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Evaluating producers as resource consumers and alternative consumption patterns: Outcomes from emergy synthesis of the jeans supply chain

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ABSTRACT

Under the mainframe of current consumption patterns and large supply chains based on profit making practices and conventional technologies, resource and energy management are key topics for sustainable development. Enhancing the resource/energy efficiency is decisive to achieve appropriate decision making, but all producers-driven actions must be in alignment with the perceptions of customers. The Textile Industry sector in Brazil has a strategic contribution to the economy of the country, employing more than 1.5 million workers and using intensive environmental, social, and economic resources. Decision making in this sector depends not only on identifying bottle necks at each textile production step to implement actions, but also on the customer sensitivity for designing and improving the effectiveness of recycling policies and programs for post-consumer materials. Emergy accounting can help measuring the environmental work required to generate their products, the linkage between resource and economy, and to monitor chains' operations. This study points out to evaluate the efficacy of producers and consumers actions on the textile supply chain system using the emergy synthesis tool. Results show that combined producer/consumer-driven actions improves the environmental performance of the chain, and help to increase the efficiency of resources use, deal with technology restrictions and recognize consumption patterns.

1. Introduction

Responsible Consumption and Production (SDG12) is targeted to guarantee sustainable consumption and production patterns that must be incorporated into policies, business and consumer attitudes, while observing international rules on emissions and waste management (UNDP, 2020). Greening supply chains and greening consumerism require understanding on how progress can be made on SDG 12, and solutions may consider different sections of supply chains ranging from agriculture and extractive industries to individual consumer needs. Responsible consumption and production in decision-making must consider the interactions between human and environmental systems through the economic system in different ways that may cause different environmental problems with non-trivial solutions (Tseng et al., 2018a). Most of these problems are multidimensional and complex with unexpected and unplanned after-effects, and within this context, emergy synthesis may be a valuable tool to handle multifaceted problems from the perspective of the environment as a supplier of energy and resources.

This study exploits a textile production chain under the lens of SDG12 applying emergy synthesis on the fifth largest textile producer in the planet. The Brazilian textile sector employs more than 1.5 million workers, which represented about 18% of industry workers in the country (IEMI, 2016). The textile production chain incorporates agriculture, industrial sectors and services, and the trajectory of textiles goes through many processes, as cotton cultivation and harvesting, fiber treatment, thread manufacture, and fabric preparation and processing, which include bleaching and dyeing processes. Jeans manufacturing is one of the principal subsectors of the textile industry and its manufacturing processes brings forward environmental concerns, whose solutions include technical improvements, organizational transformation/innovation and changes in consumer habits.

The sector has been evaluated mainly with the use of life cycle assessments (LCA). Baydar et al. (2015) provided a matrix of environmental concerns associated with the sector, and the most significant was

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related to the use of agrochemicals for cotton cultivation. A comparison of the environmental impacts of eco-t-shirts and conventional t-shirts revealed that eco t-shirts had a low potential impact on all inspected categories, with the major reduction in the potential for aquatic eutrophication. However, the global warming potential at the use phase was comparable for both t-shirts. Nieminen et al. (2007) applied LCA to five European textile industries and identified the most polluting stages within the companies. The life cycle was used to encourage the correct development of new technologies for textile products. Eryuruk (2012) analyzed how green the textile and clothing industry could be including raw material usage, design, production and logistics, and Morita et al. (2020) inspected the value of actions for improving environmental issues and energy use in the supply chain of jeans produced in Brazil. The LCA indicated CO_2 and N_2O emissions in cotton cultivation, and CH_4 and CO_2 releases at the industrial stage as the main impact sources. Still under the LCA framework, Li et al. (2020) assessed the chemical footprint to categorize the chemicals with higher toxic effect, including the initial inputs of chemical raw materials and the final emissions of chemical pollutants. Using the jeans production as a case study and the USEtox model, numerous chemical pollutants contributing to ecological and human toxicities were pinpointed during the life cycle of the wet treatment process. These authors provided a practical guidance for the reduction in the toxic impact of chemicals on individuals and ecological environment.

