chiller, bombs, cooling towers) has a historic data. The median of 1 hour of work for the entire plant is 567kWh. For 1 machine is 745 kWh/23 = 32,39 kWh. 32,39 kWh / 23,040 caps h^{-1}*
Water for cooling system	*Water, cooling, unspecified natural origin/m3*	*5.35E-06 m*	*The historic data of consumption of water due to evaporation in the cooling towers is 68 m^3. => 68m^3 / 23 injection machines => 2.96 m^3 / 552,960 caps day^{-1}*
Transport for HDPE (3)	*Truck 28t*	*2.64E-01 kg km*	*The transport distance in Brazil between the granulate and cap manufacturer is 110 km. 2.4 g x 110 km*
Plastic cap Gen. 3 (red)	*-*	*1 piece*	*Cap generation 3 (red) mass is 2.4 g.*
Waste oil	*Oil waste - GLO*	*1.81E-03 g*	*Burning of end-of-life oil.*
Polyethylene waste	*Polyethylene waste*	*2.4E-02 g*	*The plastic waste generated by the company for this product is 1%, according to historic data and including color setups. 2.4 g x 0,01*

3 Results and Discussion

Plastic Cap generation 1 (yellow) and 2 (blue)

The main results about LCIA for each one of the plastic caps generations was evaluated and discussed. The plastic cap, called in this paper as generation 1, is still being commercialized, but in a limited scale and directed for returnable packages, which did not change yet. In relation to generation 1 it was observed the impact associated to cap mass. To define the most relevant environmental impacts related to the plastic caps, that is, the impacts which have the highest values and consequently the most influence in the general results, a normalization was performed. To characterize the LCA results for plastic caps Agarski et al. (2019) selected global warming potential (GWP), photochemical oxygen-creation potential (POCP), acidifying potential (AP), and eutrophication potential (EP). GWP appeared in the work of Agarski et al. (2019) and also in the our normalized data, meeting the public concern for climate change, which is one of the most relevant aspect in our society. In addition to these, some other works bring results with the same characterization impacts for plastic materials, such as Toniolo et al. (2013) that use the LCA method to evaluate food packaging, and Xie et al. (2011) which compare different types of mild packaging in China.

The characterization was performed considering the five environmental impacts categories identified through normalization. The contribution of each entry of the inventory to the environmental impacts was observed, with emphasis on the electric energy with 49% for Carcinogens (CA) and 95% for Non-carcinogens (NC) category, the largest consume of energy is related with the injection machine operation, plus the Sliter and Liner machine that account for plastic caps generation 1 and 2.

For CA category the EVA copolymer was the most significant, representing 48% of the total impacts. In the other three main categories (RI, GWP and NRE) the most expressive entries of inventory are in the raw material phase, in which the polypropylene (PP) is responsible for around 70% and the Ethylene Vinyl Acetate (EVA) account for around 11% of these impacts. Sangwan and Bhakar (2017) performed an LCA to analyze the HDPE pipe manufacturing process in India and also found that the raw material phase to have the largest environmental impact. Energy is also very relevant, with an average of 9% for these three categories. Agarski et al.(2019) found that the energy consumption was the largest impact for plastic caps, but also relates this dimension of the impact to the mix of the type of energy generation in each country. That is the reason why in the AICV carried out in the case study company it does not carry so much of the impact of energy, since most of the energy generated in Brazil comes from hydroelectric plants.

The next step for LCIA was the single scoring step, which by adding the weighted values, aims to identify, through a comparison on the same basis, which inventory entries are most relevant in terms of environmental impacts. The single score results present that 67% of the impacts come from the production mix of the PP, followed by 12% from EVA production and the same 12% from electricity consumption, the sum of all the remaining items does not reach 9%. The last step on the LCIA was the damage assessment. This approach provides not only characterization (potential impacts of categories such as climate change) but also damage assessment for subjects such as human health, ecosystem quality and depletion of resources (Xie et al., 2011).

The Figure 2, the raw material PP is the entry with the greatest impact in three of the four damage impacts, it comprises 50% for "Human health", 64% for "Climate change", 77% for “Resources”, but only 9% for "Ecosystem quality". Polypropylene (PP) is one of the most widely used plastics (Campion et al., 2015), because of that there are transformers of this material all around the world. Taking this into account, it can be seen that the impact of transporting this material, even if it is done by truck, represents about 2% only in the average of the 4 damage categories, since the distance between the supplier and the cap factory in this case is only 110 km. The ecosystem quality, which combines the impact categories that were not previously discussed, behaves differently from the other three damage categories. The entry of the most impactful inventory is the cardboard packaging (31%) used for storage and transportation of the plastic caps between the manufacturer and the final packer of water or soda. The results show a similarity with the analysis made by Agarsky et al. (2019), reporting that the use of corrugated cardboard have the largest environmental impact for the packaging phase of the LCIA.

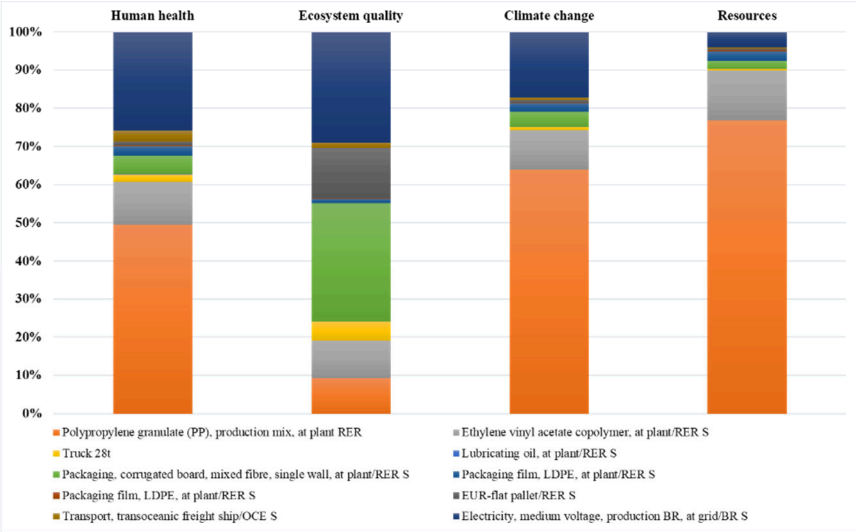


Figure 2 – Damage Assessment of Plastic Cap generation 1 (yellow caps)

The plastic caps, denominated in this study as generation 2 still being commercialized for one-way plastic bottles, but not by the biggest brands, thus having a reduced consumption volume in relation to the generation 3 caps. The concept of generation 2 plastic caps is basically the same as generation 1, with just a reduction of 0,3 g of PP on the mass of the cap. In the plastic cap generation 2, it was possible to see the same behavior as generation 1, and one of the main differences was the decrease in the representativeness of packaging inputs (cardboard box, plastic bags, stretch film, pallet), this is because the cap is a little smaller, than the number of caps per package increases (from 5,300 to 6,800 caps in the same box size) and, consequently, these impacts are divided into more times. There was also a reduction in the impact of the PP raw material and its transportation, precisely because this was the item that had a reduction in mass (11%).

