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Research article

A multi-criteria approach to assess interconnections among the environmental, economic, and social dimensions of circular economy

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ABSTRACT

The debate about the negative impacts that production and consumption cause on the environment is in vogue. Strategies that point to a sustainable, healthy, and resilient path are being sought. One of these paths is the Circular Economy, which emerges as an alternative to reduce the socio-environmental impacts caused by the linear model of production-use-disposal, presenting opportunities to generate revenue, income, and wealth with circular processes. However, despite the circular economy being considered an essential strategy to improve overall performance toward sustainability in its three dimensions, recent research has shown that the predominant focus of circular approaches is on the economic and environmental dimensions. At the same time, the social aspects still need to be explored. This article addresses this problem, aiming to explore circular economy environmental, economic, and social elements in three economic blocs from 2000 to 2020 using the Five Sector Sustainability Model, establishing a baseline to co-create an equitable and regenerative future. The results showed that ASEAN in 2000 occupied the first position in the general ranking. The European Union had the best classification in the economic sector, and Mercosur was the best regarding social benefits. In 2020, while the European bloc was better positioned in the general ranking, the South American bloc occupied the last post in almost all sectors. Comparatively, the highest-ranked bloc in 2020 in overall sustainability is more in line with the UN SDG due to circular actions oriented towards the three fundamental pillars of sustainability.

1. Introduction

The Circular Economy (CE) and its narrative are progressively attracting the attention of academics, policymakers, and professionals from different sectors because it aims to decouple economic development from the consumption of finite primary resources. According to its proponents, CE represents a new paradigm that seeks to reshape the relationships between ecological systems and economic activities through the regenerative principle where waste and by-products are reused and reinserted into production and consumption systems, thus keeping the usefulness of materials as high as possible (Haas et al., 2020, Borrello et al., 2020).

Following this perspective, the coherent idea of the rational use of natural resources within planetary limits gained transversal relevance. It went beyond the boundaries of environmental sustainability (Saidani et al., 2019; Genovese and Pansera, 2021), expanding to other domains such as innovation, human behavior, consumption, economic prosperity, and social equity for current and future generations (Padilla-Rivera et al., 2021; Castro et al., 2022). Thus, the potential benefits of CE were presented as a fundamental condition to mitigate climate change and contribute to sustainable development because it suggests a harmonious path between the economy and the environment (Geissdoerfer et al., 2017).

In addition, CE seeks to promote economically profitable, ecologically desirable, and socially viable strategies (De Angelis, 2022), providing multiple ways to address relevant challenges in terms of sustainability and, in particular, to develop workable actions to achieve the goals of the Sustainable Development Goals. – SDGs at different scales (Schroeder et al., 2019; Borrello et al., 2020). In this regard, Schroeder et al. (2019) and Walker et al. (2021) observed that despite the academic literature evolving, CE practices still need to prove their effective contribution to achieving the SDGs, especially those related to the social dimension.

However, regardless of the growing interest that CE has attracted. Its

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potential to generate benefits for the environment, society, and the economy, authors such as Ghisellini et al. (2016) and Geissdoerfer et al. (2017) observed that circularity is usually associated with the context of recycling and the social dimension is still a poorly researched topic. Moreau et al. (2017) and Castro et al. (2022) also argued a need for more interest in social aspects, especially those related to working conditions, wealth distribution, and governance systems. However, various studies address the facilitating elements for introducing these aspects in the circular concept (Geisendorf and Pietrulla, 2018).

Due to these and other factors, such as definition, objectives, and implementation forms, the concept of CE is seen as superficial and disorganized (Korhonen et al., 2018; Calisto Friant et al., 2020). New tools are needed to support professionals, decision-makers, and policy-makers in developing strategies that point towards more circular practices at different systemic levels (Saidani et al., 2019). Furthermore, the subjective methodological framework currently in place to assess and analyze the effects of CE adoption at different systemic levels has potentially harmful implications for advancing sustainability (Saidani et al., 2019; Kristensen and Mosgaard, 2020).

Given this context, several studies have proposed CE indicators and shown that existing monitoring tools are inadequate to track the progress of the transition to circularity at the regional level (Smol et al., 2017 Avdiushchenko and Zajac, 2019). For Corona et al. (2019), thematic indicator groups should combine classical economic and environmental science metrics, regardless of the monitoring tools used. Gasparatos and Scolobig (2012) reported that selecting sustainability assessment tools should be based on three broad categories: monetary, biophysical, and indicator based.

With this, several studies are being proposed and discussed to evaluate, improve, monitor, and communicate the performance of the CE, covering different purposes, scopes, and potential uses. Thus, a reliable and practical measurement process for circularity is not a simple task (Sassanelli et al., 2019). The complexity increases as time increases, and the unit of analysis expands (Calisto Friant et al., 2020). That is why CE assessments need a set of multidimensional indicators (Munda, 2005), which allow a comprehensive view of a decision that involves a plurality of aspects (Hagman and Feiz, 2021). For Mahmud et al. (2021), multi-criteria techniques allow a systematic economic, environmental, and social performance analysis under a single and coherent framework.

Based on the shortcomings presented, this article aims to explore the environmental, economic, and social aspects of CE and establish the interrelationships between these dimensions and sustainability in ASEAN, Mercosur, and the European Union using the Five Sector Model of the Sustainability Model (5SEnSU) proposed by Giannetti et al. (2019). Furthermore, the following section describes the procedures used in the research. Following, the discussion of the results of the environmental, economic, and social dimensions of CE in ASEAN, Mercosur, and the European Union between the years 2000 and 2020 is presented. Finally, in the concluding section, the points explored are pointed out under different understandings and in a holistic way.

2. Action methods and strategies

CE has become one of the most popular topics around the world for presenting itself as the solution to problems linked to the traditional linear extract-make-use-discard system, and although there are ambitious and committed strategies in the European Union, North America, China, and Japan, the research in emerging economies is still poorly explored (Márquez and Rutkowski, 2020). Much of what is known about CE comes from locations in the global north, while in the southern regions, few initiatives have been analyzed (Dewick et al., 2022). For Avdiushchenko and Zajac (2019), different regions sought to promote CE as a means of sustainable economic development based on decoupling economic activity from the consumption of finite resources, although comprehensive assessments on a macro scale are rare. There is still a need to analyze circular experiences in developing countries, as these locations are the ones that most need to develop strategies to reduce the environmental burden caused by excessive consumption (Gutberlet et al., 2017).

To explore CE's environmental, economic, and social aspects at a macro level, ASEAN, Mercosur, and the European Union (EU) were selected to compose this study. These economic blocs constitute distinct unions between countries, with consistent differences that significantly impact environmental, economic, and social conditions. Exploring the effectiveness of CE actions in these locations is crucial to estimating progress from the linear to the circular model.

