A Systematic Review of Indicators Used to Measure Industrial Sustainability

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Abstract

The purpose of this paper is to provide an in-depth analysis of the indicators that have been used to measure industrial sustainability. A systematic literature review was conducted to explore indicators published in peer-reviewed articles that are relevant to industrial sustainability performance measurement. A total of 1013 indicators were identified and analyzed: 277 for economic, 402 for environmental and 334 for social dimensions of industrial sustainability. The majority of the indicators were used only once, implying a lack of consistency and consensus on their application for measuring industrial sustainability, and invites an ongoing debate on how sustainability should be measured in different industry contexts. On the other hand, few indicators such as profit, research and development expenditure, product quality, revenue, material cost, labor cost, water consumption, energy consumption, greenhouse gas emissions, material consumption, employment/job opportunity, employee turnover and work-related injuries were consistent and frequently used for measuring industrial sustainability. The consistent indicators have been used to measure industrial sustainability performance associated with financial benefits, costs, market competitiveness, resources, emissions, wastes, employees, customers, and the community. This paper provides a comprehensive view of indicators considering the triple bottom line dimensions of sustainability. It will contribute to future academic and practitioner work on the measurement of industrial sustainability performance.

Keywords
Indicator, Triple bottom line, Performance measurement, Industrial sustainability, Manufacturing industry

1. Introduction

In recent years, sustainable manufacturing is increasingly becoming a necessity to properly manage the environmental and social impacts of manufacturing industries (Ahmad and Wong, 2019; Singh S. et al., 2014). Manufacturing industries have a significant role in the sustainable development of society (Beekaroo et al., 2019; Moldavska Anastasiia and Welo, 2019). Since they play an active role in the consumption of natural resources, and the generation of emissions and wastes, they can significantly contribute to promoting sustainability (Hendiani et al., 2020). Sustainable manufacturing has become a key factor for manufacturing firms to exist in today's competitive business environment (Singh R.K. et al., 2019). Thus, there is a need for transformation from traditional manufacturing practices that focus on economic benefits to state-of-the-art manufacturing that consider environmental and social responsibility in addition to pursuing economic benefits (Shuaib et al., 2014; Singh R.K. et al., 2019). For this purpose, manufacturing industries have taken steps to adopt sustainability into their short-term and long-term decision-making (Ahi and Searcy, 2015). Integrating sustainability practices in manufacturing industries requires a holistic approach covering products, manufacturing processes and systems. The scope varies from the production line to plant, firm and supply chain (Huang and Badurdeen, 2018). Industrial sustainability refers to the adoption of sustainability practices at the firm level (Trianni Andrea et al., 2017).

The most widely applied definition of sustainable manufacturing is provided by the US Department of Commerce, which defined it as "the creation of a manufactured product with processes that have minimal negative impact on the environment, conserve energy and natural resources, are safe for employees and communities, and are economically sound" (Ahmad and Wong, 2019; Joung et al., 2013). The definition of sustainable manufacturing addresses economic, environmental and social aspects of sustainability. Elkington (1997) proposed the triple bottom line (TBL) approach that consisting of three interrelated dimensions of sustainability (economic, environmental and social dimensions). By considering all three sustainability dimensions simultaneously, TBL provides a comprehensive approach for measuring sustainability (Ahmad and Wong, 2019). To adequately address industrial sustainability, it is necessary to adopt a holistic approach based on TBL (Cagno et al., 2019). Manufacturing activities significantly affect the three dimensions of sustainability (Ahmad, Wong, and Zaman, 2019; Ghadimi et al., 2012). Thus, manufacturing industries should simultaneously consider economic, environmental and social dimensions while producing their products and services (Eastwood and Haapala, 2015; Haapala et al., 2013; Lacasa et al., 2016; Watanabe et al., 2016).

1.1 Industrial Sustainability

Industrial sustainability has become a substantial topic of discussion (Cagno et al., 2019; Smart et al., 2017) and has gained relevance by industrial decision-makers, policymakers and scholars (Neri et al., 2018; Trianni Andrea et al., 2017). In an industry context, industrial sustainability refers to the integration of sustainability practices at the industrial plant (firm) level (Trianni Andrea et al., 2017). It accounts for actions that are taken at the levels of material, product, process, plant and production system (Tonelli et al., 2013). The term industrial sustainability was coined by the Institute for Manufacturing at the University of Cambridge, which defined it as "conceptualization, design and manufacture of goods and services that meet the needs of the present generation while not diminishing economic, social and environmental opportunity in the long-term" (Paramanathan et al., 2004). The other definition of industrial sustainability was provided by Zeng et al. (2008) and defined it as "development that meets the needs of economic growth, social development, environmental protection and results in industrial advantage for the short- and long-term future of the region". According to (Mengistu and Panizzolo, 2021) industrial sustainability is defined as a set of activities that includes considering economic, environmental and social aspects simultaneously while producing products and services; ensuring economic growth, conserving resources, and minimizing negative environmental and social impacts; and meeting stakeholder requirements in the short- and long-term.