Plastic Cap generation 3 (red)

The third generation of plastic caps presented in this study is the one that currently supplies the largest portion of the national beverage market. This cap represents the greatest technological evolution in the manufacture of caps for water and soda. For the cap of generation 3, the Sliter and Liner processes were eliminated, as the cap comes out ready in the injection process. In addition, the change of the raw material to Polyethylene high density (PE-HD) and in the product design, eliminated the need for the EVA seal. With that, the inventory for generation 3 had two entries less than the generations before, leaving out the raw material EVA and its transport.

For the carcinogens and non-carcinogens, the impact is directly related with the electricity, 73% and 96% respectively, according to Hesser et al., (2017), who tested a variety of materials and different machines of mold injection, the energy consumption dominates the contribution on impacts for all materials tested in this process. The packaging (box, bag, film and pallet) had its major impact in the carcinogen category, with a media of 8%. According to (Toniolo et al., 2013) using the IMPACT 2002+ method, it was revealed that a PET tray presents a high carcinogens impact because of the additive composition and the aluminum consumption for the additive packaging. For the other three environmental impacts (Respiratory inorganics, Global warming, Non-renewable energy) the most significant inventory entry was the raw material of HDPE with an average of 82% of influence, followed by electricity with just over 9% of average between impacts. HDPE is one of the most used material in injection moulding for plastic packaging because of its good properties, such as hardness, resistance to moisture and chemicals, flexibility, electrical insulation and recyclability (Agarski et al., 2019).

Regarding damage assessment (Figure 3), the first important point is that electricity and HDPE represent the major part of the damage associated with the inventory. It is worth mentioning that the entire impact load related to electric energy in this study, refers to the electricity spent inside the company's manufacturing plant and that the electricity used in the manufacture of HDPE resin is allocated inside the input of raw material. Repeating the previous generations, the raw material, although it was changed from PP to HDPE, continues to have the greatest expression in three of the four damage categories, with 64% of "Human health", 75% of "Climate change", 91% of "Resources" and only 12% " Ecosystem quality ". The "Ecosystem quality" category is expressed in Potentially Disappeared Fraction of species over a certain amount of square meter during a certain amount of year (PDF*m²*y) (Horodytska et al., 2020). For this category the total impact was 0,442 PDF*m²*y, being the most influential inventory entry, the cardboard boxes used for packaging (35%), followed by electricity (30%) and the wooden pallet (15%), also for packaging and transportation.

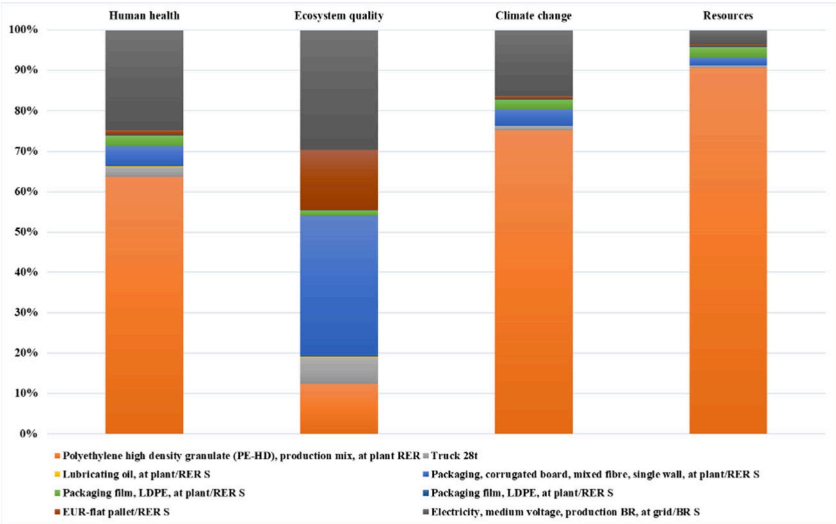


Figure 3 – Damage Assessment of Plastic Cap generation 3 (red)

Comparative ACV

Through the chart of comparative characterization between the three generations (Figure 4), taking generation 1 as a basis, is possible to quantify the environmental evolution of plastic caps. This shows that technological evolution has brought not only economic benefits (14% of cost reduction according to the case study company), such as the reduction of electricity consumption and the elimination of intermediate processes, but also a significant environmental gain for this product. The generation 2 cap had an improvement in environmental performance of around 5% considering the impact categories carcinogenic and non-carcinogenic, in addition to an average of 13% in the other 3 categories analyzed. All of this impact reduction is directly linked to the decrease in the mass of PP in the product. However, the biggest difference is in the cap generation 3, which, in relation to carcinogens, reached almost 64% reduction in impact when compared to generation 1. This environmental gain is related to the elimination of the need to use the EVA seal and its transport, which together accounted for 49% of the carcinogens in the generation 1 cap. Another favorable point was the decrease in the size of the product, generating an increase in caps by box, and thus reducing the aggregate impact of these packaging inputs on the final product. With regard to non-carcinogens, the reduction in the impact of generation 3 in relation to generation 1 was 32%, and in relation to the other three categories it was around 26%. These reductions were also impacted by the elimination of EVA, in addition to the reduction in mass, since the mass of EVA (0.4g) was not compensated with other material. Another important point for such an expressive result was the reduction in the total electric energy consumption of the process (31%), going from 6.41E-03kWh (generation 1 and 2) to 4.40E-03kWh (generation 3).

