Towards Data-Driven, Sustainable Supply Chain Quality Management 5.0 Indicators

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Abstract

There is a growing interest in the concept of Industry 5.0 (I5.0), which supports a transition towards a more sustainable, resilient and human-oriented industrial paradigm. This paper focuses on the I5.0 sustainability pillar, which is crucial to optimize and support I5.0's data-driven and circular supply chains.
In order to pursue a Sustainable Supply Chain (SSC) and improve data quality management across it, it is first imperative to understand to what extent the existing SSC quality indicators are aligned with the opportunities of the digitalization era, and if they support the path to I5.0 sustainable practices. This paper aims to do a comprehensive study and analysis of relevant groups of SSC metrics and indicators. Through a broad literature review, SSC metrics and indicators are identified. Then, they are assessed to determine if they are suitable and relevant to assist decision makers in the challenges towards SSC 5.0.
Results reveal that despite growing interest in the progress of data-driven SSC in recent years, there are still research gaps, mainly concerning the standardization of indicators, the simplification of models, and the use of consistent models for the treatment and conversion of proper data into relevant information.

Keywords
Sustainable Supply Chain, Performance Indicators, Data-driven Management, Quality Management and Industry 5.0.

1. Introduction
Industry is changing at an ever-increasing speed (Schwab and Davis 2018). However, industrial development indicators are based on economic principles, defined in the middle of the 20th century, emphasizing the returns to shareholders (EU Directorate-General for R&I et al. 2021). The paradigm is shifting towards the ideal of stakeholder value, reinforcing the role and the contribution of industry to society at large, rather than to the benefit of a few (Callaghan 2020, EU Directorate-General for R&I et al. 2021).

Industry 4.0 has focused on advanced technologies to optimize processes and increase efficiency (Ivascu 2020, Liu and Lin 2021, Rad et al. 2022). However, there have been some concerns about the dehumanization of the workplace and the social and environmental impacts of this approach (Callaghan 2020, Rad et al. 2022, Raja Santhi and Muthuswamy 2023). The concept of Industry 5.0 (I5.0) addresses some of these issues by emphasizing sustainability, human-orientation and resilience (EU Directorate-General for R&I et al. 2021). I5.0 involves a shift towards more collaborative, customized, and flexible production processes that values human intelligence and creativity, pursuing optimization between technological progress and human well-being (Longo et al. 2020).

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Overall, while industry 4.0 has been instrumental in transforming the manufacturing sector, I5.0 seeks to build on this foundation and prioritize sustainable values as essential components of modern manufacturing (Raja Santhi and Muthuswamy 2023, Saniuk et al. 2022). According to the EU 2030 action plan, it is essential that industry redesign its Supply Chain (SC) to embrace new technological opportunities and adopt metrics and indicators that allow the measurement of progress towards industry sustainability and development (EU Directorate-General for R&I et al. 2021). The European Commission has defined six industrial guidelines towards I5.0. Of these guidelines, the sixth refers exactly to the development of metrics and frameworks for smart measurement. These metrics are presented as enablers for industrial competitiveness in the context of the EU2030 goals (EU Directorate-General for R&I et al. 2021) and the United Nation's Sustainable Development Goals.

This paper will focus on the sustainability pillar of I5.0, which is crucial to optimize circular economies (Fraga-Lamas et al. 2021, Karaman et al. 2020, Morella et al. 2020), ensuring current demands without compromising future generations (EU Directorate-General for R&I et al. 2021, Karaman et al. 2020, Saniuk et al. 2022). Concentrating particularly, on the quality management of Sustainable Supply Chain (SSC) supported by metrics and indicators. SSC refers to the process of managing, planning, sourcing, making, delivering, and returning goods and services in a way that minimizes negative environmental and social impacts while maximizing economic returns (Karaman et al., 2020). It involves cooperating with suppliers, consumers and society to promote responsible sourcing, reduce waste, preserve natural resources, and ensure fair labor practices along the SC (Chen & Kitsis 2017, Resat & Unsal 2019). The goal is to develop a resilient and balanced system that meets the needs of current and future generations (EU Directorate-General for R&I et al. 2021, Karaman et al. 2020).

In fact, SSC have a crucial role in promoting the circular economy (Ivascu 2020, Rajesh 2022). This requires reducing waste and residues to a minimum (Morali and Searcy, 2013). Essentially, in a circular economy the reducing, reusing, and recycling are promoted through all the SC, from the supplier to the end user and backward, thus aggregating value for all society (Ivascu 2020, Morella et al. 2020). To close a sustainable cycle, the return process (including the recycling and reuse of products) must also be considered and evaluated (Hassini et al. 2012). Currently, the most widespread and accepted approach to sustainable development is the triple bottom line (TBL) model, developed by Elkington (1997). This approach classifies sustainability into three categories - economic, environmental, and social - and therefore this paper will be addressing sustainability in these three aspects.