Manufacturing industries are the main driving force for a country's economic growth and social development (Galal and Moneim, 2015; Zeng et al., 2008). However, they are considered to be one of the main causes leading to unintended environmental and social concerns (Zeng et al., 2008). Consequently, they are strongly needed to improve sustainability and be transparent about their sustainability practices (Trianni A. et al., 2019). Various stakeholders have put pressures on them to adopt sustainability practices (Huang and Badurdeen, 2018; Ocampo et al., 2016; Zarte et al., 2019) in order to address the growing concerns of environmental and social impacts (Beekaroo et al., 2019; Samuel et al., 2013; Wang et al., 2018). The stakeholders of industrial sustainability consisting of governments, investors, political groups, trade associations, suppliers, employees, customers and communities (Paramanathan et al., 2004). Moreover, sustainability is adopted to get a competitive advantage (Tseng et al., 2009; Veleva et al., 2001; Wang et al., 2018).

To effectively adopt sustainability in manufacturing industry, it is necessary to measure its performance (Cagno et al., 2019; Trianni A. et al., 2019). Industrial sustainability cannot be properly managed if it is not effectively measured using appropriate indicators (Feil et al., 2015; Huang and Badurdeen, 2018; Trianni A. et al., 2019). As sustainability is a holistic concept, the use of suitable multidimensional indicators for measuring its performance is crucial (Moldavska Anastasiia and Welo, 2019). The most widely applied comprehensive approach is TBL, which includes indicators based on economic, environmental and social sustainability dimensions (Ahmad and Wong, 2019; Trianni A. et al., 2019; Wang et al., 2018; Winroth et al., 2016).

1.2 Sustainability Indicators

Indicators are used to provide information about physical, social or economic issues (Veleva and Ellenbecker, 2001) by translating complex issues into manageable and easily understood information for decision-making (Samuel et al., 2013). Specifically, sustainability indicators are used to measure and evaluate progress towards achieving sustainability goals and targets (Ahi and Searcy, 2015). They are used to operationalize sustainability goals into practice (Samuel et al., 2013). There are quantitative and qualitative sustainability indicators (Ahi and Searcy, 2015; Veleva and Ellenbecker, 2001) that have been used to measure absolute and relative sustainability performance (Ahi and Searcy, 2015). Absolute indicators express sustainability performance in terms of overall performance levels in specific areas of interest (e.g., water consumption) for an organization as a whole. While, relative indicators express sustainability performance in terms of how performance in one area (e.g., water consumption) correlates to performance in another area (e.g., total production) of an organization. On the other hand, context-based indicators express an organization's sustainability performance as a function of its impact on economy, environment and social with respect to norms, standards or thresholds of being sustainable (e.g., water consumed per employee compared with a fair or equitable allocation of available renewable water supplies) (McElroy and Engelen, 2012).

As desired qualities, sustainability indicators should be measurable (simple and easy to measure either quantitatively or qualitatively), relevant (related to a purposeful aspect of sustainability), understandable (easily interpreted), reliable (provide trusted and accurate information), based on easily accessible data, timely (based on data that are available within a reasonable time frame), long-term oriented (ensure its future use, development and adoption) (Hasan et al., 2017; Joung et al., 2013). To effectively measure and manage industrial sustainability, there is a need for indicators that are suitable for different industry contexts, such as small and medium enterprises (Singh S. et al., 2014; Winroth et al., 2016). Contextual factors such as industry type, firm size and geographical area affect the use of indicators for measuring industrial sustainability performance (Cagno et al., 2019; Trianni A. et al., 2019). Eventually, the use of appropriate indicators tailored to the industrial context is essential to effectively measure and manage industrial sustainability performance (Ahmad and Wong, 2019; Hsu et al., 2017; Medini et al., 2015). In other words, it is crucial to use a manageable number of indicators that are simple and easy to apply (Veleva and Ellenbecker, 2001).

This paper aims to explore and analyze the indicators that have been published in the literature on industrial sustainability performance measurement. The remainder of the work is divided into three sections. Section 2 briefly describes the research methodology applied in this study. The results of the analysis are briefly discussed in Section 3. Finally, conclusions with future research work are presented in Section 4.