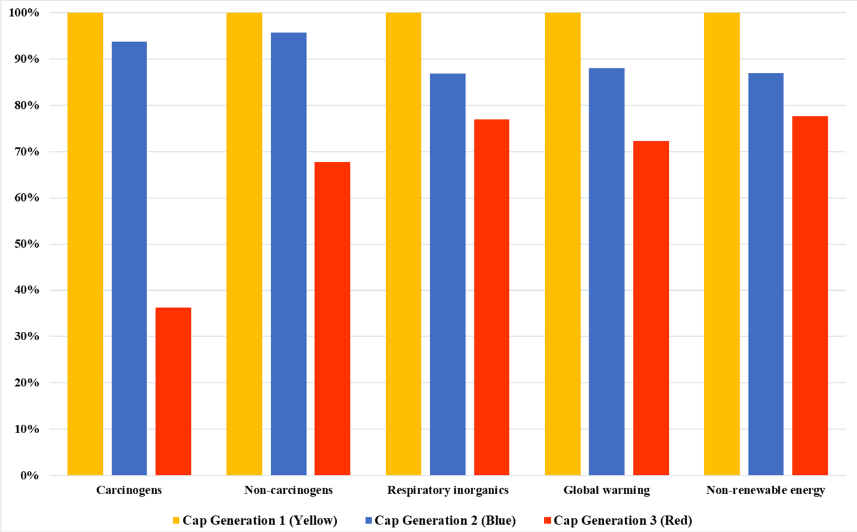


Figure 4 – Comparative characterization of the three generations

As can be seen in the comparative results obtained with each evolution of plastic caps, there is a significant reduction in aggregate environmental impacts. Another important perception is that the time to evolve from generation 2 to generation 3 was much shorter than the time to evolve from generation 1 to generation 2, that is, technological development is increasingly faster. So, what is expected for future developments? The truth is that there are already studies to further improve the environmental performance of plastic caps, such as the use of post-consumer recycled material (circular economy), the use of polymers made from renewable raw materials (biopolymers), and even more reduction of mass (dematerialization).

Conclusion

As it was shown in the results, the evolution of plastic caps is an example of what is possible to do developing Ecodesign and reducing the impact of consumption of plastic packaging, since the results of the LCA proved to be very relevant. In this scenario of evolution of plastic caps, there are some aspects to be better explored, such as: the use of biopolymers through an LCA from the cradle to the grave to assess the impacts generated and compare with the impacts with raw material from a non-renewable source. Another scenario for evaluation would be the environmental performance of the use of post-consumer recycled resin (PCR) in the injection molding process for plastic caps. Finally, the impacts of another dematerialization can be evaluated, as well as the exchange of intermediate packaging (which travels between the manufacturer of the caps and the industry that produce the water/soda) for returnable packaging such as that already exist in other industrial segments, thus being able to mitigate or even eliminate most of these impacts.

Acknowledgment – CNPq (303934/2019-0, 311531/2021-0 and 310228/2019-0)

References

Abejon, R., Bala, A., Vazquez-Rowe, I., Aldaco, R., Fullana-i-Palmer, P., 2020. When plastic packaging should be preferred: Life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. Resources Conservation and Recycling. 155.

Agarski, B., Nikolić, V., Kamberović, Ž., Anđić, Z., Kosec, B., Budak, I., 2017. Comparative life cycle assessment of Ni-based catalyst synthesis processes. Journal of Cleaner Production. 162, 7-15.

Agarski, B., Vukelic, D., Micunovic, M.I., Budak, I., 2019. Evaluation of the environmental impact of plastic cap production, packaging, and disposal. J. Environ. Manage. 245, 55-65.

Campion, N., Thiel, C.L., Woods, N.C., Swanzy, L., Landis, A.E., Bilec, M.M., 2015. Sustainable healthcare and environmental life-cycle impacts of disposable supplies: a focus on disposable custom packs. J. Clean. Prod. 94, 46-55.

Civancik-Uslu, D., Puig, R., Voigt, S., Walter, D., Fullana-i-Palmer, P., 2019. Improving the production chain with LCA and eco-design: application to cosmetic packaging. Resour. Conserv. Recycl. 151.

Elduque, A., Elduque, D., Clavería, I., Javierre, C., 2018. Influence of Material and Injection Molding Machine's selection on the electricity consumption and environmental impact of the injection molding process: An experimental approach. International Journal of Precision Engineering and Manufacturing-Green Technology. 5(1), 13-28.

Ellen Macarthur Foundation, 2018. ECONOMY, Circular. Ellen Macarthur Foundation.

Foolmaun, R.K., Ramjeeawon, T., 2012. Comparative life cycle assessment and life cycle costing of four disposal scenarios for used polyethylene terephthalate bottles in Mauritius. Environmental Technology (United Kingdom). 33(17), 2007-2018.

Kalbar, P.P., Karmakar, S., Asolekar, S.R., 2016. Life cycle-based decision support tool for selection of wastewater treatment alternatives. J. Clean. Prod. 117, 64-72.

Mendes, N.C., Bueno, C., Ometto, A.R., 2016. Avaliação de Impacto do Ciclo de Vida: revisão dos principais métodos. Production. 26(1), 160-175.

Niero, M., Hauschild, M.Z., Hoffmeyer, S.B., Olsen, S.I., 2017. Combining Eco-Efficiency and Eco-Effectiveness for Continuous Loop Beverage Packaging Systems Lessons from the Carlsberg Circular Community. Journal of Industrial Ecology. 21(3), 742-753.

Pauer, E., Wohner, B., Heinrich, V., Tacker, M., 2019. Assessing the Environmental Sustainability of Food Packaging: An Extended Life Cycle Assessment including Packaging-Related Food Losses and Waste and Circularity Assessment. Sustainability. 11(3).

Sangwan, K.S., Bhakar, V., 2017. Life cycle analysis of HDPE pipe manufacturing–a case study from an Indian industry. Procedia CIRP. 61, 738-743.

Toniolo, S., Mazzi, A., Niero, M., Zuliani, F., Scipioni, A., 2013. Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging. Resour. Conserv. Recycl. 77, 61-68.

Van Eygen, E., Laner, D., Fellner, J., 2018. Integrating High-Resolution Material Flow Data into the Environmental Assessment of Waste Management System Scenarios: The Case of Plastic Packaging in Austria. Environ. Sci. Technol. 52(19), 10934-10945.

Xie, M.H., Li, L., Qiao, Q., Sun, Q.H., Sun, T.C., 2011. A comparative study on milk packaging using life cycle assessment: from PA-PE-Al laminate and polyethylene in China. J. Clean. Prod. 19(17-18), 2100-2106.