The choice of the EU considered the advanced framework of the bloc's policies and measures for developing the CE model (Škrinjarić, 2020; Alonso-Almeida and Rodríguez-Antón, 2020). Another factor that justifies this choice is the great efforts made by the region to accelerate the transition to a CE in its territory (Pacurariu et al., 2021). ASEAN was selected based on the advances in adopting CE principles carried out in the bloc, which were not limited to reducing, reusing, and recycling (Lee, 2019) and identifying circular practices that help achieve environmentally sustainable results in Southeast Asia (Retamal, 2017) may provide valuable lessons for developing countries (Hsieh et al., 2017). Finally, Mercosur began to outline strategies to accelerate the transition to a CE, but the Latin American concept of circularity is still limited to waste management as an economical alternative (Betancourt Morales and Zartha Sossa, 2020). For Salas et al. (2021), some unique problems present in the region, such as the unbridled use of resources (Salvador et al., 2022) and the market-oriented economy (Halog and Anieke, 2021) hinder the transition to CE in its three aspects (environmental, economic, and social).

Given that regional sustainability issues are multidimensional and involve different economic, environmental, and social issues with multiple barriers (Tsamboulas and Moraiti, 2013), adequate decision-making in these environments requires appropriate information covering all sustainability aspects. Typically, a decision-making problem has more than one goal to achieve (Macharis, 2007), and multicriteria analysis is the most appropriate tool to adopt because it takes into account several criteria. Given the above, the multi-criteria approaches must be explored to assess sustainability in an integrated manner since the transition to circular systems involves complex issues that cover technical, economic, environmental, business, and social aspects (Sassanelli et al., 2019).

Multicriteria approaches are increasingly popular due to their simplicity and ease of understanding (Wu et al., 2020) and their ability to provide structure for complex decisions. These methods have been used to evaluate circularity and sustainability solutions in different dimensions. Alamerew et al. (2020) and Yazdani et al. (2021), for example, used multicriteria methods in specific fields of application and with different purposes to assess performance and sustainability based on quantitative and qualitative information.

However, although in recent years, several techniques and multicriteria approaches have been suggested to choose the probable optimal options, some of these methods have specific fields of application and, therefore, do not fully capture the environmental, social, and economic aspects comprehensively. At this point, the 5SEnSU Model is a suitable conceptual tool for this research because it includes a wide range of environmental, social, and economic aspects considered necessary to comprehensively assess sustainability (Giannetti et al., 2019). The model allows the investigation of multiple characteristics from the point of view of the natural environment, society, and the production and consumption unit (Giannetti et al., 2019), which can be a small factory, an industrial park, a city, or a region, among others.

The five sectors respond to the environment as a provider (S1), the environment as a receiver (S2), the system of interest (production unit, city, region; S3), the society as a supplier of labor and inputs (S4), and the society as a consumer/beneficiary of goods and services, S5 (Fig. 1).

The indicators to measure circularity and compose the data used in the 5SEnSU Model were selected based on an exhaustive literature

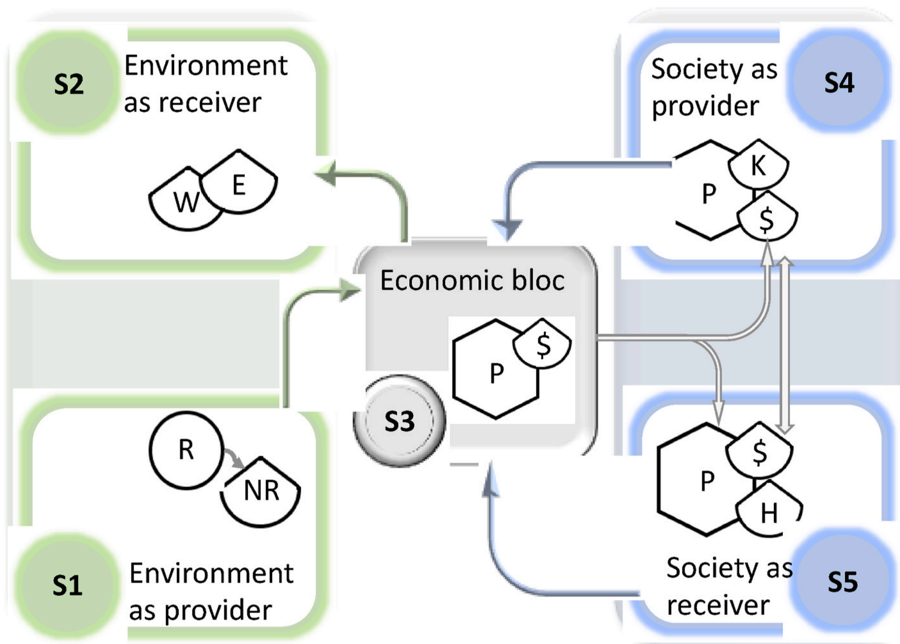

Fig. 1. Schematic representation of the 5SEnSU Model. Where W: waste; E: emissions; R and NR: renewable and non-renewable resources; Q: people; K: knowledge, and H: happiness. Straight lines refer to material and energy flows, and dashed lines to exchange rate flows.

review supported by the Sankey diagram of CE flows in the EU (EU27, 2017). The Sankey diagram shows material flows as they pass through the EU economy and eventually return to the environment or production system, thus feeding back into the economy (Fig. 2). The imports and exports flows are also considered, and the closed-loop represents waste reused or used to produce secondary raw materials or other purposes, preventing further extraction of natural resources (EU27, 2017). The selected data sought to identify the central assumptions about sustainable development through CE indicators while suggesting using a set of indicators rather than one to assess the circularity of a region. Availability, measurability, utility, sensitivity, transparency, and interpretability criteria were also followed (Jeon et al., 2013), considering the relevance of the data set to provide information that can be used in decision-making to achieve the goals established for the different dimensions associated with the system under study (Bojkovic et al., 2010; Lin et al., 2009). Thus, ten indicators were selected/calculated (two per sector) for each bloc. In S1, extracted natural resources are represented by Emergy and Renewable Energy; in S2, the dissipative flows are proxied by CO_2 Emission and Electronic Waste. S3, the economic blocs, is accounted for by GDP and GINI. S4, which also covers imports and

