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Providing decision-support for sustainable development of the Brazilian automotive textile sector

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ABSTRACT

Despite efforts to evaluate sustainability within the Brazilian automotive textile sector, there is still a lack of specific measures quantifying the social, environmental, and economic aspects. Consequently, the shift from a traditional profit-centric post-industrial culture to a modern, sustainable-focused culture presents ongoing challenges. Addressing this, a question arises: how can a decision-support framework be developed to ensure a balanced approach to sustainability management, highlighting system limitations without compromising the sector's performance? Decision support models aim to equip decision-makers with tools for making informed choices aligned with organizational objectives and goals. The proposed procedure comprises four key stages: sustainability diagnosis, creation of an illustrative panel, simulation, and normal distribution. The initial phase, sustainability diagnosis, uses the 5 SEnSU model, integrating indicators selection alongside their objectives and targets. Utilizing Goal Programming at its core, the Synthetic Indicator System Sustainability outlines the sector's performance relative to its objectives. Results are then presented in a dashboard format, offering a comprehensive view of sustainability performance trends. Subsequently, a simulation phase implements more stringent targets to identify the sector's limitations without jeopardizing its performance. These results are modeled through normal distribution curves, drawing parallels between sustainability within the system and Statistical Process Control Assessment, ensuring adherence to legal and corporate standards. Illustrating the procedure with the Brazilian textile automotive sector revealed that while the sector maintains economic sustainability, its progress has negatively impacted the environment and society. This process helped pinpoint critical areas in sustainability management and proposed strategies for optimizing resources to meet organizational sustainable objectives. Moreover, this model elevates informed decision-making and advocates for a more conscientious and efficient approach to business management across this sector and others.

1. Introduction

Globally, the textile industry positively influences the economy while posing adverse effects on the environment through its resource consumption and generation of pollution and emissions. Within the automotive sector, sustainability stands as a pivotal element and a crucial driver for competitiveness and sustained growth (Chalack et al., 2020), and assessing the performance of this industry could foster sustainable development by utilizing indicators that pinpoint critical environmental factors such as energy and material usage, as well as social sustainability across the entire supply chain (Gbolarumi et al., 2021; Schöggl et al., 2016). Integrating sustainability targets may allow a pathway for innovation within the textile industry (Harsanto et al., 2023), complementing the pursuit of long-term business success (Zamcopé et al., 2012) while maintaining business profitability as an outcome of managing environmental impacts with a sense of social responsibility (Lombardi et al., 2021).

As part of the automotive sector, the automotive textile sector has

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characteristics inherent to the textile industry and the automobile industry, in addition to its particularities. Therefore, this sector faces demands for sustainable production from both sectors (Stoycheva et al., 2018). The adoption of cleaner production practices, as suggested by Silva et al. (2021), mobilizes resources in the development of technical textiles (Brunella et al., 2020; Olhan et al., 2021; Sezer Hicyilmaz et al., 2019; Patti et al., 2021), but still also necessitates the creation of novel tools and models to enhance the segment's sustainability.

Decision-makers recognize the importance of embracing sustainable production as a strategy. However, they often articulate the challenges associated with implementing these practices, aiming to align social, environmental, and economic aspects in multifaceted decision-making processes. Most available sustainability assessments are qualitative and primarily focus on discussions on sustainable materials and processes or products (Ilgin et al., 2015; Salem et al., 2022; Friedrich, 2021). Comprehensive analysis frameworks that align with corporate objectives have yet to be identified (Shaw et al., 2022). Consequently, there is a growing demand for research addressing social, environmental, and economic aspects (Chourasiya et al., 2022a, 2022b) to create a measurement standard with a multidimensional approach, considering factors such as emissions, resource use, wages, jobs, worker health and safety, profit, etc. (Luo et al., 2021). This underscores the importance of building a decision-support framework to transition from the traditional post-industrial focus solely on profits to a modern ethos centered on sustainable development (Salvado et al., 2015), considering the complexity of advancing industrial sector management based on the assessment of a scientific model's findings. So, how can a decision support model be formulated to promote balanced sustainability management within the industrial sectors, identifying system constraints without compromising its effectiveness?

This study employs the composite index, SISS, which combines ten indicators analyzed in a historic series between the years 2001 and 2018, to which a simulation by extremes makes the targets more rigid to identify the sensitivity of the system's sustainability, allowing to distinguish the sector's interaction with each dimension and what is the impact on the whole system. Results are interpreted using a sustainability assessment panel (Giannetti et al., 2022), which allows monitoring the sector performance classified into three conditions: low, medium, and high sustainability, drawing a parallel between the sustainability assessment panel and the Kanban proposed by the Toyota Production System, integrating these elements as a Balanced Environmental Scorecard of the sector.

This research aims to introduce a model that consolidates a quantitative, multi-criteria metric for evaluating and diagnosing sustainability, intending to present outcomes straightforwardly and user-friendlyly. Additionally, to enhance the accuracy of actions, the model suggests simulation criteria that establish more stringent sustainability objectives, determining the system's potential advancements without undermining its effectiveness. This assessment uses normal distribution curves to model the Synthetic System Sustainability Indicator (SISS), enabling an approach akin to Statistical Process Control (SPC). The validation of simulation outcomes is verified through Pearson correlation analysis.

2. Literature review

Delineating the methodological trajectory, the literature review highlights the research encompassing the automotive textile industry, the sustainability multimetric models, and their representation with visual indicators.

2.1. The automotive textile sector

The complexity of the automotive textile sector constitutes the first thematic axis contextualized for implementing the proposed model. Automotive textile materials cover ceiling, floor, door panels, seats, airbags, seat belts, and tires. Numerous textile sector studies contribute to advancing technical textiles utilizing composites and natural fibers in this context. These innovations result in lighter fabrics, aiding vehicle weight reduction and decreasing resource usage and emissions. Developing new materials is a proactive solution for attaining sustainability objectives within the automotive sector (Sezer Hicyilmaz et al., 2019; Stoycheva et al., 2018). Efforts are underway in seat cover development, exploring technical textiles crafted from polymeric composites reinforced with natural fibers (Olhan et al., 2021), hollow section fiber fabrics, and recycled PET fabrics (Brunella et al., 2020). These endeavors aim to reduce vehicle weight and curb fuel consumption and emissions. Despite extensive attempts within the automotive textile sector to enhance efficiency and diminish the environmental impact, there remains a challenge in prioritizing actions and applying quantitative metrics capable of comprehensively measuring the social, environmental, and economic complexities inherent in each activity (Stoycheva et al., 2018).