Jeans manufacturing also demands a huge quantity of water. Dyeing and finishing/washing processes are the main sources of pollution in this sector, and the resulting wastewater contains large amounts of chemicals and residual dyes. Chico et al. (2013) estimated the water footprint for in five types of textiles commonly used for the jeans production, including different fibers (cotton and Lyocell) and five different methods for spinning, dyeing and weaving. The results showed that the fiber production stage is the major consumer of water, with cotton production being especially significant. The study also analyzes the effects of external factors on the product's water footprint. Garcia (2015) reviewed the radical changes that the jeans washing industry has undergone, going from an artisanal period to an intensive industry towards a knowledge-based industry, paying attention to workers and the environment. In the study, washing jeans with laser, ozone and nano-bubbles is described, and the effectiveness the proposed methods and current and future trends are discussed.

Based on the idea that eco-efficiency combines the ecological impact and economic welfare throughout the lifecycle of products. Using a lifecycle approach along and eco-efficiency indicators, Angelis-Dimakis et al. (2016) presented a methodological framework for assessing water use. The framework was applied to a regional textile industry in Italy, and the major environmental impacts were freshwater resource depletion, and human toxicity and ecotoxicity. Wu and Chang (2007) assessed the eco-efficiency of the dyeing sector in China using the input-output analysis model and claimed for the incorporation of environmental costs to be considered by the corporation's decision makers. The authors structured a green accounting model for an individual company applying input-output analysis to assess the environmental cost due to fees for conserving resources and reducing pollution loads in Taiwan.

Authors were also attentive to energy efficiency and greenhouse gas (GHG) emissions of the textile industry. Huang et al. (2017) highlighted that the textile industry has a major challenge in reducing GHG emissions in China, and their results showed that coal consumption is the main source of GHG emissions in the Chinese context. In particular, the increase in the production scale opposes to the reduction in energy intensity and the improvement in the energy structure that could effectively reduce GHG emissions. The study also summarizes the main potential energy savings, underscoring a high potential in short period for the spinning, weaving and wet processes. Jaitiang et al. (2020) followed the implementation of energy conservation procedures through the textile industry in Thailand and analyzed the implementation of renewable energy in the sector and four scenarios of energy conservation. The authors reported that solar PV systems alone cannot primarily help the textile industry to reach the country's targets and recommended increasing the use of other types of renewable energies.

In regard to organizational changes to improve the eco-efficiency of the textile sector, Maia et al. (2013) discussed the role of lean production as an organizational model to improve sustainable initiatives within companies. The authors proposed techniques to the textile and clothing industry to engage in lean production projects and reduce energy use, water and raw-materials consumption, and waste. Alkaya and Demirer (2015) conducted an evaluation for the textile sector in Turkey, and developed recommendations to diffuse the sustainable production approach within this sector. Their results indicated that the sustainable approach is not adapted in the majority of the producer firms in the country, in spite of the retailer companies' efforts to integrate the sustainable production approaches in their corporate social responsibility policies. According to Schaltegger et al. (2012), however, many companies have been trying to act in accordance to the sustainable approach, and among the deficiencies for its implementation, these authors discriminate the lack of knowledge on reduction potentials and deficient interdisciplinary interaction between environmental managers, production managers and accountants. Recently, Freudenreich and Schaltegger (2020) analyzed the clothing industry's social and ecological impacts claiming that the prevailing management and research on supply chains has underscored eco efficiency in production, recycling, and materials use. However, against the rising consumption levels, these solutions have not attained a general reduction in the unwanted environmental and social impacts. Proposing a sufficiency approach to decrease the total amount of clothing produced, used and discarded, the consumer standpoint was discussed as a potentially efficient sustainability approach.

Emergy accounting is a method that can answer most of the questions raised in the literature studies, such as the efficacy of the use of materials and recycling in the production, the best production model to be adopted (Giannetti et al., 2011), as well as the relationship between resource use and economy. The method allows to estimate the effort required by the economy and nature to supply the final product to the consumer. This effort may cover a unitary production process or the whole production chain, including the use of raw materials, energy and transportation. In spite of the potential of emergy synthesis to evaluate the complete production chain, emergy studies on the textile supply chain found in the literature only deal with the agricultural phase. Brandt-Williams (2002) analyzed twenty-three agricultural commodities in Florida, and for cotton, the renewable resource that most affected the system was evapotranspiration, followed by net loss of soil. The economic resource that contributed the most to cotton cultivation was nitrogen fertilizer. Takahashi and Ortega (2010) assessed several oleaginous crops available to produce biodiesel in Brazil, among which cotton, which showed the worst emergy indices mainly due to the high use of chemicals. Shah et al. (2019) evaluated five agriculture cultivating ecosystems including cotton for services and disservices valuation. Cotton was found the worst crop for carbon sequestration and soil erosion.

