# An indicator-based sustainability assessment model in manufacturing organisations

Yasamin Eslami, Mario Lezoche, Hervé Panetto, Michele Dassisti

# An Indicator-based sustainability assessment model in manufacturing organisations


Yasamin Eslami[a*], Mario Lezoche[b] , Hervé Panetto[b], Michele Dassisti[c]

[a]*Ecole Centrale de Nantes, Laboratory LS2N, Nantes, France*

[b] *Université de Lorraine, CNRS, CRAN, Nancy, France.*

[c] *Department of Mechanical, Mathematics and Management DMMM, Politecnico di Bari, Bari, Italy*

*Corresponding Author: Yasamin Eslami
yasamin.eslami@ec-nantes.fr



Abstract-**Several tools and methodologies were developed for manufacturing organizations to evaluate their sustainability performance. However, the growing number of methods and tools casts some doubt upon the applicability, efficiency, and capability of those methods by real manufacturing companies. Therefore, tools that offer a standard assessment of the sustainability performance of the organization with a systematic view are much needed. On the other hand, tools are not only expected to qualitatively assess sustainability but to be capable of recognizing the opportunities that help manufacturers have a more sustainable organization. To that point, the present study will focus on the following questions: *"How can we help manufacturing organizations in terms of assessing sustainability?"* and *"How can we help manufacturing organizations discover opportunities to reach a better state of sustainability?"*. To respond to the questions, the study will use the indicator-based sustainability assessment framework that has been previously introduced by the authors and to develop a composite sustainability indicator. As a contribution to the literature, knowledge extraction and formalisation methods like Formal Concept Analysis (FCA) and Association Rule Mining (ARM) are employed in the development process of the composite Indicator. In fact, FCA and ARM helped create a novel method to select and weigh and aggregate indicators and therefore develop a composite sustainability index. Furthermore, the effectiveness of the proposed framework will be examined by a real case company.**



Keywords: *Indicator-based sustainability assessment, composite indicator, Formal Concept analysis (FCA), manufacturing organizations, holistic view*


## 1. Introduction

The enforcement of the bottom-up demand of customers for more sustainable products and the top-down need to comply with the governmental rules and regulations, made the manufacturing organizations think about ways, tools and methodologies to assess the level of sustainability in the manufacturing system. As the demand for sustainability elevates in manufacturing sectors, the performance assessment on the matter is compelled consequently.

By definition, sustainability assessment is a methodology *"that can help decision-makers and policy-makers decide what actions they should take and should not take in an attempt to make society more sustainable"*(Devuyst 2001). In simpler words, (Hacking and Guthrie 2008) defined sustainability assessment as "any process that directs decision-making towards sustainability". Noting the definitions, methods have been developed trying to find a way for companies to assess their sustainability state, help the companies choose between sustainable solutions, define, and solve problems on the way to sustainability and identify potential solutions. However, there is still a place for introducing tools and methodologies for sustainability assessment that truly help manufacturers evaluate their organizations' performance in terms of sustainability without any inaccuracies.

Regarding the growing methods and tools for sustainability assessment, Moldavska & Welo (2015) questioned the applicability of those methods by real manufacturing companies and stated that there is a gap between the needs of manufacturing companies to improve their performance in terms of sustainability and the efficiency and capability of the available assessment tools. In addition, the literature still lacks a framework that can evaluate sustainable manufacturing as a whole. On the other hand, lack of a systematic view and standardization in the existing assessment methods make them ad hoc and also not capable of recognizing the opportunities to have a sustainable organization (Smullin 2016).

Indicator-based sustainability assessment has been recognized as one of the most applicable methodologies for the sustainability assessment of an organization (Nardo et al. 2005). Therefore, there is a strong tendency toward introducing composite indicators by aggregating different indices related to different aspects of sustainability. Based on (Karnib 2016) introducing an aggregated sustainability index, makes it possible to summarize the relationship among different indicators; facilitates communication with the concerned sustainable system manager; paves the path to monitoring and reporting sustainability and finally allows the comparison of progress in sustainability performance in different systems through different years.

Taking into account the challenges identified above, this paper aims to respond to two main questions: *"How can we help manufacturing organizations in terms of assessing sustainability?"* and *"How can we help manufacturing organizations discover opportunities to reach a better state of sustainability?"*. Essentially, an indicator-based sustainability assessment framework has been proposed by the authors (Yasamin Eslami et al. 2018, 2020), which will be employed for sustainability assessment purposes in the present study. Mainly, the framework tries to address manufacturing needs as discussed above and cope with the challenges manufacturing organizations are imposed while assessing their performance in terms of sustainability. Additionally, the framework is aiming at grouping highly diverse aspects in a common place to assess sustainability holistically.

This paper will first give an overview of the creation of the previously proposed framework, then it will delineate the development of the composite sustainability index which also encompasses the selection of indicators and their allocation in the framework. Finally, a real case company will be examined to observe the effectiveness of the proposed framework. The paper will end with a conclusion while stating the limitation and the future of the work.

## 2. Recapitulation of the development of the indicator-based sustainability assessment framework

### 2.1. The Systematic Literature Reviews

Acknowledging the urge manufacturing organizations are faced to improve their performance in terms of sustainability and the need for a systematic view of sustainability assessment tools, a thorough literature review has been done by the authors (Yasamin Eslami et al. 2018, 2020; Y. Eslami et al. 2019) on introducing a sustainability assessment framework with a holistic view for manufacturing organization. To find out the essentials of the framework, research questions arose in a step-by-step study:

- How is sustainability defined through its dimensions?
- What sub-dimensions can denominate sustainable manufacturing?
- How can sustainable manufacturing be achieved?
- How can sustainable manufacturing be assessed?

To scrutinize the questions and to reach a proper answer for each, two sets of systematic literature reviews were conducted through which the essence of sustainable manufacturing and sustainability assessment was extracted from investigating the scientific domain. The studies first (Yasamin Eslami et al. 2018) led to a detailed analysis of environmental, economic, and social sub-dimensions and the concerns that stand out regarding each dimension from the point of view of the scientists. In the second one (Yasamin Eslami et al. 2020), the tools and the dominant issues in terms of assessment were explored to get a step closer to the definition of the framework. On the other hand, to find out about the possible existing gap(s) between the scientific domain and the manufacturing domain in practice, 100 manufacturing organizations were studied (Yasamin Eslami et al. 2020) to inspect their strategies and the trends toward the concept of sustainability and its dimensions and sub-dimensions. Acknowledging what has been observed, the indicator-based sustainability assessment framework was proposed to provide a holistic view of the sustainability performance of a manufacturing organization.

### 2.2. Assessment Framework: The proposed three-dimensional framework

As mentioned above, the framework is the result of the studies done in both literature and the industry. By addressing the research questions defined in the review, it was concluded that the framework to address sustainability assessment in a manufacturing organization needs to cover three main criteria: 1) the three pillars of sustainability, 2) all levels of the organization (product, process, and system), and 3) the whole life cycle of the product.

On the other hand, both studies revealed that a sustainability assessment framework should a) provide a holistic view of the organization; b) comply with standards; c) be simple and manageable so it can be used by the manufacturers; d) identify the gaps and loopholes lead to low sustainable performance and finally e) be helpful in identification of overlaps and stipulation of preferred solutions. To re-join with the results, the three-dimensional framework is proposed as shown in Figure 1 to develop and to cover the gap that exists in the literature: the lack of a model-based and holistic assessment for manufacturing organizations.

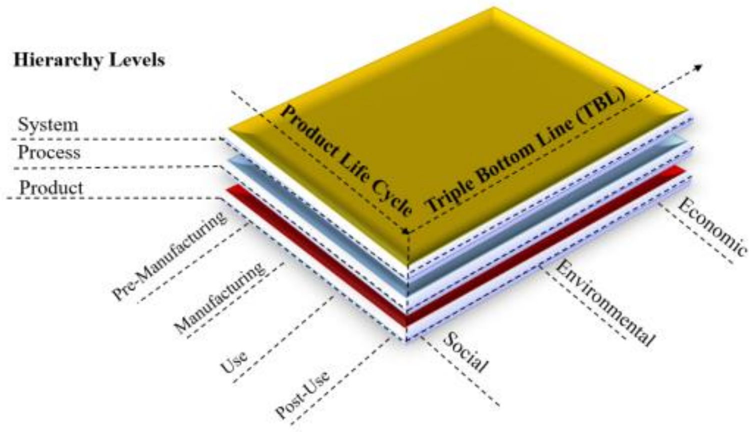



Figure 1. Three-Dimensional framework for sustainability assessment (Y. Eslami et al. 2019)

### 2.3.Assessment Method: An indicator-based framework

As mentioned above, a study was done on the adopted tools for sustainability in literature by the authors (Y. Eslami et al. 2019) to come up with a method to base the framework. To that point, a categorization of the methodologies for sustainability assessment in manufacturing was done on the primary tools used for assessment. As shown in Figure 2, Indicator based assessments were ranked first with a highly noticeable difference. Therefore, the proposed framework in the present study would be also an indicator-based assessment tool.

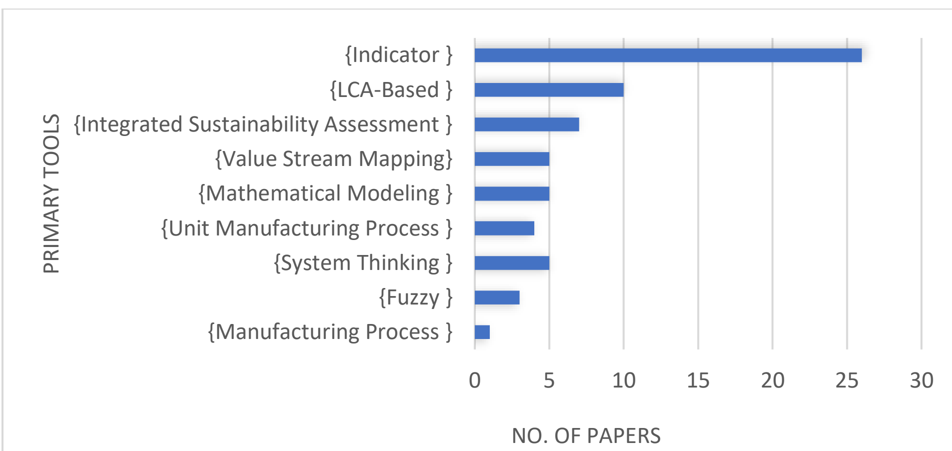



Figure 2.Primary tools for sustainability assessment after FCA analysis (Y. Eslami et al. 2019)

### 2.4. Indicator sets for the framework: GRI as a standard indicator set

In the literature, standard sets of indicators are presented. They were studied and analysed according to the fulfilment of the following criteria: 1) **Level of Application**: As the aim of the study clearly stated, the assessment needs to be done throughout the whole organisation. Therefore, the tools which are not applicable or adaptable for the factory levels were excluded from the study.

**2) Cross-Industry Comparison:** The chosen set of indicators needs to have general applicability to enable the decision-makers to make a comparison between various organizations without limitation. Thus, the product/process-specific sets limit the general use of the proposed study. **3) Holistic View over Sustainability:** As mentioned in Bellagio principle "*Assessment of progress toward sustainable development should: consider the well-being of social, ecological, and economic sub-systems, their state as well as the direction and rate of change of that state, of their component parts, and the interaction between parts.*" Therefore, the tools which are specified on just one feature, i.e., environmentally focused ones, might limit the assessment in the proposed study and will not be considered.

