Sustainability 4.0

Assessing the triple bottom line in a smart manufacturing context

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Abstract

As customers demand higher levels of service and societies call for direct action on sustainability topics, industries must adapt. Given the recent democratisation and diffusion of internet-based systems throughout the industrial fabrics, a new paradigm in manufacturing systems has been in vogue. They are becoming more digitalised, interconnected, and self-adaptive. Industry 4.0 will undoubtedly change the relationships between employers and employees, and business models, leading to new strains on both the environmental and social systems in which organisations are embedded.

This work aims, subsequently, at developing a decision-making supporting tool to assess, precisely, the impacts of the introduction of these technologies in the shop floor in terms of sustainability. For that, the outputting tool – **Sustainability 4.0** – is developed and presented. Its purpose is to identify the hotspots of the system under assessment so that a stakeholder engagement plan (SEP) can be developed to mitigate or eliminate those exact hotspots. Additionally, a four-step methodology for its application is proposed from a user manual standpoint, offering a generic perspective to the application of the tool to any given case, sector-wise. The four steps encompass the definition of the scope of the assessment, the selection of the indicators, the development of a framework on which the tool is built, and the definition of the SEP.

Moreover, an additional step, covering its validation, was included. For this work, a two-stage validation methodology was applied. Firstly, the tool was validated through a focus group with experts in the field. Then, in a second phase, the resultant pre-validated tool was further validated resorting to in-depth interviews with fifteen specialists from both the academic and business dimensions. Overall, the interviewees' reaction and receptivity to Sustainability 4.0 was overpoweringly positive whilst considering it makes a very strong case for the acclamation of Sustainability 4.0 as a tool that allows the assessment of sustainability impacts in a smart manufacturing context.

By enlarging the visibility of sustainability, it is expected that this work contributes to expand and consolidate research on a crucial topic, as well as to provide precious information to sustain decision-making processes.

Keywords: Assessment • Decision-making • Industry 4.0 • Indicators • Sustainability • Triple bottom line.

1. Introduction

Societies are going digital. Therefore, industries must adapt. This adaptation goes in favour of the current trends in automation, cloud computing, and cyber-physical systems (CPS) and has the ultimate goal of obtaining a smarter and seamlessly connected ecosystem within industries to attain greater levels of productivity and efficiency, overall [1,2]. The increasing awareness towards these new technologies is often referred to as the fourth industrial revolution or industry 4.0. It focuses on a seamless integration between CPS, manufacturing operations, information and communication technologies (ICT), and is changing the rules of the competition, triggering a renovation of current business models [3]. This new transformation era within industries will disrupt the way employees perform their tasks and impact, subsequently, the social and environmental systems that surround organisations. Sustainability enters here as the concern of balancing the pressures mankind puts in nature and its resources whilst pursuing the aspirations of attaining better life conditions and greater levels of wellbeing [4]. The concept of sustainability, in its three dimensions, *i.e.*, social, economic, and environmental, is one of great importance when dealing with the fast-paced introduction of such technologies in both business and operational contexts.

Despite the research around the topic, little or nothing is known about the impacts the introduction of these technologies will bring to our lives and to the environmental and societal ecosystems that surround an organisation's operations [5]. Therefore, it is important to study how sustainable this new industrial paradigm is and the associated impacts it will have upon implementation. The performed literature review underlined that research that combined the topics of sustainability and industry 4.0 is virtually inexistent and is merely focused on the environmental dimension. There were also no records of research that provided an adequate and comprehensive framework to assess sustainability for industry 4.0 related topics [5]. This work aims, precisely, to fill that research gap, providing an answer to the following question: *How to accurately and comprehensively assess the impacts of the introduction of industry 4.0 technologies in terms of the three dimensions of sustainability?*

Therefore, the output of this work will be the development of a generic sustainability assessment and hotspot mitigation/elimination tool – **Sustainability 4.0** –, that, firstly, allows the identification and characterisation of sustainability hotspots derived from the implementation of these technologies and, secondly, following the identification of the hotspots, sets the future course of action for the development of an SEP to mitigate or eliminate them.