This study addresses a textile supply chain dedicated to the production of jeans, and consists of the following production elements:

- Agriculture: cotton planting and harvesting.
- Cotton baling: cleaning and conditioning cotton in bales.
- Spinning: yarn manufacturing by twisting the cotton fiber.
- Weaving: production of fabric.
- Jeans manufacturing: cutting, sewing, dyeing and washing
- Jeans trade: sales to the final consumer.

The study is aimed to decision makers, who, through knowledge may identify opportunities and barriers at each textile production step, and the effect of alternative consumption patterns, encouraging producer and consumer responsibility, promoting energy/resources savings and conservation, and evaluating the effect of customer attitudes on the use recycled or reused through scenarios analysis.

2. Method

Understanding the effect of producers and consumers actions to assist decision making in large supply chains can streamline and/or optimize the chain environmental performance. This study uses emergy environmental accounting (Odum, 1996) to evaluate the production supply chain of jeans in Brazil. The production chain consists of six stages: cotton cultivation and harvesting; cotton baling (removal of seed, leaves, branches and baling); spinning (manufacture of threads); weaving (fabric production), jeans manufacture and sales. The analysis was carried out considering facilities sized according to average values of their productive capacity (IEMI, 2016) and for the annual sales of 300,000 pants.

Emergy flows are categorized in: R as renewable resources, N as non-renewable resources and the feedback from the economy, F. The three categories help understanding the system interactions with the environment, where the R and N flows are supplied by the environment and are economically free. While the renewable resources are those that can be replaced at least at the same rate as they are consumed, the non-renewable resources are depleted faster than their ability of recovery. The feedback from the economy is related to fluxes that have economic value. The outputs, Y, may include products, services and also emissions that are released to the environment. The UEVs (Unit Emergy Value) used were taken from the literature and updated (Supplementary material, Table S1), as necessary, to the revised geobiosphere emergy baseline 12.1E+24 seJ y^{-1} (Brown and Ulgiati, 2016).

Indicators are employed to assist the discussion (Brown and Ulgiati, 1997; Odum, 1996):

- Emergy Yield Ratio (EYR): calculated by the ratio between the total emergy (R + N + F) and the feedback from the economy (F). This indicator assesses the system's capability to exploit local natural resources (renewable and non-renewable) (Odum, 1996).
- Emergy Investment Ratio (EIR): calculated by the ratio between the feedback from the economy (F) and the free local resources (R + N). This indicator accesses the most economically competitive options, confronting the use of resources from the biosphere and the economy (Odum, 1996).
- Environmental Load Ratio (ELR): calculated by the ratio between the sum of the non-renewable and purchased resources (N + F) and the renewable resources (R). This indicator expresses the load that the required flows for the implantation and operation of the system impose to the environment (Odum, 1996).
- The emprice (Em$) were calculated based on the study of Giannetti et al. (2018a), who estimated the value of the UEV for Brazil in 2011 as 5.60E + 12 seJ/USD, that is, to produce a dollar in Brazil in 2011, 5.60E + 12 seJ were required. The value of Em$ equals the value of the emergy of the item divided by the UEV of currency in a given country. This measure links the human economy to its biophysical basis and estimates the necessary natural resources to generate the products that each unit of currency can buy in a given economy.

3. Results and discussion

Fig. 1 shows the energy system diagram of the jeans supply chain built using the symbols re-commended by Odum (1996).

The emergy table was built including each stage of the supply chain to establish the stages of greatest consumption of resources, the most important inputs in each stage and to highlight opportunities for applying more productive practices (Table 1).

Table 1 summarizes the resources used for the production of 300,00 jeans. The contribution of renewable resources is less than 1%, and the agricultural stage corresponds to 6% of the total emergy of the productive chain. The analysis of the complete chain shows that the steps that most use resources and energy are the jeans manufacture (49%) and sales (22%). In the jeans manufacture stage, as expected, the labor contributes with 45% of the stage emergy, followed by electricity (28%). Labor is also the main contribution to the sales stage (77%). Both stages are the most labor intensive when compared to the highly mechanized and automated systems from the previous steps of the productive chain.