2. Methodology

A systematic literature review was based on (Ahi and Searcy, 2015) was carried out to explore indicators published in peer-reviewed articles that are relevant to the sustainability performance measurement of manufacturing industries. Scopus and Web of Science (WoS) were selected as a search database, since they provide an extensive coverage of peer-reviewed journal articles. Two sets of keywords were used for the search: ("industrial sustainability" or "sustainable manufactur*" or "sustainable firm*" or "sustainable enterpri*" or "sustainable industr*" or "sustainable factory" or "sustainable production*" or "sustainable organi*" or "sustainable compan*") in the first set and (“indicator*” or “metric*” or “performance measure*”) in the second set.

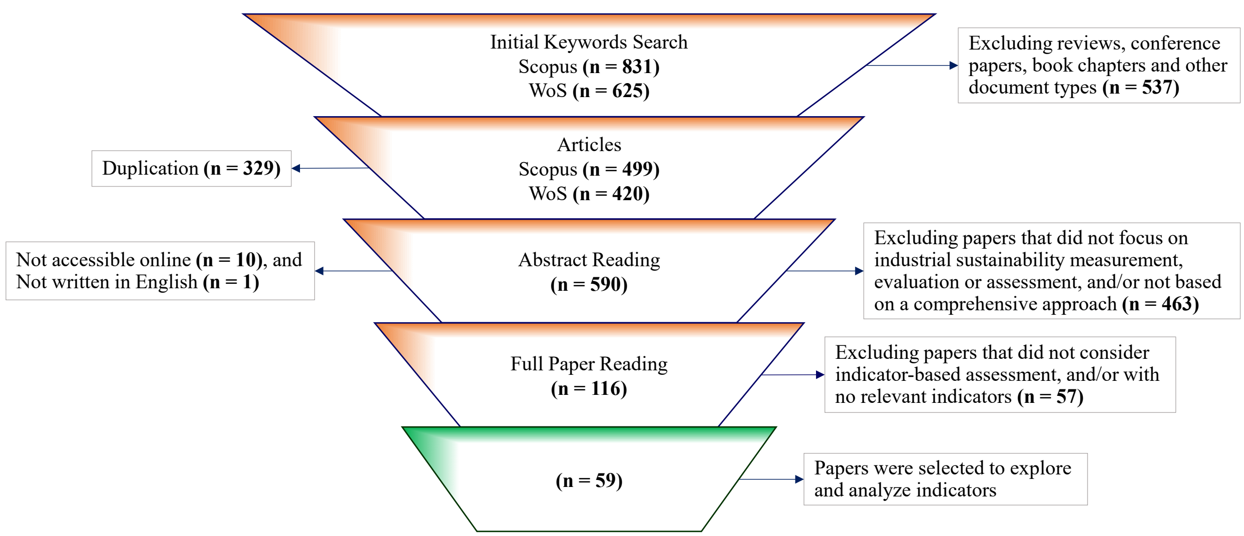

Figure 1. Approach of the systematic literature review

As seen in Figure 1, a total of 1456 papers published until 2020 were initially found using the keyword searches in Scopus and WoS. Considering 919 articles that were thoroughly peer-reviewed, a total of 537 reviews, conference papers, book chapters and other documents were excluded; and 329 articles were found to be duplicated. It was not possible to access 10 full-text papers through the online search, and 1 paper was not written in the English language. In the abstract reading, 463 that did not focus on measuring, evaluating or assessing sustainability performance of manufacturing industries, and/or were not based comprehensive approach (i.e., the TBL approach) were excluded.

Then, 57 papers that did not consider indicator-based assessment, and/or did not propose indicators relevant to the purpose of this study, were also excluded. Finally, 59 papers were selected to explore the indicators. A content analysis was conducted to identify consistent and frequently used indicators. After recording and coding all the indicators published in the papers, word-by-word and phrase-by-phrase analyses were carried out to determine their consistency and frequency of use. Indicators that were found to be essentially similar were counted together. On the other hand, indicators that were different were considered to be unique indicators (Ahi and Searcy, 2015; Ahmad, Wong, and Rajoo, 2019).

3. Results and Discussion

In this part, the results of the analysis are presented with a brief discussion. Section 3.1 presents the descriptive analysis to provide an overview on the papers' distribution by journal type, publication year and case study. Section 3.2 briefly discusses the results of the indicators analysis.

3.1 Descriptive Analysis of the Papers

Figure 2 shows the distribution of the selected papers by journal type. Six journals namely Journal of Cleaner Production, Sustainability (Switzerland), IFAC-PapersOnLine, Journal of Advanced Manufacturing Technology, Ecological Indicators and Journal of Manufacturing Systems were the leading journals that published more than 50% of the selected papers. Among them, the Journal of Cleaner Production was the top contributor to the papers.