The textile and automotive sectors have undergone assessments using various methods encompassing physical elements like facilities, machinery, and equipment alongside human resources such as skilled labor, managerial expertise, and intellectual property. Life cycle analysis remains a prevalent metric providing a comprehensive view of environmental impacts - such as energy and water use, greenhouse gas emissions, and waste generation (Gbolarumi et al., 2021; Harsanto et al., 2023; Schöggl et al., 2016), but methods involving fuzzy and other logics are also widely employed (Gbolarumi et al., 2021; Lombardi et al., 2021; Chalak et al., 2020). However, most assessments remain dispersed and fragmented (Gbolarumi et al., 2021).

2.2. Sustainability multimetric models

Recent literature widely agrees on the necessity for quantitative and multi-criteria assessment models. These models aim to facilitate an analysis that discloses the resultant performance across the social, environmental, and economic dimensions by employing indicators and objectives. In this context, sectoral sustainability assessment is pivotal in shaping decisions concerning current development across industrial sectors. However, approaches solely concentrating on environmental impacts might lack adequacy in representing organizations' overall environmental conduct. This underscores the necessity for research capable of encompassing aspects from all three dimensions of the sustainability framework.

Multiple authors have proposed models with varying scopes and objectives to address the need for a scientifically grounded conceptual model representing sustainability. Goodland (1995) delineated the components of sustainability—social, economic, and environmental—unified under the term "sustainable development," leading to the notion of strong and weak sustainability discussed by Ekins et al. (2003). Ulgiati et al. (2006) introduced the Sustainability Multicriteria Multiscale Assessment to mitigate issues linked to single-criteria approaches in life cycle assessments, which often yield partial and misleading outcomes. Pulselli et al. (2015) promoted a logical, physical, and thermodynamic framework to appraise the sustainability of production systems through an input-state-output (environmental-society-economy) relationship. This model could potentially circumvent the primary limitations of conventional sustainability representations. Rockström and Sukhdev (2016) proposed a comprehensive and broader view based on the triple bottom line, incorporating the Sustainable Development Goals (SDGs). They segmented the SDGs into three concentric rings—biosphere at the bottom, society in the middle, and economy at the top—connected by a double-arrowed line signifying the 17th SDG named "partnership for the goals." Despite these models' broader and more integrative nature, the literature review revealed a scarcity of a "functions"-based perspective, wherein the natural environment and societal dimensions are perceived as contributors and recipients of energy, materials, and information flow.

Consequently, exploring the development of a measurement standard integrating a multi-dimensional approach and a hybrid assessment system for industrial sectors is still imperative. This standard should encompass multi-criteria decision-making and strike a balance among society, environment, and economy, considering factors like wages, employment, worker health and safety, career advancement, and societal progress, among others (Luo et al., 2021; Terra dos Santos et al., 2022). Stoycheva et al. (2018) criticized the adoption of metrics for sustainability, reasoning that the utilized models need to comprehensively account for the social, environmental, and economic dimensions in a balanced manner, a gap in using multi-criteria metrics to evaluate sustainability within industrial sectors.

The 5SEnSU Model emerges as a potential solution for this discrepancy by computing the Synthetic Indicator of Systems Sustainability (SISS, Agostinho et al., 2019). This model offers flexibility in indicator selection, allowing for the (re)definition of objectives and targets (Terra dos Santos et al., 2022). Concurrently, it recognizes the dual roles played by the social and environmental dimensions: contributing resources to the production sector while bearing the consequences of the sector's operations.

The SISS, functioning as a composite index, showcases how much the system deviates from established targets, facilitating more informed discussions and robust decision-making (Giannetti et al., 2019; Moreno García et al., 2021). A thorough understanding of the relevant indicators to be selected is crucial to the accuracy and relevance of sustainability assessments, and the challenge of choosing among alternatives is prominent (Kalu, 1999). Decision-makers often encounter difficulties navigating choices, particularly in situations involving multiple criteria. This complexity extends to sustainability assessments of production systems, where a single indicator struggles to encompass all its embedded aspects (Siche et al., 2010; Giannetti et al., 2015). As more criteria, represented by indicators, are integrated into each scenario, decision-making tools supported by comprehensive, scientifically grounded multidimensional models may become increasingly robust (Scott et al., 2012). Still, Pulselli et al. (2015) argue that selecting a particular indicator over others can be contentious as each indicator possesses distinct capabilities in capturing the various aspects of sustainability.

2.3. Visual indicators to represent environmental issues

Visual representations are vital in communicating complex sustainability concepts and data to diverse audiences, enabling better understanding and decision-making (Clive et al., 2023). Despite the various visual indicators used to represent environmental issues, the Kanban dashboard was chosen for its success over time in industries seeking efficient production methods (Baumer-Cardoso et al., 2020; Pekarcikova et al., 2020). Its principles have expanded into various sectors globally due to its adaptability, simplicity, and effectiveness in improving efficiency and have made Kanban a widely embraced methodology across industries.

Initially developed for optimizing manufacturing processes, Kanban has expanded beyond traditional applications into various sectors, including environmental management (Singla and Sharma, 2023; Dieste et al., 2020). Its principles of visualizing workflow, limiting progress, and continuous improvement can be adapted effectively for environmental purposes (Dieste et al., 2020). Its visual boards are used to represent waste management (Yadav and Jha, 2022), energy consumption (Bamberg et al., 2012), and resource utilization (Naqvi et al., 2016).

2.4. Normal modeled distribution and concepts of statistical process control

Balancing priorities with effectiveness is an ongoing process that requires careful planning, continuous evaluation, and adaptability to ensure that resources are allocated to the most impactful initiatives while achieving organizational objectives. The normal distribution model is a statistical tool used to analyze and assess the stability of a system, including within industrial sectors (Braun and Han, 2017; Khakifirooz et al., 2021). Studies examining the relationship between normal distribution modeling and process stability emphasize its importance (Awwad and Thabet, 2024; Brancato et al., 2017), limitations (Landim et al., 2021), and adaptations (Kok et al., 2020) for accurate process control and improvement. The literature needs to include instances where the Normal distribution model and statistical process control concepts were applied to assess the stability of industrial sectors using performance indicators. However, using statistical methods as scientific and assertive support may improve the quality of research in any area of knowledge, giving it greater rigor and objectivity.