To realize and maximize the effects from consumer-driven and producer-driven actions and the role of consumers, six scenarios (Table 2) were explored according to the suggestions of the literature and actions proposed and already taken by the international market (https://www.thegoodtrade.com/lists/ethical-denim). Among these, some are driven by producers such as increasing the efficiency of energy and water use. Fig. 2 shows the energy system diagram highlighting the scenarios investigated. The first scenario considers the renewability of the electricity used along the supply chain. The Brazilian matrix is composed by a 45.3% share of renewable sources, against only 10.6% in the countries of the OECD and 14.3%, in the world average (MME, 2019). The share was then applied to investigate the role of renewable energy in contributing to the chain sustainability. In the second scenario, diesel was replaced by biodiesel. In this exercise, the difference in efficiency of both fuels was not taken into account and only one fuel was completely replaced by the other. The third scenario considers the use of water (Chico et al., 2013; Garcia, 2015) in manufacturing operations, as many brands claim reusing/recycling water as a way to achieve a "sustainable jeans". Considering producer actions driven by alternative consumer attitudes, reformation was considered. In this case, producers give store discounts when consumers turn in old jeans they no longer want, and jeans are made from post-consumer pieces that – instead of going to waste — are repurposed to make new pairs, also avoiding the use of new

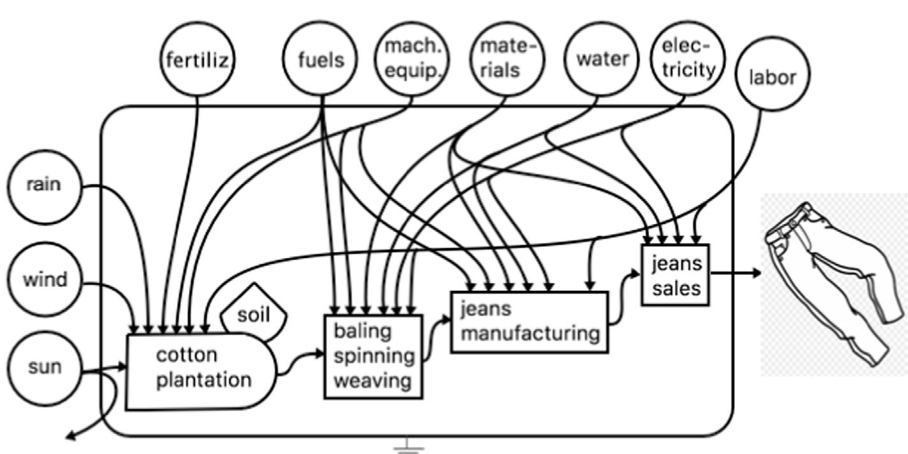

Fig. 1. Energy diagram of the textile chain for the production of jeans.

Table 1
Emergy assessment for the production of 300,000 jeans pants per year in Brazil.

