





Visualising Sustainability-Related Information: A Review of Visualisation for Sustainability in Manufacturing Industry

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Abstract. Industrial sustainability is attracting more and more attention in recent years. But sustainability data can be complex, hard to collect, and difficult to explain and use. We draw on visualisation research to improve the utility of sustainability-related information, which we categorise as normally being “invisible”. Better visualisation will facilitate practitioners to understand sustainability performance and eventually encourage better decisions to improve the sustainability performance of manufacturing industry. This research conducts a literature review through keywords searching. After filtering 319 results, we identified 28 papers as relevant ones and thematic analysis of the identified papers was conducted to understand their contents. The results of the literature review show that Life Cycle Assessment (LCA), Sustainable Value Stream Mapping (Sus-VSM), Sankey diagram, etc., appear from the identified papers as visualisation tools or methods. We revealed two levels of visualisation on sustainability-related information, they are, assessment of sustainability and presentation of data, while the second level attracts less attention. Although some papers suggested that visualisation facilitates decision-making for improving sustainability performance, few studies paid attention to the effects of the visualisation. In the last, we also suggest dynamic visualisation as one of the potential developing directions for the visualisation of sustainability-related information, while the utility of creating such a dynamic system needs to be carefully analysed in advance.

Keywords: Visualisation · Sustainable production · IoT · Decision-making · Behaviour change · Literature review

1 Introduction

Sustainability issues are becoming more and more crucial in recent years. The industry is the largest sector of energy consumption accounting for nearly 25% of global energy usage in 2019 and is the largest sector of CO₂ emission accounting for over 30% of the global GHG emission in 2010 [1, 2]. Based on these facts, industries have adopted

many approaches and tools to assess and analyse their sustainable performance. The very first step of doing so is to measure and collect sustainability-related information, which eventually influences or represents environmental performance. In this research, attentions are specifically paid to manufacturing industry and sustainability information includes consumption of materials, resources, water, energy (electricity, gas, etc.), CO₂ as well as wastes. Energy and CO₂ are physically “invisible”; therefore, proper tools and multiple sensors are necessary for visualising them. As for materials, water, resources and wastes, they are physically visible, but accurate data on inputs, outputs and flows are often not available. This is also the case for energy and CO₂. Even if all relevant data have been measured and collected, the data are often complex, in different systems, and different units. Hence there is still a challenge for practitioners to understand their characteristics and properly use them to improve sustainability performance.

As industry 4.0 is coming, more and more sensors are applied to production systems, which enables to collect and visualise sustainability-related data. Unfortunately, it still brings the question of how to use the enormous amount of data properly so that the effectiveness of accessing these data can be maximised. In industry, visualisation is always used to facilitate people to understand the situation of production and help them to make better decisions. For example, in lean manufacturing, value stream mapping is a typical tool to visualise the value chain of a production system, which is very helpful for practitioners to identify value-adding and non-value-adding activities [3]. However, proper visualisation of data needs to be analysed in order to promote actions and behaviours changes of practitioners so that they can improve the sustainability performance.

This paper aims to summarise current research about the visualisation of sustainability-related information by a literature review. It will try to answer the following research questions: RQ1: What is the visualisation used in manufacturing industry? RQ2: How are visualisations used in practice and how does visualisation facilitate practitioners for sustainability performance improvements? As it is a novel research area, thematic analysis was conducted for the identified papers after keywords searching and content selection. Based on the results of the literature review, the current focuses of visualisation of sustainability-related information from the academia will be discussed, associated with potential developing directions of sustainable visualisation tools. It has been found that the current visualisations are always used to illustrate the results of some sustainability assessment methods such as life cycle assessment (LCA); or used to display the invisible information such as energy, and one typical example can be Sustainable Value Stream Mapping (Sus-VSM) which is modified from Value Stream Mapping (VSM) and combined with sustainable features. In addition, it is argued that too much attention has been put on the visualisation itself while few papers talk about the effects of the visualisation. In other words, how on earth does the visualisation influence practitioners’ decision-making and behaviour changes? At the end, a conclusion summarises the paper.

