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Business Overall Performance and Sustainability Effectiveness: An Indicator to Measure Companies' Lean–Green Compliance

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Abstract: Within a lean context, the aim is to eliminate all forms of waste, including environmental waste, to improve productivity and reduce costs. Key to achieving this objective are operational performance and sustainability indicators. Lean companies must prioritize both operational performance and sustainability, remaining cognizant of their current status. With this in mind, the authors sought to ascertain whether lean companies demonstrate enhanced sustainability. Thus, the authors raised the following research question: does a lean company exhibit greater sustainability? However, these indicators have traditionally been measured independently, and few studies have indicated the need for a global indicator that could simultaneously address both. Such a global indicator would enable a clearer assessment and understanding of the trade-offs between operational performance and sustainability. This paper introduces such an integrated indicator, aiming to measure companies' lean–green compliance by intertwining sustainability issues with overall equipment effectiveness (OEE). The authors have termed this indicator business overall performance and sustainability effectiveness (BOPSE). Its primary goal is to evaluate business effectiveness by considering both operational performance and sustainability compliance. The sustainability strand was drawn from, adapted, and simplified based on the Global Reporting Initiative (GRI). This development was framed in a lean–green environment, emphasizing continuous efforts to identify and reduce all sources of lean waste, alongside the waste prevention perspectives of cleaner production, environmental compliance, and social responsibility, which play crucial roles in shaping the factories of the future. This paper presents the background and development of the BOPSE model. To answer the research question, two research methods were undertaken: a survey and case studies. The model was applied in three distinct case studies, demonstrating its usefulness in discerning varying levels of lean–green compliance through this integrated indicator.

Keywords: lean thinking; lean–green; lean–green model; key performance indicators; sustainability; OEE

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1. Introduction

Cleaner, sustainable, and more efficient shop floor operations are gaining traction within the broader framework of industrial competitiveness [1,2]. In this way, companies need approaches that achieve such goals. A lean production system [3,4] has proven to be a resilient production system that, over time, leads to a streamlined and efficient shop floor [5]. Lean production systems achieve this by concentrating on value-added operations and a continuous quest to eliminate all forms of waste (including environmental waste), which can hamper better productivity, better quality, better safety and morals, a better environment, and lower product pricing.

While deploying a number of lean concepts and tools may indeed lead to environmental benefits [6,7], not all authors associate its primary focus of reducing waste with the core principles advocated for by the green movement and the imperative challenge of addressing climate change [8]. On the other hand, the paramount importance of the sustainability agenda requires a more holistic approach, one that is both socially responsible and economically viable [9]. A broader approach, and at times, a novel outlook, should be adopted regarding various activities akin to manufacturing, including design, (re)manufacturing, and usage stages, while considering the overall impact on both resource utilization and waste management. The Synthesis Report for the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report [8], acknowledged the close connections between climate change adaptation, mitigation, ecosystem health, human well-being, and sustainable development.

These elements signify a fundamental shift in the paradigm, as the traditional "business as usual" approach is no longer sufficient for companies. Instead, companies must address a multitude of challenges, needing a comprehensive approach that integrates sustainability into core business strategies and embraces innovation and responsible corporate governance. Successfully navigating these challenges enables companies not only to mitigate risks but also to capitalize on opportunities for growth and long-term viability. Achieving this requires adapting to changing mindsets and aligning their operations with environmental, social, and governance (ESG) criteria and the European Union's taxonomy [10]. These considerations are crucial for companies, as they encompass a wide range of factors that impact financial performance, risk management, and relationships with stakeholders [11,12]. Embracing ESG not only addresses contemporary challenges but also positions companies for sustainable growth and success in the evolving business landscape [13].

Production, inherently, carries a significant footprint, and entirely avoiding this footprint is nearly impossible. Moreover, production remains an essential activity for human livelihood, providing goods and services crucial for addressing poverty, hunger, inequality, employment, and economic growth. However, it also contributes negatively to pollution and the consumption of water, energy, and materials. Understanding its diverse impacts on the Sustainable Development Goals (SDGs) should prompt producers to adopt management practices that enhance environmental stewardship. This could entail the pursuit of "doing more with less", a fundamental tenet of lean thinking [14]. Lean thinking promotes production without waste, eliminating activities that do not add value from the client's perspective. Particularly relevant to lean implementation is the achievement of SDG 12, responsible consumption and production [15], by eliminating the worst type of waste, overproduction, which contributes to all other waste. Even more troubling than that is the consequence of overproduction, which often entails sending quality products to landfills, such as clothing stemming from the fast fashion industry [16]. The lean elimination of waste aligns with improved environmental and green practices [6,17]. Thus, the lean–green approach might offer a framework for delivering cleaner and more valuable products.

However, the synergies between lean and green practices have not been fully explored or understood [18–20], and negative relations between these concepts have been posited [21,22]. However, several studies have explored the integration of lean and green practices and demonstrated a positive relationship between the two [23–30]. Previously, Alves et al. [7], Garza-Reyes et al. [31], and Helleno et al. [32] have also mentioned a positive relationship between lean and green. Recently, more authors [33–37] have continued reinforcing this positive relationship.

Notwithstanding this, Farias et al. (2019) stated that there is still a lack of assessment models and performance indicators to evaluate lean–green integration comprehensively [38]. Several authors pointed out the need for further research, in order to develop simple yet effective performance indicators [39–42] to evaluate companies' progress in integrating lean and green practices across operational, economic, environmental, and social dimensions.

In light of these insights, the authors of this paper were motivated to embark on research driven by the following research question: does a lean company exhibit greater sustainability? To address this question effectively, the research must attend to the imperative of aiding companies in gaining awareness of their present state concerning lean–green integration simultaneously [43–45].

The problem to address is the complexity of existing indicators, highlighting the need for integrated metrics that accurately reflect the company's status.

Having this in mind, this study aims to address the gap in research by developing an indicator to assess lean–green integration. This indicator is intended to be global, simple, feasible, and comprehensive across operational, economic, environmental, and social performance. The objective is to guide companies in assessing and comparing their green practices for sustainable business decision-making. Thus, the authors have put forward one such lean–green model to close the gap. The model aims to facilitate the evaluation of both strands, allowing for self-assessment and comparative analysis among peer companies. Coined the business overall performance and sustainability effectiveness (BOPSE), this model was designed to be a global indicator, shedding light on companies' performance in both operational efficiency and environmental impact. This model was developed within the scope of a Ph.D. thesis [46] and is in line with the assumptions and objectives of the ESG framework. Therefore, the objective of this paper is to present the BOPSE model, which assesses the synergies of lean–green production by using key indicators, as the current ones do not adequately address this issue. Section 4 will delve into the model's description. The BOPSE arose as a theoretical contribution to answer the research gap identified. It is a global indicator, tailored to measure OEE and align sustainability pillars with GRI and ESG frameworks, thereby helping companies to understand their current status. It can be used by companies with different levels of lean implementation and sustainability practices.

This paper is structured with seven sections. Initially, an introductory section outlines the relevance and motivation behind the study. Subsequently, a literature review delves into prior background works and the theoretical framework underpinning lean–green models. Section 3 elucidates the research methodology, while Section 4 details the newly proposed model for assessing lean–green compliance. Section 5 presents the outcomes derived from applying BOPSE in several case studies. Section 6 discusses the development of the BOPSE model and its implementation. Finally, the last section discusses the results and draws conclusions.

2. Background

This section elucidates the foundational concepts that underpin the design of the BOPSE model, specifically focusing on lean production, dimensions of sustainability, the eco-efficiency concept, and the existing array of lean–green models documented in the literature.

2.1. Lean Production

Lean production has its roots in a new production approach conceived by the Toyota Motor Company after the Second World War, called the Toyota Production System [4,47,48], a period marked by financial constraints and resource scarcity in Japan. Massachusetts Institute of Technology (MIT) researchers named this new paradigm the "Lean Production System", which became internationally known after the publication of the book "The Machine That Changed the World" [3].

Toyota's innovative solution, aimed at reducing consumption across the board—fewer resources, decreased human effort, reduced space requirements, and minimized inventories—was achieved through the elimination of all forms of waste. In this context, waste encompasses activities that do not add value to products from the customer's perspective. Ohno [48] identified seven primary categories of waste: (1) overproduction; (2) overprocessing; (3) transportation; (4) defects; (5) motion; (6) inventory; and (7) waiting. Subsequently, unused human potential was recognized as the eighth type of waste [49].