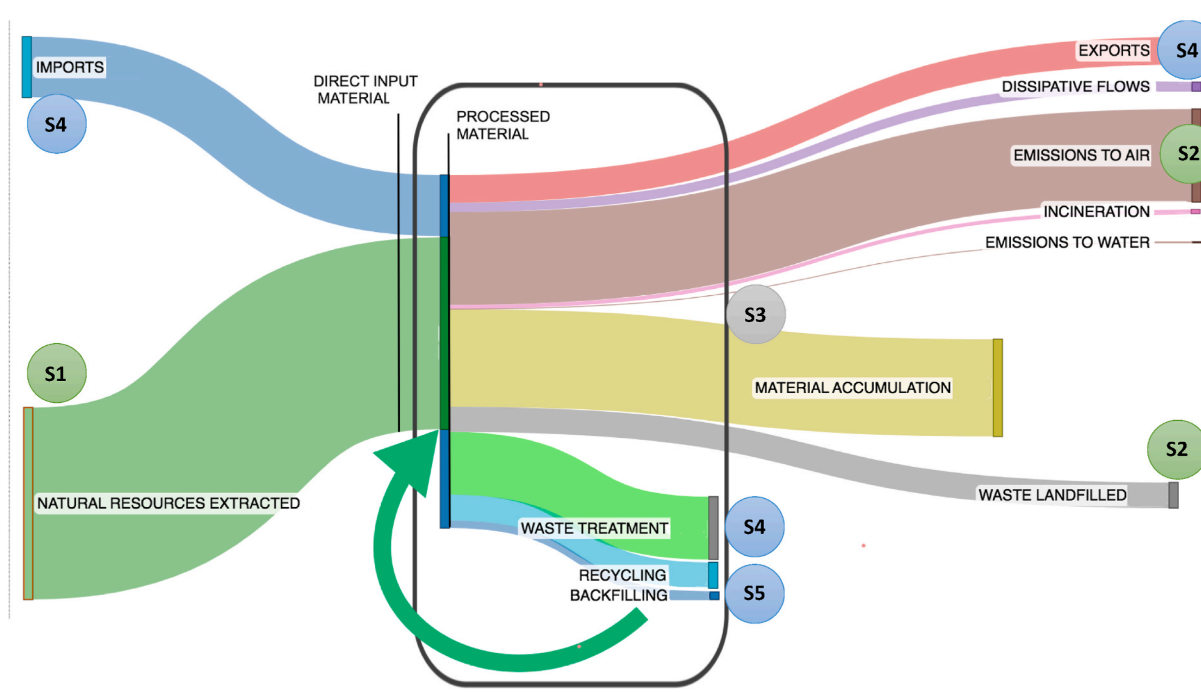

Fig. 2. Conceptual framework to establish a bridge between CE flows displayed in the Sankey diagram (UE27, 2017) and the five sectors of the 5SEnSU model. Inspired in: https://ec.europa.eu/eurostat/documents/4187653/10321591/Sankey_2020.png/9672a41b-fe7c-024e-9dc9-8f80719b8753?t=1583828235329.

exports, is represented by the degree of economic openness and the employment rate. In contrast, S5 is represented by the Human Development Index (HDI) and the Gross Happiness Index (GHI).

Indicators are represented by the letter K, followed by two numbers; the first indicates the sector, the second refers to the indicator used in that sector, and the values can be maximized or minimized according to pre-established goals for each one (Table 1).

The next step was to select the targets to be used in the 5SEnSU Model, also considering the relevance of CE practices to achieve some SDGs. For Mohan et al. (2019), SDGs 1, 2, 3, and 8 are related to socioeconomic aspects, while SDGs 6, 13, 14, and 15 are connected to ecological aspects. Heimann (2019) complements this analysis by arguing that SDGs 7, 9, and 12 relate to economic goals. Rodriguez-Anton et al. (2019) and Nikolaou et al. (2021) described that the most robust relationships between CE and sustainable development directly correlate with SDGs 6, 7, 8, 12, and 15. Schroeder et al. (2019) pointed out that CE can directly contribute to the SDGs close to the environment, economic, and sustainability dimensions and indirect or absent contribution to the SDGs related to social aspects.

Considering critical the different types of CE and their capability to contribute to sustainability through the implementation of circular practices as a natural bridge to connect to the fundamental goals of the SDGs (Dong et al., 2021), the potential effects of circular activities on sustainability were related to SDGs 1 (No poverty); SDG 3 (Good health and well-being); SDG 4 (Quality education); SDG 7 (Affordable and clean energy); SDG 8 (Decent work and economic growth); SDG 9 (Industry, innovation, and infrastructure); SDG 10 (Reduction of inequalities); SDG 11 (Sustainable cities and communities); SDG 12 (Responsible consumption and production); SDG 13 (Climate Action); SDG 15 (Life on land) and SDG 16 (Peace, justice and strong institutions). The 5SEnSU Model points out the CE's potential to contribute to different SDGs, depending on the sustainability domain, bringing together multiple data to propose diverse solutions and paths for sustainable development.

Table 1 presents the indicators and relative targets proposed to feed the 5SEnSU model in evaluating economic blocs, the justification for maximizing (MAX) or minimizing (MIN) these indicators, and their relationship with the SDGs. The proposed indicators were used to calculate the Synthetic Indicator of Sustainability of the System (SISS) - global and sector-specific – using GP (Giannetti et al., 2019; Moreno García et al., 2021), which several authors have applied to build composite indices and analyze the sustainability of systems in the context of CE. For example, Bal and Badurdeen (2020) used Goal Programming (GP) for sustainable planning of reverse logistics operations in the CE approach. Likewise, Balaman et al. (2018) and Karakutuk et al. (2021) applied GP to analyze energy efficiency in the circular context. The resulting SISS enables us to compare an actual situation with the established goals and helps people understand where they are, which way they are going, and how far they are from where they want to be. This indicator captures a broader view of a system as the most appropriate to seize a particular view of sustainability (Jeon et al., 2013). A step-by-step procedure for the SISS calculation is available in Santos et al. (2022) and in the Supplementary Material provided.

3. Results and discussion

To identify the main aspects of sustainability in the CE's discourse, the Sustainability Indicator ranking in each sector is first presented individually in a temporal analysis from 2000 to 2020, examined at five-year intervals.

3.1. Analysis of the environmental dimension of the CE

One of the crucial aspects of implementing the circular approach is the unintended environmental impacts caused by the excessive extraction of resources and the generation of emissions and waste. In this context, CE is seen as a "regenerative system in which the input and waste of resources, the emission, and energy leakage are minimized by decelerating, closing, and narrowing the cycles of materials and energy" (Geissdoerfer et al., 2017. p. 766). Thus, to explore the role and relationship of a CE with the environment over space and time, Fig. 3 presents the environmental performance of the economic blocs translated by the sustainability ranking according to their respective SSIS values of sector 1.

Considering the S1 and the importance of natural stocks (K11 - Emergy per capita and K12 - Consumption of renewable energy), it is noted that ASEAN occupied the best position from 2000 to 2015, and after this period, the EU substantially improved its performance, especially from 2015, when the circular package "Closing the cycle - an EU action plan for the circular economy" was launched aiming to promote a sustainable economy and alleviate the environmental pressures (Giannakitsidou et al., 2020). Authors such as Ghisellini et al. (2016) and Geissdoerfer et al. (2017) believe that reducing resource use and mitigating environmental impacts in the European bloc are the results of a radically different organization from the production and consumption patterns provided by the CE. However, most EU member state economies develop national CE transition policies related to resource efficiency issues even before the European Commission (Mazur-Wierzbicka, 2021). This mainly resulted in strategies related to materials recycling and reusing that aimed to increase the contribution of CE to waste management, increasing the share of recycled and reused materials and introducing new business models for reuse, refurbishment, and remanufacturing (Wilts and O'Brien, 2019). Nevertheless, the nature of consumption by citizens (Farmer, 2020) and cultural barriers

Table 1
Indicators, objectives, goals (with their respective justifications), and SDGs used in each sector of the 5SEnSU model.