3. Methods

To illustrate the proposed decision-support for sustainable development of industrial sectors, the Brazilian automotive textile sector, a hybrid of the textile and automotive sectors, was analyzed from 2001 to 2018. The procedure adopted the following steps (Fig. 1):

1. Diagnosis, with the use of the 5SEnSU model and the calculation of the SISS, reveals how far the sector is from the established target. The lower the SISS values, the better the sector performance.
2. Organization of the results in an illustrative panel allows priority actions to improve the sector's performance.
3. Simulation by extremes reveals how stringent the targets can be without compromising the sector's functioning.
4. Normal modeled distribution of the calculated and simulated SISS uses concepts of statistical process control to identify the sector's stability.

3.1. Diagnosis, with the use of the 5SEnSU model and the calculation of the SISS

The 5 SEnSU model is conceptual and holistic for assessing sustainability (Giannetti et al., 2019), seeking to identify the sector interactions with the social and environmental dimensions (Fig. 2). For further details and a complete description, please check Moreno García et al. (2021) and Giannetti et al. (2019). The first stage consists of defining the sustainability indicators for each interaction and meeting the criteria of representativeness, relevance, reliability, sensitivity, ease of understanding, comparability, and transparency (Agostinho et al., 2019). In the second stage, targets for each indicator must be defined according to international or national goals or analysts' expectations for each sector. In this phase, it is possible to assign weights to the indicators according to their relevance to the system of interest. In this study, every indicator holds equal importance in depicting sustainability; hence, all indicators were assigned a weight of one.

The SISS is computed through Goal Programming, a mathematical approach to address numerous conflicting variables. Within the 5 SEnSU model, the role of goal programming is to streamline the ultimate analysis.

Table 1 shows the indicators selected to represent each sector. The potential relationship of each sector with the Sustainable Development Goals (UN, 2015) is established in Table 2. Indicators were selected from sectoral reports (Table 1) and publications from professional associations, such as the Brazilian Textile Industry Association (ABIT, 2022); the Textile industry union (Sinditêxtil, 2019 a,b), the National Association of Automotive Vehicle Manufacturers (ANFAVEA, 2022) and government agencies, such as the National Confederation of Industry the Federation of Industries of the State of São Paulo/Center of Industries of the State of São Paulo, and the experience of the authors (Agostinho et al., 2019; Moreno García et al., 2021; Giannetti et al., 2019, 2022), to

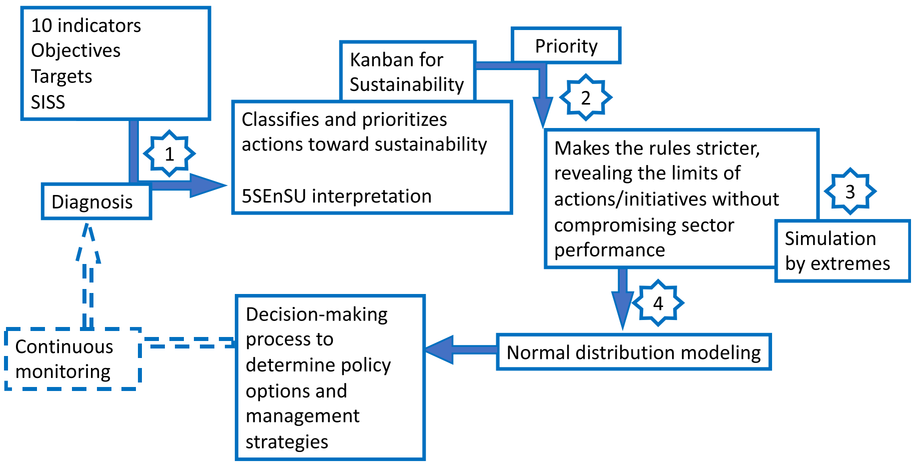

Fig. 1. Steps adopted to evaluate the sustainability of industrial sectors.

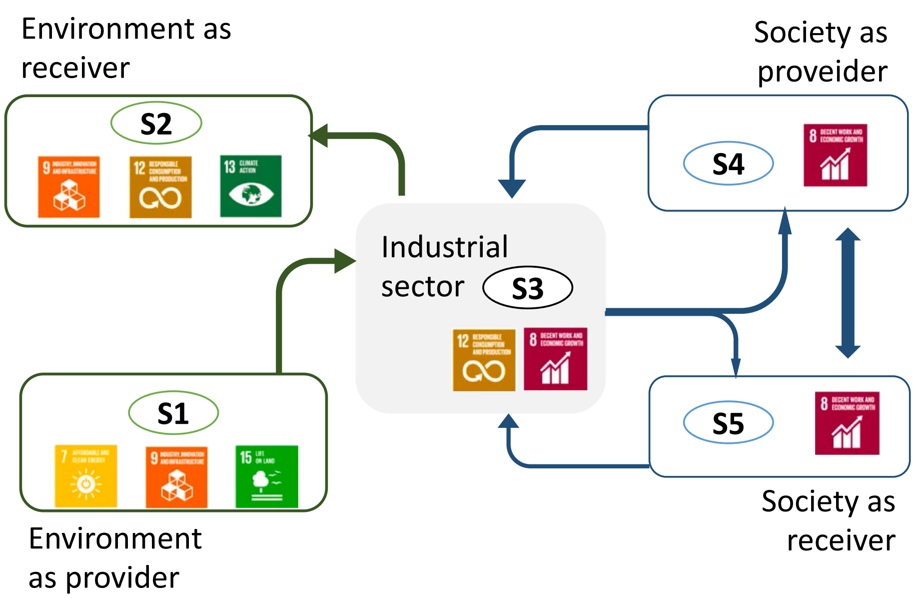

Fig. 2. 5SEnSU model adapted for the Brazilian automotive textile sector and the association of sectors with the Sustainable Development Goals (see Table 2 for further explanation).

illustrate the proposed perspective.

Having chosen the indicators and their respective targets, the next step is to define whether, according to the established targets and the objectives imposed by the analyst, the indicator should be maximized or minimized (Table 2).

Goal Programming was used to calculate how far each sector's indicators are away from the established goals (Fig. 3). A summary of the calculations is available in Supplementary Materials, section 1. Fig. 2 illustrates the steps to calculate and display the model's results.

3.2. Organization of the results in an illustrative panel

The results are organized in an illustrative panel, the sustainability Kanban, to help analysts and decision-makers prioritize actions favoring sustainability. This panel is flexible and can be organized according to the interests of analysts and decision-makers. In this study, the panel was organized in a time series covering 2001 to 2018 to highlight the evolution or involution of each of the five sectors toward the established goals.