There are different Sustainable Supply Chain Management (SSCM) metrics and performance indicators, some more complex and comprehensive and some more adapted to specific realities, suggesting different ways of measuring and analyzing an SSC (Chen and Kitsis 2017, Choudhary et al. 2021). However, the challenge is to identify the metrics that better apply to each scenario (Bai and Sarkis 2014, Saeed and Kersten 2017). While corporations are increasingly integrating the principles of sustainability into their SSCM practices to address the TBL of sustainability (Morali and Searcy 2013, Rajesh 2022), it is first imperative to understand to what extent the existing SSC quality indicators are aligned with the opportunities of digitalization era, and if they support the path to I5.0 sustainable practices.

There are several reference models that address the performance of the SC, including its sustainability. One of the most complete and accepted reference models is the SCOR (Supply Chain Operations Reference) model (Kottala and Herbert 2020), which was recently updated to include performance indicators of environmental and social sustainability (ASCM 2022). However, there is still a renovation gap in the integration of SC and Quality Management (QM) models (Chau et al. 2021, Cubo et al. 2021), and several authors argue that there is a constant need to adapt models and indicators to the reality of current industrial era (Cubo et al. 2021, Piotrowicz and Cuthbertson 2015).

In an era where data gathering is almost endless (Sharma and Arya 2022) a data-driven SSCM is crucial to support the move towards I5.0. Henceforth, it is essential to understand to what extent the existing SSC quality indicators are aligned with the opportunities of the digitalization era, and if they support the path to I5.0 practices supporting human well-being, resilience, and overall sustainability. To address this topic is crucial to answer the following research questions: 1) Are the existing SSC indicators clear and well consolidated and/or standardized? 2) Do all sustainability perspectives of triple bottom line have the same relevance in terms of measuring SSC performance? 3) Are the existing SSC metrics and indicators a good fit for the reality of I5.0?

This paper is divided into five chapters: the introduction provides a contextualization and the core concepts. It also includes the motivation and objectives of this work. Chapter two presents the employed methods and is followed by the data analyses chapter (three) where the outcomes are displayed and assessed. At chapter four, the results are discussed and evaluated. Finally, at the conclusion, chapter five, the contributions are highlighted, the research questions are answered, and the concerns and future work approaches are presented.

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2. Methods

To answer the research questions, this work reviews and evaluates a relevant group of academic studies to subsequently assess the metrics and indicators of SSC in order to define if they are suitable and relevant to assist decision makers in the challenges towards SSC 5.0. To define the initial research string, a preliminary study of possible queries was applied. It was decided to start the bibliographic research with the string "Sustainable supply chain" + "Performance indicators" For better sorting, the Scopus database was chosen, and the following inclusion and exclusion criteria were defined (Table 1).

Table 1. Inclusion and exclusion criteria

Code	Criteria	Description	Remaining articles
I1	Inclusion	When the predefined keywords exist in the title and/or keywords and/or abstract section of the paper	59
I2	Inclusion	Papers published in a scientific peer-reviewed journal	37
E1	Exclusion	Papers that are not articles (e.g. conference papers, book chapters…)	37
E2	Exclusion	Papers that are not written in the English language	37
E3	Exclusion	Papers that do not contribute to answering the research questions	34
E4	Exclusion	Papers that only address economic indicators	28
S1	Inclusion	Relevant papers found during the analysis	30

As can be seen in Table 1, there are 28 remaining articles after all inclusion and exclusion criteria were applied. In addition to the papers found by applying the research string, two papers were also included through a snowball analysis of the articles initially studied, totalizing 30 studied papers.

3. Data Analysis

The appraisal of the articles year of publication (Figure 1) does not show a clear trend. However, it can be assessed that SSC indicators are a recent research topic with a growing, but unstable interest. The analysis of publications per journal showed some distribution, with 3 articles published in *Sustainability*; two articles in each *Journal of Supply Chain Management*, *Journal of Cleaner Production* and *Annals of Operations Research*; and the remaining articles were published in other journals. Although it is possible to suggest that the studied subjects matter to a diversity of fields, most fall within the following groups of disciplines - Sustainability (39%), Operations and Management (29%), SC (19%), and Technology and Systems (10%). While the evaluation of the journal quartiles exposes an interesting trend, denoting that the studied articles are mainly of high quality, with 61% of the articles published in Q1 journals - followed by 26% in Q2 journals and 6,5% in Q3 journals.