2 Research Methodology

The literature was searched initially in the database Scopus. The Scopus was selected as it is one of the biggest academic databases, therefore, the most related paper can

be found. The literature review was conducted through keywords searching firstly. The target reviewing papers are under the topic of visualizing sustainability-related information of production for sustainability. In order to search the relevant papers, four groups of keywords were used, which are (visuali*) AND (waste OR energy OR electricity OR material OR resource OR CO₂ OR water) AND (sustainab*) AND (production OR industry OR factory OR manufactur*). “Visuali*” represents for “visualise” (“visualize”), “visualising” (“visualizing”) and “visualisation” (visualisation), “sustainab*” represents “sustainable” and “sustainability”, while “manufactur*” represents “manufacture”, “manufacturing” and “manufacturer”. 634 results were found on the database Scopus, and 319 papers were English academic journal paper within these 634 papers. Then, all the abstracts of the 319 searched papers were reviewed by the author to eliminate papers with the selected keywords but out of the scope of the research. (The search was conducted on 24 January 2021.)

The selection process is shown in Fig. 1. The first step of the selection is to identify whether the research is within the scope of manufacturing industry and production or not. The second step is to identify if the visualising contents are sustainability-related information. The third step is to figure out if the purpose of the visualisation is for sustainability. Following such a process, 28 papers were eventually identified as the most relevant.

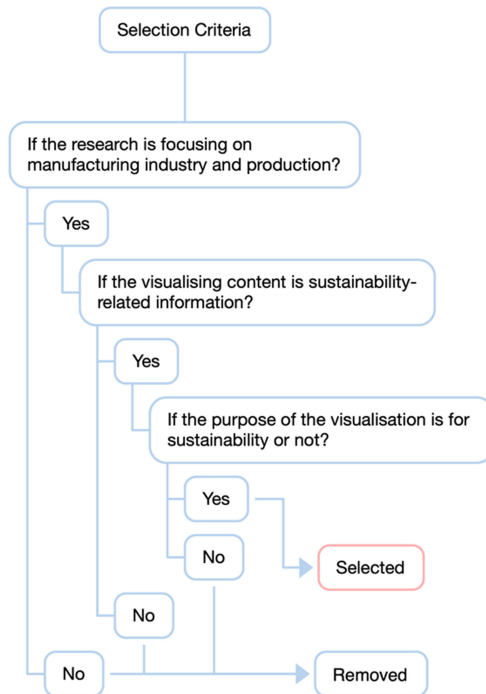


Fig. 1. Selection process of the searched papers

3 Results and Findings

3.1 Chronological Distribution

The chronological distribution of the identified 28 papers is shown in Fig. 2. The first identified paper following the mentioned selection process was published in 2012. This paper was published in *Marine Policy* and written by Hornborg, S. and his co-authors [4]. In the paper, the authors mentioned that LCA can visualise the environmental impacts of seafood production and be helpful in decision making. From Fig. 2, it can be found the number of publications by year has an upward trend (shown using the orange dashed line). In the year of 2020, there were six papers published under the topic, and it was the most productive year. Such a result indicates that the visualisation of sustainability-related information has continuously attracted attention.