The concept of lean production has undergone a significant evolution, expanding far beyond its initial applications [3]. It has permeated across various economic sectors, progressively growing in scope and impact. In 1996, Womack and Jones established the following five core principles of lean thinking, aimed at methodically eradicating this waste: value; value stream; flow; pull production; and the pursuit of perfection [50]. The pursuit of perfection entails an ongoing quest for continuous improvement (Kaizen), wherein people play a pivotal role. Within a genuine lean culture, people are encouraged to actively engage and unleash their creativity [51]. This culture embodies everlasting progression. Consequently, numerous companies have concentrated on evaluating their lean implementation processes, leading to the emergence of a new global metric. Referred to by some authors as the "leanness" level, this metric quantifies the overall impact and advancement of lean production initiatives within a company [52,53]. There are two perspectives defining leanness: (1) adoption of practices and (2) performance outcomes [52]. Several of these metrics function as key performance indicators (KPIs), such as overall equipment effectiveness (OEE) [54], which is widely used by lean companies. The OEE serves as a tool to monitor progress in waste reduction within manufacturing processes [55]. Moreover, it aids in capacity planning, process control, improvement, and computation of production losses, emphasizing the seven types of lean waste [48].

2.2. Sustainability Dimensions and the Eco-Efficiency Concept

Sustainability serves as the fundamental principle underpinning the concept of sustainable development. The Bruntland Commission report in 1987 defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [9]. However, some authors have critiqued this definition as overly broad or macroeconomic, suggesting it might be challenging for companies to implement [56,57]. For development to be truly sustainable, it must safeguard three crucial elements of human existence: the environment and natural resources, social equity, and the economy [9]. Companies aiming for sustainability must pursue economic growth while preserving their integrity. This entails a continuous effort to minimize their environmental impact throughout the entire lifecycle (cradle-to-grave) of their products. Moreover, they should uphold human rights, foster fairness, and make social investments. All three pillars—often referred to as the "triple bottom line" (3BL)—are equally vital for sustainability [58]. The concept of 3BL, developed by Elkington in 1998, is also known as "planet, people, and profit" (3P). However, the relationships between these pillars are subject to some controversy.

While it is crucial to respect nature's capacity for recovery, the scope of what needs preservation within sustainability must expand. This broader perspective includes various dimensions beyond the environmental, such as individual and cultural aspects. Some authors have introduced combined dimensions like socio-cultural [59], or spatial-political and political-temporal [60].

Sustainable development faces environmental and social challenges, owing to the growing population and rising consumption. The 17 Sustainable Development Goals (SDGs) with their 169 targets strive for universal human rights, gender equality, and the empowerment of women and girls [61]. The SDGs demand a concerted answer from all stakeholders and fields of expertise that seek to work in transdisciplinary approaches. Each SDG has specific targets; for instance, the 12th SDG—ensuring sustainable consumption and production patterns—is directly impacted by production strategies. Lean, cleaner, and responsible production is pivotal for this SDG, ensuring sustainable output from companies and promoting corresponding consumption patterns within societies.

Various sustainability frameworks exist to assess sustainability achievements, as outlined in Abreu et al. [62]. Among them, the Global Reporting Initiative (GRI) framework [63] stands out. Comprising 91 indicators (the specific standard disclosures), structured across three main categories (economic, environmental, and social dimensions), GRI serves as a comprehensive system, with 169 targets. The GRI is an independent international organization that began sustainability reporting in 1997.

At the heart of sustainable development lies the concept of eco-efficiency, originating in the early 1990s from Stephan Schmidheiny and the Business Council for Sustainable Development (BCSD) [13]. Eco-efficiency encapsulates the notion that it is feasible to deliver greater value with a reduced environmental footprint. This trend is not just significant but imperative for contemporary societies. Its foundation lies in a cradle-to-cradle premise, considering complete product lifecycles [64], guided by the following seven key elements: (1) material reduction; (2) energy conservation; (3) minimizing quantity and toxicity levels; (4) advocating for closed cycles and employing end-of-life strategies; (5) endorsing renewable resources and local sourcing; (6) enhancing product durability; and (7) maximizing the utilization of services [65]. Achieving increased value with reduced environmental impact requires companies to invest in innovative efforts, as well as a different perception on the assessment of their products' environmental performance. Pursuing sustainability through innovation often involves implementing circular economy principles, which could be facilitated by employing a lean startup methodology [66]. This approach enables engagement with stakeholders to design products or services that hold value without generating waste [67].

2.3. Lean–Green Models

The investigation into the lean–green link started in the 1990s [68,69]. Both concepts emphasize distinct aspects: lean focuses on waste reduction, while green centres on minimizing environmental impact. Given that lean principles advocate for producing only the required quantity of a product at the necessary time to avoid overproduction waste, it is worth noting that, while lean was not originally designed to address sustainability concerns [6,70], some authors have highlighted that its principles and practices yield benefits that could be placed under the umbrella of green [71–74]. The lean–green approach provides a suitable framework for guiding companies toward growth while reducing environmental impacts, conserving energy and natural resources, and ensuring safety for employees, communities, and consumers.

Recognizing this association, the U.S. Environmental Protection Agency (EPA) launched "The Lean and Environment Toolkit" [17]. Environmental waste was defined as "any unnecessary use of resources or a substance released into the air, water, or land that could harm human health or the environment" [17]. The EPA demonstrated that lean tools effectively reduce environmental waste in resource use for product or service delivery to customers and in customers' product use and disposal [74].

The literature reveals the development of various lean–green models. Abreu et al. [75] identified and compared 16 models, with twelve providing a reference model for lean–green implementation and four focusing on assessing the lean–green relationship. The latter is relatively recent, indicating a growing research interest. However, Farias et al. [38] noted a scarcity of assessment models integrating both approaches, encompassing the lean and green literature.

A literature review highlighted that numerous companies still encounter difficulties in implementing lean production [76]. Furthermore, even companies that have adopted lean practices may remain unaware of the lean–green link [77]. Another author underscored a research gap "on developing measurement methods or models for specific processes and industries" [40]. Several studies emphasized the need for performance indicators, serving as metrics for assessing lean and green relations [39–42]. These authors' paper identified sixteen lean–green models, with four focused on the assessment of the lean–green relationship, while twelve intended to provide a reference model for lean–green implementation [46,75].

Then, the BOPSE was compared against the four assessment models [78–81]. The Reis et al. [78] model was employed in six specialty coffee-producing companies in Colombia. Notably, the model grounded in the Capability Maturity Model Integration (CMMI) programme did not address any of the three pillars of sustainable development. However, some of the lean and green indicators are considered to be aligned with certain GRI topic-specific disclosures, such as materials, energy and water consumption, and emissions. Farias et al. [79] named their model the lean–green index (LGindex). The model developed a framework (using an analytical network process (ANP)) for assessing lean and green performance and introduced a composite index for evaluating both lean and green systems in an integrated manner. Carvalho et al. [80] introduced two indices, the lean index and the green index, within the supply chain context. The development of these indexes drew upon the green logistics performance index (GLPI) and utilized principal component analysis (PCA) methodology. Finally, Amrina and Zagloel [81] devised a conceptual model termed eco-socio-lean production (ESLP), presented as an input–process–output framework grounded in green–lean business objectives, resources, production processes, improvement techniques, and output measurements.

From the five papers identified in the literature as investigating lean–green integration [33–37], only two were lean–green implementation models [36,37]. Two were reviews [33,34], and one presented a lean and green decision model for lean tool selection [35].

In facing the ongoing business landscape challenges, it becomes increasingly crucial for companies to meticulously evaluate and compare their green practices. This allows for a thorough assessment of their advancement over time, facilitating well-informed decision-making closely linked to business performance. This entails measuring and monitoring continuously relevant sustainability metrics while ensuring the alignment of their operations with ESG principles and the taxonomy set forth by the European Union [10]. Considering these gaps, the development of a model emerged to address these needs.

3. Research Methodology

The BOPSE model presented in this paper emerged from research conducted as part of a Ph.D. thesis in Industrial and Systems Engineering at the University of Minho, Braga, Portugal. To develop this model, the research methodology began with an extensive literature review encompassing the concepts of lean production, sustainability and sustainable development, eco-efficiency, and lean–green, which provided the foundation on which the research was developed [43–45]. This research was driven by the analysis, investigation, and pursuit of an answer to the following research question: does a lean company exhibit greater sustainability?

The research methodology followed a framework comprising four distinct phases, as illustrated in Figure 1. This figure also displays, at the bottom of each phase, the results obtained, which were published in various conferences and journals to receive feedback from scientific community peers.