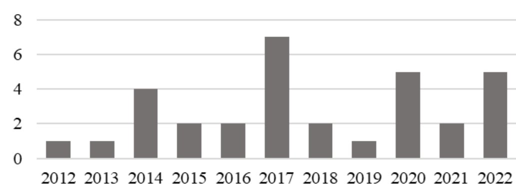

Figure 1. Year of publications

Twenty-seven articles specified the countries or regions of the studies. This data was compiled by continents (Figure 2), allowing an overview of the interest in SSC performance management worldwide. This analysis was binary, meaning that each continent was only considered once in each article – e.g. if a study was done both in China and Japan, the continent Asia was accounted once. For literature review articles, when there is a case study, the countries contemplated were the ones where the case studies are applied. This analysis reveals that Asia is the continent with more applied studies followed by Europe.

The industrial sector analysis (Figure 2) demonstrated that most of the articles were applied in the manufacturing sector. However, the distribution sector, energy, pharmaceutical, and chemical industries also have great relevance within the articles studied. This evaluation considered the articles that clearly indicate a certain sector or industry application. Opposing to the previous evaluation this analysis was non-binary, meaning that if more than one industry in the same sector was referred in an article, both were accounted – e.g. if the same study was applied to a furniture, a shoe manufacturer and to an electricity company, it was accounted 2 for manufacturing and 1 for energy. Articles were also classified accordingly to which SCOR (Figure 2) processes they addressed. Most of the articles address the processes of plan, source make and deliver, followed by those that addresses all processes including returns.

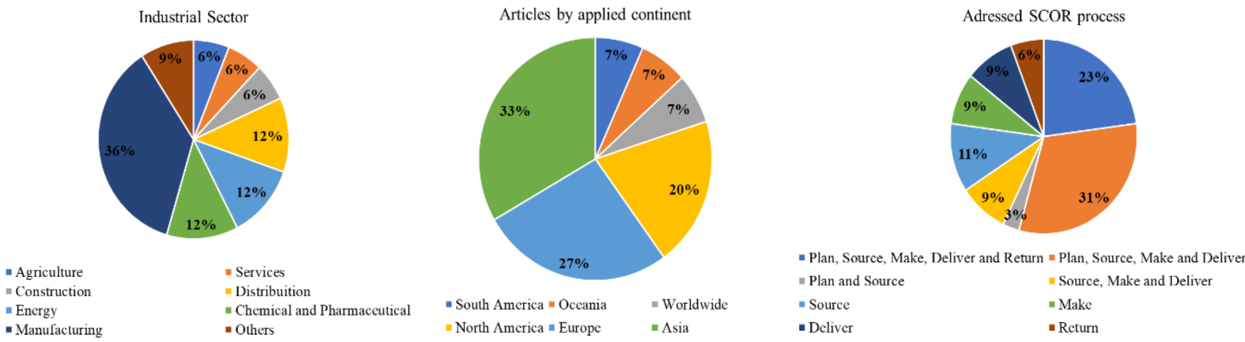

Figure 2 - Demographic analysis

The indicators and metrics discussed in the studied articles are presented in Appendix A. For the development of this analysis, the indicators were considered as presented in the articles. There are cases where similar indicators were presented with different words by different authors, intentionally those indicators were not grouped in the same line. The exception were the indicators where the differences were in the word sequencing, or between singular and plural. Finally, whenever possible, auxiliary adjectives were avoided - e.g. maximize, minimize, improve... - to avoid even greater differences between classifications. Indicators in systematic literature reviews were classified by the final set of metrics and indicators (summaries) presented in such articles. The articles by Goharshenasan et al. (2022), Karaman et al. (2020), and Morali & Searcy (2013) did not contribute to Appendix A since they only addressed the indicator models in a generalized way (e.g. GRI, LPI...), not defining more or less specific indicators or groups of greater interest for their studies. However, these articles were maintained in the rest of the review once they were considered relevant to the development of the topic.

Appendix A reveals a vast and diverse group of metrics and indicators, indicating that sustainable indicators are well spread both in industry and academia. However, it also demonstrated a lack of prioritization and standardization. Such evaluation enabled a classification of the metrics by the TBL plus innovation categories, as can be seen in Table 2. To fit the TBL approach, the process and productivity indicators were framed within the most appropriate of the 3 dimensions, usually the economic indicators. However, after the indicators analysis and considering the advances in the industry since 1997, we suggested the addition of a fourth aspect, Innovation, thus creating a quadruple bottom line.