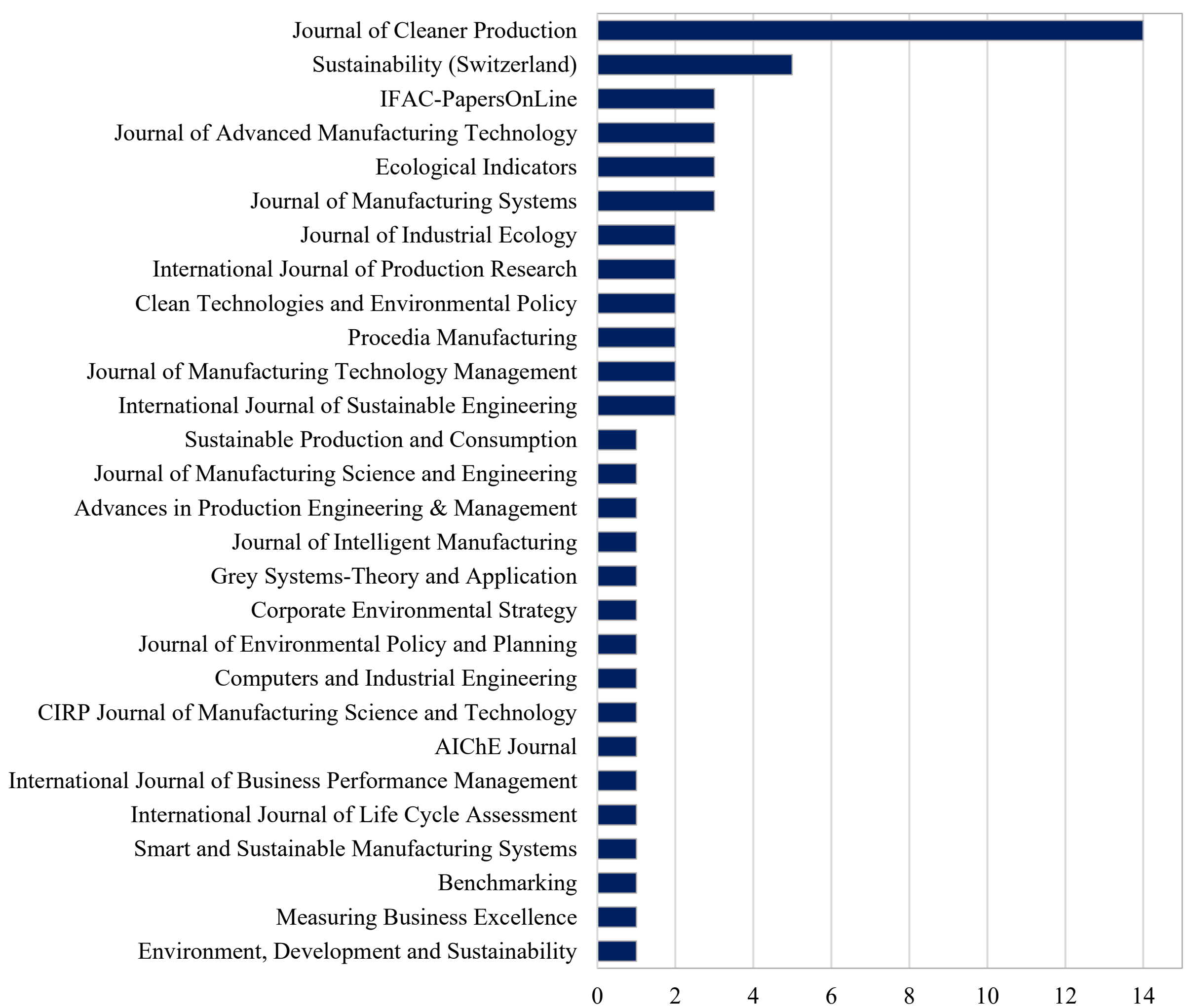

Figure 2. Distribution of the papers by journal type

As shown in Figure 3, there has been an increasing trend showing a growing research interest in sustainability performance measurement of manufacturing industries over the past 20 years (2001 to 2020). Within this time frame, a wide range of indicators were applied by the previous research for measuring industrial sustainability. From these indicators, very few were consistent and frequently used (i.e., indicators used by the old published papers were later applied by the recently published papers). For instance, profit used by Yakovleva and Flynn (2004) was later employed by Ahmad and Wong (2019) for measuring economic dimensions of sustainability. Water consumption used by Veleva and Ellenbecker (2001) was later applied by Cagno et al. (2019) to measure environmental dimension. Employment/Job opportunity used by Yakovleva and Flynn (2004) was later employed by Agrawal and Vinodh (2020) for measuring social dimension.

