Environment, Development and Sustainability (2023) 25:1979–2005
https://doi.org/10.1007/s10668-021-02053-0

REVIEW

Analysis of indicators used for measuring industrial sustainability: a systematic review

Azemeraw Tadesse Mengistu[1] · **Roberto Panizzolo**[1]

Received: 21 February 2021 / Accepted: 10 December 2021 / Published online: 26 January 2022

Abstract

This paper aims to provide an extensive analysis of the indicators that have been used for measuring industrial sustainability. To achieve this objective, a systematic review was carried out to explore the indicators in peer-reviewed articles relevant to industrial sustainability performance measurement. A total of 1041 indicators were identified and analyzed, with 290 for economic, 410 for environmental, and 341 for social dimensions. The majority were mentioned only once in the reviewed literature, showing a lack of consistency in their application (i.e., a lack of consensus regarding a single set of indicators) for measuring sustainability performance in different manufacturing industry contexts. Few of the indicators had been frequently used to measure industrial sustainability performance. These indicators had been used to measure industrial sustainability performance associated with financial benefits, costs, market competitiveness, resources, emissions, wastes, employees, customers, and community. This paper links the different indicators to the potential organizational goals used to improve industrial sustainability performance and contribute to achieving the sustainable development goals. It provides a comprehensive view of the indicators considering the triple bottom line approach. Our results have significant implications and will provide a strong basis for future academic and practitioner work on measuring industrial sustainability performance.

Keywords Indicator · Triple bottom line · Performance measurement · Industrial sustainability · Sustainable development goals · Manufacturing industry

Abbreviations

TBL	Triple bottom line
R&D	Research and development
GHG	Greenhouse gas
CO_2	Carbon dioxide
N_2O	Nitrous oxide
CH_4	Methane

✉ Azemeraw Tadesse Mengistu
azemerawtadesse.mengistu@phd.unipd.it

Roberto Panizzolo
roberto.panizzolo@unipd.it

[1] Department of Management and Engineering, University of Padova, 36100 Vicenza, Italy

CFCs	Chlorofluorocarbons
SOx	Sulphur oxides
NOx	Nitrogen oxides
CO	Carbon monoxide
SMEs	Small and medium enterprises
kg	Kilogram
kWh	Kilowatt hour
m^3	Cubic meter
m^2	Square meter
L	Liter
pc	Piece
h	Hour
uop	Unit of product
emp	Employee
USD	United States dollar
OHS	Occupational health and safety
NIST	National Institute of Standards and Technology
GRI	Global Reporting Initiative
OECD	Organization for Economic Cooperation and Development
SDGs	Sustainable Development Goals

1 Introduction

The concept of sustainability has increasingly been used to deal with growing concerns regarding the environmental and social impacts of development (Huang & Badurdeen, 2018). Specifically, sustainable manufacturing is increasingly being used to properly manage the environmental and social impacts of manufacturing industries (Ahmad & Wong, 2019; Singh et al., 2014), helping them to contribute to achieving the sustainable development goals (SDGs) (Hashim et al., 2021). Sustainable manufacturing has also become a key factor enabling manufacturing firms to stay relevant in today's competitive business environment (Singh et al., 2019). Eventually, manufacturing industries will need to transform their traditional manufacturing practices that primarily focus on economic benefits into sustainable manufacturing practices that consider environmental and social responsibility in addition to pursuing profitability (Shuaib et al., 2014; Singh et al., 2019).

For the effective adoption of sustainability in manufacturing industries, a comprehensive framework is required to measure their performance at the product, operation process, and production system levels. The scope of sustainability performance measurement varies from the production line to the plant, firm, and supply chain (Huang & Badurdeen, 2018). Industrial sustainability involves adopting sustainability practices at the firm level (Trianni et al., 2017). In this paper, our discussion of industrial sustainability considers the sustainability of manufacturing industries at the firm level. Industrial sustainability has become an essential topic of discussion (Cagno et al., 2019; Smart et al., 2017) and has been given much attention by industrial decision-makers, policymakers, and scholars (Neri et al., 2018; Trianni 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, and it stated that industrial sustainability should promote the production of goods and services that meet the needs of the present generation while not compromising economic, environmental, and social opportunities in the long-term (Paramanathan et al., 2004). According to Zeng et al. (2008) industrial sustainability should support economic growth, environmental protection, and social development to create industrial advantages in the short- and long-term.

Along with the growing significance of sustainable development, the theories of industrial sustainability have evolved. The main theories linked to industrial sustainability are corporate social responsibility, stakeholder theory, and corporate sustainability (Chang et al., 2017). Corporate social responsibility refers to practices undertaken by corporates to improve their performance so that they can achieve social responsibility and long-term sustainability and establish trust with stakeholders (Köseoglu et al., 2021). Stakeholder theory provides a logical perspective of how firms can manage their relationships with stakeholders to facilitate the development of competitive resources and attain sustainable success. It also provides useful insights into the practices of sustainable and ethical value creation (Parmar et al., 2010). Corporate sustainability focuses not only on corporates' economic aspects but also takes into account their environmental and social aspects. It helps companies to achieve economic growth while fulfilling their social responsibility and becoming more environmentally friendly (Aktaş & Demirel, 2021).

The manufacturing sector is one of the main driving forces of a country's economic growth and social development (Galal & Moneim, 2015; Zeng et al., 2008). This sector, however, is considered to be one of the main contributors to environmental degradation (Zeng et al., 2008). While the past few years have seen increasing emphasis placed on sustainability, the manufacturing sector has been slow to transform its traditional manufacturing practices, which focus primarily on economic benefits, into sustainable manufacturing practices that also consider environmental and social responsibility. Some of the sustainability challenges faced by the sector are an increase in pollution, greenhouse gases, and global warming, and a decrease in biodiversity (Aktaş & Demirel, 2021). As a result, manufacturing companies need to improve their sustainability performance and be transparent about their sustainability practices (Trianni et al., 2019). Various stakeholders have put pressure on them to adopt sustainability practices (Huang & Badurdeen, 2018; Ocampo et al., 2016; Zarte et al., 2019) to address the growing concerns of the environmental and social impacts of development (Beekaroo et al., 2019; Samuel et al., 2013; Wang et al., 2018). The stakeholders of industrial sustainability include governments, investors, political groups, trade associations, suppliers, employees, customers, and communities (Paramanathan et al., 2004). Moreover, sustainability is adopted so that companies can gain a competitive advantage (Tseng et al., 2009; Veleva et al., 2001; Wang et al., 2018). The effective implementation of sustainability practices will help companies to enhance sustainable manufacturing by ensuring economic growth, conserving natural resources, minimizing negative environmental and social impacts, and meeting the requirements of stakeholders.

To adequately address industrial sustainability, it is useful to adopt a holistic approach based on the triple bottom line (TBL) (Cagno et al., 2019). As was proposed by Elkington (1997), the TBL approach consists of three correlated dimensions of sustainability (i.e., economic, environmental, and social dimensions); and provides a comprehensive approach for measuring the sustainability performance of manufacturing industries (Ahmad & Wong, 2019). As manufacturing industries have a significant impact on the three sustainability dimensions (Ahmad et al., 2019b; Ghadimi et al., 2012), they should simultaneously consider them while producing their products and services (Eastwood & Haapala, 2015; Haapala et al., 2013; Lacasa et al., 2016; Watanabe et al., 2016). For example, the manufacturing industries in the European Union countries (EU-27) contributed a value-added of nearly 2.1 trillion Euros to the gross domestic product (Eurostat, 2019); they generated about 370 million metric tons of CO_2 equivalent greenhouse emissions (Statista, 2019) in 2019; and almost 35 million employees were working in the manufacturing industries in the European Union, including the United Kingdom in 2020 (Statista, 2020). These figures imply that manufacturing industries have significant potential to address the issues of sustainability. In order to effectively adopt sustainability practices in a manufacturing industry, measuring its performance is essential (Cagno et al., 2019; Trianni et al., 2019). Industrial sustainability cannot be properly managed if it is not effectively measured using appropriate indicators (Feil et al., 2015; Huang & Badurdeen, 2018; Trianni et al., 2019). For this purpose, the use of multidimensional indicators based on the TBL approach for measuring sustainability performance is crucial (Ahmad & Wong, 2019; Moldavska and Welo, 2019; Trianni et al., 2019; Wang et al., 2018; Winroth et al., 2016). Moreover, as contextual factors such as industry type, firm size, and geographical area affect the use of indicators for measuring industrial sustainability (Cagno et al., 2019; Trianni et al., 2019), adapting suitable indicators tailored to manufacturing industry contexts is essential (Medini et al., 2015).