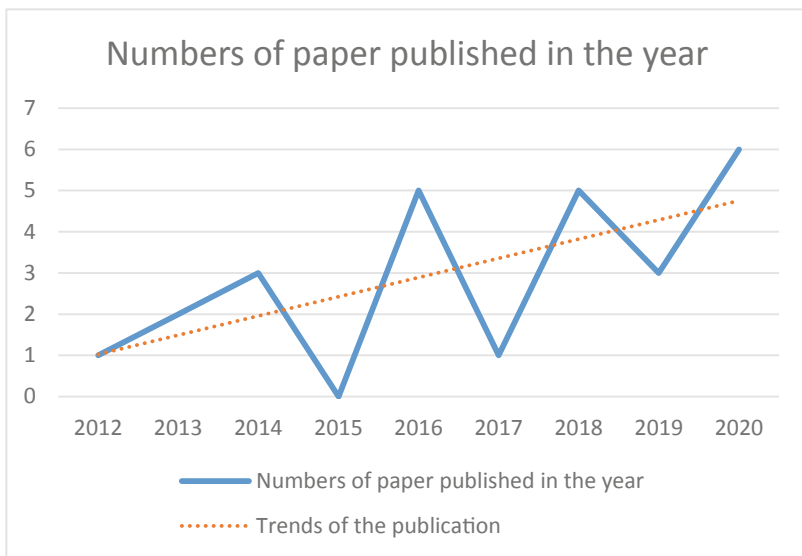


Fig. 2. Chronological distribution of the identified papers (not including the year 2021)

3.2 Analysis of Journals and Authors

The identified papers have been published in a variety of journals, which implies that visualisation has been used for different research areas and the research on visualisation of sustainability-related information has not formed a specific research sub-field. There are six papers published in the *Journal of Cleaner Production*, three papers published in *Sustainability (Switzerland)*, as well as two papers published in the *Environmental Progress and Sustainable Energy*, *International Journal of Life Cycle Assessment* and *Renewable and Sustainable Energy Reviews*, respectively (shown in Fig. 3). The other 13 papers were published in 13 different journals.

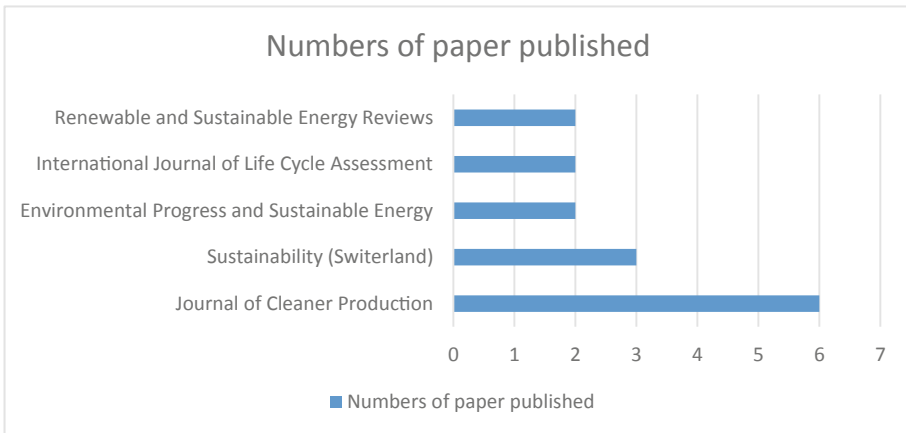


Fig. 3. Numbers of papers published in the top5 journals

As for authors, Ghannadzadeh and Sadeqzadeh published two papers together and they present their research results with visualised exergetic flowsheets [5, 6]. All other authors only contributed to one paper, which indicates again that few researchers started to pay substantive attention to this field. A special example is that Rönnlund and his collaborators published two papers under the same topic which were separated into Part 1 and Part 2. These two papers are considered as one paper here in the analysis of authors [7, 8].

3.3 Findings

Due to the novelty of the research questions, thematic analysis was conducted to understand the identified 28 papers. It is a qualitative research method for identifying, analysing and reporting the themes of the collected data which is very suitable for exploring the immature research areas [9, 10]. The identified 28 papers are identified into two themes: 1) illustrating the results of sustainability assessment tools, and 2) presenting the sustainability-related data throughout production processes (shown in Fig. 4).