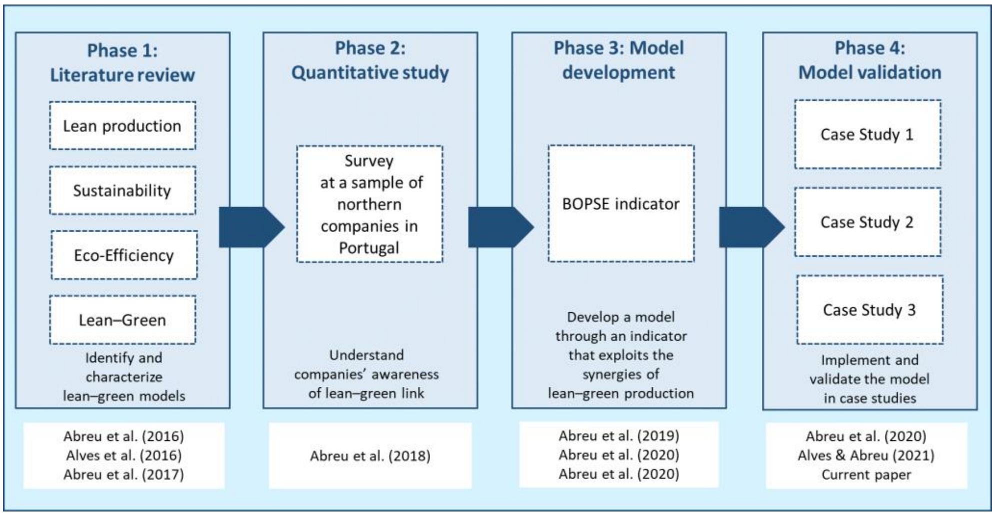

Figure 1. Research methodology framework, the cited references in each phase are: Phase 1: [43–45]; Phase 2: [82]; Phase 3: [46,62,75]; Phase 4: [46,83]. Source: elaborated by the authors.

The first phase focused on the literature review [84,85], which began with an examination of sustainability and its correlation with the lean concept, through a qualitative methodology and, then, a comparative analysis of existing lean–green models for eco-efficient production, as outlined by Abreu et al. [43]. To deepen the knowledge, a systematic literature review was conducted, aiming to scrutinize the breadth of awareness regarding the link between lean and green practices within the production and operations management domain [44]. Furthermore, this review sought to highlight, compare, and analyse various models for integrating lean and green principles [45]. Subsequent work, carried out from 2017 to 2019, aimed to update this review [46,75]. The aim was the identification and characterization of lean–green models. The literature review revealed a gap in research concerning indicators for lean–green models, highlighting the necessity for indicators that are both straightforward and practical for companies to employ effectively.

In the second phase, a questionnaire was employed to explore the status of lean implementation within companies located in the northern region of Portugal, as well as to assess how this implementation has contributed to enhancing their sustainability. The questionnaire aimed to gauge the awareness of lean and green production methodologies and to ascertain the extent to which their implementation has bolstered levels of productivity and sustainability [82].

Based on the analysis of questionnaire results and insights drawn from the literature review concerning methodologies for lean and green implementation, a model was formulated. The objective was to formulate a model using an indicator that harnesses the synergies inherent in lean–green production. The indicator was designated by Business Overall Performance and Sustainability Effectiveness (BOPSE) [46]. This was the third phase, the core of this research. A comprehensive description of the model, which harnesses the synergies of lean–green production, is made in Section 4. The final state of the BOPSE was the result of discussions held with experts and its testing, through sustainability reports and sensitivity and feasibility tests [46]. The discussion with experts took place in two distinct periods: the first during the definition of the indicators included in the model, and the second after its implementation in the three case studies.

Lastly, in the fourth phase, the model was applied to three case studies in the automotive sector [46]. These case studies allowed for the validation of the model and the collection of results, recognizing the unique nature of each company as an individual case. The cooperation and support of the participating companies were crucial for providing all the necessary information and data for the advancement of this research. The aim was to evaluate its effectiveness and functionality. The focus was on analysing and consolidating the indicator, examining its key and descriptive indicators within the model. The case studies were selected based on their interest, willingness to participate, openness, and support in providing necessary data, and were referred to as case studies A, B, and C in this paper. The protocol employed adhered to the guidelines outlined by Yin [86].

The deployment of case studies followed the following four-stage process: (1) designing the case study; (2) executing the case study; (3) analysing evidence gathered from the case study; and (4) formulating conclusions, recommendations, and implications. The initial stage involved outlining protocols, setting procedures, and establishing general rules for the case study design. The second stage encompassed company visits, meetings, interviews, and data collection. The third stage involved detailed analysis, while the final stage encompassed drawing conclusions based on evidence derived from the collected data.

Moreover, in 2021, the BOPSE was applied in twelve companies, to strengthen its validation. This assessment was conducted within the context of a course unit for fourth-year Industrial Engineering and Management (IEM) students, engaged in a project-based learning (PBL) initiative crafted through university–business collaboration. This assignment tasks them with evaluating sustainability business effectiveness within an industrial setting, employing the BOPSE [83]. These results are detailed in Section 5.5. and referred to as case studies D to O. Last year, the BOPSE was also implemented in the chemical sector by a master's student, under the supervision of two authors of this paper, designated by P, the results of which are also in Section 5.5.

4. The BOPSE Model

The BOPSE model is designed to evaluate organizations' lean–green compliance by assessing both operational performance (via OEE) and sustainability adherence (across three sustainability dimensions), which are key elements in the current business context of organizations. The schematic representation of BOPSE is depicted in Figure 2.

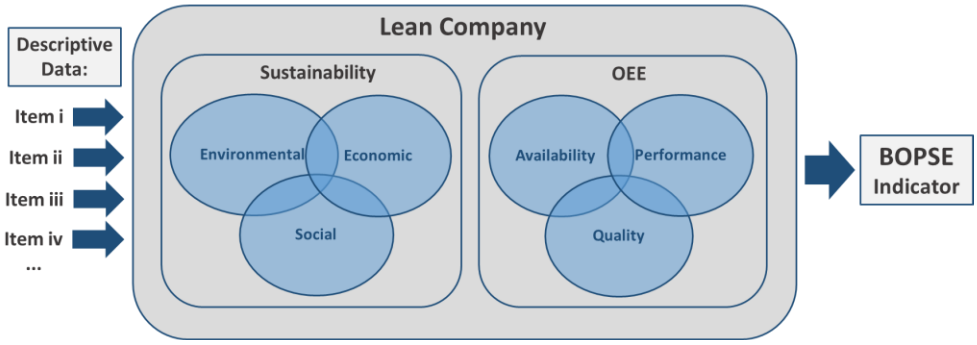

Figure 2. The BOPSE model general scheme with the main strands. Source: elaborated by the authors.

The necessity for such an indicator was substantiated by the literature review. The model hinges on an indicator that aggregates company performance from both sustainability and operational standpoints. Its objective is to be user-friendly, straightforward, and applicable for organizations, reflecting facets of operational, economic, environmental, and social performance. To construct this model, the following approach, outlined by Kibira et al. [87], was adopted: (1) identification of KPIs from existing sources; (2) definition of new candidate KPIs; (3) selection of appropriate KPIs based on predefined criteria; and (4) composition of the chosen KPIs with assigned weights into a cohesive set.

Given the widespread use of OEE as a fundamental operational performance indicator within lean companies, it was deemed essential to include it in the model. Zackrisson et al. [88] also highlighted that OEE, particularly its core components, serves as indicative of sustainability-related measures, proving valuable at the shop floor level. Regarding sustainability aspects, inspiration was drawn from the GRI, known for its widespread use in sustainability reporting, guiding the selection of sustainability metrics.

The BOPSE indicator is derived from the arithmetic mean of two primary strands, sustainability and OEE, as shown in Equation (1).

The sustainability and OEE strands carry equal weight, as they were considered both to be essential for evaluating an organization's performance. Therefore, no specific weight was assigned to either, underlining their shared priority and significance. Since OEE represents a stringent KPI as it is a product of its components, it was deemed appropriate for the sustainability strand to similarly be a product of its dimensions. The values range between zero and one; however, percentages are used throughout the text to enhance the results' comprehension, as follows:

$$\text{BOPSE} = ((\text{Sustainability} + \text{OEE}))/2 \tag{1}$$

Source: elaborated by the authors.

The overall layout of the BOPSE indicator is illustrated in Figure 3. The sustainability strand aligns with the triple bottom line (3BL) concept, encompassing economic, environmental, and social dimensions. Meanwhile, the OEE strand is computed by factoring in availability, performance, and quality, detailed in Section 4.2.

Within the three sustainability dimensions, a total of 15 key indicators were identified, further broken down into 32 descriptive indicators, as outlined in Table 1.

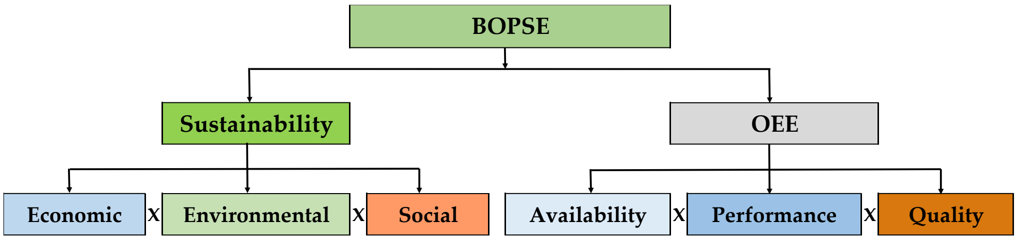

Figure 3. The BOPSE indicator structure. Source: elaborated by the authors.

Table 1. Key indicators and descriptive indicators of sustainability strand. Source: elaborated by the authors.