Normally, indicators provide information about physical, economic, or social issues (Veleva & Ellenbecker, 2001) by translating complex issues into manageable and easily understood information for decision-making (Samuel et al., 2013). In particular, sustainability indicators are used to measure and evaluate progress towards achieving sustainability goals and targets (Ahi & Searcy, 2015). They are used to put economic, environmental, and social sustainability goals into practice (Samuel et al., 2013) and help manufacturing industries report their contribution to achieving the SDGs (Moldavska and Welo, 2019). The economic dimension is the most important goal of manufacturing industries (Wang et al., 2018; Zarte et al., 2019). In the economic dimension, for instance, the indicators used to consist of *profit* (Ahmad et al., 2019a; Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019), *costs* (Ahmad et al., 2019a; Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019; Wang et al., 2018), and *investment* (Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019). The environmental dimension considers the impacts on the environment resulting from manufacturing industries' processes and products (Wang et al., 2018; Zarte et al., 2019). The indicators in the environmental dimension, for example, include *resources* (Ahmad et al., 2019a; Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019), *emissions* (Ahmad et al., 2019a; Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019; Wang et al., 2018), *wastes* (Ahmad et al., 2019a; Hasan et al., 2017; Song & Moon, 2019; Wang et al., 2018), *pollution* (Hasan et al., 2017; Joung et al., 2013), and *natural habitat conservation* (Joung et al., 2013). The social dimension considers human needs (Zarte et al., 2019). From the viewpoint of the manufacturing industry, the indicators in the social dimension address issues related to employees, customers, and the community (Ahmad et al., 2019a; Joung et al., 2013). Indicators related to employees, for instance, include *income (wage or salary)* (Ahmad et al., 2019a; Wang et al., 2018), *occupational health and safety* (Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019), *employee development* (Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019), and *employee satisfaction* (Joung et al., 2013; Song & Moon, 2019); those related to customers consist of *customer health and safety* (Ahmad et al., 2019a; Hasan et al., 2017; Joung et al., 2013; Song & Moon, 2019) and *customer satisfaction* (Ahmad et al., 2019a; Joung et al., 2013; Song & Moon, 2019); and those related to the community comprise *job opportunity* (Ahmad et al., 2019a; Hasan et al., 2017; Song & Moon, 2019), *corruption* (Ahmad et al., 2019a; Joung et al., 2013), and *community development* (Ahmad et al., 2019a; Joung et al., 2013).

The purpose of this paper is to explore and analyze the indicators that have been described in the literature for industrial sustainability performance measurement. In doing so, we will provide valuable information on the wide range of indicators available in the literature to academicians, practitioners, and policymakers that will be useful for the accounting, auditing, and management of industrial sustainability. To achieve the aim, two research questions were formulated: (1) what indicators are the consistently and frequently used to measure industrial sustainability in the literature? Additionally, (2) into which themes can the indicators be categorized? By addressing research question one, this paper provides useful insights to academicians and practitioners regarding the mainstream industrial sustainability indicators used in the literature. By addressing research question two, on the other hand, this paper helps to link the indicators to organization goals and the respective sustainable development goals. The rest of the paper is organized into three sections. Section 2 briefly describes the methodology applied in this paper. Next, the results are briefly discussed in Sect. 3. Finally, our conclusions as well as avenues for future research are described in Sect. 4.

2 Methodology

2.1 Research design

To address our research questions, a systematic review was conducted (Ahi & Searcy, 2015; Ahmad et al., 2019a; Feil et al., 2019) to explore the indicators described in peer-reviewed articles that are relevant to the sustainability performance measurement of manufacturing industries. For this purpose, Scopus and Web of Science were selected as search databases since they provide a wide coverage of peer-reviewed journal articles on research topics related to sustainability performance measurement. This paper focuses on academic literature since, unlike non-academic literature such as industry reports and sustainability standards and guidelines, it provides frequently updated indicators, making it possible to carry out consistency analysis of indicators over a substantial period of time. In this paper, the following procedures were used to carry out the systematic review (Feil et al., 2019): (a) defining the aim of the review, (b) selecting keywords and databases, (c) defining a paper screening and selection approach, (d) the coding and analysis of data from the selected papers, and (e) the presentation of the results.

2.2 Data collection

To collect data, we searched for papers in the literature using two sets of keywords related to the topic of this paper: "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. As shown in Fig. 1, a total of 1666 papers were initially found using the keywords search in Scopus and WoS. Considering the full list of 1068 articles that had been thoroughly peer-reviewed, a total of 598 reviews, conference papers, book chapters, and other documents were excluded; additionally, 387 articles were found to be duplicates. Moreover, it was not possible to access 11 full-text

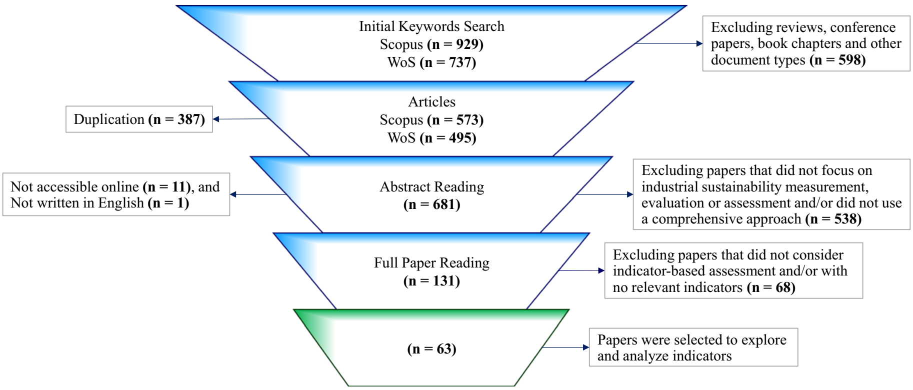


Fig. 1 Approach used for screening and selecting papers

papers through our online search, and 1 paper was not written in the English language. In our reading of the abstracts, 538 papers that did not focus on measuring, evaluating, or assessing the sustainability of manufacturing industries and/or did not use a comprehensive approach (i.e., TBL) were excluded after an analysis of the purpose, methodology and/or scope of the paper. Then, 68 papers that did not consider indicator-based assessment and/or did not propose indicators relevant to the purpose of this paper were also excluded after analyzing the detailed contents of the papers. Finally, 63 papers were selected for exploring and analyzing the indicators.

2.3 Data analysis

To address research question one, a content analysis was carried out to identify the most consistently and frequently used indicators from the selected papers. In the content analysis, all indicators described in the papers were recorded and organized in Microsoft Excel. Next, they were coded into as either economic, environmental, or social indicators based on their context and purpose. Then, a frequency count was conducted to determine how many times (i.e., by how many papers) each indicator was used. In the frequency count, word-by-word and phrase-by-phrase analyses were carried out 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 (Ahi & Searcy, 2015; Ahmad et al., 2019a).

The indicators were logically categorized into themes to address research question two. A cause-and-effect diagram was used to provide a logical causal relationship between the indicators, organizational goals, and industrial sustainability performance. To organize and map the relationship in the cause-and-effect diagram, the potential organizational goals used to improve industrial sustainability performance were defined; then, the consistently and frequently used indicators were logically linked to their respective organizational goals.

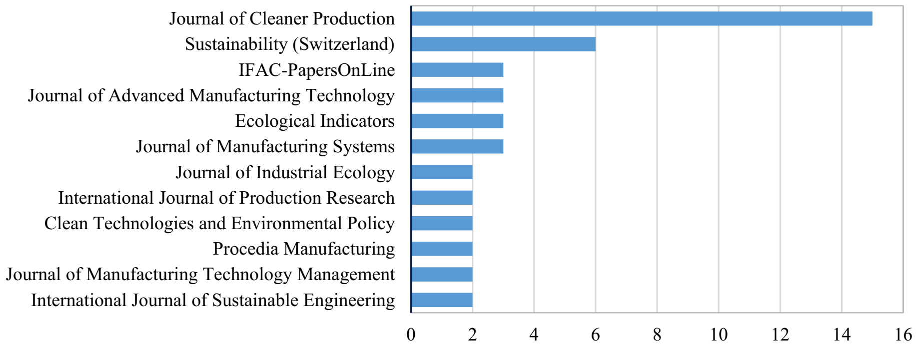
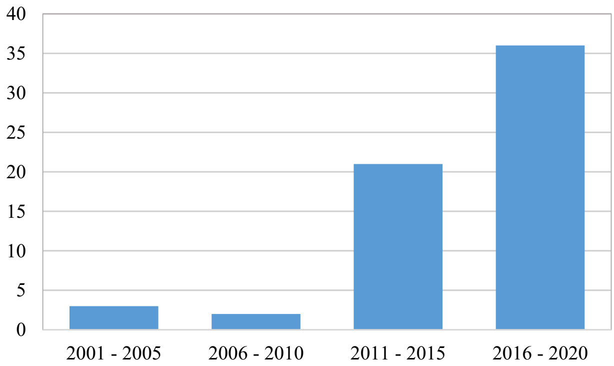


Fig. 2 Distribution of papers across the academic journals

Fig. 3 Distribution of papers according to their publication year



3 Results and discussion

3.1 Descriptive analysis of the papers

Figure 2 shows the distribution of the selected papers from academic journals that published two or more papers. It highlights the multidisciplinary nature of the systematic review conducted in this paper by examining journals focused on multidisciplinary subjects such as sustainability, engineering, and business and management (Ahi & Searcy, 2015). Six journals namely, *Journal of Cleaner Production*, *Sustainability (Switzerland)*, *IFAC-PapersOnLine*, *Journal of Advanced Manufacturing Technology*, *Ecological Indicators*, and *Journal of Manufacturing Systems* were found to be the leading journals that had published over 50% of the selected papers. Among them, the Journal of Cleaner Production was the top contributor to the papers.