Table 2. Articles classification by the triple bottom line + innovation categories

Indicators categories	**Paper (Author, year)**
Environmental	(Acquaye et al. 2017, Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Chen and Kitsis 2017, Chiarini 2017, Choudhary et al. 2021, De Sousa Jabbour et al. 2015, Feitó-Cespón et al. 2017, Guo and Wu 2022, Hassini et al. 2012, Ivascu 2020, Khan et al. 2017, Kuwornu et al. 2023, Lee and Wu 2014, Morella et al. 2020, Narimissa et al. 2020, Ngan et al. 2018, Pinto 2017, Piotrowicz and Cuthbertson 2015, Rajesh 2022, Resat and Unsal 2019, Sadeghi et al. 2022, Saeed and Kersten 2017, 2020, Tsolakis et al. 2018, Varsei et al. 2014, Wang et al. 2022)
Social	(Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Chen and Kitsis 2017, Choudhary et al. 2021, Guo and Wu 2022, Hassini et al. 2012, Khan et al. 2017, Kuwornu et al. 2023, Lee and Wu 2014, Narimissa et al. 2020, Ngan et al. 2018, Pinto 2017, Piotrowicz and Cuthbertson 2015, Rajesh 2022, Resat and Unsal 2019, Sadeghi et al. 2022, Saeed and Kersten 2017, 2020, Varsei et al. 2014)
Economic	(Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Chen and Kitsis 2017, Chiarini 2017, Choudhary et al. 2021, De Sousa Jabbour et al. 2015, Feitó-Cespón et al. 2017, Guo and Wu 2022, Hassini et al. 2012, Ivascu 2020, Khan et al. 2017, Kuwornu et al. 2023, Lee and Wu 2014, Narimissa et al. 2020, Ngan et al. 2018, Pinto 2017, Piotrowicz and Cuthbertson 2015, Sadeghi et al. 2022, Saeed and Kersten 2017, 2020, Sivarethinamohan et al. 2021, Tsolakis et al. 2018, Varsei et al. 2014, Wang et al. 2022)
Innovation	(Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Guo and Wu 2022, Ivascu 2020, Narimissa et al. 2020, Resat and Unsal 2019)
Triple bottom line	(Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Chen and Kitsis 2017, Choudhary et al. 2021, Guo and Wu 2022, Hassini et al. 2012, Khan et al. 2017, Kuwornu et al. 2023, Lee and Wu 2014, Narimissa et al. 2020, Ngan et al. 2018, Pinto 2017, Piotrowicz and Cuthbertson 2015, Resat and Unsal 2019, Sadeghi et al. 2022, Saeed and Kersten 2017, 2020, Varsei et al. 2014)
Quadruple bottom line	(Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Guo and Wu 2022, Narimissa et al. 2020, Resat and Unsal 2019)

There are several indicators that address the sustainable perspective of the SC. Furthermore, there are some widely accepted and well adapted international reference models (Chardine-Baumann and Botta-Genoulaz 2014, Piotrowicz

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and Cuthbertson 2015). Some of the most widespread reference models are the Yale Environmental Performance Index (EPI), the Product Sustainability Index (PSI), and the Global Reporting Initiative (GRI). There are also some adapted models, such as the SCOR for the SC, which currently already includes some indicators related to sustainability, and finally, some references for sustainable development, such as the OECD's core environmental indicators and the United Nations Sustainable Development Goals. However, despite the availability of such models, there is still high variability in the metrics and indicators used, and frequent neologisms were across the studied papers. Such reality made the analysis more dispersed, and even unclear sometimes. Furthermore, this variability has implications for practice, as it makes the selection of metrics and indicators more difficult and impacts the management of SC performance.Table **3** presents the articles that refer to those models at least once. Its results, when compared to Table 2, show a significant reduction in the total number of articles. This is a result of the above-mentioned lack of standardization and the tendency to create new indicators – or adapt and rename them with new names.

Table 3. Reference models occurrence. The analysis was made using the MAXQDA software

Model	Paper (Author, year)
GRI	(Chardine-Baumann and Botta-Genoulaz 2014, Chiarini 2017, Goharshenasan et al. 2022, Hassini et al. 2012, Karaman et al. 2020, Lee and Wu 2014, Morali and Searcy 2013, Narimissa et al. 2020, Pinto 2017, Saeed and Kersten 2017, Varsei et al. 2014)
PSI	(Goharshenasan et al. 2022)
EPI	(Goharshenasan et al. 2022)
SCOR	(Bai and Sarkis 2014, Chardine-Baumann and Botta-Genoulaz 2014, Choudhary et al. 2021, Pinto 2017, Piotrowicz and Cuthbertson 2015, Sadeghi et al. 2022, Saeed and Kersten 2017, 2020)
OECD	(Acquaye et al. 2017, Chardine-Baumann and Botta-Genoulaz 2014, Goharshenasan et al. 2022, Hassini et al. 2012, Karaman et al. 2020, Morali and Searcy 2013, Saeed and Kersten 2017, 2020)
SDGs	(Chiarini 2017, Ivascu 2020, Kuwornu et al. 2023, Saeed and Kersten 2017, 2020, Varsei et al. 2014)

Less than two-thirds of the studied articles refer to one or more of these reference models at least once. Furthermore, when defining the indicators, authors often source different definitions for the indicators. Even though there is some recurrence, the studied indicators still lack normalization - as can be confirmed in Table 3 and Appendix A.