SDG	Rationale		Indicator/strategy	Target
15	Minimize the environmental impact caused by the exploitation of renewable and non- renewable resources (Liu et al., 2018; Viglia et al., 2018)	**Sector 1**	Emergy/minimize	$\overline{K_{11}} + \sigma(K_{11})$
7, 15	By 2030, double the global rate of energy efficiency (Indicator 7.3.)		Renewable energy consumption/ maximize	$\overline{K_{12}} * 2$
9, 13	Reduce emissions by 7,6% each year from 2020 to 2030 (UNEP Emissions Gap Report, 2020)	**Sector 2**	CO_2 emission/minimize	$\overline{K_{21}} - 54.64\%$
9, 11, 12	CE comprehensively applied to minimize waste generation process (Sharma et al., 2020)		Electronic waste/minimize	Min $K_{22} + \sigma(K_{22})$
8	2019 global average PPP GDP per capita	**Sector 3**	GDP/maximize	21,932.67
1, 10	Lowest global average value between 2000 and 2019		GINI/minimize	0.395
10	A nation's trade opening directly influences the definition of sustainable development (Geerken et al., 2019)	**Sector 4**	Economic openness index/ maximize	$\overline{K_{41}} + \sigma(K_{41})$
8	Highest global average of the employment rate between 2000 and 2019		Employment rate/maximize	62.54
1, 3, 4, 10	HDI above 0.8 considered high	**Sector 5**	Human development Index/ maximize	0.80
3, 16	The 10 happiest countries show GHI >7.0		Gross Happiness Index/ maximize	7.80

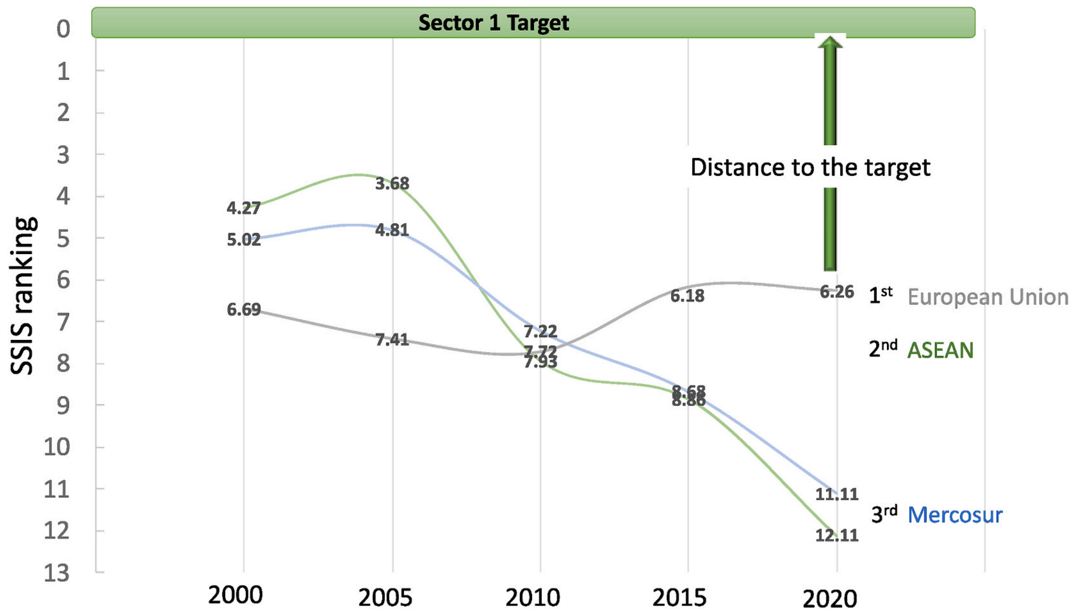

Fig. 3. Ranking and Synthetic System Sustainability Indicator (SSIS) sector 1 (environment as a supplier) of ASEAN, Mercosur, and the European from 2000 to 2020. SSIS of each economic bloc (numbers inside the circles) is a comparative measure of how close the indicator is to the targets established.

(Camacho-Otero et al., 2018) are still factors that hinder the diffusion of circular practices.

When examining the results of Mercosur, concerns arise about some crucial questions, such as whether the world economies (represented here by the South American and ASEAN blocs) are on the right path to minimize the use of resources and energy through CE practices (Haas et al., 2020). The deceleration of socioeconomic material cycles that should reduce the use of primary resources and consequently convert linear into circular systems (Zink and Geyer, 2017) seems weakened in ASEAN and Mercosur.

In sector 2, the two blocs with the best ranking in 2000 and 2005 were ASEAN and Mercosur, while in the same period, the EU had the worst performance in the sustainability ranking (Fig. 4). However, from 2010 onwards, the ASEAN and the South American bloc started to walk away from the pre-established targets. Despite the global challenge that nations face to reduce the generation of electronic waste (K22), the rapid adoption and obsolescence of electronics brought new concerns about resource consumption and waste management (Althaf et al., 2021). This was reflected in the position occupied by ASEAN and Mercosur after 2010, which increased the complexity of the sustainability transition as discarded e-waste contains potentially hazardous materials that can cause negative impacts on the environment and put public health at risk.

The EU, since 2015, occupied the first position in the S2 ranking due to the economic incentives made for the bloc's transition to a CE (Marino and Pariso, 2020; Althaf et al., 2021). These incentives effectively minimized the use of raw materials and electronic waste production,