As shown in **Erreur ! Source du renvoi introuvable.**, unlike OECD, RPA and DJSI, most of the tools covered all three dimensions of sustainability. Some like ITT Flyget sustainability index, General Motors, Composite Sustainable Development Index and Ford of Europe were product or process specific and were too much in detail that made the general applicability of the tools limited; at the same time tools such as Barometer of Sustainability were too general that makes the assessment validity and data accuracy a bit questionable. On the other hand, SDF, and UN-CSD are reasonable sets but since the base has been defined for the country level, prior adaptation is required in case of willingness to employ them on the factory level which makes the process of assessment, time and resource-consuming. Nevertheless, tools like GRI, NIST and LCSP appear to meet all our needs. However, NIST seems to be not an open-source set of indicators anymore and LCSP considers a limited and generalized assessment. therefore, GRI seems to be an effective selection of standard indicators which applies to the organization, product and process level while it is giving a holistic look at sustainability in a reasonable amount of time, and it makes cross-company comparison feasible. Indicators of GRI which are related to the three dimensions of sustainability are available through the website ( https://www.globalreporting.org/standards/gri-standards-download-center/).

GRI is a voluntary sustainability reporting initiative and published its first report on company sustainability assessment intending to support common sustainability goals with a holistic view of all three pillars of sustainability. The reporting set included 81 indicators expressed in various measurement units. The indicators are defined in 4 different groups, group 100 which defines the universal standards, group 200 on economic topics, group 300 on environmental topics and group 400 on social topics. They can be used by any company regardless of the size and the business which makes cross-industry comparison possible. The GRI report proposes the sustainability performance of the organizations and can assist decision-makers to track the performance at multiple levels of the organization as management, operation, and internal and external stakeholders.

Table 1. Indicators' set review

| Indicator Set | Description | Reference. | Level Of Application | Holistic View | | | Cross Company |
|---|---|---|---|---|---|---|---|
| | | | | Social | Environmental | Economic | |
| - | Barometer of Sustainability | (Prescott-Allen.,1997) | Factory level | Y | Y | N | ● |
| GRI | Global Reporting Initiatives | (Global Reporting Initiative,2011) | Organization Level | Y | Y | Y | ● |
| DJSI | Dow Jones Sustainability Index | (Dow Jones Sustainability Index,2012) | Organization Level | N | N | Y | ▲ |
| ISO 14031 | | (ISO 14031:2013 ,1999) | Organization Level | Y | Y | Y | ○ |
| IChemE | Institution of Chemical Engineering | (Labuschagne, Brent, and van Erck 2005) | factory Level | Y | Y | Y | ○ |
| LCSP | The Lowell Centre for Sustainable Production | (Veleva and Ellenbecker 2001) | Organization level | Y | Y | Y | ● |
| CSDI | Composite Sustainable Development Index | | Organization Level | Y | Y | Y | ▲ |
| | ITT Flyget Sustainability Index | (Chen et al. 2013) | factory Level | Y | Y | Y | ○ |
| UNCSD | UN Commission on Sustainable Development | (UN.CSD,2007) | Country Level | Y | Y | Y | ● |
| FPSI | Ford of Europe's Product Sustainability Index | (Schmidt & Taylor, 2007) | Product Level | Y | Y | Y | ○ |
| GM MSM | General Motors Metrics for Sustainable Manufacturing | (Dreher et al.,2009) | Product Level | Y | Y | Y | ▲ |
| SDF | Sustainable Development Framework | (European Commission, 2009) | To be applicable on the factory level | Y | Y | Y | ▲ |
| NIST | National Institute of Standard and Technology Sustainable Manufacturing Indicator Repository | (Thompson 2011) | Organization/Process/Product Level | Y | Y | Y | ● |
| OECD | Organization for Economic Co-Operation and Development (OECD) Sustainable Manufacturing Toolkit | (OECD, 2011) | organization level | N | Y | N | ● |

Y=YES
N=NO
NA=Not Applicable

▲= Covered with limitation
○ = Not Covered
● = Covered

## 2.5.Framework details: The cubical shape

To describe the shape of the proposed framework, Figure 3 is presented. The intersection among the three dimensions of the framework will create cubes that represent the sustainability dimension it belongs to, the hierarchical level it covers, and wherein life cycle of the product it is placed.
To respond to the need of having a global and not an ad hoc methodology, each of the mentioned cubical will introduce a standard indicator whose allocation process will be explained thoroughly after.

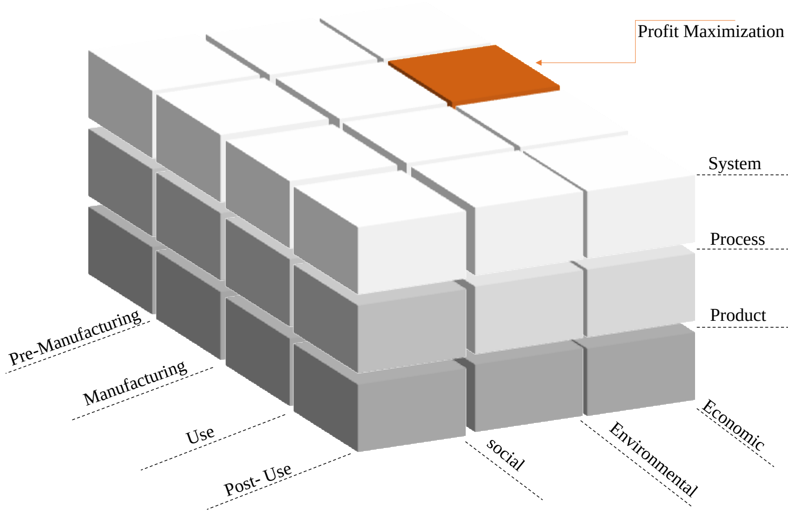



Figure 3. An example of a sustainability cubical in the framework

### 2.6. Purpose and benefits of the framework

The reference framework is aiming at grouping highly diverse aspects in a common place to holistically assess sustainability. The special characteristics of the framework are twofold: (1) it looks at the big picture while maintaining the awareness of the interconnectedness of the components of the picture; and (2) it combines the hierarchical level inside a manufacturing organization (product, process and system) with the life cycle of the product (pre-manufacturing, manufacturing, use and post-use) for the three main dimensions of sustainability (economic, social and environmental). In addition, the 6R concept (Redesign, Remanufacture, Reuse, Recover, Recycle and Reduce) will be considered inside the life cycle of the product at the "post-use" stage.

Using the present framework, the conditions have been created for the description, implementation and assessment of the sustainability concept in different dimensions. With its dimensions and its holistic view, it permits the maximum traceability of the causes and effects of sustainability in the whole organization. It is characterized in a way that it looks at the big picture while maintaining the awareness of the interconnectedness of its three axes: (1) sustainability dimensions (environmental, economic, and social), (2) hierarchical level of the organization (system, product, and process) and (3) the life cycle stages of the product (pre-manufacturing, manufacturing, use and post-use). Therefore, it enables the manufacturers to detect a sustainability prevention cause; to know to what hierarchical level it belongs; to discover in which stage of the product life cycle it occurs and to know if the specific problem comes from environmental, social or economic issues. Finally, with the indicator-based choice, it presents a generic-standardized assessment which impedes further confusion due to the abundance of the introduced-ad-hoc indicators for the manufacturers.

## 3. Filling out the framework

### 3.1.Indicator selection and allocation

Not all GRI indicators would meet the purpose of the proposed framework, consequently, some should be selected and then allocated to the cubes of the framework. The whole adopted strategy in this step is described in Figure 4 (SLR in the figure refers to the Systematic Literature reviews done by the authors).
Principally, one of the contributions of the present study comes with the indicator selection process, for which a new procedure is suggested by the authors using the Formal Concept Analysis (FCA) and the association rules (described in the following sectors).

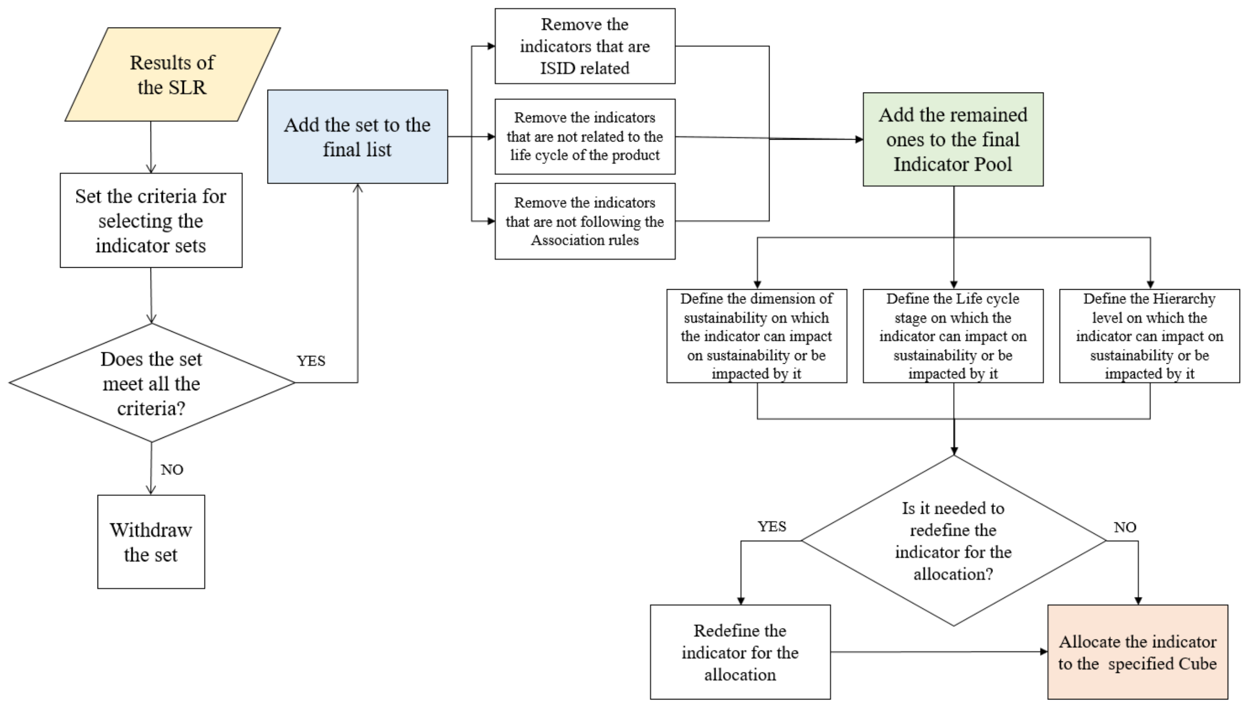



Figure 4. strategy adopted for selection and allocation of indicators

### 3.2.Methodologies applied: Formal Concept Analysis and the Association Rules

Formal Concept Analysis (FCA) is based on the lattice theory (Wille 1982) and defines a formal context to represent the relationship between objects and attributes in the studied domain. FCA is best used for knowledge representation, data analysis, and information management. It detects conceptual structures in data and consequently extraction of dependencies within the data by forming a collection of objects and their properties (Mezni & Sellami, 2017; Wajnberg, Lezoche, Massé, Valtchev, & Panetto, 2017).