4. Discussion

In this paper, a literature review was carried out following the inclusion and exclusion criteria presented in Table 1. Furthermore, the resulting data were scrutinized in relevant aspects and in Figure 1 it is possible to see that SSC indicators are a recent research topic with a growing, but unstable interest, while Figure 2 presents three demographic analyses that indicates that this subject is relevant for the various fields of industry and society worldwide. Additionally, the articles were classified according to the TBL plus innovation categories (Table **2**. Articles classification by the triple bottom line + innovation categoriesTable 2), thus demonstrating the articles that address all TBL categories and those that address only one or 2 categories. Considering the fact that Appendix A reveals a vast and diverse group of metrics and indicators with great variability, it was also important to analyze the usage of reference models in the studied papers (Table 3).

Although several authors resort in part to reference model indicators, as depicted in Table 3, it was clear that there is an extensive variety in the indicators arrangement (Appendix A.). Such variability increases the error margin in the definition and selection of the most suitable indicators, also increasing the possibility of redundant indicators. When considering the categorization of indicators by groups (Appendix A.) economic indicators take the lead with a total of 211 references. They are followed by environmental indicators, with 147 references. The social sustainability-oriented indicators have 126 mentions. These results suggest that, despite the pressure for a more balanced sustainability, the industry still values more the application of economic categories and indicators, even when the studied group is limited by the string “SSC”.

Finally, an important note must be made regarding data quality. While defining and choosing indicators to a SSC, guaranteeing that such metrics are based on valuable and reliable data is key. In an era where data collection is largely exponentiated, the quality of data is crucial to support data-driven SSCM (Sharma and Arya 2022, Varsei et al. 2014). In fact, Ivascu (2020) concludes that digitalization is a significant enabler of sustainable circular economies. As such, the quality of data behind the collection and follow-up of any sustainability indicators must also be considered. This means data that can be assessed and evaluated in real time, relying on consistent and standardized sources, in order to support decision makers for a more sustainable era.

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5. Conclusion

Well-tailored sustainable performance measurement promotes long-term competitiveness in the attained economic returns by enterprises considering its effects on the environment and society, not sacrificing the needs of stakeholders as well as the realization of the long-term goals (Bai and Sarkis 2014). As presented in previous sections, several indicators adress the sustainable perspective of the SC. However, the analysis conducted in this paper shows there is a lack of standardization of those metrics and indicators, meaning that the SSC data analysis is often confusing and diffuse (Saeed and Kersten 2020). Consequently impacting on the quality of the decision makers choices (Chiarini 2017, Choudhary et al. 2021).

This paper demonstrates the relevance of continuous growing the awareness towards a more SSC. The trends on SSC performance indicators were explored, revealing that despite the great interest in this area in the past years, there is still a lot to develop, mainly in what concerns the standardization of indicators and the simplification of models, to convert proper data into relevant information, in a way that truly help the decision makers towards an SSC adequate to I5.0. As this study portrayed, there is an enormous variety of metrics and indicators, some are clear and well consolidated although the lack of standardization makes the process of classification detached and unclear.

Metrics and indicators were assessed based on published articles on the topic of SSC quality management. Results show that most, but not all, articles consider metrics and/or indicators of the three sustainable perspectives (environmental, social, and economic). Indeed, as deliberated in chapter five, all the authors discussed the environmental perspective and most of them emphasizes the economic aspects, while fewer discussed the social indicators, suggesting that not all perspectives of TBL have the same relevance in the studied articles.

In fact, in addition to sustainability, the human orientation is one of the I5.0 pillars. This less significant interest in the social indicators implies that the relevance of each perspective is still not a perfect fit for I5.0. Furthermore, to better fit the necessities of SSC 5.0 as explained above there is a clear necessity for standardization of the indicators in a way to really beneficiates the path towards I5.0. Furthermore, to better fit the challenges of I5.0, it was concluded that SSC 5.0 would benefit from a 4th perspective (Innovation), in this way we suggest a quadruple bottom line model, including the innovation perspective.

This review demonstrated that the lack of standardization of the metrics and indicators is a major gap concerning the quality evaluation of SSC. Furthermore, to fulfill the requirements of I5.0 it is necessary to increase awareness towards the social and societal indicators. Finally, it was also clear that this subject matter for the various fields of industry and society worldwide as shown in the demographic analysis.

In future work, we aim to extend and further detail the discussion relating to Data-Driven Sustainable Supply Chain Quality Management 5.0 Indicators. Next steps include cross-referencing the indicators raised in this article with the reference models indicators, thus enabling the simplification and standardization of the performance indicators appropriate for SSC 5.0. Furthermore, and looking at the three pillars of Industry 5.0, further work is possible in characterizing, comparing, and integrating SC indicators to address not only sustainability but also resilience and human-orientation.

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Appendix A. Papers classification by metrics and indicators.