In Giannetti, B.F.; Almeida, C.M.V.B.; Agostinho, F. (editors): Advances in Cleaner Production, Proceedings of the 11h International Workshop, Florence, Italy. July 15th, 2022

The Institutionalization of the Circular Economy of Packaging in Brazil from the perspective of *stakeholders*

CERQUEIRA-STREIT, JA [a*] , GUARNIERI, P [a] , SEHNEM, S [b] , MORAIS, DO [c] , BATISTA, L [d]

a. University of Brasilia-UnB, Brasília-Brazil

b. University of Western Santa Catarina-UNOESC, Chapecó-Brazil

c. FEI University Center, São Paulo-Brazil

d. Aston University, Birmingham-United Kingdom

**Jorge Alfredo Cerqueira Streit, jorgealfredocs@gmail.com*

Abstract

According to Institutional Theory, it is possible to internalize values in society and make certain attitudes considered appropriate or correct. In recent years, the Circular Economy (CE) is popular in management reports, and the Academy follows by investigating it increasingly. Circular Economy is understood as an opportunity to do business by maximising the usefulness of the product, through different practices and strategies. Therefore, this paper aims to analyse the situation in Brazil in the different stages of the process of institutionalisation of the Circular Economy of packaging. This is an applied, qualitative and descriptive study that used the triangulation between document analysis and in-depth interviews to collect data. The intention was to enable the confrontation of the perceptions of several stakeholders (cross analysis) in the packaging sector in Brazil. Fifty-three (53) stakeholders working in the packaging chain participated in the interviews. The results of the interviews were submitted to a content analysis, supported by the NVivo® software. From the perspective of stakeholders, the results point out the initial phase of institutionalization of the Circular Economy of packaging (habitualization) in Brazil. After all, even ten years after its sanction, the Brazilian Policy of Solid Waste Management (BPSWM) presents a low level of implementation. First because the country still has problems related to disposal in dumps, low recycling rates, little socio-productive inclusion of the waste pickers and low level of integration in waste management. Additionally, several stakeholders reported conflicts (objectification) and setbacks in terms of social control, making the sedimentation phase even more distant. The limitations of the study are associated with the difficulty of carrying out on-site visits to view the reality of the sector, directly associated with the restrictions imposed by the covid 19 pandemic period. The practical contribution is associated with the identification of barriers and challenges that make it difficult to institutionalize the circular economy of packaging. Such findings generate relevant contributions to different stakeholders. As recommendations for future studies, it is recommended to carry out a longitudinal study, of a specific packaging chain, to identify the barriers that arise in this chain in different geographic regions of the country.

Keywords : Institutional Theory; Circular Economy; Packaging; Waste Management; Environmental public policy.

1. Introduction

Brazil has a large territory and is among the leading emerging economies, the so-called BRICS (IPEA, 2014). As much as the country takes advantage of the climate, vegetation and land use to develop, the report of the Organization for Economic Cooperation and Development (OECD) shows that its economic activities have been inefficient because it generates significant environmental impacts, mainly atmospheric emissions and solid waste generation (OECD, 2015).

According to data from the Brazilian Association of Public Cleaning Companies and Special Waste (ABRELPE), in Brazil, approximately 6 billion dollars more are allocated annually to public services for the management of Urban Solid Waste (MSW) and urban cleaning (ABRELPE, 2021). More than 40% of all collected material in the country is still destined for dumps and controlled landfills. These locations are considered environmentally unsuitable as they do not have the infrastructure to minimize environmental impact. As much as these areas are gradually being closed in the country, it is estimated that it would take another 55 (fifty-five) years to complete the activities of all dumps and controlled landfills in Brazil if the current pace is maintained (ABRELPE , 2020).

Therefore, the concept of Circular Economy (CE) arises as a proposal to do business innovatively way: considering the design of the products/processes, the direct and reverse logistic flow, integrating the s*upply chain* in order to reduce the negative impacts on the environment through actions of Reduction, Reuse, Recycling (3Rs), among others (Batista, Bourlakis, Smart, & Maull, 2018). The 3Rs, when applied to packaging (plastic, paper, glass, aluminium or any other material), tend to contribute not only to environmental issues but also to reduce waste management costs and to enable the socio-productive inclusion of waste pickers (Guarnieri, Cerqueira-Streit, & Batista, 2020).

Brazil still does not have any legislation or government guidelines that directly cite the Circular Economy. However, given its principles, instruments and objectives, the BPSWM (Brazilian Policy of Solid Waste Management) is closest to the concept of Circular Economy (Guarnieri et al., 2020; Pereira et al., 2020). This law, enacted in 2010 represented an important milestone in environmental legislation by legitimising the search for integrated solid waste management (BRASIL, 2010; Domingues, Guarnieri, & Cerqueira-Streit, 2016). Summarising, the BPSWM is the Brazilian legal instrument that is most in line with the principles of the circular economy and, consequently, its real implementation is what would elevate Brazil to a nation towards CE.

To make something institutionalised, according to Institutional Theory (IT), is to make it possible for society to internalize values, causing certain attitudes to be considered appropriate or correct (Peci et al., 2006) . Through the legitimation of these patterns, long-term repetition occurs, which inevitably shapes the dynamics of the actors that make up such a society (Stacey & Rittberger , 2003). A sequential logic of phases in the institutionalization process was observed and theorised by Tolbert & Zucker (1999), and the generic model created helps analysts understand various social phenomena.

According to Fischer & Pascucci (2017), there is still a lack of studies investigating the institutions involving the Circular Economy. In turn, Masi et al. (2017) noticed the absence of empirical investigations that analyse the performance of actors in the construction of a circular supply chain. CE is a topic that grows exponentially. Even though we have advanced in scientific investigations, we still have the potential for sectoral engagement, especially for the implementation of CE practices, adherence to business models and approval of federal laws and sectoral agreements that can serve as guidelines for the effective implementation of CE. In order to contribute to filling these gaps, this paper aims to analyze the situation in Brazil in the different stages of institutionalisation of the Circular Economy of packaging.

In addition to this introduction, the *paper* brings a theoretical framework on waste management for Brazil, its relationship with CE and Institutional Theory. The classifications and methodological steps of the case study performed are presented. Each of the three phases of institutionalization are explained and the country's position is demonstrated, based on the content analysis of the interviewees. Final considerations bring suggestions for future research and the main limitations of empirical investigation.

2. Methods

Institutions are standards, and models to follow; after all, they have significance in specific communities. Participants in an institutionalised environment perceive norms as something legitimate, efficient or modern and, therefore, these environments are difficult to change. In addition to being rare, institutional changes are slow and incremental (Stacey & Rittberger, 2003). Therefore, institutionalisation not only collaborates to integrate and organize society, as it is the result of a process built by different actors, internalized and transmitted over time. Qualitative research and case studies are standard methodological options for scholars of Institutional Theory. According to Tolbert & Zucker (1999), Institutional Theory was developed free of well-defined metrics or variables. This paper, in fact, is of great relevance for the studies developed later, as it offers a general model of institutionalisation that proposes a logical sequence. According to the authors, this model serves for empirical applications in analysing phenomena from the perspective of the Institutional Theory (Tolbert & Zucker, 1999).