On the other hand, FCA can also employ association rule mining which is a method for discovering interesting relations between variables. Let $I = \{i_1, i_2, \ldots, i_n\}$ be a set of n binary attributes called items. Let $D = \{t_1, t_2, \ldots, t_m\}$ be a set of transactions called the database. Each transaction in $D$ has a unique transaction ID and contains a subset of the items in the $I$. A rule is defined as an implication of the form $X \Rightarrow Y$ where $X, Y \subseteq I \text{ and } X \cap Y = \emptyset$. The sets of items (for short itemsets) $X$ and $Y$ are called antecedent and consequent of the rule (Hornik, Grün, and Hahsler 2005). The defined rule can mean that if $X$ is chosen then it is likely that $Y$ is also selected.

However, to be able to extract rules measures are defined to help the process of decision-making. The best-known measures are Support and confidence (Liu and Li 2017) that are used in the present study.

The support supp(X) of an itemset X is defined as “the proportion of transactions in the data set which contain the itemset.” For example, if the support of itemset X is 0.4 it means that the itemset occurs in 40% of all transactions. On the other hand, the confidence of a rule is defined $conf(X \Rightarrow Y) = supp(X \cup Y)/supp(X)$ and can be interpreted as “an estimate of the probability $P(Y|X)$, the probability of finding the antecedent of the rule in transactions under the condition that these transactions also contain the consequent”. For example, if the $conf(X \Rightarrow Y) = 0.5$, it means the rule $X \Rightarrow Y$ is correct in 50% of the transactions containing $X$ and $Y$ (Hornik, Grün, and Hahsler 2005).

### 3.3. Selection process: Criteria for selecting the indicators

As previously mentioned, the GRI standard was the main source for selecting the indicators. however, to be more objective-oriented, an investigation was done among GRI indicators to select the ones that meet the focal purposes of the study. Four main criteria were defined for the process of selection of the indicators.

1. Criteria 1 [C1]: The selected indicators should be measurable (Quantitative /Qualitative).
2. Criteria 2 [C2]: The selected indicators should be adaptable to the framework's three dimensions.
3. Criteria 3 [C3]: The selected indicators should be related to the industry targets SDGs (Sustainable Development Goals (“SDG”, 2015)).
4. Criteria 4 [C4]: The selected indicators should follow the Association Rules (AR) derived from the study of GRI indicators in manufacturing organizations (refer to (Eslami et al. 2019) for the complete analysis and the relationship between the indicators).

The first two criteria are clear in definition and there is no need for further elaboration. On the other hand, Criteria 3 and Criteria 4 require to be described and detailed as in the following:

#### 3.3.1. [C3]: Sustainable Development Goals

Sustainable Development Goals (“SDG”, 2015), constitute the core of the 2030 Agenda for Sustainable Development adopted by the international community on 25 September 2015, the new development framework that seeks to transform our world and will guide all global, regional and national development endeavours until the year 2030. These Goals, and their associated targets, frame the 2030 Agenda with the vision and ambition to both achieve a balance among the three dimensions of sustainable development – environmental, social and economic – and integrate them into a universal and visionary framework for global cooperation and action.

UNIDO (United Nations Industrial Development Organization), developed ISID (Inclusive and Industrial Sustainable Development) which claims that industrial development must include all countries and all peoples, as well as the private sector, civil society organizations, multinational development institutions, and all parts of the UN system, and offer equal opportunities and equitable distribution of the benefits of industrialization to all stakeholders. The term “sustainable” addresses the need to decouple the prosperity generated by industrial activities from excessive natural resource use and negative environmental impacts (“UNIDO,” 2013). ISID centres around goal 9 of the sustainable development goals, through which, the Member States of the United Nations call upon the international community to “build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”. ISID can therefore serve as a primary engine not only of job creation and economic growth but also of technology transfer, investment flows and skills development. On the other hand, ISID makes a critical contribution towards addressing the economic, social and environmental dimensions of development systemically and holistically as shown in Figure 5.


Figure 5.SDGs ranked by their importance in ISID

Based on the abovementioned, one major consideration in the process of selection of the indicators for the present study was their relations with the defined goals by ISID as “Industrial related sustainable development goals” (Figure 5). In the process of selection, the SDG(s) that the indicators are referring to was taken into account and its relation with industry was also considered (“SDG Compass Annex,” 2017). In other words, the indicators which were only addressing the SDGs that are not highly ranked in ISID or have not been frequently addressed by manufacturers were eliminated.

### 3.3.2. [C4]: The Association Rules (AR)

As described previously, FCA is a conceptual framework that can make data more understandable. It is based on the lattice theory and defines a formal context to represent the relationship between objects and attributes in the studied domain. In addition to what was formerly explained, FCA employs association rule mining which is a method for discovering interesting relations between variables.

Let $I = \{i_1, i_2, \ldots, i_n\}$ be a set of n binary attributes called items. Let $D = \{t_1, t_2, \ldots, t_m\}$ be a set of transactions called the database. Each transaction in $D$ has a unique transaction ID and contains a subset of the items in $I$. A rule is defined as an implication of the form $X \Rightarrow Y$ where $X, Y \subseteq I \; and \; X \cap Y = \emptyset$. The sets of items (for short itemsets) $X$ and $Y$ are called antecedent and consequent of the rule (Hornik, Grün, and Hahsler 2005). The defined rule can mean that if $X$ is chosen then it is likely that $Y$ is also selected. However, to be able to extract rules measures are defined to help the process of decision-making. The best-known measures are Support and confidence (Liu and Li 2017) that are used in the present study.

The support supp(X) of an itemset X is defined as "the proportion of transactions in the data set which contain the itemset." For example, if the support of itemset X is 0.4 it means that the itemset occurs in 40% of all transactions. On the other hand, the confidence of a rule is defined $conf(X \Rightarrow Y) = supp(X \cup Y)/supp(X)$ and can be interpreted as "an estimate of the probability $P(Y|X)$, the probability of finding the antecedent of the rule in transactions under the condition that these transactions also contain the consequent". For example, if the $conf(X \Rightarrow Y) = 0.5$, it means the rule $X \Rightarrow Y$ is correct in 50% of the transactions containing $X$ and $Y$ (Hornik, Grün, and Hahsler 2005).

However, the aim is to find frequent itemset ( the indicators in the present study) which can be represented as a simplification of the unsupervised learning problem called "mode finding" or "bump hunting"(Hastie, Tibshirani, and Friedman 2009). The goal is to find prototype values so that the probability density evaluated at these values is sufficiently large.

As a part of the study of the indicators for sustainability assessment, authors in ( Eslami et al. 2019) focused on indicator-based sustainability assessment in manufacturing organizations and tried to scrutinize the meaning of the choice of indicators by the organizations. Furthermore, 100 organizations were inspected on their choice of GRI indicators for assessing their sustainability status. FCA was applied as the analysis to investigate the strategies of the organizations toward sustainability and help decision-makers define a more sustainable strategy for the organization considering the trends. The study revealed which two indicators are used the most as a combination by the manufacturers and discussed the relationship between the chosen indicators. To select indicators in the present study, the GRI indicators employed by the 100 manufacturing organizations were put for further analysis so the highest and most probable correlation among the indicators can be defined. Consequently, the association rules between the indicators were extracted considering the minimum support level as 20% and minimum confidence level as 50%. The minimum levels were defined by a try-and-error procedure. To serve this purpose, the software LATTICE MINER 2.0 was adopted.

Each indicator that could pass the first three criteria of the selection process was considered the antecedent and its association rules were investigated. Consequently, the consequents with the highest confidence level were analysed and if they were eligible (based on the selection criteria formerly defined) they were selected and added to the indicator pool. As an example, Table 2 shows the association rules for indicator 201-1(Unfortunately, due to the vast number of association rules, the exhibition of all rules is not possible here) which was the most ranked indicator in the economic dimension. Looking through the rules, the highest confidence belonged to indicator 205-2 which is over the boundaries of the Life cycle of the product therefore it is eliminated from the list. Then came indicator 203-2 which unlike the other one was eligible based on the other 3 filters. Hence, the indicator was considered a candidate. Exploring the rules of the rest of the indicators, indicator 203-2 was always among the consequences with the highest confidence so it was chosen to be added to the final indicator pool.

Table 2. Association rules extracted for the min support level of 20% and min confidence level of 50% for the indicator 201-1

| # | antecedent | => | consequence | support | confidence |
|---|---|---|---|---|---|
| 1 | {201-1} | => | {203-2} | 55.00% | 63.95% |
| 2 | {201-1} | => | {205-2} | 62.00% | 72.09% |
| 3 | {201-1} | => | {205-3} | 54.00% | 62.79% |
| 4 | {201-1} | => | {201-2} | 47.99% | 55.81% |
| 5 | {201-1} | => | {201-3} | 38.99% | 45.34% |
| 6 | {201-1} | => | {204-1} | 44.99% | 52.32% |

### 3.3.3. Selected Indicators

The selection process (illustrated in detail in Figure 6) followed the 4 selection Criteria mentioned above. Each indicator that could pass the first three criteria was considered as the antecedent and its association rules were investigated. Accordingly, the consequents with the highest confidence level were analysed. If they were eligible (based on the criteria formerly defined) they were selected and added to the indicator pool. In the end, 39 indicators out of 81 were selected for all three dimensions of sustainability and are shown in Figure 6. Selection of the indicators in detail

Table 3. The table also refers to some of the selection criteria.