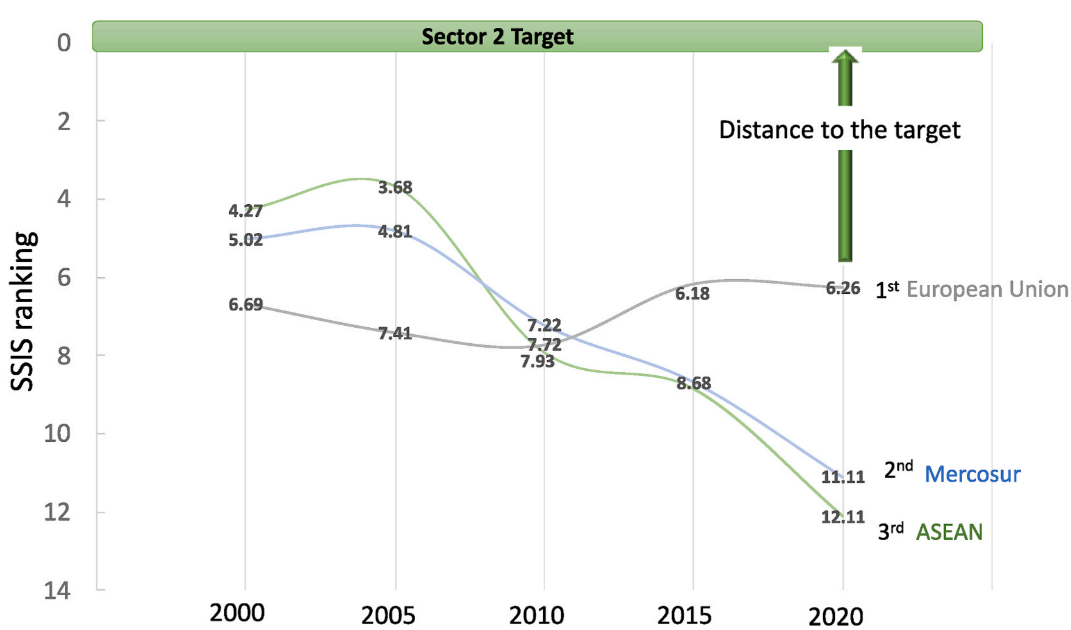

Fig. 4. Ranking and Synthetic System Sustainability Indicator (SSIS) of sector 2 considering the environment as a receiver of waste and emissions of ASEAN, Mercosur, and the EU from 2000 to 2020. The SSIS value of each economic bloc (numbers inside the circles) is a comparative measure of how close the indicator value is to the targets established.

despite the cultural barriers evidenced by the lack of consumer interest and awareness (Kirchherr et al., 2018). CO_2 emissions (K22), strongly influenced by energy use and economic development (Dar et al., 2022), were more significant in Mercosur and especially ASEAN over time. For Li et al. (2020) and Wich et al. (2020), stopping deforestation, reforestation, and increasing energy efficiency could be effective measures to reduce CO_2 in both blocs. Regarding CO_2 emissions in the EU, there was a reduction between 2000 and 2020 due to regulations that allowed the bloc to improve its environmental performance (Rada, 2019). For Aguilar-Hernandez et al. (2021), a determining factor to be considered in this analysis is the active participation of citizens, which has directly influenced the reduction of CO_2 emissions in the region. However, the trade-off between environmental impacts and socioeconomic conditions is still present.

The results regarding the environmental dimension, especially from sector 2, support that the proactive measures taken in the EU to advance circularity contributed significantly to the reduction of the SSIS values, contrary to what is observed for the ASEAN and Mercosur. The highest environmental performance in the European bloc between 2015 and 2020 is due to the close ties established between the CE and the environment, configuring a new space for research to manage the transition to sustainable development (Ruiz-Real et al., 2018). However, despite the benefits linked to CE strategies, numerous barriers still limit the scope of circularity (Schröder et al., 2019).

Given the above, it can be suggested that EC practices in the environmental dimension potentially contributed to the achievement of SDG 7 (K12) due to the increased share of renewable energy in the energy matrix and SDG 15 (K11 and K12) that alleviated resource pressure and improved environmental quality at a regional level (Liu et al., 2018), specifically in the EU and ASEAN. For Schroeder et al. (2019) and Nikolaou et al. (2021), more consistent relationships exist between these SDG goals and CE practices, despite the various existing trade-offs. However, despite Rodriguez-Anton et al. (2019) and Schroeder et al. (2019) identifying significant relationships between the CE and SDGs 9, 11, 12, and 13, analyzing sector 2 (K21 and K22) and appreciating the potential benefits, some unavoidable adverse effects were also detected. For Castro et al. (2022), the potential benefits obtained by CE may be overshadowed by systemic changes, such as increased productivity, which may evidence the existence of the rebound effect. Zink and Geyer (2017) clarified that rebound effects might occur when the impact of secondary production does not replace primary production in the same proportion, as shown by Oliveira et al. (2021), who found that between 2016 and 2018, improvements in recycling rates were overshadowed by a 4.5% increase in raw material consumption. So, there are no magical proposals that simultaneously support population growth, increased wealth, and the regeneration of environmental resources, but a need for a profound rethinking of economic development and social well-being.

3.2. Analysis of the economic dimension

To achieve sustainable development, issues involving economic, social, and environmental factors must be prioritized, especially those related to the optimal use of natural and economic resources. For Hysa et al. (2020), these issues lead to a sustainable economic system that contributes to favorable conditions for a circular design (Geissdoerfer et al., 2017). Under these conditions, the economic system (Sector 3) is strategic for all blocs, as it is related to the environmental (S1 and S2) and social (S4 and S5) conditions. The activities carried out in the economic system, in addition to directly meeting needs, must also include means to ensure sustainability since the economic blocs have improved their economies at the expense of the environment. Fig. 5 shows the SISS results from GDP and GINI for the three selected economic blocs (see Fig. 6).

The blocs with the best performance were those with the highest GDP PPC per capita and the lowest GINI indicator, those that, in addition to economic protection, seek equality. The EU and ASEAN alternated in the first position throughout the analyzed period, supported by integrating non-economic aspects to development and the cooperation of different stakeholders (Geissdoerfer et al., 2017) that reduced socioeconomic inequality by promoting CE.

However, as the CE concept is still primarily based on economics and economic development continues to be prioritized in the intrinsic appreciation of GDP (Coscieme et al., 2020), income inequality makes radical implementation of a circular system difficult (Neves et al., 2020), which can be observed in the position occupied by Mercosur. If measures are not taken to improve socioeconomic indicators in this bloc, the