3.3. Simulation by extremes, modeled distribution, and statistical process control

The study introduces simulation criteria involving extremes and employs normal distribution modeling to verify the sector's resilience and stability. Additionally, it aims to explore potential correlations between sector performance when subjected to stricter targets (Chourasiya et al., 2022a).

A twofold increase was applied when maximizing the indicator—doubling the target value to enhance the stringency of targets. For instance, in the case of K41, the extreme target would be twice the anticipated number of jobs offered by the sector. Conversely, when minimizing the indicator, the target value was halved. For instance, in K21, the objective was to reduce electricity usage by half. Six scenarios were considered in computing the SISS (Table 3).

To ascertain the analysis's strength and accuracy and to explore potential correlations between the adjusted sectors, a Pearson Correlation was conducted (refer to Supplementary Material, section 2). Table 4 presents the calculated statistical parameters.

The interval on which the curve is constructed along the x-axis spans from the mean ± 4 standard deviations. For example, the curve of the

Table 1
Summary table of indicators selected for the analysis using the 5SEnSU model and the data sources used in constructing the SISS.

Sector	Indicator	Justificative and data sources
1 – Environment as a resource provider	K11 Emergy (seJ/year)	The available energy, directly or indirectly, to make a product or provide a service; is the energy embodied in the product or service (Odum, 1996) Emergy includes the hidden costs required to operate the systems. Data source: http://www.emergy-nead.com
	K12 Electricity (Tep/year)	Electricity is included in the group of environmental indicators proposed by the Global Reporting Initiative, GRI (Salvado et al., 2015) and reveals efficiency of the production process (Silva et al., 2021) Data source: http://www.centroclima.coppe.ufrj.br
2 – Environment as a waste receiver	K21 CO_2 Emissions (kg/year)	Indicates the organization's contribution to the production of greenhouse gases that are harmful to human life Emissions management also embeds a legislation approach and can lead to obtaining an environmental seal, enhancing the sector's participation in the market (Salvado et al., 2015; Agostinho et al., 2019; Giannetti et al., 2019, 2022; Luo et al., 2021; Silva et al., 2021; Gai et al., 2022). Data source: http://www.centroclima.coppe.ufrj.br
	K22 Solid waste (kg/year)	The generation of solid waste, which is very expressive throughout the textile chain, follows the production volume of the Textile and Automotive Industry, which tends to grow until 2050. The effectiveness of controlling and measuring waste can have a great impact on the environment (Giannetti et al., 2019; Patti et al., 2021; Luo et al., 2021; Silva et al., 2021; Chourasiya et al., 2022a). Data source: Field research information; https://www.abit.org.br; https://sinditextilsp.org.br/home/
3 – Automotive textile sector	K31 Sectoral GDP ($/year)	GDP proxies the sector economic health (Giannetti et al., 2019), in addition to identifying the contribution of the automotive textile segment to the country's GDP (National Confederation of Industry, 2013; Synditextile, 2019). Data source: https://www.ipea.gov.br/ods/ods8.html; https://www.abit.org.br; https://sinditextilsp.org.br/home/
	K32 Fabric production (m^2/year)	The fabric production indicator reveals the sector's impact on the environmental performance, regarding resource use (Anfavea, 2022). Data source: Field research information; https://anfavea.com.br/site/; https://www.abit.org.br; https://sinditextilsp.org.br/home/
4 – Society as a resource provider	K41 Labor force (persons/year)	The number of jobs that a sector offers society shows the contribution of the segment to the GDP of the region and the country. The average salary level offered by the sector can impact the human development index of the region (Salvado et al., 2015; Agostinho et al., 2019; Giannetti et al., 2019; Rossi et al., 2020; Luo et al., 2021). Data source: https://www.abit.org.br; https://sinditextilsp.org.br/home/
	K42 Training (%persons/year)	The training of the workforce reveals the contribution quality that society can provide to the production unit, paving the way for innovation, sustainability and technology (Salvado et al., 2015). Data source: Field research information; https://www.abit.org.br; https://sinditextilsp.org.br/home/
5 – Society as a recipient of products and benefits	K51 Salary ($/year)	Salary is the reward in monetary form and/or benefits arising from the sale of labor and "expertise" from society to the production unit (Salvado et al., 2015; Agostinho et al., 2019; Giannetti et al., 2019; Rossi et al., 2020; Luo et al., 2021). Data source: https://www.contabeis.com.br/tabelas/salario-minimo/
	K52 Absenteeism (%persons/year)	Absenteeism can be a measure of employee satisfaction with salary and employment, or the counterpoint to them (ABIT, 2022). Data source: Field research information; https://www.abit.org.br; https://sinditextilsp.org.br/home/

normal distribution for the "original target" will lie in the interval from 124.90 to −75.39 since the starting point and the ending point on the x-axis are established (Table 5). The starting point of the x-axis was defined as the smallest point of the "mean – 4 sd" line, −147.78, the largest value of the line "mean + 4 sd", was 247.30, was selected as the x-axis ending point. For the curves to be adequate for the analyses, it was established that they should have 30 points. The increment is the gap between two points and was calculated as (end of x-axis-start of x-axis)/(number of points-1), or (247.30- (−147.78)/(30-1) = 13.62. The next step is to create the mass probability function defining the value of one of the curves for each point on the x-axis. The complete table is available in Supplementary Materials (Section 3, Table S2). It shows the number of points, the value of the x-axis for each point, and the calculation of the mass probability for each curve.

To plot the normal distribution curve, defining the x-axis values range, an average ± 4 standard deviations is employed. The selection of ±4 standard deviations aims to achieve the characteristic bell-shaped curve of the normal distribution. Deviating from this range, whether using fewer or more than 4 standard deviations, alters the curve's Gaussian shape, leading to a flattened or sharper curve.

Expanding the analysis scope by employing the modeled normal distribution allows to draw a parallel to the Statistical Process Control control chart, a renowned quality tool in Production Engineering (Liu et al., 2014; Slack, 2018). Statistical Process Control aims not only to detect failures but also to prevent and minimize process variability. Within this study, the Statistical Process Control is presented as a measure of stability. By analyzing time series data, the sector's stability is gauged through fluctuations around the midpoint of a normal distribution curve, depicting the sector's behavior across time and revealing how stringent the targets can be without compromising the sector's functioning.

4. Results

The outcomes are structured into two segments. Initially, the synthetic sustainability indicators for individual sectors and the overall outcome are computed and displayed in a panel for rapid comprehension. The subsequent section examines the system's stability under

Table 2
Indicators and targets used in the 5SEnSU Model in assessing the sustainability of the automotive textile sector and the potential relationship with the Sustainable Development Goals.