As shown in Fig. 3, an increasing trend is evident, showing the growing research interest in the sustainability measurement of manufacturing industries over the past 20 years (2001 to 2020). Within this time frame, a wide range of indicators has been employed by previous research for measuring industrial sustainability. Of these indicators, very few were consistently and frequently used (i.e., indicators used by older published papers were later applied by recently published papers). For instance, profit, as used by Yakovleva and Flynn (2004), was later employed by Grecu et al. (2020) for measuring the economic dimension of sustainability; water consumption, as used by Veleva and Ellenbecker (2001), was later applied by Jamil et al. (2020) to measure the environmental dimension; and employment/job opportunity, as used by Yakovleva and Flynn (2004), was later employed by Agrawal and Vinodh (2020) for measuring the social dimension.

As can be seen in Fig. 4, *automotive* (Ghadimi et al., 2012; Lee et al., 2014; Moldavska and Welo, 2019; Singh et al., 2018; Vinodh et al., 2016), *food* (Ahmad & Wong, 2019; Harik et al., 2015; Yakovleva & Flynn, 2004), *electronics* (Huang & Badurdeen, 2017; Li et al., 2012; Shuaib et al., 2014), and *plastic* (Ocampo et al., 2016; Song & Moon, 2019) were the industries most often used by previous studies/papers for conducting case studies. In addition, we identified the indicators that were most commonly used by these manufacturing industries for measuring their sustainability performance. Accordingly, the indicators such as *water consumption* (Ahmad & Wong, 2019; Huang & Badurdeen, 2017; Lee et al., 2014; Ocampo et al., 2016), *energy consumption* (Li et al., 2012; Song & Moon, 2019; Vinodh et al., 2016; Yakovleva & Flynn, 2004), and *material consumption* (Ahmad & Wong, 2019; Lee et al., 2014; Ocampo et al., 2016; Shuaib et al., 2014) were commonly used to measure the environmental sustainability dimension of these industries.

3.2 Analysis of indicators by frequency of use

By applying content analysis, a total of 1041 indicators (290 for economic, 410 for environmental, and 341 for social dimensions) were explored. Table 1 presents the total number of indicators identified from the literature according to their frequency of use (i.e., by how many papers they were used in) after conducting the content analysis.

As seen in Table 1, the majority of indicators (884 out of 1041) appeared only once in the reviewed literature (i.e., they were not used by more than one paper). The availability of this wide range of indicators could be due to the lack of consensus regarding whether and how sustainability performance should be measured in manufacturing industries (Ahi & Searcy, 2015; Ahmad et al., 2019a) and the differences in the contexts of the manufacturing industries affecting the use of indicators for measuring sustainability performance (Cagno et al., 2019; Trianni et al., 2019). Moreover, a lack of consensus regarding the definition of sustainability in the context of manufacturing industry, research purpose, and approach differences will affect a wide range of indicators. This result implies that measuring sustainability performance in different manufacturing industry contexts will cause an ongoing research debate and open potential research opportunities. On the other hand, few indicators have been consistently and frequently used for measuring industrial sustainability performance in the literature.

Fig. 4 Distribution of papers by case study

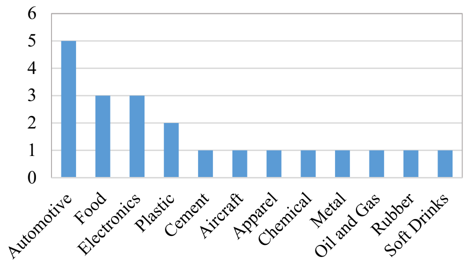


Table 1 The indicators identified according to their frequency of use

Frequency of use	Identified indicators (#)
1	884
2	57
3	33
4	17
5	16
6	12
7	4
8	3
9	1
10	1
11	4
12	1
13	1
14	1
15	1
16	1
17	1
19	1
28	1
29	1
Total	1041

As shown in Table 2, the results of the content analysis also show that 49 indicators (14 for economic, 22 for environmental, and 13 for social dimensions) were used at least 5 times (i.e., by at least by 5 papers). Due to their consistency and frequency, these indicators are considered to be the most understandable and relevant to various manufacturing industries (Ahmad et al., 2019a). Profit, water consumption, and employment/job opportunity were found to be the most consistently and frequently used indicators for measuring the economic, environmental, and social dimensions of industrial sustainability, respectively. In the economic dimension, the focus was on indicators that are used to measure the progress in obtaining significant financial benefits. These include *profit* (de Faria et al., 2021; Grecu et al., 2020; Yakovleva & Flynn, 2004) and *revenue* (Ahmad & Wong, 2019; Li et al., 2012; Song & Moon, 2019) from business activities; allocating reasonable *expenditure to R&D activities* (Beekaroo et al., 2019; Grecu et al., 2020; Li et al., 2012); reducing *material* (Agrawal & Vinodh, 2020; Ahmad & Wong, 2019; Jayal et al., 2010), *labor* (Abedini et al., 2020; Ahmad & Wong, 2019; Jayal et al., 2010), *energy* (Abedini et al., 2020; Agrawal & Vinodh, 2020; Jayal et al., 2010), *operating/operational* (Ahmad et al., 2019a; Cagno et al., 2019; Ghadimi et al., 2012), *maintenance* (Ahmad et al., 2019a; Cagno et al., 2019; Jayal et al., 2010), *production* (Abedini et al., 2020; Cagno et al., 2019; Jayal et al., 2010), *packaging* (Ahmad & Wong, 2019; Huang & Badurdeen, 2018; Jayal et al., 2010), and *inventory* (Abedini et al., 2020; Cagno et al., 2019; Ghadimi et al., 2012) costs; improving *product quality* (Agrawal & Vinodh, 2020; Hendiani et al., 2020; Singh et al., 2014); and properly managing *lead time* (Cagno et al., 2019; Medini et al., 2015;

Table 2 Sustainability indicators that appeared at least five times in the reviewed literature

Indicators for economic dimension	Frequency of use	Indicators for environmental dimension	Frequency of use	Indicators for social dimension	Frequency of use
Profit	16	Water consumption	29	Employment/Job opportunity	11
Research and development (R&D) expenditure	15	Energy consumption	28	Employee turnover	11
Product quality	14	Greenhouse gas emissions	19	Work-related injuries	10
Revenue	12	Material consumption	17	Customer satisfaction	8
Material cost	11	Renewable energy use	9	Employee satisfaction	6
Labor cost	11	Hazardous waste	8	Working hours	6
Energy cost	8	Recycled water use	7	Corruption	6
Operating/Operational cost	7	Wastewater discharge	7	Occupational health and safety	6
Maintenance cost	6	Recycled material use	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	Energy efficiency	6	Number of employees	5
On-time delivery	5	Packaging material consumption	5		
		Electricity consumption	5		
		Air emissions	5		
		Global warming potential	5		
		Energy intensity	5		
		Hazardous material use	5		
		Ozone depleting substances	5		
		Renewable material use	5		
		Waste generated	5		

Trianni et al., 2019) and *delivery time* (Raj & Srivastava, 2018; Singh et al., 2019; Winroth et al., 2016).

Regarding the environmental dimension of industrial sustainability, more attention was given to indicators that are used to measure progress in the efficient use of input resources such as *water* (de Faria et al., 2021; Jamil et al., 2020; Veleva & Ellenbecker, 2001), *energy* (Hendiani et al., 2020; Jamil et al., 2020; Veleva & Ellenbecker, 2001), and *material* (Agrawal & Vinodh, 2020; Ahmad & Wong, 2019; Veleva & Ellenbecker, 2001) consumption; the use of recycled resources which include *recycled water* (Cagno et al., 2019; Samuel et al., 2013; Zarte et al., 2019) and *recycled material* (Cagno et al., 2019; De Araujo & De Oliveira, 2012; Zarte et al., 2019); the use of renewable energy (Beekaroo et al., 2019; Cagno et al., 2019; Jayal et al., 2010); the reduction in emissions consisting of *GHG* (Abedini et al., 2020; Grecu et al., 2020; Li et al., 2012), *air* (Joung et al., 2013; Moldavska and Welo, 2018; Singh et al., 2019), and *ozone-depleting substances* (Grecu et al., 2020; Raj & Srivastava, 2018; Samuel et al., 2013); and the proper management of wastes such as *wastewater discharge* (De Araujo & De Oliveira, 2012; Wang et al., 2018; Zarte et al., 2019) and *hazardous* (Grecu et al., 2020; Huang & Badurdeen, 2017; Jayal et al., 2010), *solid* (Ahmad et al., 2019a; Beekaroo et al., 2019; Shuaib et al., 2014) and *recyclable* (Cagno et al., 2019; Li et al., 2012; Trianni et al., 2019) wastes.