Item	Unit	Quant (units/yr)	UEV (seJ/unit)	Emergy (seJ/yr)	Emprice Em$/yr	UEV ref.(*)
Agriculture						
Indigenous resources						
Sun	J	1,01E+17	1,00E+00	1,01E+17	17989	By definition
Wind	J	4,63E+12	1,28E+03	5,93E+15	1059	(a)
Rain Geopotential	J	3,56E+12	1,30E+04	4,63E+16	8270	(a)
Rain chemical	J	3,42E+14	9,71E+03	3,32E+18	592286	(a)
Net Topsoil Loss	J	5,38E+12	7,94E+04	4,28E+17	76349	(a)
Purchased inputs						
Cotton Seeds	J	2,42E+12	5,96E+04	1,44E+17	25731	(a)
Diesel	J	2,74E+13	4,59E+03	1,26E+17	22443	(a)
Nitrogen	J	4,59E+12	2,15E+06	9,87E+18	1762436	(a)
Phosphate	J	2,14E+11	5,26E+07	1,13E+19	2011580	(a)
Potash	J	1,31E+12	3,36E+06	4,38E+18	783025	(a)
Limestone	J	1,91E+08	2,06E+06	3,93E+14	70	(a)
Pesticides	J	5,08E+11	1,67E+05	8,48E+16	15146	(a)
Labor	J	1,10E+11	4,95E+06	5,44E+17	97138	(a)
Cotton baling						
Electricity	J	3,04E+13	2,06E+05	6,27E+18	1119021	(a)
Water	J	3,00E+11	6,55E+04	1,97E+16	3509	(a)
Diesel	J	1,70E+13	4,59E+03	7,82E+16	13967	(a)
Building area	m^2	3,26E+01	5,17E+15	1,69E+17	30134	(b)
Machine and Equipment	kg	8,82E+04	1,13E+13	9,97E+17	177975	(a)
Labor	J	2,42E+11	4,95E+06	1,20E+18	213734	(a)
Spinning						
Electricity	J	2,30E+14	2,06E+05	4,75E+19	8475429	(a)
Water	J	9,60E+10	6,10E+04	5,86E+15	1046	(a)
Diesel	J	8,52E+13	4,59E+03	3,91E+17	69834	(a)
Building area	m^2	9,60E+01	5,17E+15	4,96E+17	88629	(b)
Machine and Equipment	J	4,18E+10	2,19E+07	9,16E+17	163593	(a)
Labor	J	1,66E+12	4,95E+06	8,23E+18	1469089	(a)
Weaving						
Electricity	J	1,57E+14	2,06E+05	3,23E+19	5760643	(a)
Water	J	1,98E+12	6,10E+04	1,21E+17	21601	(a)
Diesel	J	5,31E+14	4,59E+03	2,44E+18	435230	(a)
Dyes	g	2,45E+08	2,14E+09	5,24E+17	93549	(c)
Chemicals	g	2,61E+09	2,14E+09	5,59E+18	998539	(c)
Building area	m^2	1,02E+02	5,17E+15	5,26E+17	93946	(b)
Machine and Equipment	J	1,07E+10	2,19E+07	2,34E+17	41736	(a)
Labor	J	6,87E+11	4,95E+06	3,40E+18	607259	(a)
Jeans manufacture						
Electricity	J	3,17E+14	2,06E+05	6,54E+19	11675786	(a)
Water	J	1,81E+14	6,10E+04	1,10E+19	1969211	(a)
Diesel	J	2,13E+14	4,59E+03	9,75E+17	174191	(a)
Chemicals (laundry)	g	1,21E+09	2,14E+09	2,58E+18	461438	(c)
Stitching Thread	J	3,97E+11	2,15E+05	8,54E+16	15242	(a)
Button/Zipper/Rivets	J	8,11E+11	2,19E+07	1,78E+19	3173310	(a)
Label (plastic)	J	1,02E+09	2,15E+05	2,19E+14	39	(a)
Tags (paper)	J	5,95E+12	2,74E+05	1,63E+18	291125	(a)
Building area	m^2	5,70E+03	5,17E+15	2,95E+19	5261768	(b)
Machine and Equipment	J	2,48E+10	2,19E+07	5,43E+17	97013	(a)
Labor	J	2,17E+13	4,95E+06	1,07E+20	19151196	(a)
Sales						
Electricity	J	1,82E+13	2,06E+05	3,74E+18	667904	(a)
Envelope (polyester)	g	3,09E+10	2,15E+05	6,65E+15	1188	(a)
Cardboard bag (paper)	J	5,74E+12	2,74E+05	1,57E+18	280890	(a)
Building area	m^2	3,60E+03	5,17E+15	1,86E+19	3326895	(b)
Machine and Equipment	J	4,31E+09	2,19E+07	9,43E+16	16846	(a)
Labor	J	5,59E+12	1,46E+07	8,16E+19	14574450	(a)
Total Emergy				**4,84E+20**	**86430471**	
TRANSFORMITIES, calculated						
Total Yield without services	g	2,26E+08	2,14E+12	seJ/g		
	pants	3,00E+05	1,61E+15	seJ/pant		
	J	3,85E+12	1,26E+08	seJ/J		
	Em$		288	Em$/pant		

(*) Unit emergy values refer to the biogeosphere baseline 12.0 × 10^{24}seJ/yea, where (a) Giannetti et al. (2019); (b) Giannetti et al. (2018b); (c) Odum (1996).

raw materials. In this context, two scenarios were explored: 10% and 50% reformation, in which used jeans return to jeans manufacture for repair and are sold in the stores. Both reformation and water recycling contribute to the circularity of the productive chain. The last scenario combined all the potential actions, except for the use of biodiesel and considering a reformation rate of 10%.