Sector	Indicators and objectives	SDG/Justificative	Target
1 – Environment as a resource provider	K11 Emergy (seJ/year) Minimize	SDG 15: Protect, restore and promote the sustainable use of Earth's ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss.	$\overline{K_{11}} + \sigma(K_{11})$
	K12 Electricity (Tep/year) Minimize	SDG 7: Ensure access to cheap, reliable, sustainable and renewable energy for all. SDG 9 (941): Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation (CO_2 emissions per GDP)	$\overline{K_{12}} + \sigma(K_{12})$
2 – Environment as a waste receiver	K21 CO_2 Emissions (kg/year) Minimize	SDG 9: Industry, innovation and infrastructure SDG 13: Action against global climate change (Reduce emissions by 76 % each yr from 2020 to 2030 UNEP Emissions Gap Report, 2020)	$\overline{K_{21}} - 7,5\%$
	K22 Solid waste (kg/year) Minimize	SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation SDG 12: Ensure sustainable production and consumption standards	$\overline{K_{22}} - 5\%$
3 – Automotive textile sector	K31 Sectoral GDP ($/year) Maximize	SDG 8: Decent work and economic growth Increase of 0.4 % according to the Sustainable Development Goal	$\overline{K_{31}} + 0,4\%$
	K32 Fabric production (m^2/year) Minimize	SDG 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all 8.4.2 - Internal consumption of materials, internal consumption of materials per capita, and internal consumption of materials per unit of GDP. SDG 12 (12.5): Ensure sustainable production and consumption standards. By 2030, substantially reduce waste generation through the Circular Economy and its actions to prevent, reduce, recycle and reuse waste.	$\overline{K_{32}} + 0,4\%$
4 – Society as a resource provider	K41 (persons/ year) Maximize	ODS 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all.	$\overline{K_{41}}$
	K42 Training (%persons/ year) Maximize	ODS 8: Decent work and economic growth (used the highest average global employment rate between the yrs 2001 and 2018).	$\overline{K_{42}} + 50\ \%$
5 – Society as a recipient of products and benefits	K51 Salary ($/year) Maximize	ODS 8: Decent work and economic growth (used the highest average global employment rate between the 2001 and 2018).	$\overline{K_{51}}$
	K52 Absenteeism (%persons/ year) Minimize	ODS 8: Decent work and economic growth (used the highest average global employment rate between 2001 and 2018). The defined target was the lowest of all years from 2001 to 2018	Lowest value of the historical series

redefined targets aligned with SDG recommendations, focusing on environmental, economic, or societal benefits (Table 3).

4.1. SISS values and the Kanban for sustainability

Table 5 presents the sectoral indicators throughout the studied period. The raw data is available in Supplementary Materials (Table S1).

Once the sectoral targets are set, the data undergo goal programming, unveiling the behavior of both sectoral SISSs and the overall system's SISS on a yearly basis. The sectoral SISS gauges the deviation of each sector's indicator from its respective set goal. Spanning a historical series of 17 years (2001–2018) within this study, for enhanced clarity and precision, the annual sectoral SISS values were allocated within each sector (Fig. 4).

Sector 1 serves as the environmental resource provider for Sector 3, the production unit. Between 2001 and 2015, emergy and electricity use remained near the established targets. However, post-2015, a rise in electricity and raw material consumption, driven by escalating production volumes, signals the sector's increasingly harmful resource extraction from the environment. The upward trajectory of $SISS_{sector1}$ indicates that the sector's growth during this period disregarded any energy conservation or resource usage reduction objectives.

Sector 2 depicts the environment as the recipient of waste from sector 3's manufacturing activities (Fig. 4). The period post-2006 exhibits a rise in $SISS_{sector2}$, attributed to the escalation of solid waste and emissions.

Sector 3 embodies the Brazilian automotive textile industry by reflecting the segment's financial input to the sector's GDP and fabric manufacturing. The analysis of $SISS_{sector3}$ highlights a concerted endeavor to meet the sector's objectives of augmenting production and revenue. However, this achievement has come at the expense of the sector's environmental impact, affecting its relationship with the environment (sectors 1 and 2).

Sector 4 represents society by providing the workforce and facilitating employee training (Fig. 4). Between 2003 and 2007, $SISS_{sector4}$ closely matched the target, signifying that during this period, job offerings from the sector aligned with societal demand, and employee training was adequate. However, the gradual increase in $SISS_{sector4}$ from 2007 onward solidifies a declining trend in job availability and subsequent reductions in training and employability. This segment's decrease in job opportunities correlates with increased industrial automation and China's emergence in the global textile scenario (ABIT, 2022).

Finally, Sector 5 embodies society by receiving benefits from Sector 3, indicated through salaries and absenteeism rates. Between 2003 and 2009, $SISS_{sector5}$ closely aligned with the target. However, post-2009, a combination of inadequate wages failing to meet employees' needs and rising absenteeism indicated a deviation from targets, signaling the sector's emphasis on economic growth in its management approach (Contábeis, 2022; FGV, 2022).

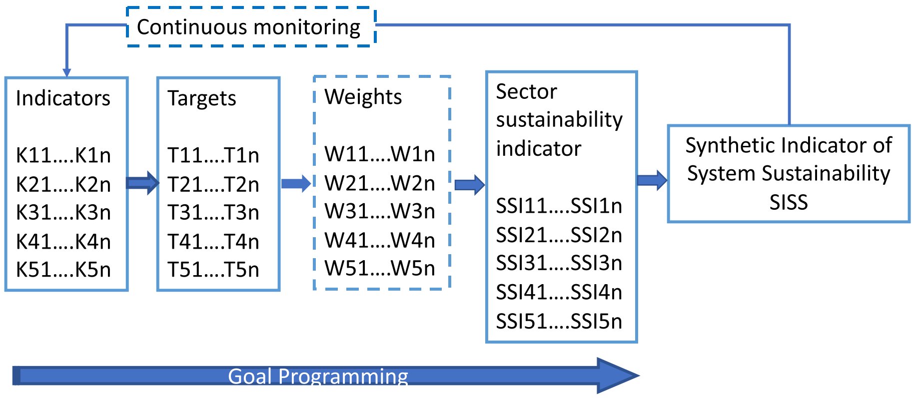

Fig. 3. Step-by-step calculations of using the 5SEnSU model. A dashed line represents the weighting phase, as no weighting was applied in this study. The SISS indicates how far from the target the sector is. The lower the SISS, the closer the indicator is to the target, and the higher the sector's sustainability.