Indicators in the social dimension placed more emphasis on measuring the progress in creating *employment/job opportunities* (Agrawal & Vinodh, 2020; Ahmad et al., 2019a; Yakovleva & Flynn, 2004); improving the well-being of employees, which consisted of minimizing *employee turnover* (Ahmad & Wong, 2019; Veleva & Ellenbecker, 2001; Vitale et al., 2019) and *work-related injuries* (Ahmad et al., 2019a; Cagno et al., 2019; Li et al., 2012), ensuring *employee satisfaction* (Ahmad et al., 2019a; Joung et al., 2013; Song & Moon, 2019) and *occupational health and safety* (Ahmad & Wong, 2019; de Faria et al., 2021; Raj & Srivastava, 2018), and providing *training and development* (Ahmad & Wong, 2019; Elhuni & Ahmad, 2017; Feil et al., 2015) and a *fair salary* (Ahmad & 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; Hendiani et al., 2020; Joung et al., 2013) and minimizing *customer complaints* (Ahmad et al., 2019b; Huang & Badurdeen, 2017; Veleva & Ellenbecker, 2001); properly managing employees working time such as *working hours* (Ahmad & Wong, 2019; Medini et al., 2015; Raj & Srivastava, 2018) and *lost working days* (Ahmad et al., 2019a; Veleva & Ellenbecker, 2001; Vitale et al., 2019); and reducing *corruption* (Ahmad et al., 2019a; Raj & Srivastava, 2018; Samuel et al., 2013).

With increasing stakeholder pressure on manufacturing industries to provide more transparency about their sustainability practices and improve sustainability performance, there has been a growing interest in measuring and evaluating industrial sustainability performance. However, as manufacturing industries have limited resources, they need to use a manageable number of suitable indicators in order to measure and report their sustainability performance effectively. The indicators analyzed in this paper can be effectively tailored to manufacturing industries' needs regarding measuring their sustainability performance. Moreover, these indicators can be applied to define, implement, evaluate and monitor policies to enhance sustainable manufacturing by considering economic, environmental, and social aspects while producing products and services, ensuring economic growth, conserving natural resources, minimizing negative environmental and social impacts, and meeting the requirements of stakeholders. Eventually, we aim contribute to the efforts to achieve the SDGs.

3.3 Categorization of the indicators

Figure 5 presents a hierarchal structure showing the categorization of the indicators that are most consistently and frequently used for measuring industrial sustainability in the literature. The indicators identified in the reviewed literature can logically be categorized for measuring industrial sustainability performance related to financial benefits, costs, and market competitiveness in the economic dimension; resources, emissions, and wastes in the environmental dimension; and employees, customers, and community in the social

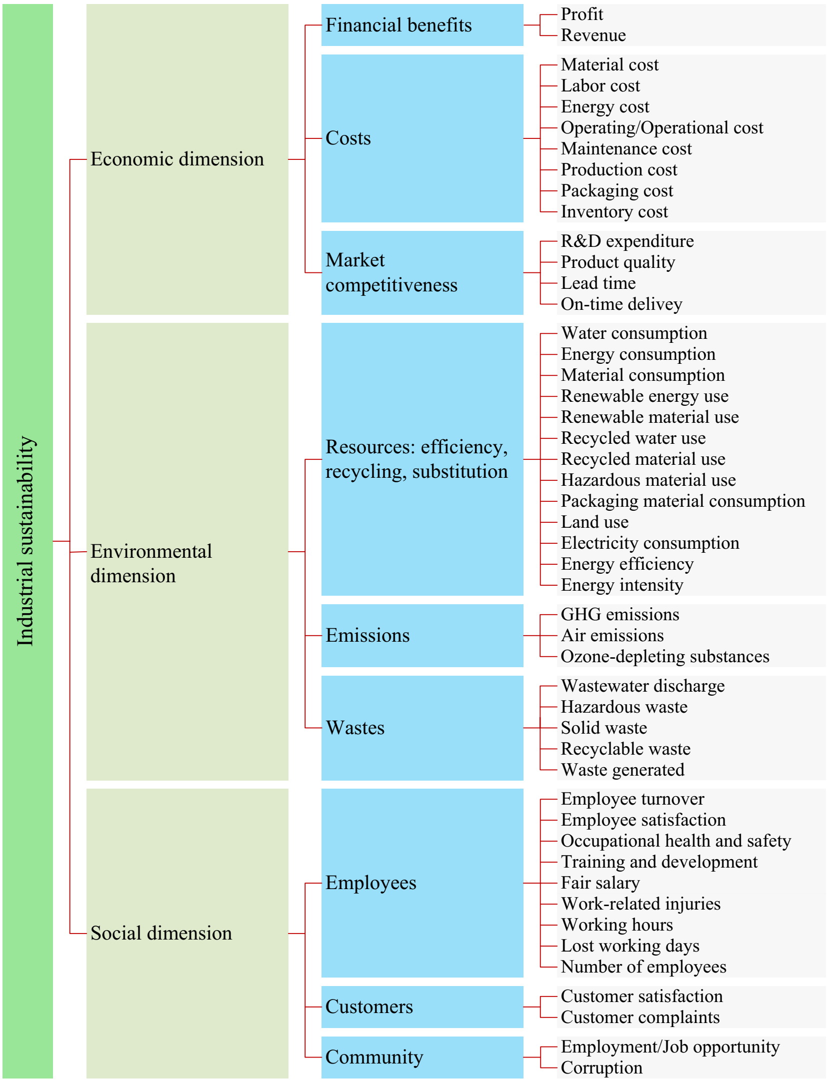


Fig. 5 Hierarchal structure of indicator categorization

dimension. Most of the proposed categories (themes) are in line with the categories of the NIST's sustainability manufacturing indicator repository (Joung et al., 2013).

The hierarchal structure of indicator categorization demonstrates that manufacturing industries always need to increase their financial benefits to maintain their existence in the market. They should also improve their market competitiveness, employ cost reduction strategies, efficiently use resources, conserve resources, properly manage wastes, and apply emissions reduction strategies while producing their products and services. In addition, they need to promote the well-being of their employees and customers and fulfill other stakeholders' needs (such as the community). The synergistic effect of these efforts can lead to achieving industrial sustainability (economic, environmental, and social) goals. To effectively measure and manage the progress towards attaining industrial sustainability goals, the use of suitable indicators is critical (Ahmad & Wong, 2019; Hendiani et al., 2020; Wang et al., 2018). We used a cause-and-effect diagram to organize and map the indicators, as shown in Fig. 6, to express their effect on the organizational goals and, in turn, on the industrial sustainability performance (overall goal). By achieving these goals, manufacturing industries can contribute to achieving the SDGs. Promoting the well-being of employees, customers, and the community can contribute to *good health and well-being (SDG 3)*. Increasing financial benefits; reducing costs; improving market competitiveness; and promoting the well-being of employees, customers, and the community can promote *decent work and economic growth (SDG 8)*. By improving the effectiveness of resource utilization, manufacturing industries can also contribute to *responsible consumption and*

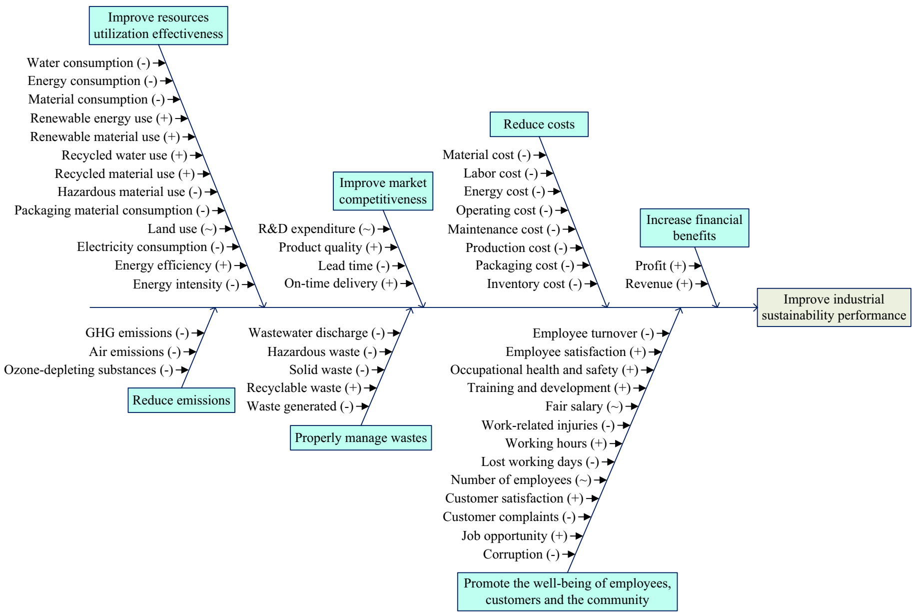


Fig. 6 Cause-and-effect diagram of the indicators. (+) implies *improve*, *increase*; (−) implies *reduce*, *minimize*; and (~) implies *optimum*, *reasonable*