2. Industry 4.0 and sustainability: the dawn of a new era

2.1. Industry 4.0: background and definition of concepts

The term "industry 4.0" was first coined in 2011 as the brand of the fourth industrial revolution given the perceptible democratisation and diffusion of internet-based systems throughout the German industrial fabric [1,2]. It is the current pinnacle of industrial breakthroughs that have been occurring over the centuries. The first industrial revolution occurred in the late 18th century and was the moment in time where mechanical production sites powered with water and steam began to appear. The second revolution followed, in the early 20th century, with the advent of mass labour production lines powered by electricity. Then, in the 1970s, the third industrial revolution marked the start of automated production lines based on recent computerised-based technologies and electronics [6]. The term industry 4.0 eventually evolved to become an umbrella term, entailing, essentially, three dimensions [3,7]:

- An horizontal integration throughout the value chain where both intelligent intra and interenterprise links are formed, meaning that enterprises collaborate with each other by sharing resources and real time information;
- An end-to-end engineering across the life cycle of the product, meaning that engineering, connectivity, and technology are integrated in the product from cradle to grave;
- A vertical integration across value chain activities, meaning the embedding of ICT across the different hierarchical levels of an organisation, allowing a seamless integration between manufacturing and management levels.

All these crosslinks and digitalisation processes are made possible resorting to ICT permanently connected to servers in a cloud. In manufacturing processes, these technologies are translated into the implementation of CPS operating in a decentralised and self-organised fashion, relying on the usage of mechatronic components such as sensors and other data collectors. This data can be interchanged through the cloud in real time, contributing to intelligently link the CPS [8,9]. The concept of internet of things (IoT) appears here as an umbrella term for the ICT enablers of these crosslinks [10,11]. It is expected that these technologies contribute to an overall reduction in setup and processing times, costs in labour and materials, and higher levels of productivity and efficiency, whilst ensuring products with higher additional value. They are also bound to optimise resource usage, which will contribute to more sustainable products and processes and to introduce technologies that will change the role of the human being in the shop floor [1,3]. Factories that implement these technologies are named smart factories, given their high resource usage efficiency, speed, and seamlessness in adapting to all changes by means of a feedback loop, meaning that the output is altered to meet the change exerted by the input or previously set managerial goals and scenarios [5,11,12]. Technologies such as artificial intelligence and collaborative robots are also bound to be disrupting factors in terms of sustainability. The implementation of these technologies must be performed in a way that values both the role of the human being within the factory and the environment by efficiently using resources and considering ecological designs, building the foundations for circular economies [12].

2.2. Sustainability: background and definition of concepts

The concept of sustainability as a policy and as a research topic boosted after the release of the Brundtland report [13], in which the concept of sustainability was defined as the concern of balancing the pressures mankind puts in nature and its resources whilst pursuing the aspirations of attaining better life conditions and greater levels of wellbeing. Sustainability is often depicted as an onion-shaped concept, as shown in figure 1, composed of three successively entailing layers: the economic layer, the social layer, and the all comprising environmental layer. This tripartite view of sustainability is known as the triple bottom line [14,15,16]. This enclosure of dimensions derives from the fact that there are flows of resources between each layer, meaning that the economic layer is constrained by the social systems that surround it, and both the economic and social layers are constrained by the existing natural resources [16].