As for nature, it is an applied investigation considering that it involves local interests (Brazilian reality in solid waste management) (Patton, 1990). Qualitative in terms of approach, since it gives up statistical techniques, as we consider the topic as subjective and too complex to be translated into numbers (Miles & Huberman, 1994). Regarding the purposes, it is a descriptive study to report what was observed in detail in the management of packaging waste in Brazil in the transition to the Circular Economy from the perspective of Institutional Theory (Cunliffe, 2011).

Regarding the technical procedures, the case study was used, whose unit of study is the packaging sector in Brazil. The case study was structured according to Eisenhardt (1989). The triangulation of data instruments was carried out (Oppermann, 2000) based on documental analysis and in-depth interviews, based on a semi-structured script. The opinions of several *stakeholders* working in the Brazilian packaging sector were also confronted. Given the COVID-19 pandemic, on-*site visits* were not carried out. The interview script underwent semantic validation by judges (Greco et al., 2015). The selection of judges was based on their well-known knowledge of the subject: all 5 (five) are PhD professors from different universities with publications on related topics. Corrections and adjustments were made after the suggestions of experts.

The actors who participated in the process of formulating the Brazilian Policy of Solid Waste Management (BPSWM), declared in Almeida & Gomes (2018), were also sought after as those who consented to the Sector Packaging Agreement. The snowball technique also helped the researchers to gather more qualified respondents. This type of sampling method is justified in contexts where the population is small or imprecise, or with groups that are difficult to access (Noy, 2008). The packaging chain in Brazil has these last two characteristics. The possibility of conducting interviews remotely expanded the researcher's ability to reach a more significant number of Federative Units. More than 200 *stakeholders* were contacted over the four months of data collection (March-June 2021), the researchers conducted 54 interviews. In one of them, the investigators did not have access to the recording (*Zoom meetings*) and therefore could not transcribe it later. By disregarding this interview, 53 (fifty-three) valid interviews with actors who work directly or indirectly with the packaging chain in Brazil.

After transcribing the recorded interviews, content analysis could be conducted. According to Bardin (2011), content analysis occurs in at least three stages: pre-analysis, exploration, interpretation and treatment of results. NVivo® allows the reading and classification of speech in codes created by the researchers. The codes are the analysis categories analised later; in this case, the codes came from the interview responses. Also, it provides the freedom to separate codes into folders and divide them into hierarchical levels and subfolders. The result of coding is the possibility of aligning and standardizing the subjects' speeches (Alves, Figueiredo Filho and Henrique, 2015).

The main categories were created *a priori* , that is, before the researchers went "into the field" to collect data. From the literature on Institutional Theory, it was understood that "Policies and incentives" was the minimum content for the first phase of institutionalization (Habitualisation). Seeking consensus and reducing divergences was the second step to advance (Objectification), and therefore, the category "Main points of divergence" was created. Finally, it is known that to reach the last phase of institutionalization (Sedimentation), it is necessary that "Alignment of processes, policies and social control", title of the last category created for this article (Tolbert & Zucker, 1999).

3. Results

3.1 First phase of the institutionalization of EC packaging in Brazil: policies and incentives

Institutionalization is the process of creating and perpetuating actions and behaviours in an actor or a social group, with the objective of solving a particular problem (Tolbert & Zucker, 1999). To the authors, the first phase, called "habitualisation" or "pre-institutionalisation" creates a structural arrangement with policies and procedures that help organizations and actors to solve the problem in question. The question of the interview script that guided this research asked each of the 53 (fifty-three) respondents to comment on existing policies and incentives for improving solid waste management in the sense of the Circular Economy. These practices were exemplified as actions to minimise the generation of waste, to face the inappropriate disposal, waste, among other problems involving the theme.

As stated by Jardim et al. (2021), most of the actors in the packaging chain who participated in this research claim that there are no policies or incentives that favour what is advocated by Law 12,305/10 and its regulatory decree (nº 7,404/10). Of these, at least 17 of the interviewees remembered that these instruments are present in the regulations, even though they do not perceive their practical applicability. The second most common opinion among those heard by this research is that economic instruments are needed to implement the BPSWM to take place and steps to be taken toward the Circular Economy. The polluter pays principle, for example, has been present in Brazilian Environmental Law since Law nº 6,938 of 1981 (PNMA - National Environmental Policy), and the BPSWM included it as one of its principles (BRAZIL, 2010). Although likely to induce less aggressive behaviour to the environment, instruments such as the polluter-pays are immersed in confusing legislation that lacks greater coherence in terms of recycling, according to Cavalcante (2014).

In Brazil, there is still no differentiated taxation for those who work with Reverse Logistics or Circular Economy practices, neither for companies nor for cooperatives and associations of recyclable materials (Araújo & Vieira, 2017). Instead of having stimuli, it is clear that double taxation is a recurring complaint from respondents. So, the (re)incidence of taxes for recyclable materials and the absence of economic incentives represent barriers to implementing the PNRS with proper socio-productive inclusion, which consequently delays the institutionalization of CE in the country.

The interviewees raised a lack of articulation between actors as a justification for the absence of programs and incentives that lead to compliance with the PNRS. It should be noted that Law 12,305/10 took more than twenty years to be enacted, and the principle of shared responsibility for the product life cycle was one of the factors that contributed to this delay (Domingues, Guarnieri and Cerqueira-Streit, 2016).

Even if in Brazil the packaging reverse logistics system were properly implemented, the packaging circular economy (CE) would not be guaranteed. After all, the comprehensive CE concept goes beyond Reverse Logistics, including refillable, returnable packaging with an appropriate *design* for reuse. In its different spheres, the Brazilian government still seeks to share the costs of waste management with the private sector, a fact that must precede broader and necessary articulations for the Circular Economy.

Even among those who do not see actions for the first phase of institutionalization of the Circular Economy in Brazil (habitualisation), part alleges a lack of political will. Besen et al. (2017) focused on the remuneration of recyclable material waste pickers, but the context is also the implementation of the reverse logistics system in the country. Political will and coordination are essential to combat the challenge of dual ownership of waste management (public and private organisations passing on responsibility for post-consumer materials to each other). The authors conclude by stating that political and economic instability does not facilitate negotiations or contribute to advancing compliance with the packaging sector agreement (Besen et al., 2017).

Some findings should be highlighted, concerning to the investigation of the first phase of the institutionalisation of CE packaging in Brazil (policies and incentives), based on the content analysis of the speeches of the interviewed *stakeholders..* The main is the essentiality of the construction and operation of economic, financial and credit instruments, as provided for by Law 12,305/10. Although it was not enough to achieve a full Circular Economy, the expansion of measures currently regionalised would bring positive consequences, such as the increase in recycling rates and consequent extension of the material's useful life.