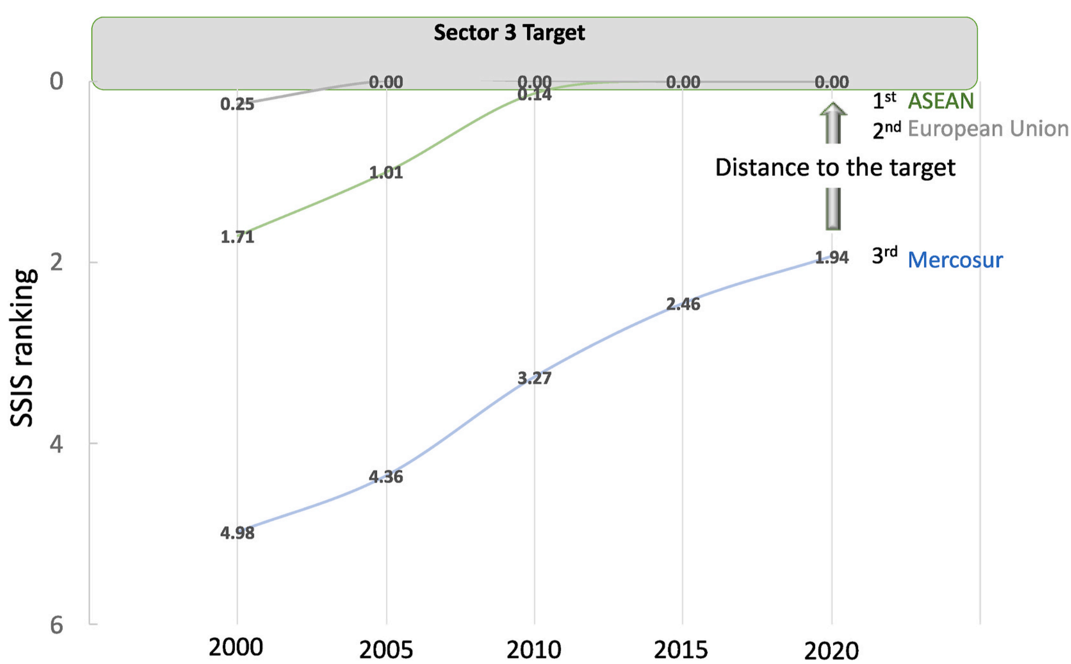

Fig. 5. Ranking and Synthetic System Sustainability Indicator (SSIS) of sector 3 considering the economic aspect of ASEAN, Mercosur, and the EU from 2000 to 2020. The SSIS value of each economic bloc (numbers inside the circles) is a comparative measure of how close the indicator value is to the targets established.

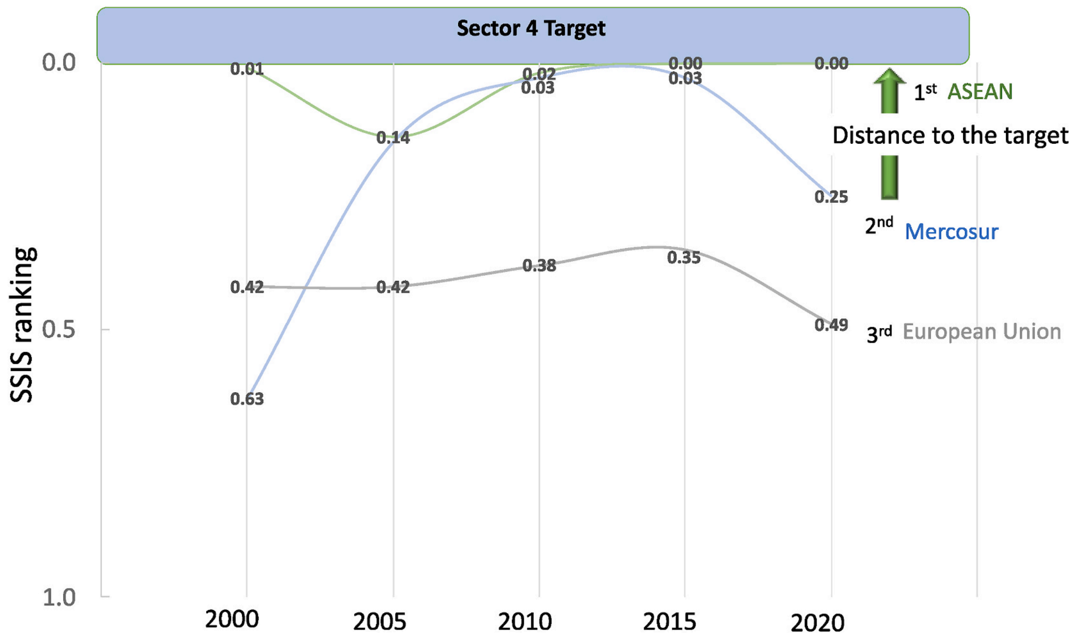

Fig. 6. Ranking and Synthetic System Sustainability Indicator (SSIS) sector 4 of ASEAN, Mercosur, and the EU from 2000 to 2020. The SSIS value of each economic bloc (numbers inside the circles) is a comparative measure of how close the indicator value is to the targets established.

objective of simultaneously achieving environmental quality, economic prosperity, and social equity will be threatened (Kirchherr et al., 2017). Hysa et al. (2020) attribute this situation to the fact that well-being is often associated with wealth and economic growth.

As the objective of a circular society is to ensure a prosperous, fair, and sustainable future for all (Calisto Friant et al., 2021), CE practices to improve the economic dimension (K21 and K22) may have significant and promising relationships with SDGs 1, 8 and 10. Schroeder et al. (2019) found that the economic objectives promoted by CE are directly related to responsible consumption and production, decent work, and economic growth. Similarly, GDP per capita (K21) can be considered a measure of progress to sustain economic development, and its continued increase could indicate progress toward SDG 8 (Coscieme et al., 2020). As the EU shows the highest GDP per capita in all analyzed periods, sustainable economic development contrasts with the second position in the sustainability ranking in 2015 and 2020. Neves et al. (2020) warn that when per capita income increases, the propensity of people to accept products containing recycled materials decreases, evidenced by the results found in sector 2.

On the other hand, Scherer et al. (2018) considered the GINI (K22) a valuable measure to analyze inequality reduction and relate it to SDG 10. In this study, it was possible to compare the three selected economic blocs and verify that inequality was less pronounced in ASEAN between 2000 and 2010 and in the EU after 2015.

3.3. Analysis of the social dimension

Assessing social impacts has become a critical aspect of achieving sustainability and social issues have become especially relevant within the CE discourse due to the intrinsic association between various stakeholders (Mies and Gold, 2021). Within the 5SEnSU Model, social performance is analyzed by the indicators of Sectors 4 and 5. Unlike the results of Sectors 1, 2, and 3, the EU presented the highest SISS indicators in S4, occupying the last position in the sustainability ranking since 2005 with only minor fluctuations in two decades. In 2000 the EU occupied a better place than Mercosur, a situation that did not hold up from 2005 onwards. On the other hand, ASEAN maintained the first position in the ranking throughout the period.

The SISS results from K41 - Economic Openness Index and K42 - Employment Rate -indicated that ASEAN and Mercosur better met the human needs of their societies. Murray et al. (2017) highlighted that localities that manage to integrate issues such as well-being and basic human needs into CE have the potential to contribute more to sustainable development.

K51 (HDI) and K52 (FIB) focus especially on the socioeconomic dimension, considering society as a recipient of some goods and/or services generated in the economic bloc (Giannetti et al., 2019), as the social dimension of sustainability is related to the ability to solve or minimize people's basic needs.

It was found that Mercosur had the best SISS indicators between 2000 and 2005. Still, from then onwards, the SISS increased continuously, and the bloc reached 2020 with the worst place in the sustainability ranking (Fig. 5). ASEAN occupied the third position in 2000 and, from 2010, the second position in this sector. On the other hand, the EU, which from 2000 to 2005 occupied the second position, started in 2010 to present the best values. The efforts undertaken by the EU strengthened the social sector as a consumer of goods and services, implicitly increased circular benefits, and led the bloc to obtain the first position in the sustainability ranking since 2010.