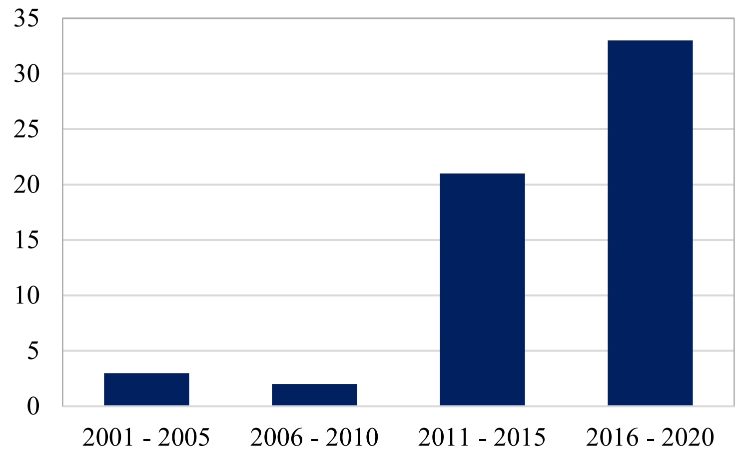

Figure 3. Distribution of the papers by publication year

As indicated in Figure 4, *automotive* (Ghadimi et al., 2012; Lee et al., 2014; Moldavska Anastasiia and Welo, 2019; Singh S. et al., 2018; Vinodh et al., 2016), *food* (Ahmad and Wong, 2019; Harik et al., 2015; Yakovleva and Flynn, 2004) and *electronics* (Huang and Badurdeen, 2017; Li et al., 2012; Shuaib et al., 2014) were mostly considered industries for conducting case studies. However, there is still a lack of empirical research on the adoption of sustainability indicators in manufacturing industries, particularly in SMEs (Trianni A. et al., 2019).

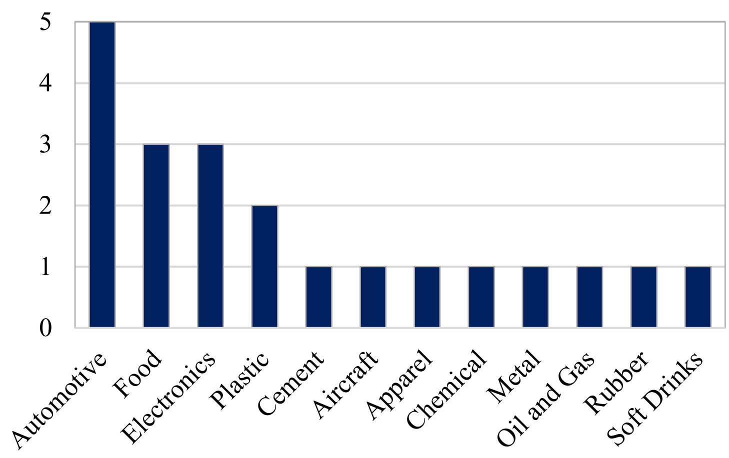

Figure 4. Distribution of the papers by case study

3.2 Analysis of Indicators

The consistent and frequently used indicators were identified by conducting content analysis (Ahi and Searcy, 2015; Ahmad, Wong, and Rajoo, 2019). In the content analysis, indicators published in the selected papers were recorded followed by coding them into economic, environmental and social indicators. Then, a frequency count was carried to determine the indicators' consistency and frequency of use. Indicators that were found to be essentially similar were counted together. On the other hand, indicators that were different were considered to be unique indicators. Subsequently, as shown in Table 1, initially 1013 indicators (277 for economic, 402 for environmental and 334 for social dimensions) were explored from the literature. Thirteen indicators (profit, research and development expenditure, product quality, revenue, material cost, labor cost, water consumption, energy consumption, greenhouse gas emissions, material consumption, employment/job opportunity, employee turnover and work-related injuries), which accounts 0.01% of the total indicators, were employed at least ten times (i.e., by at least ten papers).