3.2 Second phase of the institutionalisation of CE packaging in Brazil: reduction of conflicts and convergence of interests

According to Greenwood et al. (2004), a usual criticism of studies that use institutional theory, is the focus given to this second phase of institutionalisation: objectification. Also called semi-institutionalisation by Tolbert & Zuckert (1999), this stage is about the collective development of understanding of the fact, the sharing of socially accepted meanings and, thus, initiating the alignment of behaviours (Clegg et al., 1997).

In this sense, another question was elaborated on and applied to the stakeholders of the Brazilian packaging chain. If they do not consider a consensus among the participants in the chain, the interviewees were invited to reflect and externalise the main existing differences. Therefore, it should be noted that the same participant may have been categorised in more than one response.

The results show that, in general, there is no consensus among the participants in the packaging chain and conflicts are easily observed. The state of São Paulo is more advanced than most states in terms of implementing reverse packaging logistics, especially after CETESB began to charge companies for Reverse Logistics actions before issuing the mandatory environmental licensing (Cetesb, 2018).

Corroborating the results of this research, the low participation of manufacturers, importers and traders is understood as a major barrier to this crucial principle of packaging reverse logistics. Additionally, Ribeiro & Kruglianskas (2020) addressed the existence of "*free riders*", companies that take advantage of the fact that there is no supervision and, even without complying with the law, are not penalised due to the actions of the government or other companies (Ribeiro & Kruglianskas, 2020). Aspects such as "inaction" or "free rides" by the business community not only generate conflicts but also hinder and discourage compliance with legislation.

Within the analysis of the factors that hinder the semi-institutionalisation (phase 2) of institutionalization, it is worth emphasising the speech space that recyclable material waste picers have received since the sanction of the BPSWM. Law 12,305/10 is also considered innovative for including waste picker´s organizations in corporate and municipal programs for shared responsibility for solid waste management. According to Guarnieri & Cerqueira-Streit (2015), the socio-productive inclusion of this category is able of positively impacting the income and quality of life of thousands of workers who live on the margins of the formal labour market and find sustenance for themselves and their families in urban waste.

However, 11 of the 53 (fifty-three interviewees) mentioned the attempt to formalise the waste pickers as an amplifying factor of conflicts in the reverse logistics systems of packaging in general. Most of these 11 believe that there is an old social exclusion and that historically marginalized people will not be easily accepted by the holders of capital or even by rulers. Not only the fact that cooperatives have started to participate in management meetings has generated conflicts. There is also an understanding that traders and Brazilian civil society are still poorly aware of the consequences of poor waste management.

The regional differences revealed by the inequalities in logistics infrastructure were also remembered as a reason for conflicts between the actors. Dealing with topics such as Reverse Logistics and Recycling is less complex in southern and southeastern states when compared to the rest of the country due to the better highways and more significant presence of recycling industries.

Batista, Gong, Pereira & Jia (2019) and Rutkowski & Rutkowski (2015) also identified the lack of public infrastructure as a barrier to collecting and recycling recyclable materials. Although other interviewees had a similar opinion, this type of thinking is evident when analysing the content of the speech of the FUNASA (National Health Foundation) server located in Boa Vista-RR, here identified as PPF3:

> *PPF3: We are far from consensus. The main divergence is this: the question of social equity. The collector is the most fragile part because the "aparista" who buys from him is a millionaire and the industrialist who buys from the aparista is a multi-millionaire. Due to the infrastructural issue and financial capacity, they still cannot go much further. The law has to help reach a consensus, but… those companies pay for the Governor's campaign, understand? There is a conflict that is a national history: whoever owns the capital tends to influence more. But whoever wins the most does not want to give up, so we will be in a conflict until we have legislation that takes the issue of social equity seriously.*

Although they could be included in the category "Industry exempts itself from responsibilities", *greenwashing* practices, inadequate *design* and work overload and costs for the municipality were also reported by the interviewees. As these actors were more specific in their speech, it was decided to present separately from the broader category. *Greenwashing* can be exemplified when companies exaggerate or overestimate their environmental actions, omit relevant information about their actual impact, or provide consumers and investors with vague and untraceable information (Testa et al., 2021).

Figure 1 illustrates the factors that tend to generate disputes between participants in Brazil's packaging chain in general. In a didactic way, the aim is to highlight the results pointed out by the participants of this research.

In addition to other impacts, when trying to maintain the *status quo* and not absorb the costs and reverse logistics activities, industries also strain municipal waste management systems. City halls are increasingly pressured in the operational and in the budgetary sense if the companies that place the products and their packaging do not engage in collecting them.

Figure 1 - List of the main points of conflict in the packaging Reverse Logistics chain

In order to investigate the situation of circularity in the packaging sector in Brazil, concerning the second phase of institutionalisation of the CE, the interviewees were asked about the existence of consensus and the main differences. The responses were unanimous in indicating that there is no consensus and there are many points of conflict between *stakeholders*. Thus, it appears that Brazil is not in the second phase (objectification) of the EC of packaging in general.

3.3 Third phase of the institutionalisation of CE packaging in Brazil: alignment of processes, policies and social control

The third stage of institutionalisation can also be called sedimentation, according to Tolbert & Zucker (1999). The degree of sustainability (in the sense of maintenance) is guaranteed when a set of behaviours reaches this third level. After all, these behaviours gain a high level of alignment, standardisation and there is even a social demand for them not only to be maintained but also to be transmitted to others over time (Clegg et al., 1997). The question contained in the interview script sought to know from the packaging sector *stakeholder* interviewed about the possible existence of alignment and standardisation of processes, policies as well as the role of social control so that Brazil walks towards the Circular Economy. A minority of respondents perceive actions of standardization and social control and of these, a portion praises the work of control bodies, such as state sanitation companies and State Public Ministry (MPE).

The vast majority of respondents cannot perceive harmony between policies and waste management programs in Brazil, as well as control by society; some respondents claim to lack reliable data and collection mechanisms. Pereira et al. (2020) comment on the fragility of SINIR (National Information System on Solid Waste Management) in the face of regional inequalities present in the country. The lack of trained personnel and adequate equipment, make it difficult for many municipalities to feed the system with feasible data. In their opinion, the more industrialized the state, the more consistent the completion of the SINIR tends to be. Most interviewees believe that there is no alignment of practices, policies or social control because primary civil environmental education is lacking. After all, policies need to be discussed before they are even implemented. If the people are involved even before it is sanctioned, citizens tend to want to participate in decisions. On the other hand, there is a tendency to widen the distance between society and environmental lawmakers when there is no organic interest of the citizen due to ignorance on the subject. It is up to Environmental Education to be this helpful sensitisation instrument to summon the population to environmental practices in the environment in which it is inserted (Garcia et al., 2020).