Table 3 Link between the indicators and their respective SDGs

Dimensions of sustainability	Indicators	Sustainable development goals			
		Goal 3	Goal 8	Goal 12	Goal 13
Economic	Profit		X		
	Revenue		X		
	Material cost		X		
	Labor cost		X		
	Energy cost		X		
	Operating cost		X		
	Maintenance cost		X		
	Production cost		X		
	Packaging cost		X		
	Inventory cost		X		
	R&D expenditure		X	X	X
	Product quality		X		
	Lead time		X		
	On-time delivery		X		
Environmental	Water consumption			X	X
	Energy consumption			X	X
	Material consumption			X	X
	Renewable energy use			X	X
	Renewable material use			X	X
	Recycled water use			X	X
	Recycled material use			X	X
	Hazardous material use			X	X
	Electricity consumption			X	
	Energy efficiency			X	
	Energy intensity			X	
	Packaging material consumption			X	X
	Land use			X	X
	GHG emissions				X
	Air emissions				X
	Ozone-depleting substances				X
	Wastewater discharge				X
	Hazardous waste			X	X
	Solid waste			X	X
	Recyclable waste			X	X
	Waste generated			X	X

Table 3 (continued)

Dimensions of sustainability	Indicators	Sustainable development goals			
		Goal 3	Goal 8	Goal 12	Goal 13
Social	Employee turnover	X	X	X	
	Employee satisfaction	X	X		
	Occupational health and safety	X			
	Training and development		X		
	Fair salary		X		
	Work-related injuries	X			
	Working hours	X	X	X	
	Lost working days	X	X	X	
	Number of employees	X			
	Customer satisfaction	X			
	Customer complaints	X			
	Employment/job opportunity		X		
	Corruption		X	X	

production (SDG 12). The reduction of emissions and proper management of wastes can have an impact on *climate action (SDG 13)*.

By linking the indicators to their respective SDGs, as shown in Table 3, this paper provides a valuable insight into how manufacturing industries can use the indicators to track their progress towards achieving the SDGs. Furthermore, the link between the indicators and their respective SDGs provides a broader view of sustainability to manufacturing industries to ensure the well-being of stakeholders, decent work and economic growth, sustainable consumption and production, and combat climate change and its impacts. Therefore, following a bottom-up approach, manufacturing industries need to apply the indicators to measure and manage their organizational goals, improve sustainability performance, and contribute to achieving the SDGs.

3.4 Metrics defined for the indicators

Defining quantifiable metrics is essential in order to make industrial sustainability measurable and manageable (Shuaib et al., 2014). As shown in Tables 4, 5, and 6, both absolute and relative metrics were defined for the consistent and frequently used economic, environmental and social indicators, respectively (Mengistu & Panizzolo, 2021). The metrics defined for the indicators can enable us to carry out industrial sustainability performance measurement using data science. By providing a predefined list of indicators and their

Table 4 Metrics defined for the economic dimension indicators

Indicators	Metrics		Adapted from
	Absolute	Relative	
Profit	Net profit gained (USD, Euro)	Net profit to total revenue ratio (%)	Elhuni and Ahmad (2017)
Revenue	Total revenue generated (USD, Euro)	Revenue generated per unit of product sold (USD, Euro/uop)	Ahmad et al. (2019b)
R&D expenditure	R&D spending (USD, Euro)	R&D spending to total revenue ratio (%)	Ahmad et al. (2019b); Grecu et al. (2020)
Material cost	Total material cost (USD, Euro)	Percentage of material cost relative to total revenue (%)	Ahmad et al. (2019b)
Labor cost	Total labor cost (USD, Euro)	Percentage of labor cost relative to total revenue (%)	Ahmad et al. (2019b)
Energy cost	Total energy cost (USD, Euro)	Percentage of energy cost relative to total revenue (%)	Huang and Badurdeen (2018)
Operating/Operational cost	Total energy cost (USD, Euro)	Percentage of energy cost relative to total revenue (%)	Cagno et al. (2019)
Maintenance cost	Total maintenance cost (USD, Euro)	Percentage of maintenance cost relative to total revenue (%)	Ahmad et al. (2019b)
Production cost	Total production cost (USD, Euro)	Production cost per unit of product produced (USD, Euro/uop)	Cagno et al. (2019)
Packaging cost	Total packaging cost (USD, Euro)	Percentage of packaging cost relative to total revenue (%)	Ahmad et al. (2019b); Huang and Badurdeen (2018)
Inventory cost	Total inventory cost (USD, Euro)	Percentage of inventory cost relative to total revenue (%)	Cagno et al. (2019)
Product quality	Total number of products that met customer requirements (#)	Percentage of products that met customer requirements (%)	Proposed metrics
Lead time	Total number of products produced within the required lead time (#)	Percentage of products produced within the required lead time (%)	Proposed metrics
On-time delivery	Total number of products delivered on time (#)	Percentage of products delivered on time (%)	Proposed metrics

metrics, manufacturing industries will not be overloaded with information whose utility is uncertain. Additionally, this improves the effectiveness of sustainability performance measurement in manufacturing industries. However, conducting an empirical study is necessary in order to refine and normalize the indicators and their metrics (i.e., modifying, adding, and/or deleting indicators and their metrics) and tailor them according to manufacturing industries' needs and priorities.

As shown in Table 4, the metrics can be used to properly measure and manage the economic dimension sustainability performance associated with financial benefits (profit and revenue), costs (material, labor, energy, operating, maintenance, production, packaging, and inventory), and market competitiveness (R&D expenditure, on-time delivery, lead time, and product quality). Measuring and managing cost reduction, on-time delivery, lead time and product quality is essential in order to maintain market competitiveness and financial benefits in the short run. Moreover, it is crucial to determine reasonable expenditure levels in order to conduct R&D activities to promote the production of sustainable products and enhance market competitiveness in the long run.

From Table 5, it can be seen that the metrics are defined to effectively measure and manage the environmental sustainability dimension performance related to resources (water, energy, material, and land), emissions (GHGs, air, and ozone-depleting substances), and wastes (hazardous, solid, and recyclable). The metrics can be used to measure progress towards improving resource utilization efficiencies such as energy and material efficiency, the use of recycled resources such as recycled water and materials, the use of renewable energy and materials, the use of eco-friendly and biodegradable materials, and the use of non-hazardous materials to improve product safety and quality. They can also be used to address the performance of different waste management strategies.

Table 6 shows the metrics defined to measure and manage performance in the social sustainability dimension, associated with the well-being of employees, customers, and the community. Measuring the social sustainability dimension has been difficult compared to the other sustainability dimensions (Ahmad et al., 2019a). The metrics presented in Table 6 will be helpful for easily measuring the social sustainability dimension. Subsequently, the metrics defined for employee turnover, employee satisfaction, occupational health and safety, training and development, fair salary, and work-related injuries can be used to measure progress in improving employee well-being. It is also necessary to measure progress in promoting customer well-being. For this purpose, the metrics for customer satisfaction and customer complaints are useful. The metrics for employment/job opportunity and corruption can be used for measuring progress towards community development. Moreover, the metrics for working hours and lost working days can be used to measure performance associated with employees' time management.