Table 3
The scenarios considered when calculating the SISS with varying target strictness to benefit a given sector and maintain the initial targets for the other sectors.

SCENARIO	APPLIED SIMULATION	SISS	BENEFICIARY
ORIGINAL	baseline for the original targets	$SISS_{original}$	
ADJUSTED S1	halving emergy and electricity use	$SISS_{S1}$ adjusted	environmet
ADJUSTED S2	halving CO_2 emissions and solid waste	$SISS_{S2}$ adjusted	environmet
ADJUSTED S3	doubling sectoral GDP and fabric production	$SISS_{S3}$ adjusted	economy
ADJUSTED S4	doubling offered jobs and training programs	$SISS_{S4}$ adjusted	society
ADJUSTED S5	doubling salaries and halving absenteeism	$SISS_{S5}$ adjusted	society

4.2. Organization of the results in an illustrative panel

The overall SISS can be depicted in a panel, serving as a visual and potent tool that showcases the development of each sector across the historical series spanning 2001 to 2018 (Fig. 5). The panel demonstrates that the rapport with sector 1 (emergy and electricity use) remained satisfactory from 2001 to 2015. Yet, improper disposal of solid waste and escalating emissions emerged from 2007 onwards. A comparable pattern is discernible in the sector's interaction with sectors 4 and 5, indicating that the sector's economic advancement occurred at the expense of exploiting the environment and society. The automotive textile sector reveals a lack of initiatives in the social sphere, indicating a shortfall in meeting social demands or requirements. According to Abreu et al. (2012), the Brazilian automotive textile industry enforces coercive isomorphism across its supply chain, signifying manufacturers' pressure to uphold existing precarious operational structures, particularly in the social aspect. With job displacement due to industrial automation (ABIT, 2022), establishing partnerships with technical training institutions could help maintain or enhance employees' skills and competencies, offering the potential to regain and sustain employment within this sector.

4.3. Simulation by extremes, modeled distribution, and statistical process control

The utilization of the extremes criterion seeks to heighten target stringency to assess the sensitivity of the system's sustainability, enabling the differentiation of interactions between sectors and their influence on the SISS. This criterion introduces the initial scenario with original targets and five additional scenarios, each aligned with an adjusted sector (Table 6).

The results of the simulation by extremes were obtained and modeled in normal distribution curves (Fig. 6). The resulting curve should mirror a normal distribution, aiding in the assessment of system stability by analyzing its shape and to assess the stability of the process using normal distribution curves, the approach followed aligns with the principles of The Statistical Process Control, a well-established quality tool outlined in ISO IATF 16949 (IATF 16949: 2016).

Stability curves illustrate how the process repeats regardless of any occurring or imposed changes or, in this case, the target adjustments. A flatter curve signifies less stability, with values scattered further from the mean. The closer values align with the mean, the smaller the variation, indicatingg greater stability within the sector.

When comparing the shapes of the original and adjusted curves, it's evident that sectors 1 to 4 maintain stability, indicating that changes over time haven't disrupted the relationship among these sectors. Significant alterations, like implementing stricter environmental regulations, can be introduced without compromising sector stability and functionality. Conversely, the curve representing sector 5 displays a fragile relationship, with variations surpassing acceptable limits due to the flattened curve aspect (Dudek-Burlikowska, 2005; Siddiqui et al.,

Table 4
Parameters for the modeled normal distribution.

Parameters of the modeled normal distribution	Original target	Adjusted S1	Adjusted S2	Adjusted S3	Adjusted S4	Adjusted S5
Average	24.75	32.41	34.85	28.23	28.30	49.76
Standard deviation	25.04	26.43	25.86	24.75	24.66	49.38
Average + 4sd	124.90	138.11	138.29	127.24	126.96	247.30
Average – 4sd	−75.39	−73.29	−68.59	−70.78	−70.35	−147.78
x-axis starting point	−147.78					
x-axis ending point	247.30					
Number of points	30.00					
Increment	13.62					

Table 5
Sectoral indicators of the Brazilian automotive textile sector used to calculate the SISS according to the 5SEnSU model from 2001 to 2018.

	Emergy	Electricity	CO_2 emission	Solid waste	Sectoral GDP	Raw material	Labor force	Training	Salary	Absent
	10^{18} seJ/yr	10^5 Tep/yr	10^8 kg CO_2/yr	kg/yr	10^9 R$/yr	kg/yr	10^3 person/yr	% person/yr	10^6 R$/yr	% person/yr
Year	K11	K12	K21	K22	K31	K32	K41	K42	K51	K52
2001	3.04	2.66	1.86	17580	196	87901	464	84.55	140	0.43
2002	3.14	2.72	1.94	17183	221	85916	437	45.95	146	0.37
2003	3.42	2.79	2.01	18249	256	91246	441	75.64	177	0.23
2004	3.99	2.85	2.09	21873	292	09366	452	71.43	197	0.22
2005	3.61	2.89	2.16	24576	324	122881	464	86.79	233	0.21
2006	3.74	2.96	2.20	24898	360	124491	464	83.95	272	0.25
2007	3.77	3.00	2.28	29374	406	146869	477	69.95	304	0.22
2008	4.47	3.07	2.35	31787	465	158937	496	33.16	345	0.24
2009	4.03	3.12	2.40	30251	497	151255	500	21.29	390	0.16
2010	4.55	3.70	3.13	34701	581	173505	509	40.28	435	0.24
2011	4.44	3.24	2.50	36668	654	183342	495	16.75	450	0.61
2012	4.33	3.29	2.60	33890	720	169448	490	13.45	511	0.80
2013	4.66	3.38	2.67	37211	797	186056	494	14.84	561	0.94
2014	4.77	3.40	2.73	31121	863	155607	485	10.96	589	0.82
2015	4.07	2.73	2.07	23197	538	115984	465	12.95	615	0.88
2016	4.66	3.50	2.85	20685	936	103427	455	8.55	672	1.62
2017	4.99	3.51	2.94	25643	979	128216	464	8.47	729	2.59
2018	5.47	3.60	3.00	28296	1020	141478	458	18.89	733	2.73