Selective collection in households and the participation of waste pickers for collection and sorting are fundamental for the Circular Economy to occur in Brazilian territory. However, for the population there is still a lack of formal and non-formal educational programs. For collectors, there is a lack of physical structuring and business models that include it. In addition, there is a discrepancy in the payment to waste pickers. Given that, normally, these actors receive only the material sold and not the environmental service provided to remove waste from the streets across the country (Monte & Brega Filho, 2021).

As it occurs in Brazil today, the management of solid waste allocates public money to various actors who profit from not adopting circularity measures. Industries, municipalities and urban cleaning companies (*stakeholders* influential) shy away from greater changes while waste pickers, NGOs, universities and civil society (considered less significant *stakeholders*) suffer the consequences of an excluding and polluting system. Given the results obtained, the discussion with the literature and the findings made, the *framework* of Tolbert & Zucker (1999) was adapted for the case studied (Figure 2).

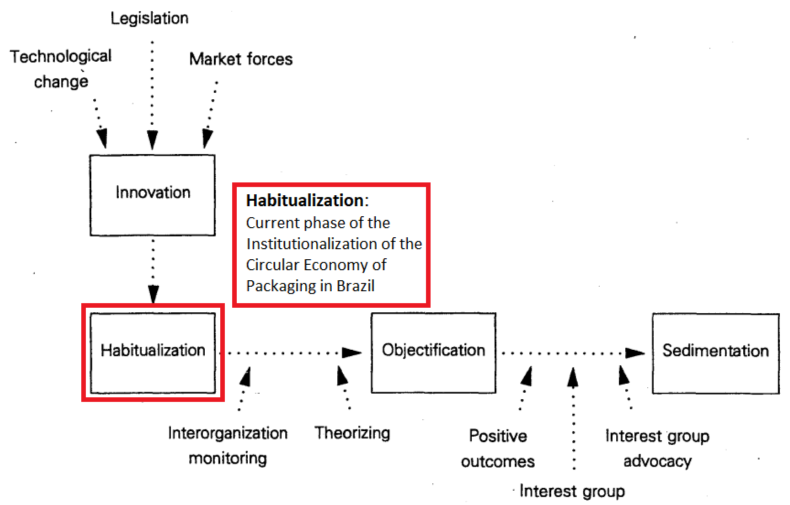


Figure 2 – The components of the process and the current phase of institutionalisation of the Circular Economy of packaging in Brazil - Adapted from Tolbert & Zucker (1999)

Challenges related to the population's lack of knowledge, lack of political will on the part of government officials, *lobbies* and obscure contracts with urban cleaning companies, among others related to the logistical infrastructure and dismantling of the BPSWM, lead this research to the conclusion that Brazil is in the phase of habitualisation of institutionalisation of the Circular Economy, based on the perception of *stakeholders* interviewed, and without the intention of generalisation. After all, according to the document analysis and the semi-structured interviews carried out, there are still many conflicts between the actors, strong resistance from interest groups as well as a low level of alignment of practices and social control.

4. Final Remarks

Directly answering the question of this research: Brazil is in the phase of habitualization of institutionalization of the Circular Economy of packaging. For full institutionalization, it is necessary to overcome the resistance of coalitions/interest groups and make society itself, inspecting such behaviour.

Historically in Brazil, industries have enough influence and power to manipulate public policies. Additionally, the attempt to include waste pickers (for legal compliance) tends to be an amplifier of conflicts in the chain, considering that, for decades, this category was distant from decision-making. The social and economic crisis that Brazil is going through tends to aggravate class conflicts, and the resumption of growth is usually driven by consumption. Thus, a paradoxical situation arises: the current capitalist logic does not seek to reduce waste. On the contrary, greater consumption is stimulated, and society wants it. And this process is currently more profitable for industries, distributors, retailers and waste pickers.

The main theoretical contribution of the study is associated with the systematization of evidence that signal the current stage of institutionalization of the circular economy of packaging in Brazil. The practical contribution is associated with the identification of barriers and challenges that make it difficult to institutionalize the circular economy of packaging. Such findings generate relevant contributions to different stakeholders, namely:

a) Government: which needs to advance in the official formalization of legal guidelines for the implementation of the circular economy in the most different sectors and levels (micro, organizational, sectoral, regional and country level). Specific public policies for regions and sectors to accelerate this transition;

b) Sectoral chains: the need to articulate between the links in the production chains to find mechanisms to overcome the barriers and challenges of institutionalization in the country. In addition, the implementation of basic infrastructure to make circular economy possible and efficient;

c) Sectoral entities: the need to create awareness campaigns, cooperation, engagement and understanding of barriers and challenges, to create strategies to overcome them;

d) Educational institutions: to provide research that can support the advancement of the circular economy in the country at different levels;

e) Citizens in general: the study highlights a set of findings that should serve as a reflection for society in general to change behaviours. For this to be possible, public policies and legal guidelines are necessary.

The limitations of the study are associated with the difficulty of carrying out on-site visits to view the reality of the sector, directly associated with the restrictions imposed by the covid 19 pandemic period. As recommendations for future studies, it is recommended to carry out a longitudinal study, of a specific packaging chain, to identify the barriers that arise in this chain in different geographic regions of the country. As it is a continental country, the infrastructure available in the different territorial regions can be an obstacle to the agility of institutionalization of the circular economy in certain regions.

References

ABRELPE, Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais, 2021. *Panorama dos Resíduos Sólidos no Brasil 2021*.
Almeida, L. de A., & Gomes, R. C., 2018. Discurso e Poder na Formulação de Políticas Públicas Ambientais: O Caso da Política Nacional de Resíduos Sólidos. *Desenvolvimento Em Questão*, *16*(44), 133-167.
Alves, D., Figueiredo Filho, D., & Henrique, A., 2015. O poderoso NVivo: Uma introdução a partir da análise de conteúdo. *Revista Política Hoje*, *24*(2), 119–134.
Araújo, M.G., & Vieira, A.O., 2017. A Economia Circular pode ser solidária. In *Política nacional de resíduos sólidos: implementação e monitoramento de resíduos urbanos*. 57–70. IEE-USP: OPNRS.
Bardin, L., 2011. *Content Analysis* . Editions 70.
Batista, L., Bourlakis, M., Smart, P., & Maull, R., 2018. In search of a circular supply chain archetype–a content-analysis-based literature review. *Production Planning and Control* , *29*(6), 438–451.

Batista, L., Gong, Y., Pereira, S., Jia, F., & Bittar, A., 2019. Circular supply chains in emerging economies: a comparative study of packaging recovery ecosystems in China and Brazil. *International Journal of Production Research*, *57*(23), 7248-7268.