Table 5 Metrics defined for the environmental dimension indicators

Indicators	Metrics		Adapted from
	Absolute	Relative	
Water consumption	Total volume of water consumed (m^3)	Water consumption per unit of product produced (m^3/uop)	Veleva and Ellenbecker (2001)
Recycled water use	Total recycled water consumed (m^3)	Percentage of recycled water used (%)	Huang and Badurdeen (2018)
Energy consumption	Total electricity consumed (kWh); Total amount of fuel consumed (L, m^3, tonne)	Electricity consumption per unit of product produced (kWh/uop); fuel consumption per unit of product produced (L, m^3, tonne/uop)	Veleva and Ellenbecker (2001)
Renewable energy use	Total energy consumption from renewable sources (kWh, L, kg)	Percentage of energy consumption from renewable sources (%)	Veleva and Ellenbecker (2001)
Energy efficiency	******	Ratio of energy used for production to the total input energy (%)	Song and Moon (2019)
Material consumption	Total weight or volume of materials consumed (kg, m^3, L, m^2, pc)	Material consumption per unit of product produced (kg, m^3, L, m^2, pc/uop); material efficiency (%); percentage of biodegradable materials used (%); percentage of renewable materials used (%); percentage of hazardous materials used (%)	Huang and Badurdeen (2018); Veleva and Ellenbecker (2001)
Recycled material use	Total weight or volume of recycled materials used (kg, m^3, L, m^2, pc)	Percentage of recycled materials used (%)	Huang and Badurdeen (2018)
Packaging material consumption	Total weight or volume of packaging material used (kg, m^3, L, m^2, pc)	Packaging material used per unit of product produced (kg, m^3, L, m^2, pc/uop)	Ahmad et al. (2019b); Huang and Badurdeen (2018)
Land use	Land for industrial use (m^2)	Land use per employee (m^2/emp)	Trianni et al. (2019)
Greenhouse gas emissions	Total GHG emissions generated (tonne)	GHG emissions generated per unit of product produced (tonne/uop)	Huang and Badurdeen (2018)
Air emissions	Total air emissions generated (tonne)	Air emissions generated per unit of product produced (tonne/uop)	Ahmad et al. (2019b); Moldavska and Welo (2018)
Ozone-depleting substances	Total ozone-depleting substances generated (tonne)	Ozone-depleting substances generated per unit of product produced (tonne/uop)	GRI (2016)
Wastewater discharge	Total wastewater discharged (m^3)	Percentage of wastewater discharged (%)	GRI (2016)

Table 5 (continued)

Indicators	Metrics		Adapted from
	Absolute	Relative	
Hazardous waste	Total weight or volume of hazardous waste (kg, m^3, L, m^2, pc)	Percentage of hazardous waste (%)	Trianni et al. (2019)
Solid waste disposal	Total weight or volume of solid waste disposed (kg, m^3, L, m^2, pc)	Percentage of solid material disposed (%)	Huang and Badurdeen (2018)
Recyclable waste	Total weight or volume of recyclable waste (kg, m^3, L, m^2, pc)	Percentage of recyclable waste (%)	Trianni. et al. (2019)
Waste generated	Total weight or volume of waste generated (kg, m^3, L, m^2, pc)	Waste generated per unit of product produced (kg, m^3, L, m^2, pc/uop)	(Veleva & Ellenbecker, 2001)

Table 6 Metrics defined for the social dimension indicators

Indicators	Metrics		Adapted from
	Absolute	Relative	
Employee turnover	Total employee turnover (#)	Percentage of employee turnover (%)	Huang and Badurdeen (2018); GRI (2016)
Employee satisfaction	Total number of employees who reported job satisfaction (#)	Percentage of employees who reported job satisfaction (%)	Huang and Badurdeen (2018); Veleva and Ellenbecker (2001)
Occupational health and safety	Total number of employees covered by OHS program (#); Total number of fatalities as a result of work-related injuries (#); Total number of fatalities as a result of work-related illnesses (#); Total number of cases of work-related illnesses (#)	Percentage of employees covered by OHS program (%); percentage of fatalities as a result of work-related injuries (%); percentage of fatalities as a result of work-related illnesses (%); percentage of cases of work-related illnesses (%)	GRI (2016)
Training and development	Total number of employees who received a regular performance and career development review (#); Total training hours (h)	Percentage of employees who received a regular performance and career development review (%); average training hours per employee (h/emp)	GRI (2016)
Fair salary	******	Average salary per employee (USD, Euro/emp)	Ahmad et al. (2019b)
Work-related injuries	Total number of work-related injuries (#)	Work-related injuries per employee (#/emp)	GRI (2016)
Working hours	Total working hours (h)	Average working hours per employee (h/emp)	(Zarte et al., 2019)
Lost working days	Total lost working days due to injuries and illness (day)	Percentage of lost working days due to injuries and illness (%)	Tseng (2013); Veleva and Ellenbecker (2001)
Number of employees	Total number of active employees (#)	Number of active employees per unit of product produced (#/uop)	Cagno et al. (2019); Veleva and Ellenbecker (2001)
Customer satisfaction	Total number of customers who reported satisfaction with the products and services offered (#)	Percentage of customers who reported satisfaction with the products and services offered (%)	Ahmad et al. (2019b)
Customer complaints	Total number of customer complaints (#)	Customer complaints per unit of product sold (#/uop)	Ahmad et al. (2019b); Veleva and Ellenbecker (2001)
Employment/Job opportunity	Total number of new employees hired (#)	Recruitment efficiency (%)	GRI (2016)

Table 6 (continued)

Indicators	Metrics		Adapted from
	Absolute	Relative	
Corruption	Total number of confirmed incidents of corruption (#); Total number of employees who received training on anti-corruption (#)	Number of confirmed incidents of corruption per employee (#/emp); Percentage of employees who received training on anti-corruption (%)	GRI (2016)

4 Conclusions

This paper provides an in-depth analysis of indicators that have been published in the literature related to the sustainability performance measurement of manufacturing industries. Our findings show that the majority of the indicators available in the literature have only been used once, showing a lack of consistency in the use of indicators (i.e., the lack of consensus on a single set of indicators) to measure sustainability performance in different manufacturing industry contexts. However, a few of the indicators were consistently and frequently used; these indicators emphasized measuring industrial sustainability performance correlated with financial benefits, costs, and market competitiveness for the economic dimension; resources, emissions, and wastes for the environmental dimension; and employees, customers, and the community for the social dimension. These results suggest that manufacturing industries need to focus on applying indicators for measuring and managing progress towards achieving industrial sustainability goals in terms of increasing financial benefits, reducing costs, improving market competitiveness, improving the effectiveness of resources utilization, reducing emissions, properly managing wastes, and improving the well-being of stakeholders (employees, customers, and the community). In doing so, manufacturing industries can contribute to achieving the SDGs by promoting health and well-being, promoting sustainable economic growth, providing productive employment and decent work, ensuring responsible consumption and production, and combating climate change and its impacts. To this end, this paper emphasizes the necessity of tailoring these indicators to the contexts of different manufacturing industries in order to effectively measure and manage the progress made towards achieving industrial sustainability goals.

This paper has relevant academic, practical, and policy implications. From an academic perspective, this paper will provide a substantial theoretical basis for future research on measuring the sustainability performance of manufacturing industries. We have carried out an extensive analysis of the wide range of sustainability indicators available in the literature, which can contribute to the existing theory and knowledge in the field of industrial sustainability performance measurement. The quantifiable metrics defined for the indicators can also be used by future research to envision the sustainability of manufacturing industries using data science. From a practical perspective, manufacturing industries can adapt the indicators and metrics provided by this paper to measure sustainability performance and contribute to achieving the SDGs. Moreover, these metrics will help the manufacturing industries to identify the data that need to be collected and organized for measuring their sustainability performance effectively. It also has policy implications, as linking the indicators to their respective SDGs could be used as an input for policymakers in the field of sustainable manufacturing that can influence policies such as socio-economic, environmental, and social responsibility.

The significant number of indicators that are only used once in the reviewed literature should inform future research agendas; by conducting a detailed analysis of the classification of these indicators, further investigation into the possible reasons why the majority of indicators are not commonly used for measuring industrial sustainability, the pattern analysis of indicators, and the identification of indicators for emerging sustainability trends. Although this paper provides a comprehensive methodological approach for identifying and analyzing the indicators described in peer-reviewed journal articles, its scope was limited at the firm level. However, it would be helpful to determine additional indicators that could be used to measure sustainability performance at the supply chain level to obtain a more comprehensive view of sustainable manufacturing. Hence, it would be interesting for future research to expand the methodological approach applied in this paper to the entire supply chain in the stages of supply, production, distribution, use, and post-use. Furthermore, we focused on the indicators that have been used by scientific papers (i.e., academic papers). Thus, as an additional avenue, future research could consider analyzing indicators that have been used by organizations engaged in sustainability performance measurement. The other limitation of this paper is that it does not support its findings with empirical analysis to refine and normalize the indicators and their metrics. Therefore, it would also be interesting for future research to tailor the indicators to different manufacturing industry contexts by carrying out an empirical study. Furthermore, it would also be valuable to conduct an empirical study such as a survey on the use of these indicators (i.e., similarities and differences) from the perspective of national and geographical contexts.

Acknowledgements The authors gratefully acknowledge the advice and contributions from Prof. Cipriano Forza, a member of the faculty of the PhD program in Management Engineering at the University of Padova. The authors would also like to thank the Cassa di Risparmio di Padova e Rovigo (CARIPARO) Foundation for its financial support.

Authors' contributions ATM conceptualized the research work, conducted the systematic review and wrote the manuscript; RP guided the design of the research work, reviewed the manuscript and supervised the research.

Funding Not applicable.

Availability of data and material Not applicable.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

Code availability Not applicable.