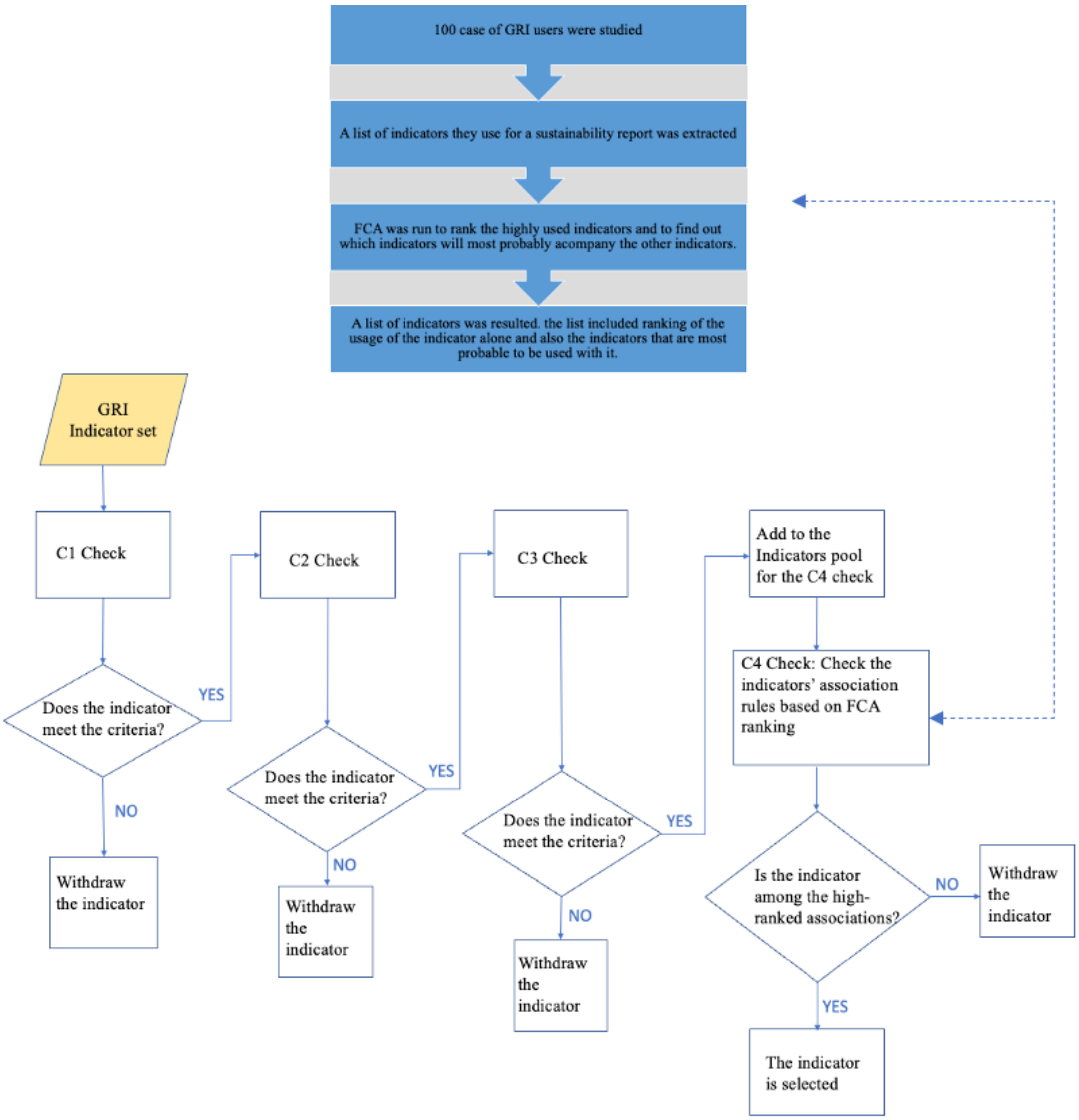



Figure 6. Selection of the indicators in detail

Table 3. selected indicators

| **Indicators** | **Code** | **C1** | **C2** | | | **C3** |
|---|---|---|---|---|---|---|
| | | | **Economic** | **Environmental** | **Social** | |
| Direct economic value generated and distributed | 201-1 | Quantitative | ● | | | 8,9 |
| Financial implications and other risks and opportunities due to climate change | 201-2 | Quantitative | ● | | | 13 |
| Significant indirect economic impacts | 203-2 | Quantitative | ● | | | 1,3 |

| Indicators | Code | C1 | C2 | | | C3 |
|---|---|---|---|---|---|---|
| | | | Economic | Environmental | Social | |
| Proportion of spending on local suppliers | 204-1 | Quantitative | ● | | | 8 |
| Operations assessed for risks related to corruption | 205-1 | Quantitative | ● | | ● | 16 |
| Material used by weight or volume | 301-1 | Quantitative | | ● | | 8,12 |
| Specific recycled material used | 301-2 | Quantitative | | ● | | 8,12 |
| Reclaimed products and their packaging materials | 301-3 | Quantitative | | ● | | 8,12 |
| Energy consumption within the organization | 302-1 | Quantitative | | ● | | 7,8,12,13 |
| Energy consumption outside of the organization | 302-2 | Quantitative | | ● | | 7,8,12,13 |
| Energy intensity | 302-3 | Quantitative | | ● | | 7,8,12,13 |
| Reduction of energy Consumption | 302-4 | Quantitative | | ● | | 7,8,12,13 |
| Reduction of energy required for product and service | 302-5 | Quantitative | | ● | | 7,8,12,13 |
| Water recycled and reused | 303-3 | Quantitative | | ● | | 6 |
| Direct (Scope 1) GHG emissions | 305-1 | Quantitative | | ● | | 3,12,13,14,15 |
| Energy Indirect (Scope 2) GHG emissions | 305-2 | Quantitative | | ● | | 3,12,13,14,15 |
| Other Indirect (Scope 3) GHG emissions | 305-3 | Quantitative | | ● | | 3,12,13,14,15 |
| GHG emissions Intensity | 305-4 | Quantitative | | ● | | 3,13,14,15 |
| Reduction of GHG emissions | 305-5 | Quantitative | | ● | | 13,14,15 |
| Nitrogen oxides (NOX), sulfur oxides (SOX), and other significant air emissions | 305-7 | Quantitative | | ● | | 3,12,14,15 |
| Waste water amount | 306-1 | Quantitative | | ● | | 3,6,12,14 |
| Waste by type and disposal method | 306-2 | Quantitative | | ● | | 3,6,12 |
| Significant Spills | 306-3 | Quantitative | | ● | | 3,6,12,14,15 |
| Negative environmental impacts in the supply chain and actions taken | 308-2 | Qualitative | | ● | | 6,14,15 |
| New employee hires and employee turnover | 401-1 | Quantitative | | | ● | 5,8,10 |
| Minimum notice periods regarding operational changes | 402-1 | Quantitative | | | ● | 8 |
| Types of injury and rates of injury, occupational diseases, lost days, and absenteeism, and number of work-related fatalities | 403-2 | Qualitative | | | ● | 8 |
| Average hours of training per year per employee | 404-1 | Quantitative | | | ● | 4,5,8,10 |
| Percentage of employees receiving regular performance and career development reviews | 404-3 | Quantitative | | | ● | 5,8,10 |
| Operations that have been subject to human rights reviews or impact assessments | 412-1 | Quantitative | | | ● | 16 |
| Operations with local community engagement, impact assessments, and development programs | 413-1 | Quantitative | | | ● | 1,2 |
| Operations with significant actual and potential negative impacts on local communities | 413-2 | Qualitative | | | ● | 1,2 |
| New suppliers that were screened using social criteria | 414-1 | Quantitative | | | ● | 5,8,16 |
| Incidents of non-compliance concerning the health and safety impacts of products and services | 416-2 | Quantitative | | | ● | 16 |
| Requirements for product and service information and labelling | 417-1 | Quantitative | | | ● | 12 |
| Incidents of non-compliance concerning product and service information and labelling | 417-2 | Quantitative | | | ● | 16 |

| Indicators | Code | C1 | C2 | | | C3 |
|---|---|---|---|---|---|---|
| | | | Economic | Environmental | Social | |
| Incidents of non-compliance concerning marketing communications | 417-3 | Quantitative | | | ● | 16 |
| Substantiated complaints concerning breaches of customer privacy and losses of customer data | 418-1 | Quantitative | | | ● | 16 |

***Code: the codes are the defined codes for the indicators in GRI sets. 200 is dedicated to Economic topics, 300 to Environmental and 400 to Social.**

### 3.4.Indicators' allocation

After the selection of the indicators, they were allocated to the cubes of the framework. In the allocation process, 3 main areas were considered: 1) to which dimension of sustainability they belong, 2) to what stage of the life cycle they relate to and finally 3) what hierarchical level of organization they deal with. On the other hand, some indicators needed to be broken into different stages based on the cube they were assigned to. For instance, 201-1, which covers the economic value generated, must be divided into two groups: economic value created, and economic value distributed in different stages of the life cycle. The two defined stages are recognizable by different colours in the layers. As another example, the three indicators of 305-1(Direct (Scope 1) GHG emissions), 305-2 (Energy Indirect (Scope 2) GHG emissions) and 305-3 (Other Indirect (Scope 3) GHG emissions) can be merged and create a new indicator as "the total GHG emissions".

## 4. Development of the composite indicator

After the allocation of the selected indicators, a series of actions needed to be taken to develop the composite indicator which represents the index of sustainable development. Figure 7 demonstrates a schematic approach toward creating the index and the steps are described in detail in the following sectors.

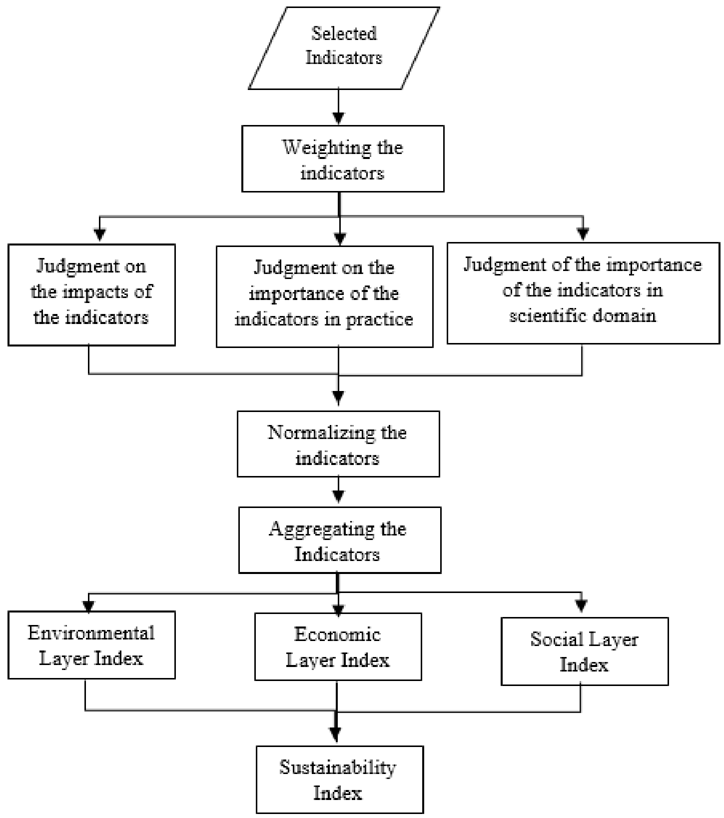



Figure 7. Flowchart for creating a composite indicator

## 4.1.Weighting indicators

The focal point of developing a composite indicator is the meaningful combination of various dimensions which are measured in different scales (Nardo et al., 2005). Consequently, the importance (weight) of the indicators selected for the assessment procedure has a significant effect on the final composite indicator. Different techniques to weigh indicators have been introduced by OECD ( Nardo et al., 2005).Among which, some are derived from statistical models such as factor analysis, data envelopment analysis, and unobserved components models, or participatory methods such as budget allocation processes, analytic hierarchy processes and conjoint analysis. However, weights are recognized as “valued judgements” regardless of the technique used for their calculation(Tokos, Pintarič, and Krajnc 2012). In the present study, three main criteria have been used to weigh the selected indicators:

1. **Their impact on sustainability:** the indicators were judged whether their increasing values have a positive impact on sustainability development ($I^+$) or a negative impact ($I^-$). However, in Table 4, some indicators’ impact is shown as ND (Not definable) since they depend on the specific organization employing them therefore, a general address of the impact is impossible.
2. **The importance of the indicator in the scientific domain**: in (Eslami et al. 2018) a very thorough analysis was done on dimensions and sub-dimensions of sustainability. The importance of sustainability in the scientific domain was also investigated. Regarding the results derived from that

study, a weight has been defined to the indicator due to the sub-dimension it belongs to and according to the solo or pair-application of the sub-dimension formerly stipulated (Table 5).

3. **The importance of the indicator in the manufacturing domain in practice:** based on the explorations done in (Eslami et al. 2018) and the brief description mentioned above, a weight has been dedicated to each indicator based on their application in practice which reflects the importance of the selected indicator from the point of view of manufacturers.