Metrics and indicators	(Acquaye et al. 2017)	(Ivascu 2020)	(Lee and Wu 2014)	(Morella et al. 2020)	(Khan et al. 2017)	(Wang et al. 2022)	(Feitó-Cespón et al. 2017)	(Sadeghi et al. 2022)	(Kuwornu et al. 2023)	(Chen and Kitsis 2017)	(Ngan et al. 2018)	(Bai and Sarkis 2014)	(Rajesh 2022)	(Varsei et al. 2014)	(Chiarini 2017)	(Choudhary et al. 2021)	(Guo and Wu 2022)	(Narimissa et al. 2020)	(Tsolakis et al. 2018)	(Resat and Unsal 2019)	(De S. Jabbour et al. 2015)	(Saeed and Kersten 2020)	(Pinto 2017)	(Saeed and Kersten 2017)	(Hassini et al. 2012)	(Piotrowicz et al. 2015)	(Chardine. and Botta 2014)
Environmental																											
Air emissions																							X				
Air pollution																											X
Air/water pollution										X																	
Atmospheric emissions																					X	X		X			
Carbon footprint											X																
Chemical usage in products																				X							

CO_2 emission	X				X																					X	
CO_2 emission from infrastructure																										X	
CO_2 emission from transportation																										X	
Consumption of hazardous/harmful/toxic materials										X				X				X			X				X		
Dangerous inputs																											X
Dangerous outputs																											X
Dangerous wastes																											X
Design for the environment													X														
Electricity-CO_2 transform coefficient kg CO_2/kw·h						X																					
End of life treatment													X														
Energy consumption efficiency										X		X			X							X		X	X		
Energy consumption/revenue																										X	
Energy consumption				X	X	X								X	X						X					X	
Energy consumption from fossil fuel					X																						
Energy consumption wasted (ex. Breakdowns, waiting period)				X																							
Energy footprint											X																
Environmental accidents Frequency										X							X				X						
Environmental budget																											X
Environmental certification																											X
Environmental costs								X				X								X							
Environmental damage																									X		
Environmental impact			X				X			X																	
Environmental impact saving							X					X															
Environmental impacts of products and services sold															X												
Environmental impacts of transportation															X												
Environmental improvements assistence												X															
Environmental information accuracy												X															
Environmental knowledge transfer												X															
Environmental laws Compliance										X					X							X		X			X
Environmental management system																											
Environmental protection management									X																		
Environmental revenues								X																			
Establishment of environmental protection standards																		X									
General practices of environmental management									X																		
Green energy usage																									X		
Green food production									X																		
Green image								X																			
Green manufacturing													X														
Green supply chain management																		X									
Greenhouse gas emission		X			X											X									X		
Greenhouse gas emission direct														X	X												
Greenhouse gas emission indirect														X	X												
Impacts on biodiversity															X												
Inputs stemming from the recycling																											X
Land pollution																											X
Land use																						X		X			X
LCA indicators							X																				
Logistic sustainable competence					X																						
Manage product life cycle																		X									
Material efficiency																						X		X			
Natural resources Use										X																	
Nitrogen oxides emissions															X												
Other pollution																											X
Ozone-depleting substances emissions															X												
Packaging materials															X												
Pollution control																		X		X							
Preservation of natural resources and eco-system Level										X																	
Recycling and re-use level										X					X					X						X	X
Recycling, re-use level and return index																		X							X		
Renewable energy																											X
Renewable resources Usage																									X		
Resource consumption		X														X											
Resources utilized on production															X												
Respect of biodiversity																											X
Single plastic use													X														
Sulphur oxide emission	X														X												
Supplier assessment according to enviromental performance																						X		X			
Sustainable packaging									X																		
Waste effluent																					X						
Waste level								X						X	X	X		X					X			X	X
Waste management																						X		X			
Waste solid																					X						
Water																							X				
Water consumption											X			X												X	
Water discharge															X												
Water footprint																			X								
Water management																						X		X			
Water pollution																											X
Water recycled and reused															X												X
Water source and withdrawal															X												
Water use direct	X																										
Water use indirect	X																										
Social																											
Access to essential services																											X
Accident frequency employees																		X					X				
Accident frequency non-employees																		X								X	
Accident gravity index																		X					X				
Accident number employees																										X	
Adaptability													X														
Age profile																							X				
Anti-corruption measures																						X		X			X
Anti-corruption measures audits										X																	
Break down by gender																							X				
Child and forced labor																											X
Complaint escalation rate																	X										
Community amenity			X																								
Consumer issues																						X		X			
Continuity and flexibility								X																			
Cooperation level												X															