References

Abedini, A., Li, W., Badurdeen, F., & Jawahir, I. S. (2020). A metric-based framework for sustainable production scheduling. *Journal of Manufacturing Systems, 54*, 174–185. https://doi.org/10.1016/j.jmsy.2019.12.003

Agrawal, R., & Vinodh, S. (2020). Sustainability evaluation of additive manufacturing processes using grey-based approach. *Grey Systems: Theory and Application, 10*(4), 393–412. https://doi.org/10.1108/GS-08-2019-0028

Ahi, P., & Searcy, C. (2015). An analysis of metrics used to measure performance in green and sustainable supply chains. *Journal of Cleaner Production, 86*, 360–377. https://doi.org/10.1016/j.jclepro.2014.08.005

Ahmad, S., & Wong, K. Y. (2019). Development of weighted triple-bottom line sustainability indicators for the Malaysian food manufacturing industry using the Delphi method. *Journal of Cleaner Production, 229*, 1167–1182. https://doi.org/10.1016/j.jclepro.2019.04.399

Ahmad, S., Wong, K. Y., & Rajoo, S. (2019a). Sustainability indicators for manufacturing sectors: A literature survey and maturity analysis from the triple-bottom line perspective. *Journal of Manufacturing Technology Management, 30*, 312–334. https://doi.org/10.1108/JMTM-03-2018-0091

Ahmad, S., Wong, K. Y., & Zaman, B. (2019b). A Comprehensive and integrated stochastic-fuzzy method for sustainability assessment in the Malaysian food manufacturing industry. *Sustainability*. https://doi.org/10.3390/su11040948

Aktaş, N., & Demirel, N. (2021). A hybrid framework for evaluating corporate sustainability using multi-criteria decision making. *Environment, Development and Sustainability, 23*(10), 15591–15618. https://doi.org/10.1007/s10668-021-01311-5

Beekaroo, D., Callychurn, D. S., & Hurreeram, D. K. (2019). Developing a sustainability index for Mauritian manufacturing companies. *Ecological Indicators, 96*, 250–257. https://doi.org/10.1016/j.ecolind.2018.09.003

Cagno, E., Neri, A., Howard, M., Brenna, G., & Trianni, A. (2019). Industrial sustainability performance measurement systems: A novel framework. *Journal of Cleaner Production, 230*, 1354–1375. https://doi.org/10.1016/j.jclepro.2019.05.021

Chang, R.-D., Zuo, J., Zhao, Z.-Y., Zillante, G., Gan, X.-L., & Soebarto, V. (2017). Evolving theories of sustainability and firms: History, future directions and implications for renewable energy research. *Renewable and Sustainable Energy Reviews, 72*, 48–56. https://doi.org/10.1016/j.rser.2017.01.029

De Araujo, J. B., & De Oliveira, J. F. G. (2012). Towards a balanced scoreboard for assessing manufacturing processes sustainability. *International Journal of Business Performance Management, 13*(2), 198–221. https://doi.org/10.1504/IJBPM.2012.046201

de Faria, D. R. G., de Medeiros, J. L., & Araújo, O. Q. F. (2021). Sustainability assessment for the chemical industry: Onwards to integrated system analysis. *Journal of Cleaner Production, 278*, 123966. https://doi.org/10.1016/j.jclepro.2020.123966

Eastwood, M. D., & Haapala, K. R. (2015). A unit process model based methodology to assist product sustainability assessment during design for manufacturing. *Journal of Cleaner Production, 108*, 54–64. https://doi.org/10.1016/j.jclepro.2015.08.105

Elhuni, R. M., & Ahmad, M. M. (2017). Key performance indicators for sustainable production evaluation in oil and gas sector. *Procedia Manufacturing, 11*, 718–724. https://doi.org/10.1016/j.promfg.2017.07.172

Elkington, J. (1997). *Cannibals with forks: The triple bottom line of 21st century business* (1st ed.). Capstone.

Eurostat. (2019). Gross Value Added. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do, Accessed on June 19, 2021.

Feil, A. A., de Quevedo, D. M., & Schreiber, D. (2015). Selection and identification of the indicators for quickly measuring sustainability in micro and small furniture industries. *Sustainable Production and Consumption, 3*, 34–44. https://doi.org/10.1016/j.spc.2015.08.006

Feil, A. A., Schreiber, D., Haetinger, C., Strasburg, V. J., & Barkert, C. L. (2019). Sustainability indicators for industrial organizations: Systematic review of literature. *Sustainability, 11*(3), 854. https://doi.org/10.3390/su11030854

Galal, N. M., & Moneim, A. F. A. (2015). A mathematical programming approach to the optimal sustainable product mix for the process industry. *Sustainability, 7*(10), 13085–13103. https://doi.org/10.3390/su71013085

Ghadimi, P., Azadnia, A. H., Mohd Yusof, N., & Mat Saman, M. Z. (2012). A weighted fuzzy approach for product sustainability assessment: A case study in automotive industry. *Journal of Cleaner Production, 33*, 10–21. https://doi.org/10.1016/j.jclepro.2012.05.010

Grecu, V., Ciobotea, R.-I.-G., & Florea, A. (2020). Software application for organizational sustainability performance assessment. *Sustainability, 12*(11), 4435. https://doi.org/10.3390/su12114435

GRI. (2016). *GRI Sustainability Reporting Standards (GRI Standards)*. GRI.

Haapala, K. R., Zhao, F., Camelio, J., Sutherland, J. W., Skerlos, S., Dornfeld, D. A., Jawahir, I. S., Clarens, A. F., & Rickli, J. L. (2013). A review of engineering research in sustainable manufacturing. *Journal of Manufacturing Science and Engineering-Transactions of the Asme, 135*, 041013. https://doi.org/10.1115/1.4024040

Harik, R., El Hachem, W., Medini, K., & Bernard, A. (2015). Towards a holistic sustainability index for measuring sustainability of manufacturing companies. *International Journal of Production Research, 53*, 4117–4139. https://doi.org/10.1080/00207543.2014.993773

Hasan, M. S., Ebrahim, Z., Wan Mahmood, W. H., & Ab Rahman, M. N. (2017). Sustainable-ERP system: A preliminary study on sustainability indicators. *Journal of Advanced Manufacturing Technology, 11*(1), 61–74.

Hashim, M., Nazam, M., Abrar, M., Hussain, Z., Nazim, M., & Shabbir, R. (2021). Unlocking the sustainable production indicators: a novel tesco based fuzzy AHP approach. *Cogent Business & Management, 8*(1), 1870807. https://doi.org/10.1080/23311975.2020.1870807

Hendiani, S., Liao, H., Bagherpour, M., Tvaronavičienė, M., Banaitis, A., & Antucheviciene, J. (2020). Analyzing the status of sustainable development in the manufacturing sector using multi-expert multi-criteria fuzzy decision-making and integrated triple bottom lines. *International Journal of Environmental Research and Public Health, 17*(11), 3800. https://doi.org/10.3390/ijerph17113800

Huang, A., & Badurdeen, F. (2017). Sustainable manufacturing performance evaluation at the enterprise level: Index- And value-based methods. *Smart and Sustainable Manufacturing Systems, 1*, 178–203. https://doi.org/10.1520/SSMS20170004

Huang, A., & Badurdeen, F. (2018). Metrics-based approach to evaluate sustainable manufacturing performance at the production line and plant levels. *Journal of Cleaner Production, 192*, 462–476. https://doi.org/10.1016/j.jclepro.2018.04.234

Jamil, N., Gholami, H., Saman, M. Z. M., Streimikiene, D., Sharif, S., & Zakuan, N. (2020). DMAIC-based approach to sustainable value stream mapping: Towards a sustainable manufacturing system. *Economic Research-Ekonomska Istraživanja, 33*(1), 331–360. https://doi.org/10.1080/1331677X.2020.1715236

Jayal, A. D., Badurdeen, F., Dillon, O. W., Jr., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. *CIRP Journal of Manufacturing Science and Technology, 2*(3), 144–152. https://doi.org/10.1016/j.cirpj.2010.03.006

Joung, C. B., Carrell, J., Sarkar, P., & Feng, S. C. (2013). Categorization of indicators for sustainable manufacturing. *Ecological Indicators, 24*, 148–157. https://doi.org/10.1016/j.ecolind.2012.05.030

Köseoglu, M. A., Yee Yick, M. Y., & Parnell, J. A. (2021). The dissemination of corporate social responsibility into the intellectual structure of strategic management. *Journal of Cleaner Production, 311*, 127505. https://doi.org/10.1016/j.jclepro.2021.127505

Lacasa, E., Santolaya, J. L., & Biedermann, A. (2016). Obtaining sustainable production from the product design analysis. *Journal of Cleaner Production, 139*, 706–716. https://doi.org/10.1016/j.jclepro.2016.08.078

Lee, J. Y., Kang, H. S., & Noh, S. D. (2014). MAS2: An integrated modeling and simulation-based life cycle evaluation approach for sustainable manufacturing. *Journal of Cleaner Production, 66*, 146–163. https://doi.org/10.1016/j.jclepro.2013.11.029