Table 4. Selected indicators and their impact

| Indicators | Code | Economic | Environmental | Social | Impact |
|---|---|---|---|---|---|
| Direct economic value generated and distributed | 201-1 | ● | | | $I^+$ |
| Financial implications and other risks and opportunities due to climate change | 201-2 | ● | | | ND |
| Significant indirect economic impacts | 203-2 | ● | | | ND |
| Proportion of spending on local suppliers | 204-1 | ● | | | $I^+$ |
| Operations assessed for risks related to corruption | 205-1 | ● | | ● | ND |
| Material used by weight or volume | 301-1 | | ● | | $I^-$ |
| Specific recycled material used | 301-2 | | ● | | $I^+$ |
| Reclaimed products and their packaging materials | 301-3 | | ● | | $I^+$ |
| Energy consumption within the organization | 302-1 | | ● | | $I^-$ |
| Energy consumption outside of the organization | 302-2 | | ● | | $I^-$ |
| Energy intensity | 302-3 | | ● | | $I^+$ |
| Reduction of energy Consumption | 302-4 | | ● | | $I^+$ |
| Reduction of energy required for product and service | 302-5 | | ● | | $I^+$ |
| Water recycled and reused | 303-3 | | ● | | $I^+$ |
| Direct (Scope 1) GHG emissions | 305-1 | | ● | | $I^-$ |
| Energy Indirect (Scope 2) GHG emissions | 305-2 | | ● | | $I^-$ |
| Other Indirect (Scope 3) GHG emissions | 305-3 | | ● | | $I^-$ |
| GHG emissions Intensity | 305-4 | | ● | | $I^-$ |
| Reduction of GHG emissions | 305-5 | | ● | | $I^+$ |
| Nitrogen oxides (NOX), sulfur oxides (SOX), and other significant air emissions | 305-7 | | ● | | $I^-$ |
| Waste water amount | 306-1 | | ● | | $I^-$ |
| Waste by type and disposal method | 306-2 | | ● | | $I^-$ |
| Significant Spills | 306-3 | | ● | | $I^-$ |
| Negative environmental impacts in the supply chain and actions taken | 308-2 | | ● | | $I^-$ |
| New employee hires and employee turnover | 401-1 | | | ● | ND |
| Minimum notice periods regarding operational changes | 402-1 | | | ● | ND |
| Types of injury and rates of injury, occupational diseases, lost days, and absenteeism, and number of work-related fatalities | 403-2 | | | ● | $I^-$ |
| Average hours of training per year per employee | 404-1 | | | ● | $I^+$ |
| Percentage of employees receiving regular performance and career development reviews | 404-3 | | | ● | $I^+$ |
| Operations that have been subject to human rights reviews or impact assessments | 412-1 | | | ● | $I^+$ |
| Operations with local community engagement, impact assessments, and development programs | 413-1 | | | ● | $I^+$ |
| Operations with significant actual and potential negative impacts on local communities | 413-2 | | | ● | $I^-$ |
| New suppliers that were screened using social criteria | 414-1 | | | ● | $I^+$ |

| Indicators | Code | Economic | Environmental | Social | Impact |
|---|---|---|---|---|---|
| Incidents of non-compliance concerning the health and safety impacts of products and services | 416-2 | | | ● | $I^-$ |
| Requirements for product and service information and labeling | 417-1 | | | ● | ND |
| Incidents of non-compliance concerning product and service information and labeling | 417-2 | | | ● | $I^-$ |
| Incidents of non-compliance concerning marketing communications | 417-3 | | | ● | $I^-$ |
| Substantiated complaints concerning breaches of customer privacy and losses of customer data | 418-1 | | | ● | $I^-$ |

Table 5. Weight of sub-dimensions calculated based on (Eslami et al. 2018)

| Sub-Dimension | Related GRI | Related SDG | weight |
|---|---|---|---|
| Economic Performance | 201 | 8,9,13, | 0.53 |
| Indirect Economic Impacts | 203 | 1,3,5,8,9,11 | 0.30 |
| Procurement Practices | 204 | 8 | 0.17 |
| Anti-Corruption | 205 | 16 | 0.05 |
| Material | 301 | 8,12 | 0.17 |
| Energy | 302 | 7,8,12,13 | 0.21 |
| Water | 303 | 6,12 | 0.16 |
| Emission | 304 | 6,14,15 | 0.20 |
| Effluents and Waste | 306 | 3,6,12,14,15 | 0.20 |
| Supplier Environmental Assessment(transport) | 308 | 6,14,15 | 0.07 |
| Labour/Management Relations | 402 | 8 | 0.17 |
| Occupational Health and Safety | 403 | 3,8,16 | 0.18 |
| Training and Education | 404 | 4,5,8,10 | 0.08 |
| Human Right Assessment | 412 | 16 | 0.08 |
| Local Communities | 413 | 1,2 | 0.08 |
| Supplier Social Assessment (social policy compliance) | 414 | 5,8,16 | 0.12 |
| Product responsibility | - | 8,12 | 0.12 |
| Marketing and Labelling (customer satisfaction) | 417 | 12,16 | 0.12 |

### 4.2.Normalization

So-far-selected indicators are all expressed in different units while normalisation is needed for aggregating them into a composite unit. Pollesch & Dale (2016) stated that the major motivation for normalization in sustainability assessment is "to *transform measurement of indicators, typically obtained in different units, to a common unit of measurement to compare them to or prepare them for inclusion in an aggregate score of sustainability*." Plenty of normalization methods have been introduced and discussed by OECD ( Nardo et al. 2005), among which some are used for sustainability assessment. (Krajnc and Glavič 2005) suggested two schemes for sustainability assessment. The first one, which has been the reference for the formalisation process and therefore will be used for the present study, normalizes the indicator $i$ by dividing its value in time (year) $t$ with its average value of all the time in years measured. (Equations (1) and (2)).

$$I_{N,ijt}^{+} = \frac{I_{A,ijt}^{+}}{\bar{I}_{A,ij}^{+}} \quad (1)$$

$$I_{N,ijt}^{-} = \frac{\bar{I}_{A,ij}^{-}}{I_{A,ijt}^{-}} \quad (2)$$

Where $I_{N,ijt}^{+}$ is the normalized indicator $i$ (with positive impact) for a group of indicators $j$ for time (year) $t$ and $I_{N,ijt}^{-}$ is the normalized indicator $i$ (with negative impact) for a group of indicators $j$ for the same time (year) $t$.

Nonetheless, the scheme offers the possibility of incorporating different kinds of quantities with different units of measurement. Since all indicators are normalized through this scheme, the clear compatibility of different indicators can be named as the advantage of the abovementioned scheme used for the present study.

### 4.3.Aggregation

Based on the above-mentioned and due to the abundance of indicators for sustainability assessment, having a holistic view of the sustainable development of the organization has become a matter of importance. Decision-makers most likely care for integrated information since it eases the evaluation of the performance of the organization (Krajnc and Glavič 2005). Three main methodologies are introduced by OECD (Michela Nardo et al. 2005) for aggregating indicators: Additive, Geometric and non-compensatory Multi-Criteria Approach (MCA). Additive aggregation methods, which are known to be the most used methodology among the three (mostly used 86.5% of the time), simply offer functions and normalized weighted indicators to form a sustainability index. The geometric aggregation method (with 8.3% usage) employs multiplicative functions instead. The non-compensatory method, unlike the first two, implies that the compensation among the sub-components of sustainability is accepted (used 5.2% of the time). However, while additive and geometric methods will result in a final index and an output value, non-compensatory methods reveal a final ranking. On the other hand, the latter method faces a computational limitation associated with the increasing number of indicators (Gan et al. 2017). Consequently, the additive method has been chosen for the present study as the method for aggregating the sub-indicators and introducing a final sustainability index. It must be noted that the MCA was tried to be applied at the beginning for aggregation of the sub-indices, but it failed in the computation of the ranks due to the number of the selected indicators.
As shown in figure 7, the calculation process of the $I_{CSD}$ is a step-by-step procedure of grouping indicators into the sub-index of the $(I_{S,j})$ for each group of sustainability indicators $j$. Sub-indices can be derived as equation (5).

$$I_{S,jt} = \sum_{jit}^{n} W_{ji} \,.\, I_{N,jit}^{+} + \sum_{jit}^{n} W_{ji} \,.\, I_{N,jit}^{-} \quad (3)$$

$$\sum_{ji}^{n} W_{ji} = 1,\ W_{ji} \geq 0$$

Where ($I_{S,j}$) is the sustainability sub-index for a group of indicators $j$ (economic, $j =$ 1, environmental, $j = 2$, social, $j = 3$) in time (year) $t$, $W_{ji}$ is the weight of indicator $i$ for the dimension j which has been discussed above.
Ultimately, as seen in figure 1, by using equation (4), sub-indices are combined into the composite sustainable development index $I_{CSD}$:

$$I_{CSD} = \sum_{jt}^{n} W_j \,.\, I_{S,jt} \qquad (4)$$

Where $W_j$ represents the weight given to the sustainability dimension $j$ (economic, $j = 1$, environmental, $j = 2$, social, $j = 3$), based on the frequency of application of dimension alone and in pair with other dimensions due to the investigations done in (Eslami et al. 2018) (shown in Table 6). However, the weight given to the sustainability dimension reflects the importance of the performance of the organizations in each dimension.

Table 6. Calculation of the weight of the sustainability groups ($\boldsymbol{W_j}$)

| Studied Dimension | No. of papers |
|---|---|
| Economic Only | 3 |
| Environmental Only | 24 |
| Social Only | 2 |
| Economic & Environmental | 19 |
| Economic &Social | 1 |
| Environmental & Social | 4 |
| All three | 62 |

| $j$ | Dimension | $W_j$ |
|---|---|---|
| 1 | Economic | 0.22 |
| 2 | Environmental | 0.64 |
| 3 | Social | 0.14 |

## 5. Case study

**THE EFFECTIVENESS OF THE FRAMEWORK HAS BEEN TESTED IN A REAL CASE STUDY. THE CHOSEN COMPANY IS A GLOBAL DIVERSIFIED TECHNOLOGY AND MULTI-INDUSTRIAL LEADER WHICH IS SERVING A WIDE RANGE OF CUSTOMERS IN MORE THAN 150 COUNTRIES. THE NAME CANNOT BE MENTIONED HERE DUE TO DATA PRIVACY. TO TRACK THE SUSTAINABILITY DEVELOPMENT IN THE COMPANY, THE FRAMEWORK HAS BEEN APPLIED TO THE CASE COMPANY FOR THE YEARS 2014 TO 2017. AS SEEN IN**

Table 7, the performance indicators of the case company are listed. It should be noted that the time-frequency of their tracking and calculating was the calendar year defined by the company. Indicators as seen above are selected from the GRI set and are equipped with their code and unit of measurement. The sustainability performance indicators have been grouped under three sections covering the economic, environmental, and social dimensions of sustainability.