Countries with history of human rights violations the firm conduct										X																	
Countries with stringent anti-corruption regulations the firm conduct										X																	
Customer satisfaction on social aspect																		X									
Decent work														X													
Development of urban and rural areas																											X
Discrimination																											X
Diversity improvement										X																	
Eco-systemic services																											X
Education and training													X			X		X				X		X			X
Employee absenteeism										X													X				
Employee commitment										X																	
Employee life Quality																											
Employee motivation																		X									
Employee performance										X						X											
Employee satisfaction																										X	
Employee skills																		X									
Employee stress level										X																	
Employee Training hours																		X					X				
Employee turnover										X													X				
Employees rights protection									X									X		X							
Employment																											X
Employment creation rates																X		X									X
Export control incidents per year																	X										
Fair labor practices																									X		
Fair trade practices																									X		X
Fair treatment of customers Level										X																	
Freedom of association																											X
Health and safety at work																				X		X					
Health and security																											X
Health incidents																	X										
Health performance								X			X		X														
Health/safety accidents										X																	
Healthcare and security																											X
Human resources development																											X
Human rights														X								X		X			
Improvement in strengthening community ties										X																	
Incentive policy for using local suppliers																		X									
Income per capta					X																						
Injury prevention																X											
Injury quantity																							X				
Investment in health and safety										X																	
Involvement in local community																											X
Job opportunity											X																
Job satisfaction level										X																	
Labor cost spent on training																		X								X	
Labor equity																X											
Noise emission in urban areas																										X	
Noise rates																X											
Noise time emission																										X	
Noise volume																										X	
Number of actions for community																							X				
Perceived value of product																X											
Product safety incidents per year																	X										
Production responsibility														X													
Promotion of corporate social responsibility in the sphere of																											X
Protection of private life																											X
Public awareness and acceptance											X																
Quality of employment																		X									
Recruitment cost										X																	
Respect of social dialog																											X
Response to environmental product requests												X															
Safe and humane conditions at suppliers' sites level										X																	
Safety performance								X			X		X														
Safety incidents																	X										
Safety practices Adoption																X											
Safety system and occupational health																		X									
Safety training																				X							
Security performance								X																			
Social compliance																						X		X			
Social responsibility													X														
Social service and philanthropy									X																		
Societal investment																											X
Speed of acquiring environmental information												X															
Stakeholders' involvement																X											
Supplier evaluation on social aspect																		X									
Supply chain reliability																		X									
Supply chain responsibility																		X									
Supportive activities for worker																				X							
Welfare performance								X																			
Work conditions																											X
Working hours lost due to illness																							X				
Economic																											
Account payables turnover																	X										
Account receivables turnover																	X										
Accuracy of sales quotations																	X										
Average delivery time																	X										
Average development time per project																	X										
Average number of stop per route																	X										
Average resolution time																	X										
Capacity utilization																X	X										
Carbon emission tax per ton																											
Cash asset ratio																	X										
Cash flow										X																	
Cash-to-cash cycle																	X										
Certification of quality management systems																		X									
Cicle time												X															
Cost of production																	X			X							X
Cost of compliance											X																
Cost of delivery																		X									X

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Cost of design																											X
Cost of investment																X											
Cost of logistic																X											
Cost of maintenance																		X									
Cost of non-compliance (fines and sanctions)															X												
Cost of purchase																		X									X
Cost of return																											X
Cost of supplier selection																X											
Cost of the supply chain																		X									X
Cost of transportation																										X	
Cost savings due to reduction in energy consumption										X																	
Cost savings due to reduction in material use										X																	
Cost savings due to waste reduction										X																	
Critical quality issues																	X										
Current ratio																	X										
Customer effort score																	X										
Customer rejection rate																	X										
Customer retention																X	X										
Customer return rate																	X										
Customer satisfaction								X								X	X	X								X	
Customer service level							X																				X
Cycle time																	X										
Defect-free deliveries level												X															
Deliver availability																											
Delivery flexibility																											X
Delivery late												X															
Delivery reliability												X															
Delivery responsiveness																											X
Delivery time								X																			
Demand/supply cost per $1000 in revenue																	X										
Design responsiveness																											X
Downtime in proportion to operating time																	X										
Earnings per share																	X										
EBITDA																	X					X					
Economic growth					X																						
Efficiency of process		X						X																			
EMS expenditures and investments															X												
Energy cost per unit																	X										
Facilities location and layout																									X		
Fill rate																	X										
Finished goods inventory turns																	X										
Fixed costs							X																				
Fleet yield																	X										
Flexibility of supply methods																		X									
Flow to client							X																				
Food safety management									X																		
Forecast accuracy																	X									X	
Forecast attainment																	X										
Forecast error																	X										
Forecast model bias																	X										
Forecast reliability																											
Foreign Direct Investment (FDI) flows					X																						
Freight bill accuracy																	X										
Freight cost per unit																	X										
Gross profit margin																	X										
Income distribution																						X		X			
Information Exchanged																		X									
Interest coverage ratio																	X										
Inventory absence as a percentage of total inventory																	X										
Inventory turnover																	X								X		
Investment for lift						X																					
Investment for shuttle						X																					
Investment for storage slot						X																					
Lead time																											
Lean management level												X															
Loading capacity utilization																										X	
Local influence								X																			
Logistics competence					X																						
Logistics performance					X																						
Manufacturing yield																	X										
Market competitiveness																						X		X			
Market share																	X										
Material flow							X																				
Materials variety												X															
Net profit margin																	X										
Net promoter score																	X										
Number of converted leads																	X										
Number of successful tenders																	X										
On-time delivery																	X				X					X	
Operating expense ratio																	X										
Operating self sufficiency																	X										
Operations cost							X																				
Order fill rate																	X									X	
Overall equipment effectiveness																	X										
Payment conditions Flexibility																				X							
Percent of truckload/ container capacity utilized																	X										
Period over period error trend																	X										
Planning and product design																X											
Product amount																					X						
Product and service variety												X															
Product development time												X															
Product lateness																										X	
Product line level																					X						
Production capacity		X																		X							
Production downtime		X																									
Production efficiency		X																									
Production flexibility																											X
Production quality																											X
Production responsiveness																											X