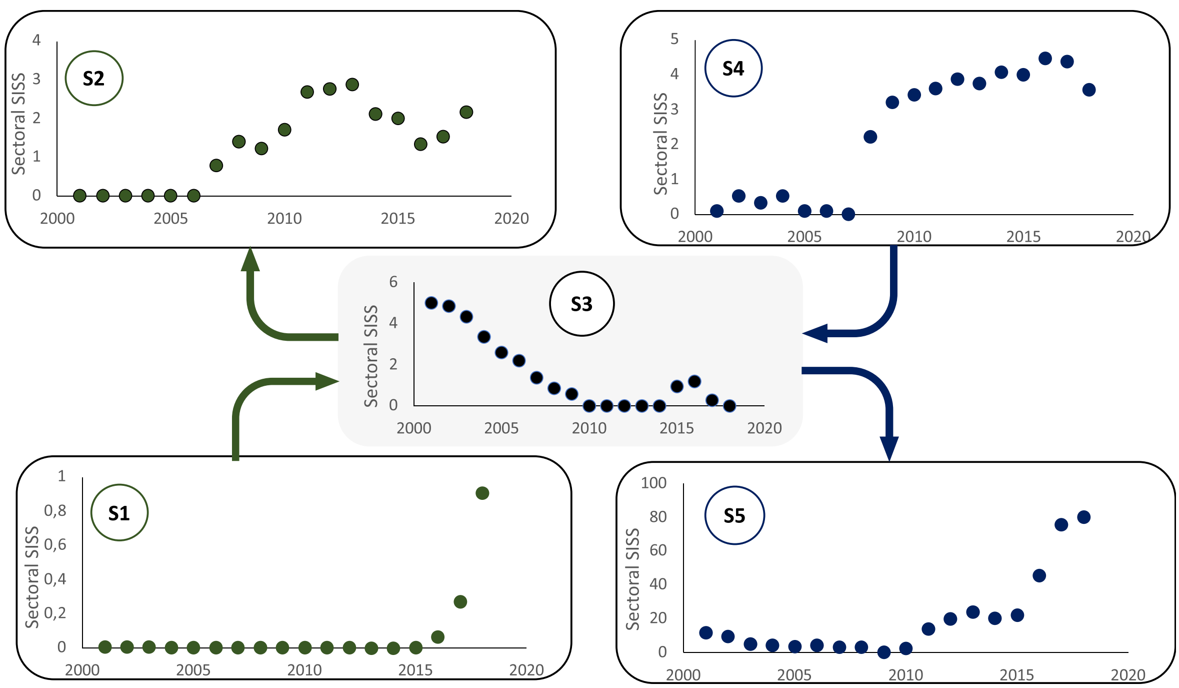

Fig. 4. Sectoral SISSs calculated for the Brazilian automotive textile sector from 2001 to 2018.

2015).

5. Discussion

The primary aim of this paper is to contribute to the need to integrate sustainability principles into industrial sectors and quantitatively evaluate the impact of their actions to provide systemic feedback for informing future initiatives. Utilizing a time series and the 5SEnSU model, the SISS outcomes enabled the assessment of environmental and social tendencies within the sector displayed in a Sustainability Kanban.

Visual indicators can emphasize areas for improvement or inefficiencies, assisting in more informed environmental decision-making. Comprehensively considering multiple indicators within a multicriteria perspective to yield a single value like the SISS would be arduous. However, as acknowledged by Bastianoni et al. (2016), condensing numerous specific indicators into one offers simplicity for decision-makers aiming for a macroscopic perspective. However, also recognizing that this aggregation might lead to information loss and could potentially hinder decisions (Gibari et al., 2021), apart from offering an aggregated result, the Kanban for Sustainability insights for each assessed sector, aiding in establishing priority areas among sectors and tendencies over the years.

Regarding the Brazilian automotive textile sector, the results exposed the sector's behavior over the years. They emphasized priorities to aid the transition from traditional operational methods to a more sustainable approach. In the diagnostic phase, the model has already pinpointed that the sector maintains economic sustainability, yet it has boosted profitability by causing adverse effects on the environment and society. Studies focusing on developing novel materials could enhance the sector's environmental alignment. New materials (Sezer Hicyilmaz

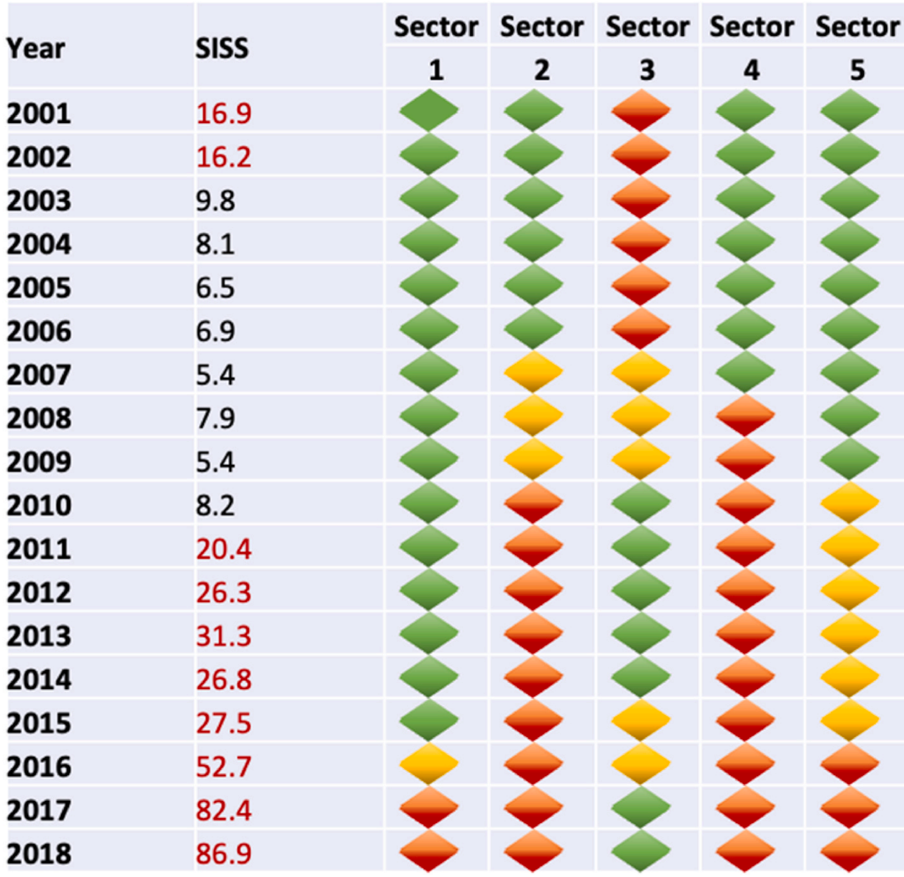

Fig. 5. Kanban for sustainability of the Brazilian automotive textile sector from 2001 to 2018.