In the socioeconomic dimension, the selected SDGs seek to promote sustainable development through full and productive employment (SDG 8) while reducing inequality within and between countries (SDG 10). These elements were explored in sector 4 using the Index of Economic Openness (K41) and the Rate of Employment (K42), which, except for the EU, showed promising results in the transitions to achieve these SDGs.

On the other hand, a series of relationships connect the different SDGs to sector 5 (K51 and K52). The more evident seeks to eliminate poverty and inequality and create a healthy life (SDG 1, 3, and 10), ensuring inclusive and equitable education (SDG 4). The one not so evident refers to building effective, accountable, and inclusive institutions at all levels (SDG 16), which may directly impact the happiness index of the blocs. However, Moreau et al. (2017) and Club and Tennant (2020) warn that the transformational shift towards a circular system will only be possible if production efficiency is combined with cultural and behavioral changes that move society away from a high-growth and high-consumption culture and until that happens, radical social and environmental transformations will not materialize (see Fig. 7).

3.4. Global analysis of the 5 sectors

Starting from the initial mapping of CE practices in environmental, economic, and social aspects, the general scores translated by SISS in the 5SEnSU Model (Fig. 8) show the general performance of the analyzed blocs. Regions with lower indicator values may be considered more sustainable or closer to sustainability since their overall performance is closer to the established targets (Giannetti et al., 2019).

The EU has been the most sustainable bloc since 2015, especially after the introduction of the Roadmap for a Resource-Efficient EUROSTAT (2017) and the Circular Economy Action Plan (2015), which caused systemic changes in several areas to implement the CE concept (Domenech and Bahn-Walkowiak, 2019; Sverko Grdic et al., 2020). However, the results from recent years, especially those of Sector 3, generated a negative environmental impact on the consumption of raw materials and energy (sector 1), greenhouse gas emissions, and waste generation (sector 2) since that economic objectives do not necessarily collide with environmental protection (Sverko Grdic et al., 2020).

Although the other blocs are still developing strategic actions to support the transition to a CE, their place in the sustainability ranking has remained below that of the EU since 2015. ASEAN 2000–2010 occupied the first position, but after that period, an increasing trend resulted in second place since 2015. For Matsumoto et al. (2021), CE may be more favorable in developed countries, as they can make their industrial structures more flexible through regulations, improve resource efficiency and awareness of negative impacts on the environment and thus reduce barriers to achieving circularity. This explains, in part, the results of the Asian bloc. Kuah and Wang (2020) complement this by reporting that Asian consumers resist accepting CE, notably on issues related to closing the electronics cycle.

The worst place in the overall ranking belongs to Mercosur, which despite the pre-existing circular behavior due to the repair, reuse, and waste sorting activities that reduce the use of primary materials (Salas et al., 2021), the transition to CE still faces the low economic revenue of the pre-existing circular activities and the lack of institutional and technological policies (Ferronato et al., 2019). For Betancourt Morales and Zartha Sossa (2020), the concept of CE in Latin America (here represented by Mercosur) has been restricted to waste management as an economical alternative (Becerra et al., 2020; Salas et al., 2021).

In 2000, ASEAN, in addition to being the most sustainable bloc from a global perspective, also presented the lowest results in the environmental aspect (sectors 1, 2), partially in the social aspect (sector 4 in the first place, contrasting with the last position of the sector ranking 5) and intermediate in the economic aspect (sector 3). In 20 years, the bloc's development has privileged the economic aspect (sector 3) with benefits to society (sectors 4 and 5) while neglecting environmental systems (sectors 1 and 2).

The EU in 2000 occupied the second position in the overall SISS and the social aspect (sectors 4 and 5); however, the bloc had the worst results regarding the environmental aspect, evidenced by the last position in the ranking. This selective development, prioritizing the economic dimension, may have overshadowed the benefits achieved by CE. On the other hand, the results of the EU show that by implementing the CE concept, it is possible to achieve economic development while preserving the environment and reducing the consumption of natural resources (Sverko Grdic et al., 2020), and this is evident in the results of the EU in 2020.

The significant changes in Mercosur indicators in these twenty years have taken place in sectors 1 and, especially in sector 5, where the bloc occupied the first position in 2000 and the highest distance to the target in 2020. Despite the region having great natural wealth, the strategies used to overcome poverty and inequality, unfortunately, affected policies and actions aimed at protecting and managing the environment (Betancourt Morales and Zartha Sossa, 2020). To Xavier et al. (2021), developing countries must coordinate integrated solutions to deal with environmental, social, and economic impacts to underpin the CE culture in their territories. The SISS results confirm the bloc's difficulty in dealing with these issues in 2000 and 2020.

As highlighted, the results of this study confirm the conclusions made by Kirchherr and Van Santen (2019) that the change to CE practice in emerging and developing countries is hampered by the inability to align several economic, social, and environmental aspects simultaneously accurately. The analysis of different aspects of CE revealed significant shortcomings and pointed out that a more balanced integration of sustainability is essential to achieve a genuinely sustainable alternative to the current economic system.

Given the above, Geissdoerfer et al. (2017) and Club and Tennant (2020) describe that the practical approach of CE revolves around

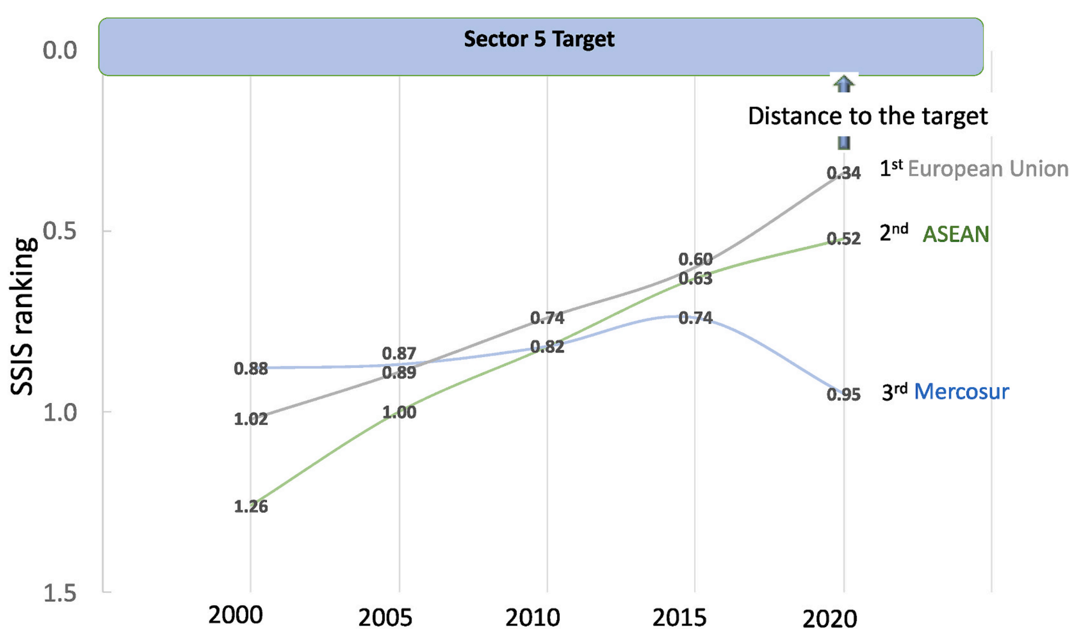

Fig. 7. Ranking and Synthetic System Sustainability Indicator (SSIS) of sector 5 of ASEAN, Mercosur, and the EU from 2000 to 2020 The SSIS value of each economic bloc (numbers inside the circles) is a comparative measure of how close the indicator value is to the target established.