Table 7. Performance indicators of the case company during the time

| Indicator | Unit of Measurement | 2017 | 2016 | 2015 | 2014 | Average |
|---|---|---|---|---|---|---|
| **Economic** | | | | | | |
| **201-1** | **Million USD** | 31.1 | 37.7 | 37.2 | 42.8 | 37.2 |
| **201-2** | **USD** | 0 | 0 | 0 | 0 | 0 |
| **203-2** | **Million USD** | 23 | 21 | 22.3 | 21 | 21.825 |
| **204-1** | **Percentage** | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| **205-1** | **Percentage** | 100% | 100% | 100% | 100% | 1 |
| **Environmental** | | | | | | |
| **301-1** | **Internally Used Materials** | 21% | 21% | 21% | 21% | 0.21 |
| **301-2** | **Percentage** | 73% | 72% | 72% | 74% | 0.7275 |
| **301-3** | **Percentage** | 80% | 80% | 80% | 80% | 0.8 |
| **302-1** | **GJ** | 19079534 | 19915275 | 20125251 | 20118169 | 19809557 |
| **302-2** | **GJ** | 1.02E+08 | 1.19E+08 | 1.29E+08 | 1.29E+08 | 1.2E+08 |
| **302-3** | **GJ Per Million USD In Revenue** | 632 | 54 | 551 | 544 | 445.25 |
| **302-4** | **GJ** | 204823 | 310374 | 114255 | 114270 | 185930.5 |
| **302-5** | **GJ** | 1.42E+08 | 1.43E+08 | 1.13E+08 | 67654876 | 1.16E+08 |
| **303-3** | **Cubic Meters** | 0 | 0 | 0 | 0 | 0 |
| **305-1** | **Metric Tons** | 964378 | 826050 | 874549 | 908590 | 893391.8 |
| **305-2** | **Metric Tons** | 1355140 | 1701447 | 1630006 | 1624334 | 1577732 |
| **305-3** | **Metric Tons** | 28571800 | 35327000 | 40031000 | 37419826 | 35337407 |
| **305-4** | **Metric Tons Per Million USD In Revenue** | 76.9 | 68.6 | 68.6 | 68.5 | 70.65 |
| **305-5** | **Metric Tons** | 99982 | 47047 | 15783 | 30846 | 48414.5 |
| **305-7** | **Kg Per Million USD In Sales** | 14.7 | 17.7 | 21.1 | 20.5 | 18.5 |
| **306-1** | **Cubic Meters** | 3315614 | 3306441 | 3449580 | 3067655 | 3284823 |
| **306-2** | **Metric Tons** | 345518 | 511654 | 508486 | 483763 | 462355.3 |
| **306-3** | **Total Number** | 0 | 3 | 2 | 3 | 2 |
| **308-2** | **Number of Impacts** | 0 | 0 | 0 | 0 | 0 |
| **Social** | | | | | | |
| **401-1** | **Rate** | 22.6 | 25.9 | 23.4 | 20.5 | 23.1 |
| **402-1** | **Days** | 60 | 60 | 60 | 60 | 60 |
| **403-2** | **Rate Per 200000 Hours** | 0.56 | 0.62 | 0.74 | 0.76 | 0.67 |
| **404-1** | **Hours** | 24.09 | 25.56 | 11.72 | 18.83 | 20.05 |
| **404-3** | **People** | 40 | 77 | 90 | 92 | 74.75 |
| **412-1** | **Percentage** | 100% | 100% | 100% | 100% | 1 |
| **413-1** | **Percentage** | 100% | 100% | 100% | 100% | 1 |
| **413-2** | **Percentage** | 0 | 0 | 0 | 0 | 0 |
| **414-1** | **Percentage** | 100% | 100% | 100% | 100% | 1 |
| **416-2** | **Number of Incidents Per Year** | 0 | 0 | 0 | 0 | 0 |
| **417-1** | **Percentage** | 100% | 100% | 100% | 100% | 1 |
| **417-2** | **Percentage** | 0 | 0 | 0 | 0 | 0 |
| **417-3** | **Percentage** | 0 | 0 | 0 | 0 | 0 |
| **418-1** | **Percentage** | 0 | 0 | 0 | 0 | 0 |

The sustainability performance values presented in Table 7, were normalized using equations (1) and (2) as they were having a positive or a negative impact on sustainable development of the case company. Table 8 shows the normalized indicators in dimensions of economic, environmental and social and their sub-dimensions.

Table 8.Normalized data

| Indicator | Weight | 2017 | 2016 | 2015 | 2014 |
|---|---|---|---|---|---|
| **Economic Normalized data** | | | | | |
| **Economic Performance** | | | | | |
| **201-1** | 0.57 | 0.8360215 | 1.0134409 | 1 | 1.1505376 |
| **201-2** | 0.43 | 0 | 0 | 0 | 0 |
| **Indirect Economic Impacts** | | | | | |
| **203-2** | 1 | 0.027879 | 0.025455 | 0.02703 | 0.025455 |
| **Supplier assessment** | | | | | |
| **204-1** | 1 | 1 | 1 | 1 | 1 |
| **Environmental Normalized Data** | | | | | |
| **Material** | | | | | |
| **301-1** | 0.39 | 1 | 1 | 1 | 1 |
| **301-2** | 0.35 | 1.003436426 | 0.989690722 | 0.989691 | 1.017182 |
| **301-3** | 0.26 | 1 | 1 | 1 | 1 |
| **Energy** | | | | | |
| **302-1** | 0.26 | 1.038262111 | 0.994691625 | 0.984314 | 0.98466 |
| **302-2** | 0.15 | 1.176331777 | 1.008138391 | 0.930292 | 0.923326 |
| **302-3** | 0.23 | 1.419427288 | 0.12128018 | 1.237507 | 1.221786 |
| **302-4** | 0.22 | 1.101610548 | 1.669301164 | 0.614504 | 0.614584 |
| **302-5** | 0.14 | 1.219709828 | 1.229003283 | 0.969135 | 0.582152 |
| **Water** | | | | | |
| **303-3** | 1 | 0 | 0 | 0 | 0 |
| **Emission** | | | | | |
| **305-1** | 0.2 | 0.926391726 | 1.081522668 | 1.021546 | 0.983273 |
| **305-2** | 0.19 | 1.164257567 | 0.927288361 | 0.96793 | 0.97131 |
| **305-3** | 0.16 | 1.236793167 | 1.000294591 | 0.882751 | 0.94435 |
| **305-4** | 0.17 | 0.918725618 | 1.029883382 | 1.029883 | 1.031387 |
| **305-5** | 0.16 | 2.065125117 | 0.97175433 | 0.325997 | 0.637123 |
| **305-7** | 0.12 | 1.258503401 | 1.04519774 | 0.876777 | 0.902439 |
| **Waste** | | | | | |
| **306-1** | 0.34 | 0.990713334 | 0.993461852 | 0.952239 | 1070793 |
| **306-2** | 0.39 | 1.338151124 | 0.903648364 | 0.909278 | 0.955748 |
| **306-3** | 0.37 | 0 | 0.666666667 | 1 | 0.666667 |
| **Supplier assessment** | | | | | |

| Indicator | Weight | 2017 | 2016 | 2015 | 2014 |
|---|---|---|---|---|---|
| **308-2** | 1 | 0 | 0 | 0 | 0 |
| **Social Normalized Data** | | | | | |
| **Employment** | | | | | |
| **401-1** | 0.57 | 0.978355 | 1.121212 | 1.012987 | 0.887446 |
| **402-1** | 0.43 | 1 | 1 | 1 | 1 |
| **Occupational health and safety** | | | | | |
| **403-2** | 1 | 1.196429 | 1.080645 | 0.905405 | 0.881579 |
| **Education** | | | | | |
| **404-1** | 0.47 | 1.201496 | 1.274813 | 0.584539 | 0.939152 |
| **404-3** | 0.53 | 0.535117 | 1.0301 | 1.204013 | 1.230769 |
| **Human right** | | | | | |
| **412-1** | 1 | 1 | 1 | 1 | 1 |
| **Local Communities** | | | | | |
| **413-1** | 0.57 | 1 | 1 | 1 | 1 |
| **413-2** | 0.43 | 0 | 0 | 0 | 0 |
| **Social Policy Compliance** | | | | | |
| **414-1** | 1 | 1 | 1 | 1 | 1 |
| **Product Responsibility** | | | | | |
| **416-2** | 0.51 | 0 | 0 | 0 | 0 |
| **417-1** | 0.49 | 1 | 1 | 1 | 1 |
| **Customer satisfaction** | | | | | |
| **417-2** | 0.32 | 0 | 0 | 0 | 0 |
| **417-3** | 0.31 | 0 | 0 | 0 | 0 |
| **418-1** | 0.37 | 0 | 0 | 0 | 0 |

After the normalization of the indicators, the sustainability index for each dimension needs to be calculated. To serve the purpose, sub-dimension weights based on Table 5, were considered and economic, environmental and social sustainability indices were computed as seen in Table 9. Equations (3) was used for the calculation. Ultimately, the sustainable development index was measured using equation (4), and the weights in Table 6. Figure 8 shows a variation of the sustainable development indices and the dimensions indices based on the achieved results in the studied time period.

Table 9.Sustainability index

| (Sub)Dimension | Weight | 2017 | 2016 | 2015 | 2014 |
|---|---|---|---|---|---|
| Economic Performance | 0.53 | 0.47 | 0.58 | 0.57 | 0.66 |
| Indirect Economic Impacts | 0.3 | 0.027 | 0.03 | 0.03 | 0.03 |
| Supplier assessment | 0.17 | 1 | 1 | 1 | 1 |
| **Economic Index** | **0.22** | **0.43** | **0.48** | **0.48** | **0.53** |

| (Sub)Dimension | Weight | 2017 | 2016 | 2015 | 2014 |
|---|---|---|---|---|---|
| Material | 0.17 | 1.00 | 1.00 | 1.00 | 1.01 |
| Energy | 0.21 | 1.19 | 0.98 | 0.95 | 0.89 |
| water | 0.16 | 0 | 0 | 0 | 0 |
| Emission | 0.20 | 1.242 | 1.009 | 0.862 | 0.918 |
| waste | 0.20 | 0.00 | 0.94 | 1.05 | 0.98 |
| supplier assessment | 0.07 | 0 | 0 | 0 | 0 |
| **Environmental Index** | **0.64** | **0.67** | **0.76** | **0.75** | **0.74** |
| Employment | 0.17 | 0.99 | 1.07 | 1.01 | 0.94 |
| Occupational Health and Safety | 0.18 | 1.20 | 1.08 | 0.91 | 0.88 |
| Education | 0.08 | 0.85 | 1.15 | 0.91 | 1.09 |
| Human Right | 0.08 | 1 | 1 | 1 | 1 |
| Local Communities | 0.08 | 0.57 | 0.57 | 0.57 | 0.57 |
| Social Policy Compliance | 0.12 | 1 | 1 | 1 | 1 |
| Product Responsibility | 0.12 | 0.49 | 0.49 | 0.49 | 0.49 |
| Customer Satisfaction | 0.12 | 0 | 0 | 0 | 0 |
| **Social Index** | **0.14** | **0.76** | **0.77** | **0.71** | **0.71** |
| **Sustainability Index** | | **0.63** | **0.70** | **0.69** | **0.69** |

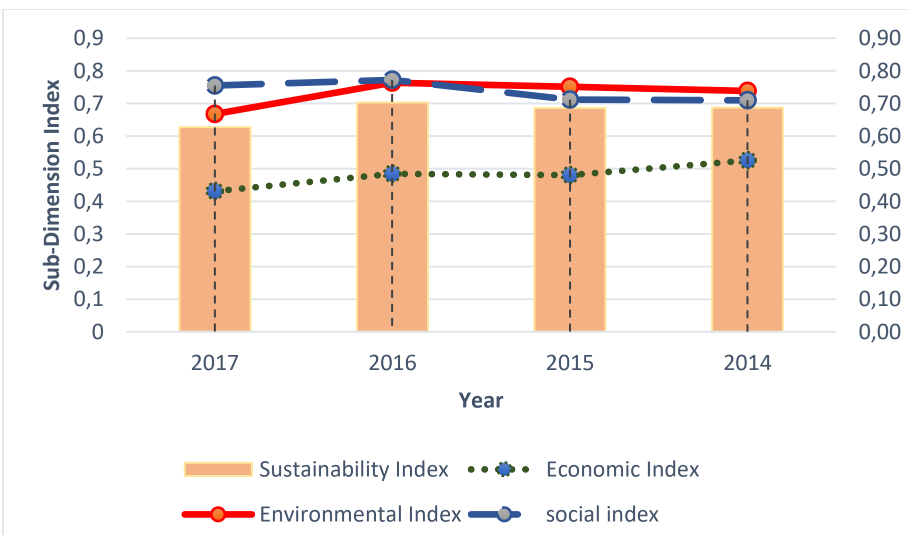



Figure 8. variation of sustainability index and sub-dimension index of the case study in time