Table 1: Identified indicators by frequency of use

Frequency of use	Identified indicators (#)
1	860
2	58
3	35
4	16
5	13
6	10
7	6
8	1
9	1
10	1
11	4
12	1
13	1
14	2
17	1
18	1
26	1
27	1
Total	1013

Table 1 also shows that majority of the indicators (about 85%) were used only once in the literature, and this is due to (1) a lack of consistency and consensus on how sustainability should be measured in manufacturing industries (Ahi and Searcy, 2015) and (2) industry context differences affect the use of indicators for measuring industrial sustainability (Cagno et al., 2019; Trianni A. et al., 2019). It is obvious that the essentiality of indicators are not the same for all industrial contexts (Ahmad, Wong, and Rajoo, 2019). The result indicates that measuring industrial sustainability will continue to invite an ongoing debate and open potential research opportunities.

Table 2: Frequently used TBL sustainability indicators

Indicators for economic dimension	Frequency of use	Indicators for environmental dimension	Frequency of use	Indicators for social dimension	Frequency of use
Profit	14	Water consumption	27	Employment/Job opportunity	11
Research & development expenditure	14	Energy consumption	26	Employee turnover	11
Product quality	13	Greenhouse gas emissions	18	Work-related injuries	10
Revenue	12	Material consumption	17	Customer satisfaction	7

Indicators for economic dimension	Frequency of use	Indicators for environmental dimension	Frequency of use	Indicators for social dimension	Frequency of use
Material cost	11	Renewable energy use	9	Employee satisfaction	6
Labor cost	11	Recycled water use	7	Working hours	6
Energy cost	8	Recycled material use	7	Corruption	6
Operating/Operational cost	7	Wastewater discharge	7	Occupational health and safety	5
Maintenance cost	6	Hazardous waste	7	Training and development	5
Production cost	6	Land use	6	Fair salary	5
Packaging cost	6	Solid waste	6	Customer complaints	5
Lead time	6	Recyclable waste	6	Lost working days	5
Inventory cost	5	Packaging material consumption	5		
On-time delivery	5	Electricity consumption	5		
		Air emissions	5		
		Global warming potential	5		
		Energy efficiency	5		
		Energy intensity	5		

As shown in Table 2, forty-four indicators (14 for economic, 18 for environmental and 12 for social dimensions) were used at least five times (i.e., by at least five papers). Profit, water consumption and employment/job opportunity were the most consistent and frequently employed indicators for measuring the economic, environmental and social dimensions of industrial sustainability, respectively. Indicators in the economic dimension gave more weight on measuring the progress in obtaining high financial benefits including *profit* (Ahmad and Wong, 2019; Cagno et al., 2019; Vitale et al., 2019) and *revenue* (Ahmad and Wong, 2019; Cagno et al., 2019; Song and Moon, 2019) from their business activities; allocating reasonable *expenditure to R&D activities* (Ahmad and Wong, 2019; Beekaroo et al., 2019; Cagno et al., 2019); reducing costs such as *material* (Agrawal and Vinodh, 2020; Ahmad and Wong, 2019; Singh R.K. et al., 2019), *labor* (Abedini et al., 2020; Ahmad and Wong, 2019; Singh R.K. et al., 2019), *energy* (Abedini et al., 2020; Agrawal and Vinodh, 2020; Huang and Badurdeen, 2018), *operating/operational* (Ahmad, Wong, and Rajoo, 2019; Cagno et al., 2019; Hasan et al., 2017), *maintenance* (Ahmad, Wong, and Rajoo, 2019; Cagno et al., 2019; Huang and Badurdeen, 2018), *production* (Abedini et al., 2020; Cagno et al., 2019; Ocampo et al., 2016), *packaging* (Ahmad and Wong, 2019; Ghadimi et al., 2012; Huang and Badurdeen, 2018) and *inventory* (Abedini et al., 2020; Cagno et al., 2019; Singh R.K. et al., 2019) costs; improving *product quality* (Agrawal and Vinodh, 2020; Cagno et al., 2019; Wu et al., 2019); and properly managing *lead time* (Cagno et al., 2019; Huang and Badurdeen, 2018; Trianni A. et al., 2019) and *delivery time* (Hsu et al., 2017; Raj and Srivastava, 2018; Singh R.K. et al., 2019).