Production time																				X							
Productivity		X						X																			
Productivity per employee																											
Profit before tax																											
Profit margin											X								X								
Projected versus actual performance																	X										
Purchase responsiveness																											X
Quality guarantee																		X									
Quality level		X						X																			
Quality of goods supplied																		X									
Quality of product																				X	X						X
Quality performance of suppliers																											X
Quick ratio																	X										
Reliance on revenue source																	X										
Return goods																		X									
Return on assets																	X										
Return on Assets (ROA)										X																	
Return on equity																	X										
Return responsiveness																											X
Revenue																	X										
Revenue from new offerings																	X										
Roi										X						X	X										
Rolling out-of-sample errors																	X										
Sales																							X				
Scalability (yes or no)		X																									
Schedule or production attainment/planned																	X										
Sectorial growth					X																						
Security level		X																									
Sell responsiveness																											X
Service level														X													
SGA to sales																	X										
Shareholder equity										X																	
Source cost																											X
Source responsiveness																											X
Stability and profitability																						X		X			
Stock level																					X						
Stock-outs																										X	
Stock’s reliability																											
Supplier ability to respond to quality problems												X															
Supplier evaluation																		X									
Supplier incoming quality																	X										
Supplier lead time e against industry norm												X															
Supplier rejection rate												X															
Supplier wrong delivery												X															
Suppliers booking												X															
Suppliers’ flexibility																											X
Suppliers’ service																											X
Supply chain responsiveness																											X
Supply flexibility																											X
Sustainability expenditures																						X		X			
Sustainable practices and process																									X		
Throughput																	X										
Time of process		X																									
Timeliness of sales quotations																	X										
Total asset turnover																	X										
Total cost			X					X			X			X		X										X	
Transportation errors		X																									
Tranasportantion time			X																								
Variable costs							X																				
Vehicle turnover time																	X										
Visibility of goods in the SC		X																									
Volume of active issues																	X										
Volume of resolved issues																	X										
Warehouse rent cost per square meter						X																					
WIP inventory/turns																	X										
Working capital																	X										
Account payables turnover																	X										
Inovation																											
Application of eco-friendly technologies																		X									
Artificial intelligence investment (applied to SSCM system)																											
Automation level		X																									
Culture and technological development																											X
Database resource efficiency of goods resources																		X									
Identifying problems time		X																									
Incremental sales-driven by new innovation																	X										
Innovation implementation cost																											
Innovation level		X										X															
Introduction of new processes												X					X										
Number of intellectual property																	X										
Number of projects meet planned targets																											
Performance of applied systems																		X									
Speed to market																	X										
Technological capability levels												X								X							
Time to make change over																	X										
Total investment in growth project																	X										

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André M. Carvalho, Assistant Professor in the of Department of Mechanical and Industrial Engineering at NOVA School of Science and Technology, Universidade NOVA de Lisboa, Portugal. André holds a PhD (University of Minho, 2020) in Engineering Design and Advanced Manufacturing, in a joint program between Portuguese Engineering Schools and the Massachusetts Institute of Technology. He has been a Visiting Student and Research Affiliate at the Sociotechnical Systems Research Center at MIT (2018-2020), a Visiting Scholar at Northeastern University (2019), and a Postdoctoral Researcher at the Technical University of Denmark (Engineering Systems Design group, 2020). His research focuses on engineering management, exploring how technology, people and processes intermingle in the ongoing business transitions. Looking at subjects such as quality and performance management, organizational cultures, technology use, and organizational agility, he has sought to identify how organizations can best adapt to respond to the challenges of the world around us. His research has been recognized by organizations such as the Industrial Engineering and Operations Management (IEOM) Society, the International Academy for Quality (IAQ) and American Society for Quality (ASQ).