Sustainability Dimension	Key Indicators	Descriptive Indicators	
Economic (Eco)	Economic performance (Eco 1)	Eco 1.1	Net profit margin
		Eco 1.2	Research and development/innovation
	Market presence (Eco 2)	Eco 2.1	Standard entry-level wage
		Eco 2.2	Local senior management
	Procurement (Eco 3)	Eco 3.1	Spending on local suppliers
Environmental (Env)	Materials (Env 1)	Env 1.1	Materials used
		Env 1.2	Recycled input materials used
	Energy (Env 2)	Env 2.1	Useful energy
		Env 2.2	Renewable energy
	Water (Env 3)	Env 3.1	Water used
		Env 3.2	Recycled and reused water
		Env 3.3	Net water needs reduction
	Biodiversity (Env 4)	Env 4.1	Biodiversity investment
	Emissions (Env 5)	Env 5.1	GHG [1] emissions intensity
		Env 5.2	GHG emissions reduction
	Effluents and waste (Env 6)	Env 6.1	Spills
		Env 6.2	Hazardous industrial residues
		Env 6.3	Recycled residues
	Environmental compliance (Env 7)	Env 7.1	Environmental compliance
Social (Soc)	Employment (Soc 1)	Soc 1.1	Effective contracted employees
		Soc 1.2	Female employees
		Soc 1.3	Women in management
		Soc 1.4	Employee turnover
	Occupational health and safety	Soc 2.1	Absenteeism
	(Soc 2)	Soc 2.2	Accident rate
		Soc 2.3	Fatalities
	Training and development (Soc 3)	Soc 3.1	Budget in training and development
		Soc 3.2	Training and development hours
		Soc 3.3	Employees' engagement
	Local communities (Soc 4)	Soc 4.1	Employees engaged in volunteering
		Soc 4.2	Donations
	Socioeconomic compliance (Soc 5)	Soc 5.1	Socioeconomic compliance
Total	15	32	

[1] GHG: greenhouse gas.

The development of the BOPSE model involved several iterative stages. Initially, a preliminary version was formulated. Subsequently, collaborative sessions with experts were conducted, to deliberate and assess the relevance of both key and descriptive indicators. Adjustments were made in the third stage following initial testing. The fourth stage engaged experts once again, refining and substantiating specific descriptive indicators.

Calculations were executed using a spreadsheet, integrating the formulas detailed in Sections 4.1 and 4.2.

4.1. Sustainability Strand

After a meticulous examination and analysis of sustainability frameworks, the sustainability strand was derived, modified, and streamlined from the GRI. This decision was grounded in the widespread adoption and credibility of the GRI Sustainability Reporting Standards, which have been the global benchmark for sustainability reporting since 1997 [63]. The GRI's mission, aimed at empowering decisions to foster social, environmental, and economic benefits for all, aids both businesses and governments in comprehending and articulating their impacts on critical issues such as climate change, human rights, governance, and social well-being [63]. The sustainability strand intricately interlinks the three dimensions: economic, environmental, and social, calculated as a composite product of each dimension, as illustrated in Equation (2). The values range from zero to one; however, percentages are used throughout the text to enhance the results' comprehension, as follows:

$$\text{Sustainability} = \text{Economic} \times \text{Environmental} \times \text{Social} \tag{2}$$

Source: elaborated by the authors.

Within the sustainability strand, equal weight is assigned to each dimension, signifying equal importance. Key indicators have been identified to characterize each dimension, detailed in Table 1. The calculation for each dimension involves computing the simple arithmetic mean derived from the results of these key indicators. The formulas were developed through extensive analysis and discussions with experts. The formulas for the economic, environmental, and social dimensions are presented in Equations (3)–(5).

For the variables k, l, or m, assuming values of 3, 7, or 5, respectively, signifies that all key indicators were successfully collected. Conversely, if they take on lower values, it indicates that not all key indicators were available, adjusting the arithmetic computation accordingly based on the total available key indicators, as follows:

$$\text{Eco} = \frac{\sum_{i=1}^{k} \text{Eco}_i}{k} \tag{3}$$

Source: elaborated by the authors.

$$\text{Env} = \frac{\sum_{i=1}^{l} \text{Env}_i}{l} \tag{4}$$

Source: elaborated by the authors.

$$\text{Soc} = \frac{\sum_{i=1}^{m} \text{Soc}_i}{m} \tag{5}$$

Source: elaborated by the authors.

For example, in the economic dimension (Eco), the variable "k" can range from one to three and corresponds to the number of key economic indicators that comprise it. Eco_i represents each of the three key economic indicators listed in Table 1. The same applies to the environmental (Env) and social (Soc) dimensions, where Env_i and Soc_i represent the key environmental (seven in total) and key social (five in total) indicators, respectively, as depicted in Table 1.

For each identified key indicator (as outlined in Table 1), a set of descriptive indicators has been carefully chosen as the most pertinent and representative [62]. Consequently, each key indicator is calculated either as the simple arithmetic mean of its constituent descriptive indicators or, in some instances, from a single descriptive indicator (applicable to four key indicators). The selection of these key indicators was inspired by the GRI standards [89,90] and was arrived at after meticulous analysis aimed at determining which indicators would succinctly describe each key indicator. Selection criteria were based on the following: (1) the examination of sustainability reports from companies; (2) identifying the most significant indicators from the analysed sustainability reports; (3) the investigation of topic-specific standards within GRI that best represented companies' environmental performance; (4) the ease of data collection; and (5) previous expertise of the authors in this domain.

Each descriptive indicator encapsulates essential information concerning sustainability practices. Each one is specifically delineated, incorporating the following elements: identification of the descriptive indicator/calculation formula, value range or ranking, trend analysis to discern whether a higher result denotes better or worse sustainability terms, and justification for the indicator and/or definition of the ranking. These aspects are detailed in Tables 2–4. Data for these descriptive indicators were sourced from various outlets, such as Eurostat for metrics like research, development, and innovation expenditure [91] and legal stipulations for standard entry-level wages, accessed from wage-related legislation [92].

This meticulous process was reiterated for all defined descriptive indicators. Due to industry-specific nuances and normalization requisites, rankings were assigned to 27 descriptive indicators, where direct computation was not feasible. These rankings were calibrated for the automotive sector, establishing performance intervals (refer to Tables 2–4) to standardize the descriptive indicator values between low (set at 60%), medium (set at 80%), and high performance (set at 100%). The performance intervals were defined with the assumption of making the calculation as objective as possible and thus avoiding subjective interpretations, which naturally depend on each person's role, experience, and surrounding context. Therefore, for each descriptive indicator, representative values were researched from different sources, and the three performance levels were defined. Such adaptations of the BOPSE model necessitated judicious discernment to ensure temporal relevance and sector-wide comparability. Each descriptive indicator is comprehensively characterized across the following three sections.

Table 2. Economic descriptive indicators. Source: elaborated by the authors.

Descriptive Indicator/Equation	Range/Ranking (%)		Trend/Justification
Net profit margin (Npm) $Npm = \frac{Total\ amount\ of\ net\ profit}{Total\ amount\ of\ revenues} \times 100$	<1 >1 to 5 >5	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on New York University Stern School of Business [93].
Research and development/innovation (Rdi) $Rdi = \frac{Total\ amount\ of\ RDI}{Total\ amount\ of\ revenues} \times 100$	0 to 1 >1 to 3 >3	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on Eurostat data [91,94].
Standard entry level wage (Selw) $Selw = \frac{Entry\ level\ wage}{Local\ minimum\ wage} \times 100$	100 to 110 >110 to 120 >120	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on minimum wage established by law [92].
Local senior management (Lsm) $Lsm = \frac{Number\ of\ top\ managers\ from\ lc}{Number\ of\ top\ managers} \times 100$ lc: local community	0 to 40 >40 to 80 >80	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on the assumption that each company should engage and develop the local community.
Spending on local suppliers (Sls) $Sls = \frac{Spending\ on\ local\ suppliers}{Global\ spending\ on\ suppliers} \times 100$	0 to 35 >35 to 70 >70	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on the assumption that sometimes a company has to comply with group buying policies.

4.1.1. Economic Dimension

This dimension comprises three key indicators and five descriptive indicators, outlined in Table 1. Each key dimension is derived from the simple arithmetic mean of its descriptive indicators. For example, the key indicator "economic performance" is calculated as the simple arithmetic mean of "net profit margin" and "research and development/innovation". The specific details of the five economic descriptive indicators are provided in Table 2.

4.1.2. Environmental Dimension

The environmental dimension encompasses seven key indicators and 14 descriptive indicators, outlined in Table 1. For example, the key indicator "materials" is derived from the simple arithmetic mean of "materials used" and "recycled input materials used". Detailed information on the 14 environmental descriptive indicators is available in Table 3.

Table 3. Environmental descriptive indicators. Source: elaborated by the authors.