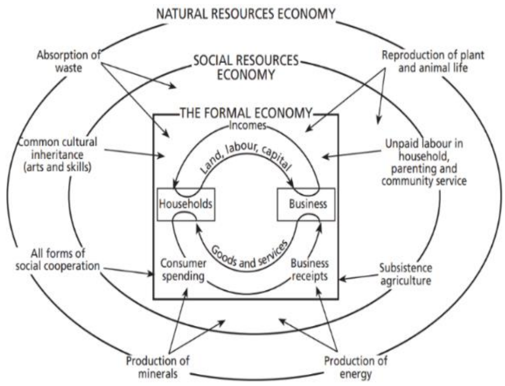

Figure 1 – The three dimensions of sustainability [16]

Despite the research that has been done on the topic, there is a general sense that the concepts of sustainability lack standardisation. This fact is more conspicuous in the field of social sustainability due to the cultural and ethical differences existing around the world and the fact that there are not clear key performance indicators (KPIs) to determine how much more sustainable a given organisation is on a comparative basis. This is one of the reasons why organisations continue to disregard environmental and social issues in opposition to the economic ones [17,18]. Increasing environmental pressures and generalised social disparities triggered by global development are the drivers for the promotion of *sustainable-development-oriented* business models in industries across the world, but their implementation is not yet satisfactory. This is mostly due to the struggle enterprises and academics face in correctly and objectively use indexes to measure sustainability. Such tools can provide a solid ground to support decisions and implement new strategies. They are, therefore, a relevant topic in the field of decision-making [19].

Given the lack of standardisation, it is important to focus the course of this work to find appropriate sustainability indicators, KPIs, and assessment tools that are suitable to the topics of industry 4.0 and smart manufacturing.

3. Sustainability metrics for industry 4.0

Assessing sustainability has proven to be a difficult task due to the high amount of subjectivity and lack of standardisation involved in the process. There is, therefore, a need to identify and determine which KPIs and methodologies are best suited to fulfil this task. Each dimension has its own appropriate indicators to ensure they are used correctly in decision-making processes that may arise from making the shift to industry 4.0 a more sustainable process.

3.1. Economic dimension

The Global Reporting Initiative (GRI) defines the economic dimension of sustainability as the effects a given organisation prompts in the economic conditions of its stakeholders. It is the dimension that is primarily spoken about when handling sustainability concepts within the business context, since it is the one that, without attaining it, the organisation cannot survive. The result is that it is always put in first plane, disregarding the other two dimensions [18,20]. One of the reasons for the disregard of the social and environmental dimensions is the accessibility and availability of information that allows to measure and assess economic sustainability. Data regarding the economic performance of any organisation can be found in its financial and accounting statements which are, most of the times, demanded by law. Reports regarding an organisation's economic performance may also provide information on whether its financial viability is achieved at the cost of creating significant externalities that may affect several stakeholders. However, what is often less reported, and is frequently desired, is the organisation's contribution to the sustainability of a larger economic system [20]. Indicators regarding the economic dimension of sustainability are, therefore, intended to assess, evaluate, and measure in what way and to what extent the economic performance is altered when implementing industry 4.0 related technologies within an organisation. The data condensed in the several indexes will, ultimately, highlight the flows of capital between several stakeholders and the main economic impacts the organisation prompts in the social system it is embedded into [20,21].

To analyse the potential economic impacts that the introduction of these technologies might have prompted, it is important to make a comparative evaluation of the period prior to that introduction with the moment after. What follows is a listing of common indicators and tools used by some influential entities, such as the GRI and the Institution of Chemical Engineers (IChemE), to assess the economic dimension of sustainability.

3.1.1. Profitability and investment analysis

Making the shift to industry 4.0 entails a great financial effort [1,2]. Therefore, it is important to assess to what extent these investments have contributed to add value. This is where investment analysis enter the discussion. Some authors [21,22] propose a list of investment analysis indicators:

- Return on assets (ROA);
- Economic value added (EVA);
- Net present value (NPV);
- Return on equity (ROE);
- Return on investment (ROI);
- Return on capital employed (ROCE).