The choice of using renewable energy improves the value of the indicators of environmental load and investment in emergy (Table 2). ELR and EIR values fall approximately 8 times. This result highlights that the textile industry would implement more renewable-related resources and

Table 2
Emergy indices for scenario analysis of consumer-driven and producer-driven actions ([a]).

			Producer-driven			Consumer-driven		Combined
		Actual	Renewable Energy	Renewable Energy + biodiesel	50% water recycling	10% Reformation	50% Reformation	
Total emergy	sej/year	**4,84E+20**	**4,36E+20**	**6,36E+20**	**4,78E+20**	**4,62E+20**	**3,75E+20**	**4,16E+20**
R	sej/year	3,32E+18	2,21E+19	2,21E+19	3,32E+18	4,92E+19	1,89E+20	6,16E+19
N	sej/year	4,28E+17	4,28E+17	4,28E+17	4,28E+17	3,85E+17	2,14E+17	3,85E+17
F	sej/year	5,25E+20	4,13E+20	6,13E+20	4,75E+20	4,13E+20	1,86E+20	3,54E+20
EYR		1,0	1,1	1,04	1,0	1,12	2,02	1,18
ELR		159	19	28	143	8	1	6
EIR		140	18	27	127	8	1	6
Emprice	Em$	288	259	379	267	275	223	248

[a] Complete tables can be found in Supplementary Materials, Tables S2–S7.

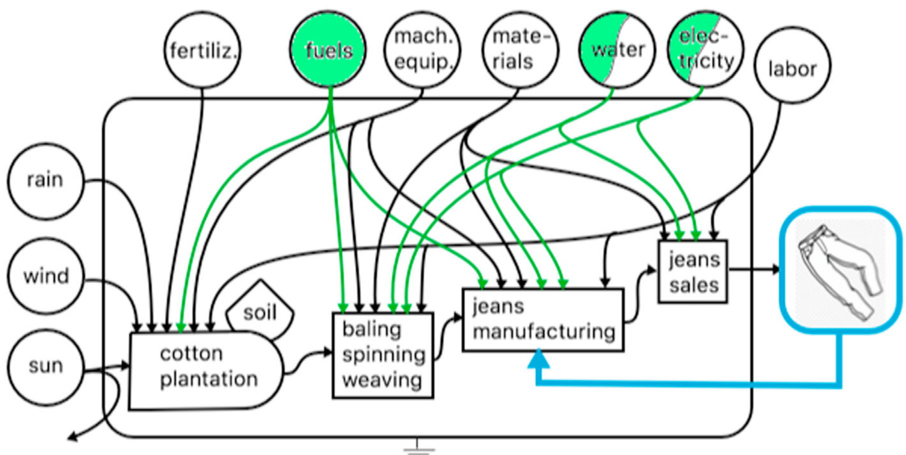

Fig. 2. Emergy diagram of the textile chain for the production of jeans with identification of the producer-driven (in green) and consumer-driven (in blue) scenarios.

energy, not only targeting the reduction of the environment load, but also the reduction of GHG emissions that result from the energy consumption (Jaitiang et al., 2020). The partial closed loop of water in which at least 50% of the water is recycled and reused in the production processes, shows a slight reduction in the total emergy (about 1%), and a negligible reduction in the environmental load from 159 to 143. This result shows that single loops within the supply chain may not be effective in improving the total contribution to sustainability and that conjoined and multiple closed-loop supply chain systems must be implemented together for boosting the reuse and recycle possibilities (Tseng et al., 2020).

The partial closed loop of pants, in which recycled and reused materials from a preceding life cycle are restored with new value and the same functionality, reduces the total emergy by approximately 5% (Table 3), but there is a significant reduction of the environmental load and the emergy investment. This result in agreement with those of Freudenreich and Schaltegger (2020) who observed that in a scenario of rising consumption levels, solutions from the industrial sector alone will not result in a significant reduction in the unwanted social and environmental negative impacts. Such change in the consumption pattern brings companies and consumers together in new relationships that improves the circularity by using the existing resources for re-manufacturability or recyclability to get a (new)product life cycle. The re-manufactured product can be reformed starting a new life cycle adding values to the post-consumer resources. Sustainable consumption is a growing concern that may inspire changes in economic policies to safeguard the supply chains' environmental costs, and to encourage supplementary sustainable production and consumption arrangements (Tseng et al., 2020). Additional benefit from re-manufacturability or recyclability arise from the change in land use, since cotton agriculture is considered a major chemicals consumer (Brandt-Williams, 2002; Takahashi and Ortega, 2010), and the unused soil for cotton production could be used for energy (Takahashi and Ortega, 2010) or food (Shah et al., 2019) production. It is also worthy to note that the loop promoted by the reform process takes place in the two parts of the chain that are labor intensive, which would prevent the loss of jobs that are especially important for developing countries like Brazil.