Descriptive Indicator/Equation	Range/Ranking (%)		Trend/Justification
Materials used (Mu) $Mu = \frac{Total\ materials\ incorporated\ in\ fp}{Total\ input\ materials} \times 100$ fp: final product	Min: 0 Max: 100		The higher, the better. By direct calculation. This percentage will be high, as most input materials will be incorporated into the final product.
Recycled input materials used (Rim) $Rim = \frac{Total\ recycled\ input\ materials\ used}{Total\ input\ materials} \times 100$	0 to 25 >25 to 50 >50	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on Eurostat data [95].
Useful energy (Ue) $Ue = \frac{Energy\ consumption\ in\ the\ factory}{Total\ energy\ consumption} \times 100$	Min: 0 Max: 100		The higher, the better. By direct calculation. Based on Environmental Status Report from Portuguese Environment Agency (APA) ([96], p. 33).
Renewable energy (Re) $Re = \frac{Renewable\ energy\ used}{Total\ energy\ consumption} \times 100$	0 to 25 >25 to 50 >50	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on Eurostat [94] and APA [96].
Water used (Wu) $Wu = \frac{Water\ consumption\ in\ the\ factory}{Total\ water\ consumption} \times 100$	0 to 25 >25 to 50 >50	60% (low) 80% (medium) 100% (high)	The higher, the better. Gives insight into total water consumption in the factory.
Recycled and reused water (Rrw) $Rrw = \frac{Total\ recycled\ and\ reused\ water}{Total\ water\ consumption} \times 100$	0 to 25 >25 to 50 >50	60% (low) 80% (medium) 100% (high)	The higher, the better. Gives insight into total recycled and reused water incorporated into product.
Net water needs reduction (Nwnr) $Nwnr = \frac{Previous\ yearwc - Current\ year\ wc}{Previous\ yearwc} \times 100$ wc: water consumption	<1 >1 to 3 >3	60% (low) 80% (medium) 100% (high)	The higher, the better. Gives insight into net water needs evolution in the company.
Biodiversity investment (Bi) $Bi = \frac{Total\ amount\ invested\ on\ biodiversity}{Total\ amount\ of\ revenues} \times 100$	0 to 0.02 >0.02 to 0.05 >0.05	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on European Environment Agency (EEA) [97] and the Environmental Status Report from APA [96].
GHG emissions intensity (GHGei) $GHGei = \frac{Total\ GHG\ emissions}{Total\ amount\ of\ revenues}$	0 to 0.2 kg/EUR >0.2 to 0.4 kg/EUR >0.4 kg/EUR	100% (high) 80% (medium) 60% (low)	The lower, the better. Based on 2019 Environmental Status Report from APA [96].

Table 3. *Cont.*

Descriptive Indicator/Equation	Range/Ranking (%)		Trend/Justification
GHG emissions reduction (GHGer) $GHGer = \frac{Previous\ ye - Current\ ye}{Previous\ ye} \times 100$ ye: year emission	<1 >1 to 5 >5	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on Europe 2020 Strategy [98] and APA report [96].
Spills (Sp) $Sp = \frac{Total\ volume\ of\ spills}{Total\ effluents\ discharged} \times 100$	0 >0 to 0.1 >0.1	100% (high) 80% (medium) 60% (low)	The lower, the better.
Hazardous industrial residues (Hir) $Hir = \frac{Total\ hazardous\ industrial\ residues}{Total\ residues} \times 100$	0 to 2 >2 to 10 >10	100% (high) 80% (medium) 60% (low)	The lower, the better. Based on sustainability reports: Navigator [99]; EDP [100]; Lameirinho [101]; and Sonae [102] and on Environment Statistics [103].
Recycled residues (Rr) $Rr = \frac{Recycled\ residues}{Total\ residues} \times 100$	0 to 60 >60 to 85 >85	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on "Car production and Sustainability" [104] and sustainability reports: Navigator [99].
Environmental compliance (Ec) $Ec = Number\ of\ enc\ cases$ enc: environmental non-compliance	0 to 2 enc >2 to 5 enc >5 enc	100% (high) 80% (medium) 60% (low)	The higher, the better. According the GRI definition ([89], p. 6).

4.1.3. Social Dimension

This dimension comprises five key indicators and 13 descriptive indicators, as outlined in Table 1. For instance, the key indicator "employment" is derived from the simple arithmetic mean of "effective contracted employees", "female employees", "women in management", and "employee turnover". Table 4 provides details on the 13 social descriptive indicators.

Table 4. Social descriptive indicators. Source: elaborated by the authors.

Descriptive Indicator/ Equation	Range/Ranking (%)		Trend/ Justification
Effective contracted employees (Ece) $Ece = \frac{Number\ of\ ece}{Total\ number\ of\ employees} \times 100$	Min: 0 Max: 100		The higher, the better. By direct calculation.
Female employees (Fe) $Fe = \frac{Number\ of\ femal\ eemployees}{Total\ number\ of\ employees} \times 100$	0 to 25 >25 to 50 >50	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on EDP sustainability report ([105], p. 43).
Women in management (Wim) $Wim = \frac{Number\ of\ Wim}{Total\ number\ of\ einmanagment} \times 100$ e: employees	0 to 25 >25 to 50 >50	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on 2019 INE report, of "Sustainable Development Goals—Indicators for Portugal—Agenda 2030" [106] and sustainability report from EDP [107].
Employee turnover (Et) $Et = 1 - \frac{Number\ of\ e\ who\ left\ organization}{Total\ number\ of\ employees} \times 100$ e: employees	Min: 0 Max: 100		The higher, the better. Based on social report from attorney general's office [108].
Absenteeism (Ab) $Ab = \frac{Total\ number\ of\ days\ in\ absence}{Total\ number\ of\ workable\ days} \times 100$	0 to 5 >5 to 10 >10	100% (high) 80% (medium) 60% (low)	The lower, the better. Based on 2018 report of attorney general's office from prosecutor's office [108] and Eurofound data [109].

Table 4. *Cont.*

Descriptive Indicator/ Equation	Range/Ranking (%)		Trend/ Justification
Accident rate (Ar) $Ac = \frac{Number\ of\ wri}{Number\ of\ hw} \times (200,000\ or\ 1,000,000)$ wri: work-related injuries; hw: hours worked	0 to 10 >10 to 30 >30	100% (high) 80% (medium) 60% (low)	The lower, the better. Accident rate based on the GRI definition [90]. Based on sustainability reports: Navigator [99] and Lameirinho [101].
Fatalities (Fa) $Fa = \frac{Number\ of\ work\ related\ fatalities}{Number\ of\ work-related\ injuries} \times 100$	0 to 5 >5 to 10 >10	100% (high) 80% (medium) 60% (low)	The lower, the better. Based on sustainability reports: EDP [110].
Budget in training and development (Btd) $Btd = \frac{Investment\ in\ training\ and\ development}{Total\ amount\ of\ revenus} \times 100$	0 to 0.02 >0.02 to 0.5 >0.5	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on sustainability reports: Galp [111]; EDP [100]; and Bosch [112].
Training and development hours (Tdh) $Tdh = \frac{Total\ number\ of\ tdh}{Total\ number\ of\ working\ hours} \times 100$	0 to 2 >2 to 4 >4	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on sustainability reports: Galp [111]; EDP [100]; Lameirinho [101]; and Guerreiro [113].
Employees' engagement (Ee)	Min: 0 Max: 100		The higher, the better. Questionnaire assessing the employees' satisfaction, motivation and commitment.
Employees engaged in volunteering (Eeiv) $Eeiv = \frac{Number\ of\ employees\ in\ volunteering}{Total\ number\ of\ employees} \times 100$	0 to 10 >10 to 25 >25	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on sustainability reports: Galp [111] and EDP [100].
Donations (Do) $Do = \frac{Total\ donations}{Total\ amount\ of\ revenues} \times 100$	0 to 0.01 >0.01 to 0.2 >0.2	60% (low) 80% (medium) 100% (high)	The higher, the better. Based on sustainability reports: Galp [111]; EDP [100]; Navigator [99]; Lameirinho [101]; and Sonae [102].
Socioeconomic compliance (Sec) $Sec = Number\ of\ snccases$ snc: socioeconomic non-compliance	0 to 2 snc >2 to 5 snc >5 snc	100% (high) 80% (medium) 60% (low)	The lower, the better. According to the GRI definition [89].

4.2. OEE Strand

The OEE strand is derived as the product of availability, performance, and quality according to Nakajima [54], as shown in Equation (6). As mentioned previously, the values range between zero and one; however, percentages are used throughout the text to enhance the results' comprehension.

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (6)$$

The OEE reveals critical sources of productivity decline known as the "six big losses" across three primary categories, providing metrics that serve as a gauge to assess an organization's position and opportunities for enhancement. The primary aim of OEE is to pinpoint these losses and facilitate their improvement. Each component holds equal significance, carrying the same weight.