For the first theme, various sustainability assessment tools are introduced to reveal sustainability issues that lack necessary attentions. 11 out of 28 papers used the visualisations to present their results of LCA, which is the biggest field. LCA is a tool to analyse environmental factors and the potential impact of a product or a service throughout its whole life cycle, from the cradle to the grave. With the LCA thinking, tools for different purposes can be further developed. For example, Sharma and his colleagues created a tool to visualise the hotspots of friction stir processing during different stages of a product life cycle to improve sustainability [11]. Moreover, exergy analysis with exergetic flowsheets was used by two papers to present their research outcomes [5, 6]. In addition to LCA and exergy analysis, there are some other sustainability assessment tools. For instances, Cai and Lai assessed the sustainability in mechanical manufacturing system [12].

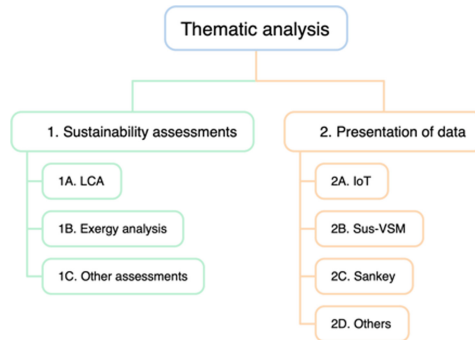


Fig. 4. Thematic analysis of the identified 28 papers

As for the second theme, due to the invisible nature of sustainability-related information, such as energy, electricity and CO₂ emissions, tools have been developed to measure, collect and visualise such information. Especially, the rapid development of Internet of Things (IoT), coming with the big background of Industry 4.0, has remarkably empowered the ability to do so in real-time. For example, Lavalle and his colleagues published a paper in 2019, discussing improving the sustainability of electricity production by facilitating practitioners to understand the potential failures with the help of an IoT based real-time system [13]. In addition, Brown, Amundson and Badurdeen developed Sustainable Value Stream Mapping based on the lean tool – Value Stream Mapping [14]. VSM is a typical tool used for identifying and visualising wastes of value, and Sus-VSM extends its efficacy and adds sustainability metrics into the tool. Sus-VSM provides a unique direction of developing visualisations of sustainability-related information. Another interesting finding is that some researchers used Sankey diagram as a decision support tool [15]. Sankey diagram can illustrate the flows of material, energy, elements, etc., which is commonly be used to present the results of material flow analysis (MFA).

At last, the findings of the literature review answer the first research question: what is the visualisation used currently in manufacturing industry? While as for the second research question, few studies on how visualisation affects the practitioners and facilitate improving sustainability were found which implies a research gap and a potential direction for future research.

4 Discussion

This literature review was conducted through keywords searching, therefore all papers under the selected topic that mentioned visualisation have been reviewed. However, due to the universality of visualisation, some papers might not be covered through the searching. Also, some papers might use visualisation but the word “visuali*” is not used in the titles, keywords and abstracts, therefore, these papers are also missing. As a result, the samples of this literature review (N = 28) are relatively small due to the particularity of the focused research topic. To further understand the visualisation of

sustainability-related information, it might be helpful to conduct snowballing searching starting with the identified 28 papers. Also, the results have revealed some relevant keywords, such as LCA, Sus-VSM, Sankey, etc. Studying these topics could provide a further understanding of the visualisation of sustainability-related information. Nevertheless, with the identified 28 papers, there are some interesting findings for developing the visualisation tool of sustainability-related information that worth to be discussed. Figure 5 illustrates the proposed logic of how the visualisation of sustainability-related information improves sustainability performance.

From the results of the literature review, the identified two themes are indicating two levels of visualisation of sustainability-related information as shown in Fig. 5: 1) the assessment of sustainability, and 2) the presentation of the data. The first level of visualisation focuses on revealing the new or unaware environmental metrics of production through professional sustainability assessment tools from different aspects, such as LCA and exergy analysis. For example, LCA enables people to see the environmental impacts of one product or one service throughout its entire life cycle rather than just focusing on its manufacturing process in seafood production [4]. The environmental impacts of other phases of the product or the service can be invisible before applying LCA. While the second level of visualisation focuses on the presentation of the data, which can be the results of the assessment tools or sustainability-related data collected from the production process. Normally, it can be diagrams, figures, graphs or charts. Sankey diagram is one of the typical examples, which is used to present the results of LCA or Material Flow Analysis (MFA) [11, 15].