Table 6
Application of the extreme simulation criterion to the original data.

Synthetic indicator of sustainability adjusted, SISS.						
Year	Original targets	Adjusted S1	Adjusted S2	Adjusted S3	Adjusted S4	Adjusted S5
2001	16.89	20.90	22.00	19.37	20.82	31.16
2002	16.23	20.62	21.54	18.79	20.47	28.67
2003	9.77	14.96	15.81	12.59	13.95	18.02
2004	8.13	14.67	15.93	11.43	12.54	16.18
2005	6.47	12.34	15.64	10.17	10.30	14.43
2006	6.87	13.19	16.34	10.75	10.82	16.32
2007	5.41	11.93	16.19	9.51	9.97	14.11
2008	7.87	16.06	19.28	12.01	11.64	17.44
2009	5.36	12.76	16.58	9.78	8.61	12.69
2010	8.20	18.00	21.91	12.43	12.20	18.09
2011	20.36	28.95	33.04	24.08	23.44	41.72
2012	26.25	34.76	38.63	29.94	29.23	53.18
2013	31.32	40.78	44.49	34.36	34.33	62.32
2014	26.84	36.59	38.97	30.15	29.74	53.93
2015	27.47	33.82	35.68	31.99	30.47	56.27
2016	52.71	62.45	62.11	55.45	55.48	104.30
2017	82.43	92.68	93.96	85.44	85.24	163.98
2018	86.98	97.87	99.17	89.85	90.20	172.89

et al., 2019; Stoycheva et al., 2018) and recycled alternatives (Brunella et al., 2020) have the potential to reduce vehicle weight, consequently reducing fuel consumption and emissions, benefiting not just the sector itself but also extending advantages to other industries like transportation.

Once priorities are set, it becomes imperative to assess their feasibility - determining the extent to which one can safeguard the environment or benefit society without jeopardizing the sector's stability.

Modeling normal distribution curves through extreme simulations serves not only to evaluate system stability amid drastic changes but also to delineate the boundaries for modifications without undermining performance. The analysis revealed that Sectors 1, 2, and 4 could embrace more assertive policies without substantially disrupting the industrial sector operational model. Notably, substantial changes, such as implementing stricter environmental regulations, can be introduced without jeopardizing the stability and functionality of the industrial sector. However, the connection between the industrial sector and Sector 5 (salaries and absenteeism) displayed a delicate nature, indicating a significant predominance of economic priorities over social interests, a notion supported by existing literature (Abreu et al., 2012; Cano, 2012). Therefore, when considering changes for sector 5, caution is advised due to its delicate relationship with society as a primary beneficiary of this industrial sector.

6. Conclusions

This research combines a scientific sustainability model (5SEnSU) with a practical implementation showcased via a visual representation known as Kanban for Sustainability, examining the impact of identified priorities on the sector's stability. Analyzing the potential effect of making the rules or regulations more stringent helped to understand how policy and decision-makers can enhance sustainability without compromising the overall viability and functioning of the industrial sector.

The case study - the Brazilian automotive textile sector – allowed to exemplify the assessment of this segment's economic, social, and environmental performance over an 18-year. The suggested Sustainability Kanban consolidates key sustainability elements, encouraging continuous evaluation and enhancement of environmental practices and nurturing a culture of sustainability within the industrial sector. For the

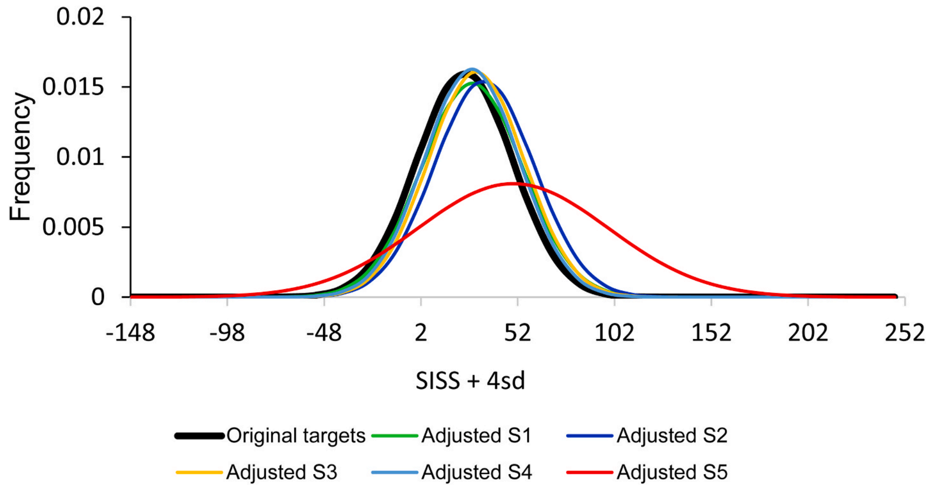

Fig. 6. Modeled normal distribution of simulation by extremes.

Brazilian automotive textile sector, the comprehensive overview facilitated by the 5SEnSU model enabled a holistic visualization, allowing prioritization of the sector's weakest relationship with society.

The decision support model proved its effectiveness by relying on precise criteria to define indicators, acknowledging the dual roles played by the social and environmental dimensions as providers of resources to the industrial sector and as recipients of the outcomes and impacts resulting from the sector's operations. The procedure facilitated the identification of pivotal elements in sustainability management and proposed strategies to optimize resources toward the sector's sustainability objectives. The findings validate the viability of employing this approach to evaluate the sustainability of industrial sectors across various scenarios, aiding decision-making regarding policy implementation through benchmarking for enhanced sustainability. This model presents an innovative tool for assessing sustainability within industrial sectors, organizations, and companies. Moreover, it encourages informed decision-making and promotes a more conscientious and practical approach to business management, exerting influence beyond this sector to others.

CRediT authorship contribution statement

Cristhiane E. Santos: Investigation, Methodology, Writing – original draft. **Biagio F. Giannetti:** Formal analysis, Methodology, Supervision. **Feni Agostinho:** Data curation, Formal analysis, Supervision. **Yutao Wang:** Supervision, Validation, Writing – review & editing. **Cecilia M.V.B. Almeida:** Conceptualization, Formal analysis, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that this work has not been published previously, and it is not under consideration for publication elsewhere.

Data availability

data were taken from open sources (cited within the text) and all raw data and calculations are available in the Supplementary file provided

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Appendix A. Supplementary data

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