Availability measures the effective time available for production (the operating time), considering the losses due to downtime. It is computed using Equation (7), according to Vorne Industries [114], as follows:

$$\text{Availability(Avai)} = \frac{\text{Operating time or Run time(min)}}{\text{Planned production time(min)}} \quad (7)$$

Performance gauges the net operating time for production, accounting for speed losses that hinder the process from operating at its maximum potential speed. It is computed using Equation (8), according to Vorne Industries [114], as follows:

$$\text{Performance}(\text{Perf}) = \frac{\text{Ideal cycle time}(\text{min}) \times \text{Total pieces}(\text{number of pieces})}{\text{Operating time or Run time}(\text{min})} \tag{8}$$

Quality assesses the pieces produced that fulfil the quality standards (the fully productive time), accounting for all quality losses, including those that fail to meet requirements and those necessitating rework. This is calculated using Equation (9), according to Vorne Industries [114], as follows:

$$\text{Quality}(\text{Qual}) = \frac{\text{Good pieces}(\text{number of pieces})}{\text{Total pieces}(\text{number of pieces})} \tag{9}$$

The OEE serves as a benchmark and/or baseline and a means to monitor advancements in waste reduction within manufacturing processes. An OEE score of 100% represents flawless production, implying the manufacturing of only high-quality parts at maximum speed, without any downtime. OEE is utilized as a key metric in total productive maintenance and lean manufacturing, providing a consistent measure for evaluating production effectiveness and efficiency [114]. OEE can assist management in uncovering hidden capacity and, consequently, reducing overtime expenses. Beyond being a performance metric, the OEE also aids in capacity planning, process control, process enhancement, and estimating costs linked to production losses, pinpointing the seven lean wastes [48]. Furthermore, by reducing changeover times and enhancing operator performance, it aids in diminishing process variability. These advantages improve the production bottom line and enhance companies' competitiveness [115]. Also, Ali and Deif ([55], p. 578) asserted that "OEE measurement is commonly used as a key performance indicator (KPI) in conjunction with lean manufacturing efforts to provide an indicator of success". This indicates that OEE associated with lean practices is a usual metric for assessing a company's performance. Consequently, the OEE was selected for its relevance as a robust lean indicator, deemed suitable for manufacturing organizations. As emphasized by Zackrisson et al. [88], the OEE and its constituent elements serve as examples of sustainability-related indicators valuable at the operational level. Still, this year, Zehra et al. [116] presented an approach integrating OEE with sustainability principles to improve operational efficiency and sustainability. Hence, this rationale guided the choice of the OEE to encapsulate the lean aspect within the BOPSE indicator.

5. Application of the BOPSE Model in Case Studies

The BOPSE model was put to the test through three real-world case studies, playing a pivotal role in evaluating its significance, operational viability, and applicability. Feedback garnered from these case studies was crucial in appraising the relevance of both key and descriptive indicators. A meeting was scheduled to introduce the study's objectives, the BOPSE model, and the survey findings regarding the awareness of the lean–green link among companies in Portugal [82]. The survey was addressed to a database of national and international companies with activity in the northern region of Portugal, and 447 questionnaires were sent ([82], pp. 2 and 3). The procedure for calculating the BOPSE indicator within these case studies unfolded as follows:

1. Data collection: relevant data from participating companies was initially gathered;
2. Data entry: these data were then entered into a spreadsheet for comprehensive analysis;
3. Key indicator calculation: the 15 key sustainability indicators were calculated;
4. Sustainability dimension calculation: calculations were made for the three sustainability dimensions;
5. Sustainability strand calculation: the sustainability strand, a crucial component of BOPSE, was determined;

6. OEE strand calculation: the three constituent components of OEE were computed;
7. OEE calculation: utilizing the individual OEE components, an OEE score was derived;
8. BOPSE calculation: finally, employing the calculated sustainability strand and OEE score, the ultimate BOPSE indicator was determined.
9. The sequence of computing the main strands could be inverted in some instances.

5.1. Case Study A—Multinational Producer of Automotive Components

Upon receiving the data, a step-by-step sequence of calculations unfolded to determine the BOPSE indicator. Initially, the process involved computing the descriptive indicators, considering the distinct rankings outlined in Section 4.1. Subsequently, the key indicators were calculated, followed by the derivation of both the sustainability and OEE strands, ultimately leading to the BOPSE calculation.

In the sustainability strand, the social dimension took the lead with a value of 89%, followed by the environmental and economic dimensions, each at 77%. Notably, the social dimension significantly surpassed the benchmark for medium performance (80%). The overall sustainability strand was 53%, while the reported OEE was 78%. Consequently, the BOPSE was determined to be 65%, as depicted in Figure 4.

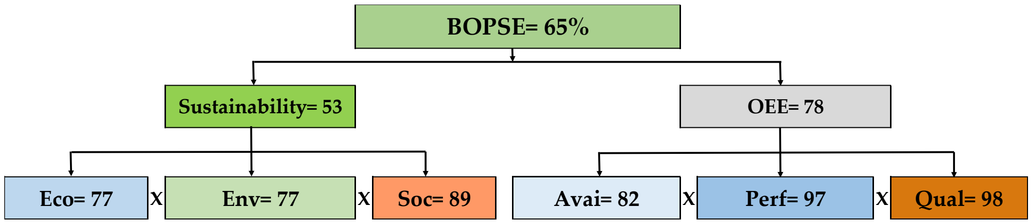

Figure 4. BOPSE calculation and result for case study A. Source: elaborated by the authors.

The outcome positions case study A slightly below the medium performance threshold (66%), which is computed when considering a standard of medium performance (80%) for both OEE and each sustainability dimension. Nonetheless, the BOPSE value is just 3% lower than the BOPSE achieved for medium performance, recorded at 68%. This medium performance benchmark was derived from a world-class firm boasting an OEE of 85% and a sustainability score of 51%, assuming an 80% standard for each sustainability dimension [117].

5.2. Case Study B—Multinational Producer of Car Seat Covers

Following data collection, the diverse indicators, strands, and BOPSE indicator were computed for case study B. The sustainability results showcased the social dimension leading at 79%, followed by the environmental dimension at 73%, while the economic dimension posted the lowest score at 70%. Conversely, the reported OEE stood at 51%, signalling that the company has room for improvement in its operational performance. Specifically, the OEE performance was 20% below the benchmark set by a world-class firm.

The BOPSE value achieved for case study B was 46%, as depicted in Figure 5. Overall, the BOPSE performance fell below the medium performance benchmark set at 66%.

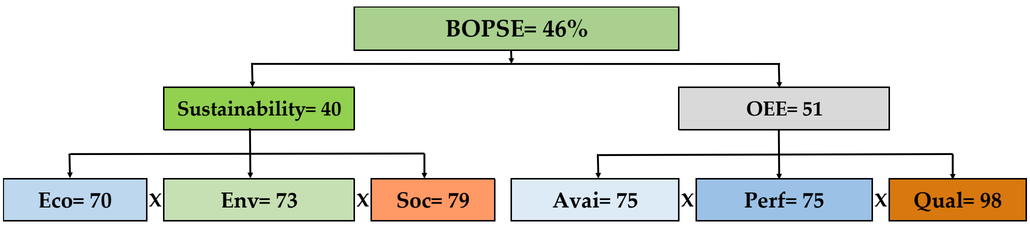

Figure 5. BOPSE calculation and result for case study B. Source: elaborated by the authors.

5.3. Case Study C—Multinational Automotive Supplier

The data necessary for case study C were eventually received from the facility situated in the inner centre of Portugal. It is worth noting that this facility had recently initiated a project to reduce its ecological footprint. However, despite several emails sent to request the economic data, and assurances of data confidentiality, these values were not provided, causing a delay of approximately a month.

Upon receiving and processing the sent data, various indicators, strands, and the BOPSE indicator were calculated. The sustainability results showcased the social dimension achieving the highest score at 82%, followed closely by the environmental dimension at 77%. However, due to missing economic data, two estimates were derived for this dimension, resulting in values of 60% and 80% (referring to case study C (1) and case study C (2)) in Table 5.

Table 5. BOPSE case studies comparison, taking into account economic performance—low (1) and medium (2)—for case study C.

Strands	Case Study A	Case Study B	Case Study C (1)	Case Study C (2)
Sustainability (%)	53	40	38	51
Economic (%)	77	70	60	80
Environmental (%)	77	73	77	77
Social (%)	89	79	82	82
OEE (%)	78	51	81	81
Availability (%)	82	75	84	84
Performance (%)	97	75	97	97
Quality (%)	98	90	99	99
BOPSE **(%)**	65	46	60	66

The sustainability strand score landed between the reference values for medium and low performances (51% and 22%), placing it at 36%. For a detailed view of the BOPSE calculation, refer to Figure 6.