### 5.1.Analysis of the results

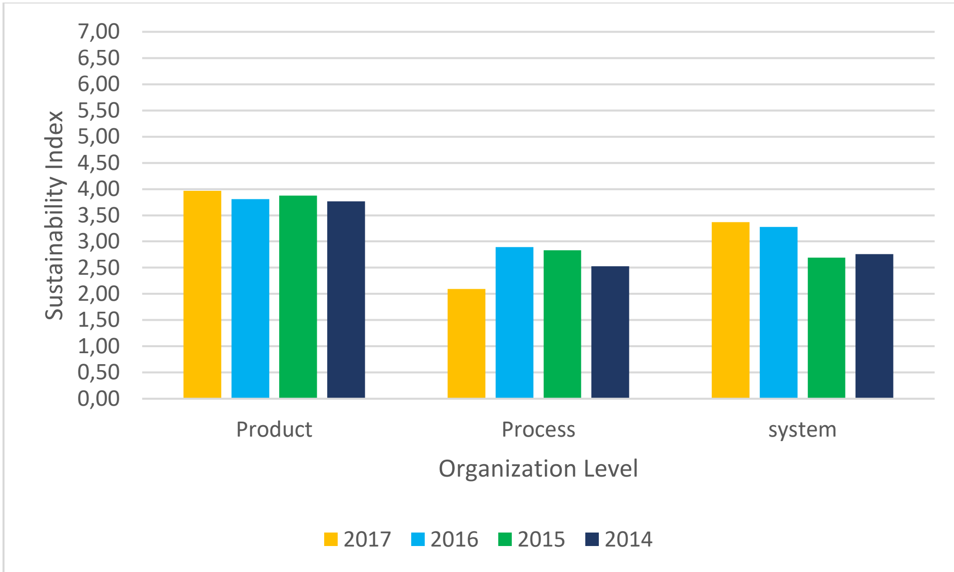
Previously selected indicators were aggregated into sustainability sub-indices for a case company and finally aggregated into the $I_{CSD}$ as presented in Table 10. On the other hand, and to make a better comparison, the variation of sustainability sub-indices and the $I_{CSD}$ for the case company over a time period of 2014-2017 has also been presented in Figure 9.

The final results of the case study facilitate the interpretation of the sustainable development of the case company in time. The company attains high in the $I_{CSD}$ in a certain year if the average of its individual sustainability sub-indices (economic, environmental and social indices) is high compared to the other years. The higher is the value of the $I_{CSD}$, the greater is the improvement of the company towards sustainability. The same rule goes for the sustainability indices for sub-dimensions. For any given year, the $I_{CSD}$ and sub-indices reveal the development of the company in that year relative to the other years. Following the $I_{CSD}$ of the case company from 2014 to 2017, a fluctuation in the sustainability development is observed and a noticeable decrease in the year 2017 is shown in comparison with the year 2016. To get deeper into the analysis and to find out the root causes of the drop-down, the sub-dimensions are considered.

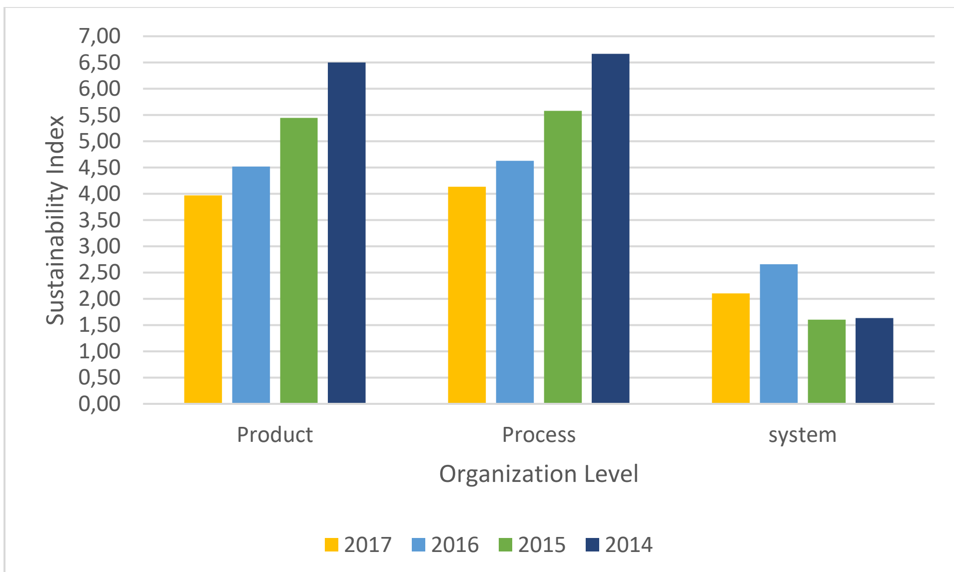
As Figure 9 clearly shows, the most significant fall was related to the environmental dimension. Hereof, a deeper analysis was conducted on the referenced dimension based on the allocated indicators to this layer of the model. Indicators were assigned to the model based on the life cycle stage and the organizational level they belong to. Table 10 shows the normalized indicators for each cube of the environmental layer in the defined period. It is important to note that, the indices mentioned in the table are considered without the weight of each cube as they are for one dimension only. The weighting can be applied while measuring the whole system to reach sustainability indices between 0 and 1. Consequently, variation of the sustainability performance of each organizational level for the life cycle stages of pre-manufacturing, manufacturing, use and post-use is graphically presented in Figure 9. The same interpretation applied above for the sustainability performance is applicable for the following figures.

Table 10. Detailed sustainability performance in Environmental Dimension without weight application

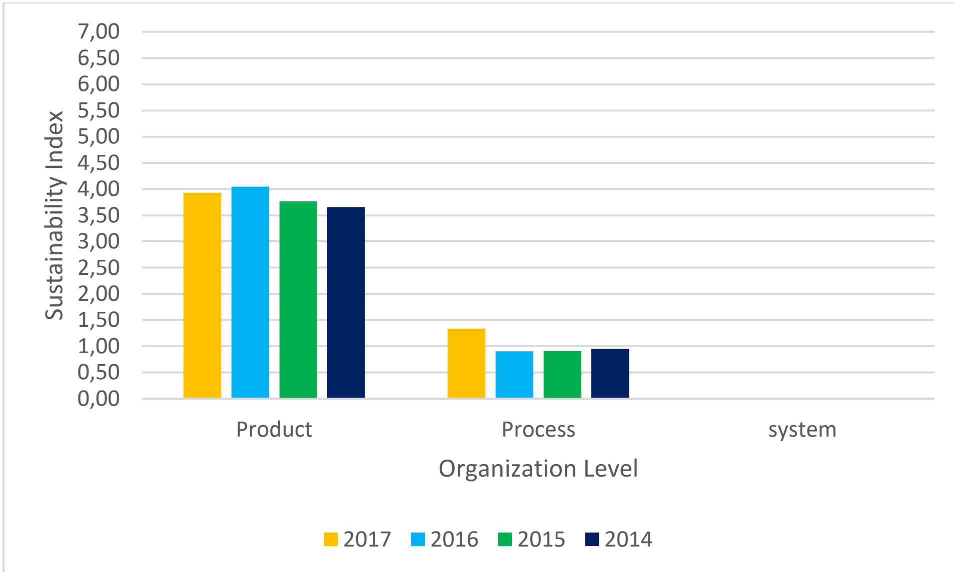
| **Pre-Manufacturing** | | | | **Manufacturing** | | | | **Use** | | | | **Post-Use** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Product** | | | | **Product** | | | | **Product** | | | | **Product** | | | |
| 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 |
| 3.97 | 3.81 | 3.87 | 3.76 | 3.97 | 4.52 | 5.44 | 6.50 | 3.93 | 4.05 | 3.77 | 3.66 | 3.97 | 4.53 | 5.45 | 6.48 |
| **Process** | | | | **Process** | | | | **Process** | | | | **Process** | | | |
| 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 |
| 2.10 | 2.89 | 2.83 | 2.52 | 4.13 | 4.63 | 5.58 | 6.67 | 1.34 | 0.90 | 0.91 | 0.96 | 4.13 | 4.64 | 5.59 | 6.65 |
| **System** | | | | **System** | | | | **System** | | | | **System** | | | |
| 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 | 2017 | 2016 | 2015 | 2014 |
| 3.37 | 3.28 | 2.69 | 2.76 | 2.11 | 2.66 | 1.60 | 1.63 | 0.00 | 0.00 | 0.00 | 0.00 | 2.20 | 2.67 | 1.58 | 1.58 |


7,00
6,50
6,00
5,50
5,00
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Sustainability Index
Product
Process
system
Organization Level
2017
2016
2015
2014

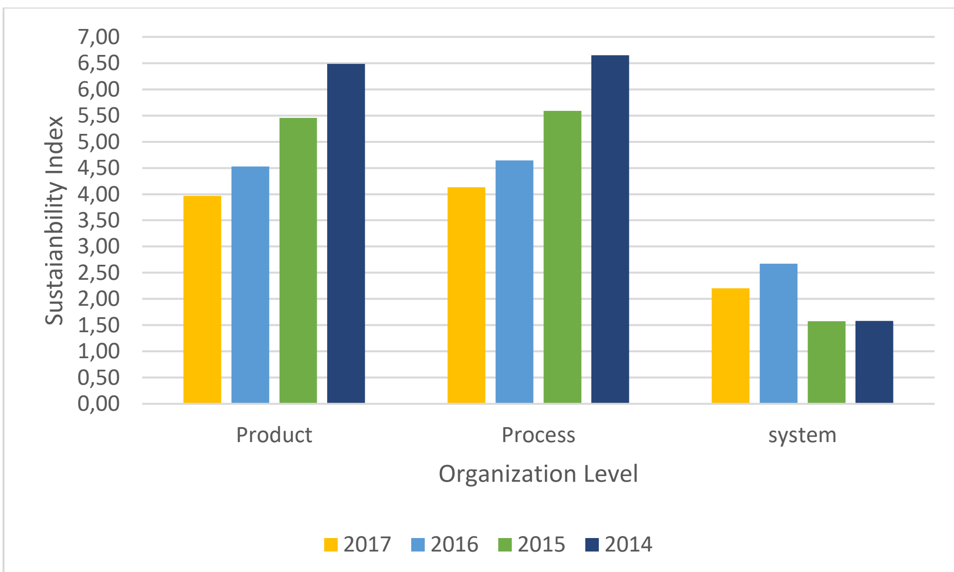
(a)


7,00
6,50
6,00
5,50
5,00
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Sustainability Index
Product
Process
system
Organization Level
2017
2016
2015
2014

(b)




(c)




(d)

Figure 9. Sustainability performance in (a) Pre-Manufacturing Stage; (b) Manufacturing Stage; (c) Use Stage; (d) Post- Use Stage

Going through the figures, the following outcomes are detected:

- Regarding the life cycle stages of the environmental dimension, pre-manufacturing and use show a fairly fixed sustainability performance moving from 2016 to 2017 while a noticeable drop-down is visible in the manufacturing and post-use stages during the time.
- Considering the organizational levels, the process was the level that was prone the most to the fall of the sustainability index and the system was the least affected one.