Although the identified papers are all relevant to visualisation, few papers have written about the design theory of the visualisation. Especially for the second level of visualisation, few papers mentioned how the presentation of the data influences the delivery of the content. Lavallo and her colleagues specifically proposed a guideline of defining the goals of visualisation when developing IoT based on real-time visualisation while such efforts have not been found in other papers [13]. In addition, a few papers mentioned that visualisation can be used as a support for decision-making [4, 11, 15–17]. However, few papers analyse how visualisation affects decisions (red arrows in Fig. 5). We believe that decision making is not a simple process, the design of the visualisation should consider its effects, e.g., which part of the production process needs to be improved, what countermeasures should be taken for effective improvements, etc. The identified papers pay much more attention to the visualisation itself, pursuing higher precision and finding new angles of seeing challenges rather than achieving practical impacts. Katzeff and his colleagues conducted a study on exploring sustainable practices in workplace setting through the visualisation of energy consumption [18]. They tried to study how people receive and interpret the visualisation, but the research was conducted in the workplace and it just focused on visualising the overall use of electricity rather than combined with the production process. A research gap between the assessment, collection and presentation of the sustainability-related data and decision-making, behaviour and action changes of practitioners emerges from the result of the literature review.

Last but not least, it has been found that the majority of the visualisation is presented in a static form. With the help of IoT sensors, factories can collect real-time data, which

enables dynamic visualisation of sustainability-related information. A new approach is desirable to support decision-making taking into account dynamic changes, such as temporal changes, material and energy balance, and improvements due to various countermeasures. To this end, system dynamics could be used to enable dynamic simulations. However, it needs further research on whether it is worth creating such a dynamic system by comparing the efforts with the benefits on sustainability performance. The level of the dynamic should be carefully considered before setting up the system.

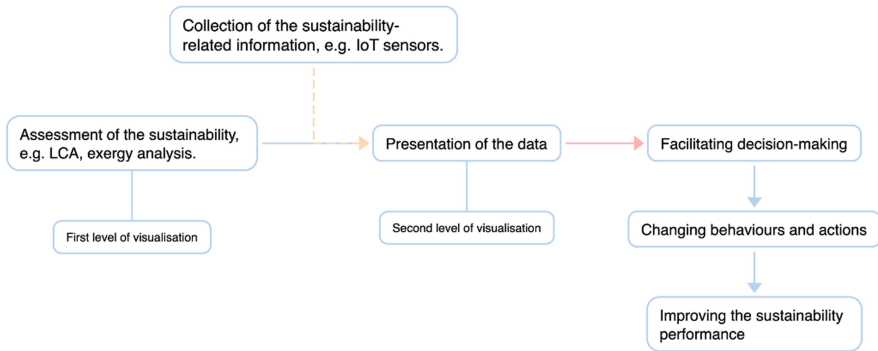


Fig. 5. How visualisation of sustainability-related information improves sustainability performance.

5 Conclusion

The visualisation of sustainability-related information can be a key factor for decision-making on improving sustainability performance. This paper conducted a literature review through keywords searching. Based on the identified 28 papers after filtering from 319 searched results, thematic analysis was conducted, and two levels of the visualisation have been revealed – the assessment of the sustainability and the presentation of data. It has been found that the current research pays more attention to the first level of visualisation, which aims at higher precision and better analysis. However, the delivery of information and the effects of the visualisation has hardly been studied. Therefore, a research gap between the visualisation of sustainability-related information and decision-making and behaviour and action changes has been identified. In addition, the IoT sensors enable collecting data in real-time, which allows developing dynamic visualisation. But the advantage of the dynamic visualisation compared to a static one needs to be further studied. To sum up, the visualisation of sustainability-related information can be essential for increasing practitioners' sustainable awareness and promoting sustainable decisions and actions, but the road between these two concepts needs to be further explored.

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