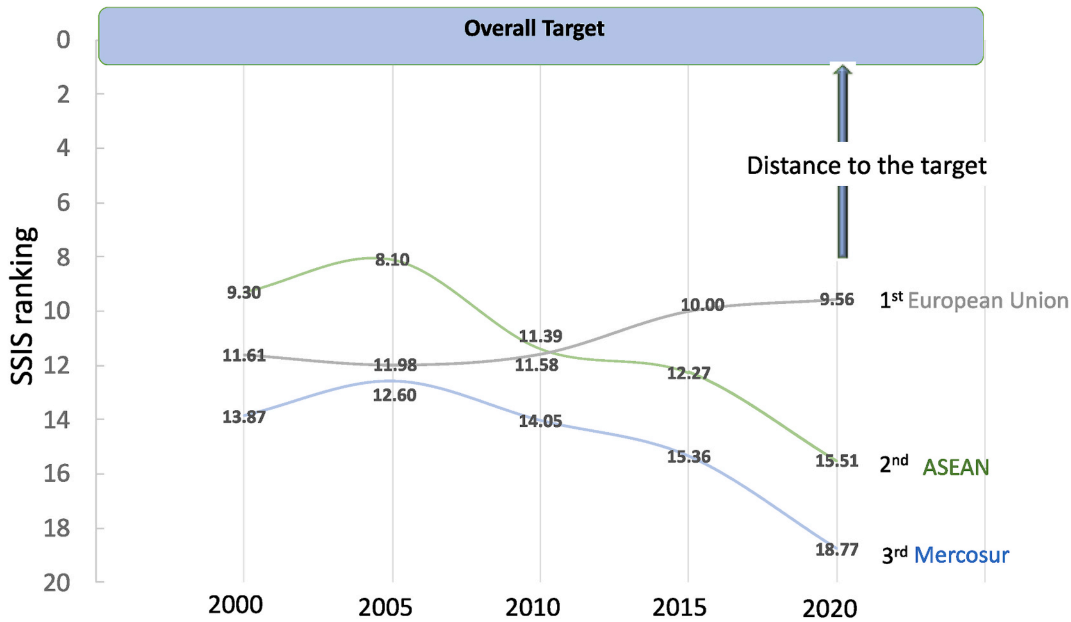

Fig. 8. Ranking and Synthetic System Sustainability Indicator (SSIS) of 5SenSU considering the global performance of ASEAN, Mercosur, and the EU from 2000 to 2020. SSIS of each economic bloc (numbers inside the circles) is a comparative measure of how close the indicator value is to the targets established through target programming.

various interpretations of reduction, reuse, and recycling strategies. This environmental stance suffocates the social dimension that is underrepresented in studies on the subject. Thus, to improve the SSIS of the 5SEnSU model and, consequently, approach the set targets, public policies or even private actions must be focused mainly on reducing the environmental impact present in Mercosur (third place in sector 1 with SSIS of 4 0.52) and ASEAN (third place in sector 2 with SSIS of 12.11).

Although the 5SEnSU model has holistically evaluated the impacts of some EC strategies on the sustainability of ASEAN, Mercosur, and the EU, it is not possible to say which block is more sustainable since the performances were observed through a prism restricted to some indicators. The main methodological limitations of the research related to the data choice, which despite focusing on the academic literature, was based on the authors' experience assessment of what is relevant in the environmental, economic, and social dimensions of CE and/or sustainability. Furthermore, the limited number of CE studies comparing regions outside the EU-China geographic axis has limited the ability to draw more specific conclusions.

For Schroeder et al. (2019) and Sharma et al. (2021), EC also offers the potential to develop synergies between various SDGs, with positive impacts that can deliver economic, environmental, and social benefits. The information presented by the 5SEnSU model (Fig. 8) captured the multidimensional aspects of CE, clearly connecting circularity with sustainability, which can help the analyzed blocks to understand the consequences of current policies or choices in each sector.

4. Conclusions

This research used the 5SEnSU multicriteria approach to explore CE's environmental, economic, and social aspects under different time and space scales and in multiple dimensions of sustainability in ASEAN, Mercosur, and EU between the years 2000 and 2020. Since the transition to a CE requires systematic changes at all levels, the economic development in the studied blocks influenced environmental issues, especially in ASEAN and Mercosur, due to the political and structural limitations of these locations. The results suggest that the benefits of sustainable development preached by the implementation of CE need to be reassessed. The improvement in the social aspect, with increased well-being, increased the consumption of resources (sector 1), the emission of $CO_{2,}$ and the generation of electronic waste (sector 2). On the other hand, the environmental load generated benefits for society both as a provider (sector 4) and as a recipient of resources (sector 5) in all blocks. These results pointed out that circularity alone does not guarantee social, economic, and environmental performance, as trade-offs still need to be resolved.

Finally, this article explored the need for a multi-criteria approach to assess the sustainable transition to an EC. While existing individual assessment methods may be capable of addressing environmental, social, and economic issues, the change to an EC needs assessment tools capable of simultaneously analyzing multiple dimensions of sustainability at different scales, both temporal and spatial. In this sense, the 5SEnSU model proved to be a useful tool providing information on the performance of the blocks concerning specific targets within the three dimensions of sustainability.

The methodological contribution of this work consists of the proposal to use a multicriteria approach (5SenSU model) that creates a composite index of sustainability that makes it possible to monitor and compare regions in different locations in a given period since the application of several indicators as individual measures of sustainability may present some limitations in monitoring sustainability trends.

In addition to the subjectivity present in multicriteria approaches, other limitations of the research and the generated results refer mainly to the lack of data for some indicators of the 5SEnSU Model, even though the collection was carried out directly from open international databases and statistical yearbooks. However, these restrictions and the performance of this study open up several possibilities for future research to overcome the presented limitations. Further research may include the impacts of COVID-19 on the CE as soon as data are updated for 2020–2022. Another fundamental point for future research lies in identifying the effects generated by the Russia and Ukraine war, especially in the EU, which would complement the sustainability results provided in this article.

Author contribution statement

Luiz C. Terra dos Santos: Data curation, Writing – original draft. **Biagio F. Giannetti:** Methodology. **Feni Agostinho, Gengyuan Liu:** Methodology, Writing – review & editing. **Cecilia M.V.B. Almeida:**

Conceptualization, Supervision.

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.118317.

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