In the environmental dimension, more emphasis was given to indicators that measured progress in efficient use of input resources such as *water* (Ahmad and Wong, 2019; Cagno et al., 2019; Vitale et al., 2019), *energy* (Abedini et al., 2020; Agrawal and Vinodh, 2020; Song and Moon, 2019) and *material* (Agrawal and Vinodh, 2020; Ahmad and Wong, 2019; Cagno et al., 2019) consumption; the use of recycled resources such as *recycled water* (Cagno et al., 2019; Huang and Badurdeen, 2018; Zarte et al., 2019) and *recycled material* (Cagno et al., 2019; Huang and Badurdeen, 2017; Zarte et al., 2019); the use of renewable energy (Beekaroo et al., 2019; Cagno et al., 2019; Huang and Badurdeen, 2018); reduction of emissions consisting of *GHG emissions* (Abedini et al., 2020; Beekaroo et al., 2019; Zarte et al., 2019) and *air emissions* (Hasan et al., 2017; Moldavska A. and Welo, 2018; Singh R.K. et al., 2019); and the proper management properly of wastes including *wastewater discharge* (Hasan et al., 2017; Wang et al., 2018; Zarte et al., 2019), *hazardous waste* (Hasan et al., 2017; Huang and Badurdeen, 2017; Winroth et al., 2016), *solid waste* (Ahmad, Wong, and Rajoo, 2019; Beekaroo et al., 2019; Demartini et al., 2018) and *recyclable waste* (Cagno et al., 2019; Demartini et al., 2018; Trianni A. et al., 2019).

Regarding the social dimension of industrial sustainability, the focus was on indicators that were used to measure the progress in creating *employment/job opportunity* (Agrawal and Vinodh, 2020; Ahmad, Wong, and Rajoo, 2019; Cagno et al., 2019); improving the well-being of employees by minimizing *employee turnover* (Ahmad and Wong, 2019; Demartini et al., 2018; Vitale et al., 2019), minimizing *work-related injuries* (Ahmad, Wong, and Rajoo, 2019; Cagno et al., 2019; Vitale et al., 2019), ensuring *employee satisfaction* (Ahmad, Wong, and Rajoo, 2019; Ocampo et al., 2016; Song and Moon, 2019) and *occupational health and safety* (Ahmad and Wong, 2019; Raj and Srivastava, 2018; Singh R.K. et al., 2019), providing *training and development* (Ahmad and Wong, 2019; Elhuni and Ahmad, 2017; Feil et al., 2015) and a *fair salary* (Ahmad and Wong, 2019; Harik et al., 2015; Samuel et al., 2013); improving the well-being of customers in terms of *customer satisfaction* (Cagno et al., 2019; Moldavska A. and Welo, 2018; Song and Moon, 2019) and minimizing *customer complaints* (Ahmad, Wong, and Zaman, 2019; Huang and Badurdeen, 2017; Watanabe et al., 2016); properly managing employees working time in terms of *working hours* (Ahmad and Wong, 2019; Lacasa et al., 2016; Raj and Srivastava, 2018) and *lost working days* (Ahmad, Wong, and Rajoo, 2019; Eastwood and Haapala, 2015; Vitale et al., 2019); and reducing *corruption* (Ahmad, Wong, and Rajoo, 2019; Elhuni and Ahmad, 2017; Raj and Srivastava, 2018).

As shown in Figure 5, the indicators are mapped in the cause-and-effect diagram to provide a meaningful relationship between indicators and goals. To describe implicitly, manufacturing industries always need to increase their financial benefits to exist in the market. They should also improve their market competitiveness, employ cost reductions strategies, efficiently use resources, conserve resources, properly manage wastes, and apply emissions reduction strategies while producing their products and services. They need to promote the well-being of their employees and customers, and fulfill other stakeholders' needs (such as the community). To effectively measure and manage progress towards improving industrial sustainability, the use of appropriate indicators is critical (Ahmad and Wong, 2019; Hendiani et al., 2020; Wang et al., 2018). Improving industrial sustainability performance can contribute to achieving the sustainable development goals (SDGs) such as promoting health and well-being (SDG 3), promoting sustainable economic growth, productive employment and decent work (SDG 8), ensuring sustainable consumption and production (SDG 12), and combating climate change and its impacts (SDG 13).