The prices announced by jeans manufacturers who, in some way, claim that their product contributes to sustainability range from USD 50 to USD 178 (https://www.thegoodtrade.com/lists/ethical-denim). These prices, when compared to the Em$ values obtained (Table 2), show that consumers make less effort to obtain the currency to pay for the product than the system (natural and economic) for the production of the pair of jeans. This result suggests that economic instruments to promoting discounts on recycled or reused products should reflect the contribution of alternative consumer attitudes to improve the sustainability of the productive chain encouraging consumer responsibility and extended producer responsibility (Hvass, 2014; Bukhari et al., 2018). The calculated emprice may also help corporation's decision makers to incorporate environmental costs to the final product or to estimate fees for conserving resources and reducing pollution load (Wu and Chang, 2007).

As expected, the combined scenario that integrates producer/consumer-driven actions shows the best results. If the reformation reached 50% of the pants purchased by consumers, the environmental load indicator would be even lower (ELR = 0.8), with the lower emprice Em$ = 215.

4. Research limitations and future directions

The scenarios studied focused mainly on resource efficiency and alternative consumption patterns, and further studies are required to determine potentiall improvement in regard to economic viability, additional economic incentives and governmental support in order to be considered feasible by all shareholders. Recognizing that infinite recycling is not realistic, new ideas such as biochemical processes for recycling cotton (Tzanov et al., 2001), alternative washing processes (Garcia, 2015) and the use of post-consumer elastomers to increase durability (Shen et al., 2010) or reduce emissions Chico et al. (2013) should be further investigated before implementing a sustainable plan.

The contribution of the textile sector to sustainability also requires a varied approach, and should include the involvement of stakeholders at every stage, as producer-driven actions alone are not enough; partnerships for re-manufacturing/recycling to achieve scalability and commercial success; and more research to determine the level of benefit measured against the environmental costs. This approach requires different points of view and different tools from several relevant domains such as social and management sciences, operations, economics, and engineering revealing the need for inter and transdisciplinary research.

5. Conclusions

Six stages of the Brazilian production chain were examined and opportunities for producer-driven and consumer-driven actions were identified in order to establish restorative and regenerative actions by design to keep products, energy and materials at their highest usefulness and value, and contributing to reach environmental responsibility.

The textile industry sector combines technical and biological cycles, and claims for complex measures, since partial measures, such as water recycling, proved to be not enough, although they can help as trial initiatives on small scales, before larger investment is made. The Brazilian renewable share of the internal energy supply allows the use of more than 40% of renewable energy sources, thus scale and geographic location are key concerns in the sustained supply of quantity and quality of energy achieved locally to prevent increasing environmental load.

Customers' trust and the firms influence on consumer's discernment of remanufactured products are remaining gap in the market (Tseng et al., 2018b; Wang, 2017), and their engagement proved to be crucial. This engagement requires studies of the customer perceived value of remanufactured products as function of perceived environmental benefits and price advantage. The development of alternative consumer attitudes requires understanding on how to intensify the consumers' role in a supply chain. Part of this understanding lays on the consumer disposition to pay and their tolerance for remanufactured products.

This paper explores that producer-driven actions have limitations on technology and resource/material savings, hence alternative consumption patterns are key to ensure sustainability. Understanding the multiple and partial closed loop within supply chains can help to restructure and re-design those chains but must rely on scientific assessment/monitoring methods to enhance the value of the product and the chain environmental performance. Combined producer/consumer-driven actions increase the multiplier effect because they help to maximize the efficiency of resources use, cope with technology limitations and recognize consumption patterns.

The results obtained in the comparison of seven scenarios for the Brazilian textile supply chain show that the emergy synthesis is a valuable tool for identifying and quantifying how partial loops within the supply chain can contribute to sustainability, fulfilling research gaps from both resource/material and consumption pattern perspectives.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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