Li, T., Zhang, H., Yuan, C., Liu, Z., & Fan, C. (2012). A PCA-based method for construction of composite sustainability indicators. *International Journal of Life Cycle Assessment, 17*, 593–603. https://doi.org/10.1007/s11367-012-0394-y

Medini, K., Da Cunha, C., & Bernard, A. (2015). Tailoring performance evaluation to specific industrial contexts: Application to sustainable mass customisation enterprises. *International Journal of Production Research, 53*(8), 2439–2456. https://doi.org/10.1080/00207543.2014.974844

Mengistu, A. T., & Panizzolo, R. (2021). Indicators and framework for measuring industrial sustainability in Italian footwear small and medium enterprises. *Sustainability*. https://doi.org/10.3390/su13105472

Moldavska, A., & Welo, T. (2018). Testing and verification of a new corporate sustainability assessment method for manufacturing: A multiple case research study. *Sustainability*. https://doi.org/10.3390/su10114121

Moldavska, A., & Welo, T. (2019). A Holistic approach to corporate sustainability assessment: Incorporating sustainable development goals into sustainable manufacturing performance evaluation. *Journal of Manufacturing Systems, 50*, 53–68. https://doi.org/10.1016/j.jmsy.2018.11.004

Neri, A., Cagno, E., Di Sebastiano, G., & Trianni, A. (2018). Industrial sustainability: Modelling drivers and mechanisms with barriers. *Journal of Cleaner Production, 194*, 452–472. https://doi.org/10.1016/j.jclepro.2018.05.140

Ocampo, L. A., Clark, E. E., & Promentilla, M. A. B. (2016). Computing sustainable manufacturing index with fuzzy analytic hierarchy process. *International Journal of Sustainable Engineering, 9*(5), 305–314. https://doi.org/10.1080/19397038.2016.1144828

Paramanathan, S., Farrukh, C., Phaal, R., & Probert, D. (2004). Implementing industrial sustainability: The research issues in technology management. *R&amp D Management, 34*(5), 527–537. https://doi.org/10.1111/j.1467-9310.2004.00360.x

Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L., & de Colle, S. (2010). Stakeholder theory: The state of the art. *The Academy of Management Annals, 4*(1), 403–445. https://doi.org/10.1080/19416520.2010.495581

Raj, A., & Srivastava, S. K. (2018). Sustainability performance assessment of an aircraft manufacturing firm. *Benchmarking, 25*(5), 1500–1527. https://doi.org/10.1108/BIJ-01-2017-0001

Samuel, V. B., Agamuthu, P., & Hashim, M. A. (2013). Indicators for assessment of sustainable production: A case study of the petrochemical industry in Malaysia. *Ecological Indicators, 24*, 392–402. https://doi.org/10.1016/j.ecolind.2012.07.017

Shuaib, M., Seevers, D., Zhang, X., Badurdeen, F., Rouch, K. E., & Jawahir, I. S. (2014). Product sustainability index (ProdSI): A metrics-based framework to evaluate the total life cycle sustainability of manufactured products. *Journal of Industrial Ecology, 18*(4), 491–507. https://doi.org/10.1111/jiec.12179

Singh, R. K., Modgil, S., & Tiwari, A. A. (2019). Identification and evaluation of determinants of sustainable manufacturing: A case of Indian cement manufacturing. *Measuring Business Excellence, 23*(1), 24–40. https://doi.org/10.1108/MBE-08-2018-0056

Singh, S., Olugu, E. U., & Fallahpour, A. (2014). Fuzzy-based sustainable manufacturing assessment model for SMEs. *Clean Technologies and Environmental Policy, 16*(5), 847–860. https://doi.org/10.1007/s10098-013-0676-5

Singh, S., Olugu, E. U., Musa, S. N., & Mahat, A. B. (2018). Fuzzy-based sustainability evaluation method for manufacturing SMEs using balanced scorecard framework. *Journal of Intelligent Manufacturing, 29*(1), 1–18. https://doi.org/10.1007/s10845-015-1081-1

Smart, P., Hemel, S., Lettice, F., Adams, R., & Evans, S. (2017). Pre-paradigmatic status of industrial sustainability: A systematic review. *International Journal of Operations & Production Management, 37*(10), 1425–1450. https://doi.org/10.1108/IJOPM-02-2016-0058

Song, Z., & Moon, Y. (2019). Sustainability metrics for assessing manufacturing systems: A distance-to-target methodology. *Environment, Development and Sustainability, 21*(6), 2811–2834. https://doi.org/10.1007/s10668-018-0162-7

Statista. (2019). Greenhouse gas emissions. Retrieved from https://www.statista.com/statistics/999434/industrial-ghg-emissions-european-union-eu/, Accessed on June 22, 2021.

Statista. (2020). Employment. Retrieved from https://www.statista.com/statistics/1195197/employment-by-sector-in-europe/, Accessed on June 22, 2021.

Tonelli, F., Evans, S., & Taticchi, P. (2013). Industrial sustainability: Challenges, perspectives, actions. *International Journal of Business Innovation Research, 7*(2), 1751–2252. https://doi.org/10.1504/IJBIR.2013.052576

Trianni, A., Cagno, E., & Neri, A. (2017). Modelling barriers to the adoption of industrial sustainability measures. *Journal of Cleaner Production, 168*, 1482–1504. https://doi.org/10.1016/j.jclepro.2017.07.244

Trianni, A., Cagno, E., Neri, A., & Howard, M. (2019). Measuring industrial sustainability performance: Empirical evidence from Italian and German manufacturing small and medium enterprises. *Journal of Cleaner Production, 229*, 1355–1376. https://doi.org/10.1016/j.jclepro.2019.05.076

Tseng, M. L. (2013). Modeling sustainable production indicators with linguistic preferences. *Journal of Cleaner Production, 40*, 46–56. https://doi.org/10.1016/j.jclepro.2010.11.019

Tseng, M. L., Divinagracia, L., & Divinagracia, R. (2009). Evaluating firm's sustainable production indicators in uncertainty. *Computers and Industrial Engineering, 57*(4), 1393–1403. https://doi.org/10.1016/j.cie.2009.07.009

Veleva, V., Bailey, J., & Jurczyk, N. (2001). Using sustainable production indicators to measure progress in ISO 14001, EHS system and EPA achievement track. *Corporate Environmental Strategy, 8*(4), 326–338. https://doi.org/10.1016/S1066-7938(01)00138-5

Veleva, V., & Ellenbecker, M. (2001). Indicators of sustainable production: Framework and methodology. *Journal of Cleaner Production, 9*(6), 519–549. https://doi.org/10.1016/S0959-6526(01)00010-5

Vinodh, S., Ben Ruben, R., & Asokan, P. (2016). Life cycle assessment integrated value stream mapping framework to ensure sustainable manufacturing: A case study. *Clean Technologies and Environmental Policy, 18*(1), 279–295. https://doi.org/10.1007/s10098-015-1016-8

Vitale, G., Cupertino, S., Rinaldi, L., & Riccaboni, A. (2019). Integrated management approach towards sustainability: An Egyptian business case study. *Sustainability, 11*(5), 1244. https://doi.org/10.3390/su11051244

Wang, C., Wang, L., & Dai, S. (2018). An indicator approach to industrial sustainability assessment: The case of China's Capital Economic Circle. *Journal of Cleaner Production, 194*, 473–482. https://doi.org/10.1016/j.jclepro.2018.05.125

Watanabe, E. H., da Silva, R. M., Tsuzuki, M. S. G., Junqueira, F., dos Santos Filho, D. J., & Miyagi, P. E. (2016). A framework to evaluate the performance of a new industrial business model. *IFAC-PapersOnLine, 49*(31), 61–66. https://doi.org/10.1016/j.ifacol.2016.12.162

Winroth, M., Almström, P., & Andersson, C. (2016). Sustainable production indicators at factory level. *Journal of Manufacturing Technology Management, 27*(6), 842–873. https://doi.org/10.1108/JMTM-04-2016-0054

Yakovleva, N., & Flynn, A. (2004). Innovation and sustainability in the food system: A case of chicken production and consumption in the UK. *Journal of Environmental Policy and Planning, 6*(3–4), 227–250. https://doi.org/10.1080/1523908042000344096

Zarte, M., Pechmann, A., & Nunes, I. L. (2019). Indicator framework for sustainable production planning and controlling. *International Journal of Sustainable Engineering, 12*(3), 149–158. https://doi.org/10.1080/19397038.2019.1566410

Zeng, S. X., Liu, H. C., Tam, C. M., & Shao, Y. K. (2008). Cluster analysis for studying industrial sustainability: An empirical study in Shanghai. *Journal of Cleaner Production, 16*(10), 1090–1097. https://doi.org/10.1016/j.jclepro.2007.06.004