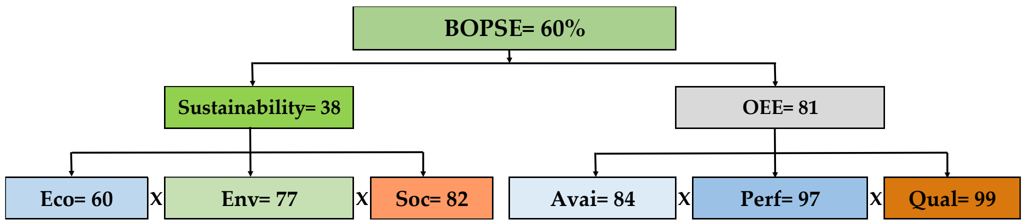

Figure 6. BOPSE calculation and result for case study C. Source: elaborated by the authors.

As evident from the results, the attained BOPSE value was 60%. Within this, the sustainability strand accounted for 38%, while the OEE strand contributed 81%. The reported OEE scored 81%, exhibiting only a marginal 4% difference from the benchmark of a world-class firm.

5.4. Case Studies Comparison

The outcomes produced by the BOPSE model in the three case studies are presented in Table 5.

Case study A secured the highest BOPSE value, reaching 65%, followed closely by case study C with a score of 60%. Case study A represents a company within a large multinational group, a top producer of automotive components globally, indicating a stable operational process. With an OEE nearly at 80%, this case study showed the highest sustainability strand value among the cases. This firm had previously published a sustainability report from 2018 to 2019, outlining its initiatives spanning from 2015 to 2017. Prior interactions through student internships in Industrial Engineering and Management consistently highlighted this company's dedication to social and sustainability aspects.

In contrast, case study B exhibited the lowest score at 46%, attributing its lower standings in both strands to its current state—a growth phase accompanied by increased human resource demands, necessitating training and coping with ongoing changes. A notable turnover rate of 56% might also account for these results. Previous engagements and supervisory roles in Industrial Engineering and Management student internships since 1996 revealed a company experiencing growth but exhibiting unstable behaviour due to shifts in company partnerships.

Case study C, despite presenting the highest OEE, showcased the lowest sustainability strand. The absence of economic data due to confidentiality requirements necessitated an estimation (considering 60% as low performance) in column (1) of Table 5. However, assuming a medium performance (80%) for the economic dimension (column (2) in Table 5) would yield a more favourable sustainability strand value of 51%. This adjustment elevates the BOPSE value to 66%, a notably more attractive score than the 60% initial estimation.

These findings suggest a pattern in sustainability performance, where a company exhibiting good sustainability practices achieves a score above 50%. Furthermore, for a promising BOPSE value, a company would typically score above 65%.

5.5. BOPSE Application through University–Business Collaboration

In 2021, the BOPSE was applied in thirteen additional companies to further validate its effectiveness. This evaluation was undertaken within the framework of a course unit, at the University of Minho, attended by fourth-year Industrial Engineering and Management (IEM) students, participating in a PBL initiative established through collaboration between the university and businesses. The assignment involved assessing the sustainability and business effectiveness within twelve industrial contexts, using the BOPSE [83]. Moreover, teams were tasked with reflecting on the data collection process, including any challenges encountered. Furthermore, guided by the results of the BOPSE indicator, teams were challenged with proposing environmental and operational improvement actions aimed at reinforcing it. The BOPSE results undertaken for the twelve companies are in Table 6, being mentioned as case studies D to O. The columns "Data" and "Sust. Report" are used to identify the source on which the BOPSE calculation was based, whether it was through data collected within the respective company or through information found in a sustainability report.

Table 6. BOPSE calculation.

Case Study	Company Sector	Data	Sust. Report	Sustainability (%)	OEE (%)	BOPSE (%)
D	Automotive	X		67	66	67
E	Commercial and industrial scales	X		57	64	61
F	Automotive components	X		44	79	62
G	Boat building	X		44	40	42
H	Electric mobility	X		56	h1: 60 h2: 80	58 68
I	Voltage transformers	X		50	54	52
J	Information Technology and electronics		X	48	90	69
K	Metallurgical parts	X		62	52	57
L	Plastics for automotive interiors	X		56	51	54
M	Furniture manufacturing	X		58	49	54

Table 6. *Cont.*

Case Study	Company Sector	Data	Sust. Report	Sustainability (%)	OEE (%)	BOPSE (%)
N	Energy		X	52	h1: 60	56
					h2: 80	66
					h3: 100	76
O	Exotic rock transformation	X		47	h1: 60	54
					h2: 80	64
					h3: 90	69
					h4: 100	74
					83 [1]	65 [1]
P	Chemical	X		55	67	61

[1] average value.

Last year, the BOPSE was also implemented in a chemical company within a master's thesis in Engineering and Operations Management—Industrial Management Branch, under the guidance of two authors of this paper, and referred as P in Table 6.

Out of the 13 companies, only two were not authorized by the company to collect the data, and we carried out the calculation through the sustainability report of another company.

As shown in Table 6, for two teams, there were estimated various scenarios for OEE (denoted by "h" in Table 6) due to companies withholding data for confidentiality reasons. Additionally, for case study N, the OEE scenarios were estimated based on information from its sustainability report. In total, nine companies reported sustainability values exceeding 50%, while the remaining four fell below this threshold and needed to implement corrective actions to enhance their sustainability performance. Regarding OEE, six companies identified actions to improve their OEE scores. Considering these factors, it became evident that BOPSE values, particularly for companies scoring below 60%, needed enhancement. While this may seem like a modest outcome, it is essential to recognize the rigorous nature of sustainability and OEE formulas, as outlined in Section 4. Consequently, each company must interpret their results, as they are not inherently straightforward. Interestingly, the company under case study F is the same company of case study A, in Section 5.1. As can be seen, it improved its performance by 1% in terms of OEE score, but worsened by 9% in terms of sustainability, thus reflecting this in the BOPSE value, which decreased by 3%. This highlights the need for the continuous and sustained commitment of companies to sustainability.

The most significant aspect of this assignment was the difficulty in obtaining the data, which reinforces the need for companies to systematize all available information and adapt its format, with the ultimate goal of making appropriate, relevant, and timely decisions. Furthermore, difficulties related to the time and resources needed for BOPSE calculation, as well as the level of commitment from companies towards BOPSE, were also mentioned.

6. Discussion

In the literature review of lean–green models, it was noted that there existed a gap in research regarding indicators for lean–green models, emphasising the necessity of simplicity and feasibility for corporate application. Consequently, during the model development phase, several considerations were taken into account: it should be straightforward, user-friendly, and include a suitable, essential, and pertinent number of indicators. The overarching aim was to ensure the relevance and proper characterization of the BOPSE model.

In the initial version of the model, 34 descriptive indicators were identified. Following consultations with experts, adjustments were made to the BOPSE model to integrate the foremost conclusions reached:

1. Evaluation of the relevance of each key indicator: they were deemed necessary and appropriate;
2. Evaluation of the importance of each descriptive indicator: they were deemed necessary and appropriate;

3. Certain environmental and social calculation formulas were revised to more accurately depict the indicator;
4. Rankings were established to ensure comparability among indicators;
5. Calculation of BOPSE: an arithmetic mean of sustainability and OEE;
6. Evaluation of BOPSE suitability: Both BOPSE key and descriptive indicators were considered essential for its characterization.

The applicability of BOPSE was further evaluated using sustainability reports and sensitivity and feasibility tests. The objective was to gauge its effectiveness and comprehend the impact of the performance intervals defined for the rankings on the key indicators, dimensions, strands, and BOPSE itself.

Defining the rankings posed challenges, as it was arduous to locate information in the appropriate format. It required sourcing data for the same descriptive indicator from various sources. Rankings were established for descriptive indicators to standardize them, ensuring comparability.

During the design stage of the BOPSE, the consideration of incorporating additional indicators arose. However, some were excluded, due to concerns that they would lead to a more complex and labour-intensive model. Reflecting on whether sustainability and OEE strands should have different weights was contemplated but dismissed, opting for equal weighting to ensure a fair assessment without bias towards any strand. Furthermore, there was discussion about establishing different weights for sustainability dimensions. Ultimately, it was decided to mirror the structure of the formula established for OEE to maintain coherence and simplicity. BOPSE, a straightforward arithmetic mean of sustainability and OEE, offers an accurate depiction of a company's status.

The BOPSE model underwent comparison with four assessment models previously identified in the literature review of lean–green models [75]. Meanwhile, no other lean–green assessment models were identified in the literature [33–37]. Nevertheless, two papers presented lean–green implementation models, those of Machingura et al. [36] and Siegel et al. [37].

Table 7 presents the characterization and comparison of the assessment models with the BOPSE model. The criteria employed for comparison included the conceptual foundations, the KPI and key environmental performance indicators (KEPIs) used, the company sector, and the number of implementations/applications.

Table 7. Characterization and comparison of assessment models (adapted from Abreu et al. [75]).