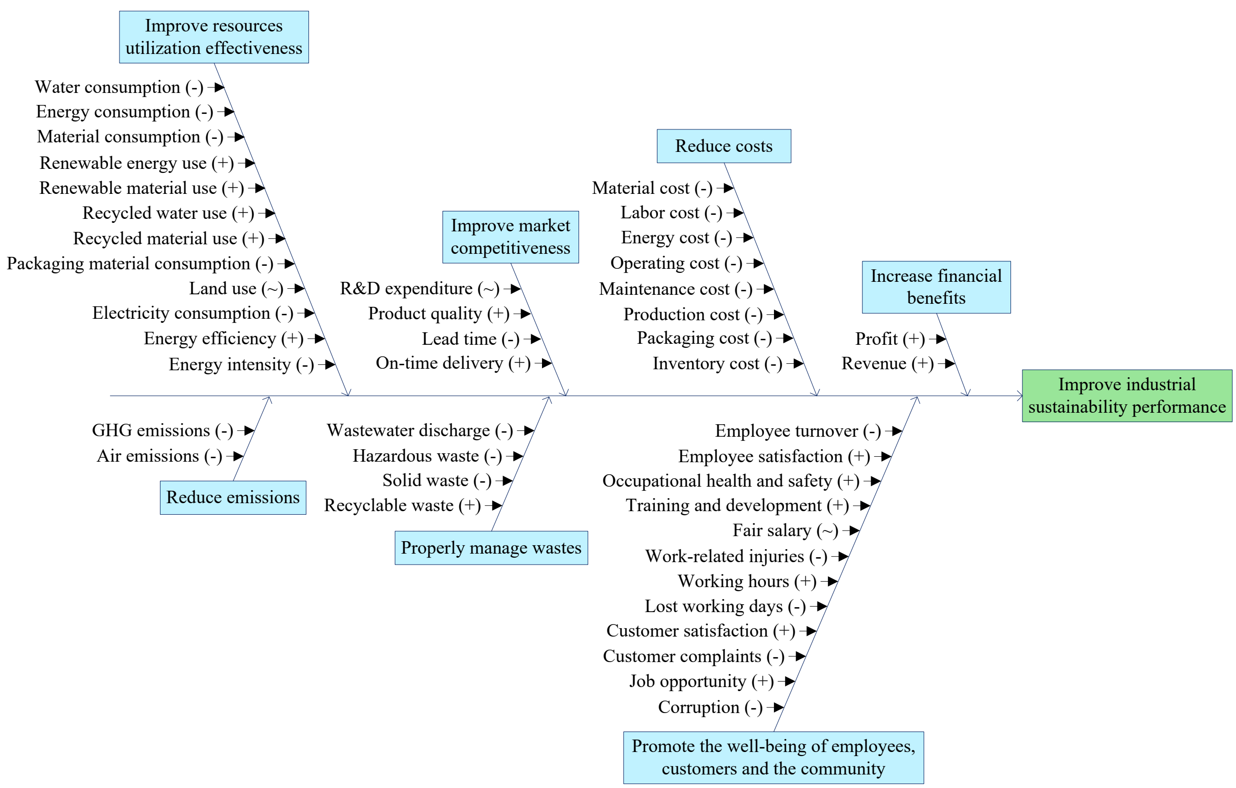

Figure 5. Cause-and-effect diagram of the indicators

Note: (+) implies *improve*, *increase*; (-) *reduce*, *minimize*; and (~) *optimum*, *reasonable*.

4. Conclusıons

This paper analyzed indicators published in the literature on sustainability performance measurement of manufacturing industries. The findings revealed that the majority of the indicators available in the literature were used only once, showing a lack of consistency and consensus on the use of indicators to measure sustainability performance in different industry contexts. On the contrary, few indicators were found to be consistent and frequently used for measuring sustainability performance in manufacturing industries. These indicators used to measure industrial sustainability goals in terms of increasing financial benefits, costs reduction and improving market competitiveness, improving resources utilization effectiveness (efficiency improvement, recycling and substitution), emissions reduction, properly managing wastes, and improving the well-being of employees, customers and the community. This paper stresses the essentiality of tailoring the indicators to different industry contexts such as industry type, firm size and geographical area to effectively measure and manage the progress towards achieving industrial sustainability goals. Eventually, manufacturing industries can contribute to achieving the sustainable development goals.

This paper has important implications for academics, practice and policy. From an academic viewpoint, it can act as a good theoretical base for future research in measuring the sustainability performance of manufacturing industries. It conducted an in-depth analysis of the wide range of sustainability indicators available in the literature that can contribute to the existing theory and knowledge of industrial sustainability measurement. From a practical viewpoint, it provides consistent and frequently used multidimensional indicators that can promote a comprehensive sustainability measurement in manufacturing industries. It presents the cause-and-effect diagram of the indicators that can help to define potential sustainability goals and objectives. It also has policy implications by providing a logical link between industrial sustainability and the sustainable development goals.

This paper analyzed sustainability indicators published in scientific papers (i.e., academic papers). As an additional avenue, future research can consider analyzing the indicators that have been used by organizations engaged in the measurement of sustainability performance. The scope of analyzing indicators was limited the firm level. However, to get a more comprehensive view of sustainability, it would be better to analyze indicators used at the supply chain level. Hence, it would be interesting for future research to expand the methodological approach used in this paper to the entire supply chain consisting of supply, production, distribution, use and post-use. It would also be interesting to conduct empirical study in order to tailor and demonstrate the indicators at different industry contexts.

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