- Putting it all together, it seems that the case company's most vulnerable is in process-related activities during the manufacturing and post-manufacturing stages of the life cycle of the product. Therefore, employing more sustainable techniques for the production processes and/or excursing the concept of 6R in the case company can be a silver lining to reach higher levels of sustainability in the upcoming years.

## 6. Limitations

Among the many advantages of the framework mentioned above, there were some limitations in the process of developing the framework. The first limitation was related to the set of indicators. During the little survey conducted on the available sets of indicators by ( Eslami et al. 2019) the set GRI was selected for further study. However, a much deeper analysis could have been done by merging two or three sets and making a full indicator pool. As an example, the set GRI lacks some indicators like "line stop due to safety concern", "job satisfaction" or "customer satisfaction" separately. Putting two or three sets together would have made a much more thorough indicator pool and would have led to a more precise assessment. Nonetheless, the NIST set of Indicators is no more open source and reaching the indicators and the reports is not possible. Therefore, for the time of doing FCA and extracting association rules, there will be a lack of consistency in the data. The second limitation was due to the number of indicators and the size of the framework, which made it impossible to use other methods of aggregation rather than the additive one. The first decision was to move on with non-compensatory aggregation methods which consider a perspective of multi-criteria decision-making (MCDM). However, based on the computational limitation the method faced (Gan et al. 2017), the size of the present model seemed to be too large and the aggregation method was not responsive.

## 7. Conclusion and Future Work

Acknowledging the urge for manufacturing organizations to improve their performance in terms of sustainability and the need for a systematic view of sustainability assessment tools, the presented study has been devoted to development of a composite sustainability indicator based on a proposed sustainability assessment framework with a holistic view for manufacturing organizations. the work indeed aims to respond to two main issues: *"How we can help manufacturing organizations in terms of assessing sustainability"* and *"How we can help manufacturing organizations discover opportunities to reach a better state of sustainability"*.

A framework was proposed which can provide a holistic view of the sustainability performance of the manufacturing organization considering 3 different points of view: first sustainability dimensions (economic, environmental and social), second the life cycle of the product (pre-manufacturing, manufacturing, use and post-use) and third the organizational level (product, process and system). Furthermore, a step-by-step development of a composite sustainability index was described from the selection of the indicators to their normalization, weighting, and aggregation of the indicators to achieve the final index. Finally, the effectiveness of the framework was validated through its application to a real manufacturing case company.

In addition to the proposed indicator-based sustainability assessment framework, the study mostly contributes to the process of selection and weighting of the indicators which has been done based on two knowledge formalisation methodologies: Formal Concept analysis (FCA) and association Rule Mining (ARM).

As the case study demonstrated, the application of the framework led to a clear showcase of the sustainability performance of the manufacturing organization during the time. The case company itself has a documented sustainability report only mentioning the performance in each section without giving the opportunity of a holistic view of the overall performance of the company. Applying the framework for the case company, shed light on the sustainability state of the whole organization during the time in addition to highlighting the opportunities for improvement toward the concept of sustainability development.

As a work in process, the framework is to be validated in two different manners and compared. The first one will be through clustering techniques such as Formal Concept Analysis (FCA) and Rational concept analysis (RCA). The second one will be through applications by creating instances like the ORANGE[1] application.

Evidently, the framework has the potential for improvement and further studies to be more accurate. As an example, investigations on more precise associations and relationships between indicators of each layer of the framework can help improve its effectiveness. In addition, the next step of the study can be the efforts to model the framework employing system-engineering tools to create a more complete and holistic view for the manufacturers and final users.

## Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

## References


Chen, D., T. Schudeleit, G. Posselt, and S. Thiede. 2013. "A State-of-the-Art Review and Evaluation of Tools for Factory Sustainability Assessment." In , 9:85–90. doi:10.1016/j.procir.2013.06.173.

Devuyst, Dimitri. 2001. *How Green Is the City?: Sustainability Assessment and the Management of Urban Environments*. Columbia University Press.

"Error 404 | Sustainability Indices." 2018. Accessed July 26. http://www.sustainability-index.com/dow-jonessustainability-indexes.

Eslami, Y., M. Dassisti, H. Panetto, and M. Lezoche. 2019. "Sustainability Assessment of Manufacturing Organizations Based on Indicator Sets: A Formal Concept Analysis." *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 11231 LNCS: 36–44. doi:10.1007/978-3-030-11683-5_4.

Eslami, Yasamin, Michele Dassisti, Mario Lezoche, and Hervé Panetto. 2018. "A Survey on Sustainability in Manufacturing Organisations: Dimensions and Future Insights." *International Journal of Production Research* 0 (0): 1–21. doi:10.1080/00207543.2018.1544723.

Eslami, Yasamin, Mario Lezoche, Hervé Panetto, and Michele Dassisti. 2020. "On Analysing Sustainability Assessment in Manufacturing Organisations: A Survey." *International Journal of Production Research* 0 (0). Taylor & Francis: 1–32. doi:10.1080/00207543.2020.1755066.


[1] https://orangedatamining.com/

Gan, X., I.C. Fernandez, J. Guo, M. Wilson, Y. Zhao, B. Zhou, and J. Wu. 2017. “When to Use What: Methods for Weighting and Aggregating Sustainability Indicators.” *Ecological Indicators* 81: 491–502. doi:10.1016/j.ecolind.2017.05.068.

“General Motors.” 2018. Accessed July 27. http://scholar.googleusercontent.com/scholar?q=cache:q8PfseqqWYQJ:scholar.google.com/&hl=it&as_sdt=0,5.

“Global Reporting Initiative.” 2018. Accessed July 26. https://www.globalreporting.org/Pages/default.aspx.

Hacking, Theo, and Peter Guthrie. 2008. “A Framework for Clarifying the Meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment.” *Environmental Impact Assessment Review* 28 (2): 73–89. doi:10.1016/j.eiar.2007.03.002.

Hastie, Trevor, Robert Tibshirani, and Jerome Friedman. 2009. *The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Second Edition*. 2nd ed. Springer Series in Statistics. New York: Springer-Verlag. //www.springer.com/it/book/9780387848570.

SDG(2015). Retrieved September 19, 2018, from https://www.globalreporting.org/standards/resource-download-center/sdg-compass-annex-linking-the-sdgs-and-gri-standards/

Hornik, Kurt, Bettina Grün, and Michael Hahsler. 2005. “Arules - A Computational Environment for Mining Association Rules and Frequent Item Sets.” *Journal of Statistical Software* 14 (October). doi:10.18637/jss.v014.i15.

“ISO 14031:2013 - Environmental Management -- Environmental Performance Evaluation -- Guidelines.” 2018. Accessed July 26. https://www.iso.org/standard/52297.html.

Karnib, A. 2016. “A Methodological Approach for Sustainability Assessment: Application to the Assessment of the Sustainable Water Resources Withdrawals.” *International Journal of Sustainable Development* 19 (4): 402–17. doi:10.1504/IJSD.2016.080515.

Krajnc, D., and P. Glavič. 2005. “A Model for Integrated Assessment of Sustainable Development.” *Resources, Conservation and Recycling* 43 (2): 189–208. doi:10.1016/j.resconrec.2004.06.002.

Labuschagne, Carin, Alan C. Brent, and Ron P. G. van Erck. 2005. “Assessing the Sustainability Performances of Industries.” *Journal of Cleaner Production* 13 (4): 373–85. doi:10.1016/j.jclepro.2003.10.007.

Liu, Y., and X. Li. 2017. “Application of Formal Concept Analysis in Association Rule Mining.” In , 203–7. doi:10.1109/ICISCE.2017.52.

Mezni, Haithem, and Mokhtar Sellami. 2017. “Multi-Cloud Service Composition Using Formal Concept Analysis.” *Journal of Systems and Software* 134 (December): 138–52. doi:10.1016/j.jss.2017.08.016.

Moldavska, A., and T. Welo. 2015. “On the Applicability of Sustainability Assessment Tools in Manufacturing.” In , 29:621–26. doi:10.1016/j.procir.2015.02.203.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *State-of-the-Art Report on Simulation and Indicators*. D7.

Nardo, Michela, Michaela Saisana, Andrea Saltelli, Stefano Tarantola, Anders Hoffman, and Enrico Giovannini. 2005. “Handbook on Constructing Composite Indicators,” August. doi:https://doi.org/10.1787/533411815016.

“OECD Sustainable Manufacturing Indicators - OECD.” 2018. Accessed July 27. https://www.oecd.org/innovation/green/toolkit/oecdsustainablemanufacturingindicators.htm.

Pollesch, N.L., and V.H. Dale. 2016. “Normalization in Sustainability Assessment: Methods and Implications.” *Ecological Economics* 130: 195–208. doi:10.1016/j.ecolecon.2016.06.018.

Schmidt, Wulf-Peter, and Andy Taylor. n.d. “Ford of Europe’s Product Sustainability Index,” 6.

“SDG Compass Annex: Linking the SDGs and GRI Standards.” 2018. Accessed September 19. https://www.globalreporting.org/standards/resource-download-center/sdg-compass-annex-linking-the-sdgs-and-gri-standards/.

Smullin, Matteo M. 2016. “An Information Modeling Framework and Desktop Application to Compose Unit Manufacturing Process Models for Sustainable Manufacturing Assessment,” November. http://ir.library.oregonstate.edu/xmlui/handle/1957/60059.

Thompson, Kristy D. 2011. “Sustainable Manufacturing Indicator Repository (SMIR).” *NIST*. February 17. https://www.nist.gov/services-resources/software/sustainable-manufacturing-indicator-repository-smir.

Tokos, Hella, Zorka Novak Pintarič, and Damjan Krajnc. 2012. “An Integrated Sustainability Performance Assessment and Benchmarking of Breweries.” *Clean Technologies and Environmental Policy* 14 (2): 173–93. doi:10.1007/s10098-011-0390-0.

“UNIDO | United Nations Industrial Development Organization.” 2018. Accessed September 16. https://www.unido.org/.

“Untitled.” 2018. Accessed July 26. https://scholar.googleusercontent.com/scholar?q=cache:akdKQhKuvRkJ:scholar.google.com/+barometer+of+sustainability&hl=it&as_sdt=0,5&as_vis=1.

Veleva, V., and M. Ellenbecker. 2001. “Indicators of Sustainable Production: Framework and Methodology.” *Journal of Cleaner Production* 9 (6): 519–49. doi:10.1016/S0959-6526(01)00010-5.

Wajnberg, Mickael, Mario Lezoche, Blondin Alexandre Massé, Petko Valtchev, and Hervé Panetto. 2017. “Complex System Tacit Knowledge Extraction Trough a Formal Method.” *INSIGHT - International Council on Systems Engineering (INCOSE)* 20 (4): 23–26. doi:10.1002/inst.12176.

Wille, Rudolf. 1982. “Restructuring Lattice Theory: An Approach Based on Hierarchies of Concepts.” In *Ordered Sets*, 445–70. NATO Advanced Study Institutes Series. Springer, Dordrecht. doi:10.1007/978-94-009-7798-3_15.