Authors/ Designation	Year	Based on:	Number of KPI and KEPI	Company Sector	Number of Cases Studies
Reis et al. [78]/ LGS	2018	CMMI	20 performance indicators (10 lean and 10 green)	Coffee production	6
Farias et al. [79]/ LGindex	2019	ANP	Six operational, five environmental (three repeated)	Footwear manufacturing	1
Carvalho et al. [80]/ Lindex and Gindex	2019	GLPI and PCA	Lean index (nine variables) and green index (five variables)	*	*
Amrina and Zagloel [81]/ ESLP	2019	3 SD pillars	Twelve eco-socio-lean dimensions, three performance metrics, and four improvement strategies, to achieve two objectives	**	0
Abreu et al. [62]/ BOPSE	2019	GRI and OEE	18 key indicators, 32 descriptive indicators	Case study A, B, C and 13 sectors in Table 6 ***	16

* European Manufacturing Survey 2012 in Portugal, with 62 valid responses. ** There was no mention of any specific sector. *** Automotive; commercial and industrial scales; automotive components; boat building; electric mobility; voltage transformers; IT and electronics; metallurgical parts; plastics for automotive interiors; furniture manufacturing; energy; exotic rock transformation; chemical.

The Reis et al. [78] model, in comparison to the BOPSE model, did not address any of the three pillars of sustainable development, nor did it incorporate standard indicators such as OEE or GRI. Their model was implemented in six companies from the production coffee sector. As the previous author, the Farias et al. [79] model did not incorporate references to the three pillars of sustainable development and did not include descriptions of standard indicators like OEE or GRI. The model was implemented in a footwear manufacturing company. Similar to previous models, the Carvalho et al. [80] approach did not reference the three pillars of sustainable development. Furthermore, unlike the BOPSE model, this model did not specify any standard indicators such as OEE or GRI. The indexes were constructed using the data obtained from the European Manufacturing Survey (EMS) in Portuguese companies. Although, the Amrina and Zagloel [81] model addressed the three pillars of sustainable development, it did not make reference to any standard indicators like OEE or GRI, and it had not been implemented. The BOPSE was implemented in three companies from the automotive sector and applied in thirteen companies from very different sectors, as outlined in Table 6.

The main critique identified in the reported models in the literature review concerns the need for a more straightforward and meaningful integration model. This model should be easily implementable by companies to measure and monitor key indicators, particularly the combined effectiveness of both leaner and greener industrial practices. Thus, the BOPSE arose as a theoretical contribution to answer the research gap identified.

The BOPSE model is grounded in established standard indicators, specifically the OEE for the lean paradigm and some GRI indicators for the green paradigm. In this way, the authors intended to answer the question “Does a lean company exhibit greater sustainability?”, emphasising the notion that excelling in just one strand is not enough; rather, a company must exhibit proficiency in both strands. It integrates the three pillars of sustainable development, to evaluate sustainability performance and the production losses to assess operational performance. Thus, it helps prevent biased outcomes and trade-offs among strands. The proposed version of the BOPSE model is grounded on an integrated indicator, which, hopefully, will translate to a broader adoption and dissemination. It is designed to be straightforward enough for smaller companies, such as small and medium-sized enterprises (SMEs), to find it practical and cost-effective to use. Furthermore, the model integrates familiar concepts and indicators, such as those found in OEE and GRI, which should facilitate comprehension and implementation, especially if already present within the company.

Interestingly, all case studies uncovered challenges in furnishing specific data, particularly concerning environmental metrics, such as materials used and net water needs reduction.

Insights from these real cases impacted the BOPSE indicators, prompting a subsequent consultation with experts. In this second consultation stage, the BOPSE was refined into its final version, comprising 32 descriptive indicators in the sustainability strand. This demands a total of 45 input data points specifically for sustainability. However, it is noteworthy that some data points are repeated; for instance, the total revenue amount is used in multiple indicators across economic, environmental, and social dimensions. Similar duplication occurs with some environmental and social indicators as well. Rankings were established for 27 descriptive indicators. The key indicators were considered fundamental and the BOPSE calculation was settled as the arithmetic mean of sustainability and OEE.

For companies that already publish sustainability reports and measure OEE, collecting data and calculating the BOPSE will be significantly streamlined. However, for those solely measuring OEE or sustainability, data collection efforts would be required for the respective strands. Companies lacking data for both OEE and sustainability will need to gather information for both strands. Hence, the BOPSE evaluation is feasible for companies holding different levels of lean–green implementation.

In terms of practical contributions, the findings from the case studies highlighted significant aspects: the acknowledgment by companies of their current state and the visual management of this state, which offers a comprehensive view of key metrics and performance indicators, helping users to promptly assess and comprehend all pertinent information. Additionally, there was substantial emphasis on the capacity to make informed decisions regarding the future. This research has the potential to identify weaknesses within companies concerning performance and sustainability, thereby presenting opportunities for enhancing overall competitiveness.

This study was conducted using case studies. However, to address its limited generalization resulting from the case study strategy, it should be applied to a larger sample of companies [86]. Further investigation using additional case studies could contribute to generating a portfolio of sustainability and BOPSE scores, providing insights to support the establishment of reference values.

7. Conclusions

The conceptualization of the lean–green assessment model BOPSE stemmed from a comprehensive literature review and insights drawn from industry consultations. Its development was a collaborative effort involving an exchange of ideas and dialogues with multidisciplinary experts, aiming to define crucial indicators, representative criteria, and precise calculations across various dimensions. This paper objective was to present a new lean–green model, which includes a comprehensive indicator to simultaneously assess compliance on both lean and sustainability, as an answer to the research question: Does a lean company exhibit greater sustainability? BOPSE integrates two strands derived from well-established KPIs in corporate spheres: the OEE for shop floor performance evaluation (lean) and the GRI as the inspiration for measuring sustainability performance (green). Each strand encompasses three dimensions.

Validation of the BOPSE model occurred using three case studies, representing manufacturing firms in the northern region of Portugal. Afterwards, the model was applied in thirteen further companies through a PBL initiative between fourth-year IEM students from the University of Minho and businesses. A BOPSE score of around 65% was identified as indicative of a commendable lean–green performance, while companies displaying good sustainability practices typically scored above 50%.

This model necessitates the quantification of all indicators, enabling a comprehensive understanding of a company's status across economic, social, environmental, and operational domains. Therefore, it helps prevent biased outcomes and trade-offs among strands. Identifying weaknesses facilitates informed decision-making and the formulation of strategies to address them. Designed to be user-friendly and cost-effective, the BOPSE model caters to companies at varying levels of lean implementation and sustainability practices, reflected in their respective BOPSE scores. Higher scores signify companies with more stable processes and sustainable practices, whereas lower scores signify areas ripe for improvement.

BOPSE assessments empower companies to gauge their strengths and weaknesses, aligning their actions with the Sustainable Development Goals (SDG). By influencing shifts towards sustainable consumption and production patterns, these actions contribute to targets associated with 13 of the 17 SDGs, particularly SDG 12, responsible consumption and production, emphasizing the necessity of "ensuring" sustainable consumption and production patterns.

The BOPSE model, created to fill a research gap in lean–green models, serves as an accessible lean–green assessment tool, featuring an integrated and easily applicable indicator. In light of the findings and with the research question "Does a lean company exhibit greater sustainability?" in mind, there appears to be a discernible trend, albeit not entirely conclusive, indicating that lean companies may indeed exhibit greater sustainability. Results from the case studies suggest a degree of favourable evidence, as the companies with the highest sustainability scores had been actively engaged in a lean journey for several years, and their processes were considered stable. However, further investigation through additional case studies is needed to corroborate these findings. Moreover, the willingness of companies to strive for continuous improvement signals a sustained commitment to enhancing performance—an identifiable trait of lean that has also demonstrated significance. Its envisioned final version aims for widespread adoption and dissemination.

Therefore, the BOPSE arose as a theoretical contribution to answer the research gap identified. This research will advance the development and dissemination of knowledge concerning lean and green production and its resulting synergies. Furthermore, the research could facilitate the establishment of benchmark values for various sectors of the economy, contingent upon a substantial number of cases utilizing the BOPSE. Subsequent widespread adoption of it could yield valuable insights for validating and refining its effectiveness.

As practical contributions, companies employing BOPSE can be aware about their current state through visual management techniques such as dashboards, providing a comprehensive overview of essential metrics and performance indicators. This enables quick assessment and comprehension of companies' strengths and weaknesses. Consequently, it empowers the ability to make well-informed decisions for the future, taking weaknesses into account as areas for improvement. Thus, BOPSE offers companies the potential to identify performance and sustainability weaknesses, thereby presenting opportunities to enhance overall competitiveness.

Concerning this research's limitations, the BOPSE demands a number of data items to fill the indicator values that, sometimes, are not immediately available. All case studies revealed challenges in providing specific data, particularly regarding environmental metrics. Another limitation was that the survey sample used was restricted to the north of Portugal. Acknowledging its limitations, further validation in diverse contexts and geographical settings is crucial for its global applicability, akin to the OEE standard. Future work should address developing user-friendly applications, potentially through mobile apps and dashboards, for companies to implement independently.

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