Besen, G.R., Jacobi, P. R., & Freitas, L., 2017. *Política Nacional de Resíduos Sólidos: implementação e monitoramento de resíduos urbanos*. São Paulo-SP. IEE USP: OPNRS.

Brazil, 2010. *Lei nº 12.305 de 2 de agosto de 2010 que institui a Política Nacional de Resíduos Sólidos*.

Cavalcante, D.L., 2014. Instrumentos fiscais na efetivação da Política Nacional de Resíduos Sólidos: do poluidor-pagador ao protetor-recebedor. In *Tributação ambiental: reflexos na Política Nacional de Resíduos Sólidos*. 141–158. Editora CRV.

Cetesb, Companhia Ambiental do Estado de São Paulo, 2018. Decisão De Diretoria Nº 076/2018/C, de 03 de Abril de 2018. *Diário Oficial Estado de São Paulo - Caderno Executivo I*, *128*(61), 86–87.

Clegg, S., Hardy, C., & Nord, W., 1997. *Handbook of Organization Studies*. SAGE Publications.

Cunliffe, A.L., 2011. Crafting qualitative research: Morgan and smircich 30 years on. *Organizational Research Methods*, *14*(4), 647-673.

Domingues, G. S., Guarnieri, P., & Cerqueira-Streit, J. A., 2016. Princípios e Instrumentos da Política Nacional de Resíduos Sólidos: Educação Ambiental para Implementação da Logística Reversa. *Revista Em Gestão, Inovação e Sustentabilidade*, *2*(1), 191–216.

Eisenhardt, K.M, 1989. Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

Fischer, A., & Pascucci, S., 2017. Institutional incentives in circular economy transition: The case of material use in the Dutch textile industry. *Journal of Cleaner Production*, *155*, 17–32.

Garcia, M. A., Zaneti, I. C., Yonamine, S. M., Silverio, A. P., Cerqueira, E. N., & Meira, M. G. L. (2020). Duas décadas da PNEA: Avanços e Retrocessos no Brasil. *Revista Brasileira de Educação Ambiental (RevBEA)*, *15*(5), 250–270.

Greco, P. J., Perez Morales, J. C., Aburachid, L. M., & Silva, S. R. (2015). Evidência de validade do teste de conhecimento tático processual para orientação esportiva - TCTP: OE. *Revista Brasileira de Educação Física e Esporte*, *29*(2), 313–324.

Greenwood, R., Oliver, C., Sahlin, K., & Suddaby, R., 2004. *The Sage Handbook of Organizational Institutionalism*. Thousands Oaks: Sage.

Guarnieri, P., & Cerqueira-Streit, J.A, 2015. Implications for waste pickers of Distrito Federal, Brazil arising from the obligation of reverse logistics by the National Policy of Solid Waste. *Latin American Journal of Management for Sustainable Development*, *2*(1), 19–35.

Guarnieri, P., Cerqueira-Streit, J., & Batista, L., 2020. Reverse logistics and the sectoral agreement of packaging industry in Brazil towards a transition to circular economy. *Resources, Conservation and Recycling*, *153*, 104541.

IPEA, Institute for Applied Economic Research, 2014. VI BRICS Academic Forum.

Jardim, A., Biazini Filho, F., Mello, I.O., Machado Filho, J.V., & Penido, M.R., 2021. Reflexões sobre os instrumentos econômicos da Política Nacional de Resíduos Sólidos decorridos 10 anos da sua implementação. In: *10 anos da Política Nacional de Resíduos Sólidos: caminhos e agendas para um futuro sustentável*, 55–61. IEE-USP: OPNRS.

Masi, D., Day, S., & Godsell, J., 2017. Supply chain configurations in the circular economy: A systematic literature review. *Sustainability (Switzerland)*, *9*(9), 1602

Miles, M., & Huberman, M., 1994. *Qualitative data analysis: An expanded sourcebook* (Vol. 2). SAGE Publications.

Monte, W.R., & Brega Filho, V., 2021. Pagamento por Serviços Ambientais aos catadores de materiais recicláveis como instrumento de inclusão social. *Direito Ambiental e Sociedade*, *11*(1), 125–157.

Noy, C., 2008. Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology*, *11*(4), 327-344.

OCDE, Organização para a Cooperação e Desenvolvimento Econômico., 2015. *OCDE - Avaliações de Desempenho Ambiental: Brasil*.

Oppermann, M., 2000. Triangulation: A Methodological Discussion. International Journal of Tourism Research, *146* (2), 141–146.

Patton, M., 1990. Designing Qualitative Studies. In SAGE (Ed.), *Qualitative evaluation and research methods* , 169–189.

Peci, A., Vieira, M. M. F., & Clegg, S. R., 2006. A construção do "Real" e práticas discursivas: o poder nos processos de institucionaliz(ação). *Revista de Administração Contemporânea*, *10*(3), 51–71.

Pereira, A., Ribeiro, F.M., Jeffrey, R., & Doron, A., 2020. Waste policy reforms in developing countries: A comparative study of India and Brazil. *Waste Management and Research*, *38*(9), 987-994.
Ribeiro, F.M., & Kruglianskas, I., 2020. Critical factors for environmental regulation change management: Evidence from an extended producer responsibility case study. *Journal of Cleaner Production*, *246*, 119013.
Rutkowski, J.E, & Rutkowski, E.W., 2015. Expanding worldwide urban solid waste recycling: The Brazilian social technology in waste pickers inclusion. *Waste Management and Research*, *33*(12), 1084–1093.
Stacey, J., & Rittberger, B., 2003. Dynamics of formal and informal institutional change in the EU. *Journal of European Public Policy*, *10*(6), 858–883.

Testa, F., Di Iorio, V., Cerri, J., & Pretner, G., 2021. Five shades of plastic in food: Which potentially circular packaging solutions are Italian consumers more sensitive to. *Resources, Conservation and Recycling*, *173* (1), 105726.

Tolbert, P.S, & Zucker, L.G, 1999. The Institutionalization of Institutional Theory. *Studying Organization: Theory & Method*, *1*, 169–184.

realization by

UNIVERSITÀ DEGLI STUDI FIRENZE

UNIP UNIVERSIDADE PAULISTA — Graduation Program on Production Engineering, Master and Doctorate Levels

organized by

Advances in Cleaner Production Network

Boosting Knowledge Exchange Seeking Sustainability

in participation with

ACPN Global Center

ACPN African Center

ACPN Asian Center

ACPN European Center

ACPN North American Center

ACPN Center American, South American and Caribbean Center

ACPN Oceanian Center