3.1.2. Productivity and quality

One of the premises of the implementation of industry 4.0 technologies in the shop floor is the expectation that they will contribute to reduce setup and processing times, higher levels of productivity, and an increase in quality standards [1,2,3,12]. Productivity and quality metrics are, naturally, a centrepiece of any organisation's economic sustainability. Some productivity and quality indicators can be found in the literature, sustainability reports, and in several organisation's performance reports [20,21,23]:

- Throughput time;
- Capacity utilisation rate (CUR);
- Scrap rate;
- Defect rate.

3.1.3. Financial implications

The GRI employs this category to assess the financial implications and opportunities for the organisation's activities that are associated to climate change. It also involves risks and opportunities to all intervenient stakeholders. Some particular risks that pose a threat to the financial health of a company are the increasing regulatory pressures imposed by governments in an effort to regulate activities that contribute to climate change. This regulatory risk may result in an increase in costs, impacts in productivity, and competitivity [20].

3.1.4. Financial autonomy

This indicator assesses the degree of dependability of an organisation regarding governmental funding. It quantifies the amount of funds received by a company that have come from State-owned organisations. These contributions need to be compared with the amount of taxes payed by the receiving party. The transactions of capital must not correspond to the exchange of goods and services but to the incentives and compensations for actions taken or costs of a given asset, meaning that these incentives represent a significant form of financial aid and that the State does not expect a direct form of reimbursement for that [20].

3.1.5. Local community practices

The proportion of expenditure of an organisation regarding other local enterprises and communities are taken into account in this category. By settling in a given region, the influence sphere of an organisation covers more than the direct jobs and payment of wages to its employees since it also covers the surrounding enterprises that may interact with it (*e.g.* suppliers, partners, *etc.*). These interactions may be responsible for the creation of additional value which may attract additional benefits to the region [20].

3.1.6. Direct and indirect economic impacts

Investments made by organisations that impact the general public, whether by commercial involvement or *pro bono* activities, are considered in this category as a direct economic impact. Investments in infrastructures, services, and the overall distribution of created economic value can affect the surrounding economic systems and can be seen as a way for organisations to compensate any externalities they may be responsible for. Regarding indirect economic impacts, this impact category identifies and describes the effects of transactions of value between the organisation and its stakeholders and can be either monetary or non-monetary [20].

3.2. Environmental dimension

The GRI defines this dimension of sustainability as the effects an organisation prompts on living and non-living natural systems [20]. It accounts for the use of natural resources and energy, waste management, carbon footprints, and other related concepts. The topic of sustainable manufacturing has been in vogue since it branched out from the Brundtland report [13] and several subsequent works conducted by the United Nations such as its 2030 sustainable development agenda. Additionally, increasing regulatory pressures by governments have forced organisations, especially those that operate in manufacturing industries, to implement and pursue greener processes in their operations. Given this, a greater understanding of environmental impacts of services and products is required [24].

In order to achieve this, it is essential to have a complete assessment of the operations involved in manufacturing from the resource point of view. This is where the Life Cycle Assessment (LCA) enters the discussion as a methodology that is employed to assess the environmental performance of a given process, product, or service. LCA is widely used within enterprises and academia when seeking to evaluate how green their activities are, whether for benchmarking purposes, for legal compliance, or even for marketing reasons [25].

LCA is a standardised methodology used to assess how and to what extent a given product, process, or service impacts the environmental and social spheres in all of its life cycle. It focuses on the identification and quantification of inputs and outputs that integrate the life cycle, lists the environmental benefits and trade-offs, and identifies areas where the achievement of improvements is possible [26,27].

An LCA comprises four steps. The first step is the definition of the scope of the assessment. Here, the object of analysis (*e.g.* system, products, processes, *etc.*) and the boundaries of the assessment are defined, alongside with the statement of the desired outputs of the analysis. In the second stage, inventory analysis, a listing of all inputs and outputs of the system is performed. With this, the analyst has access to accurate data regarding the required resources for each stage of the life cycle. The following step is impact assessment, in which the most relevant environmental impacts throughout the life cycle are assessed. Lastly, in the interpretation phase, the results of both the inventory analysis and impact assessment are compiled and evaluated so that a decision on what is the best product, process, or service, in environmental terms, is made. This information can be used to assist decision-making processes, to foster the development of more sustainable products/processes, to comply with governmental policies and regulations, or even for marketing reasons, as demand for increasingly more sustainable products is on the rise [25,26,27]. The core of LCA is, therefore, comprised of two sequential phases:

- **Life Cycle Inventory (LCI)**, where the collection and analysis of data regarding the environmental interactions is performed. This data is related with the extraction of raw material and to the consumption of resources throughout production and disposal phases;
- **Life Cycle Impact Assessment (LCIA)**, which is the estimation of indicators of environmental pressures in terms of, for instance, climate change, summer smog, resource depletion, human health effects, *etc.*, associated with the environmental interactions attributable to the life cycle.

Methods used for LCIA resort to indicators that are useful to describe the impacts the object of study may have prompted in the environment. Several authors have proposed their own methods to perform this LCA step, making them reliable and verified procedures in terms of assessing environmental sustainability [25,28]. LCIA is made on the assumption that the impacts an object of analysis prompts can be clustered into impact categories through a midpoint approach, *i.e.*, each midpoint represents an impact category. These impact categories are then associated to an endpoint that represents a damage category, correlating different impact categories. These endpoints have associated weights that allow to compute a single score, enabling direct benchmarking. Endpoint methods look at environmental impacts in the end of a given cause-effect chain whereas midpoint methods look at the impact earlier along the same cause-effect chain, *i.e.*, before the endpoint is reached [28].

The environmental impacts considered in LCIA methods can be clustered into a reduced group of indicators that are useful to assess the environmental performance of a company in an industry 4.0 context. The categories below represent a clustering of suitable impact categories from the ReCiPe and Impact 2002+ LCIA methods in an industry 4.0 context [29].

- 〉 Biodiversity;
- 〉 Emission of greenhouse effect gases;
- 〉 Human health;
- 〉 Toxicity;
- 〉 Water and energy consumption;
- 〉 Generated waste.

Industry 4.0 technologies are bound to be game changers in these fields. The foreseeable constant and real time monitoring of all inputs and outputs of a system, alongside with an optimised use of resources, are bound to be great allies in the reduction of environmental impacts.

3.3. Social dimension

The social dimension of sustainability is the most disregarded one due to the lack of clear KPIs to assess it, but also because businesses fail to understand the integration of this dimension as part of sustainable development [18]. The GRI defines it as the effects and impacts a given enterprise prompts in the social systems in which it operates [20]. Social sustainability is also about fulfilling the needs of people and society. It handles topics such as health and safety standards and regulations, the topic of human-centred design of work (ergonomics), the empowerment of individuals, work-life balance, among several other aspects where there is a linkage between an organisation and its stakeholders [24]. What follows is an exposition of commonly used methodologies, tools, and indicators to assess an organisation's social sustainability practices [17,20].

3.3.1. Social Life Cycle Assessment

Social Life Cycle Assessment (SLCA) is a methodology that, much like LCA, assesses both positive and negative impacts an object of study (*e.g.* product, process, system, *etc.*) prompts throughout its life cycle with regard to the social dimension. Its overall goal is to promote wellbeing and positive social conditions which interfere with the economic and environmental dimensions [17,20]. SLCA follows the same generic framework as LCA. However, SLCA tends to be more complex than LCA since it assesses, in a quantitative manner, intangible attributes such as, for instance, stakeholder's wellbeing [30]. Whilst arguing that SLCA needs a more comprehensive approach and a clearer methodology, a group of authors [31] have developed their own five-step methodology to conduct such an assessment that, despite being designed to be applied in early stages of process design evaluations in industrial projects, can be extrapolated to subsequent phases.

3.3.2. Stakeholder analysis and management

An accurate analysis, evaluation, and categorisation of all stakeholders that are bound to either affect or be affected by a given project is essential for any assessment in the field of social sustainability [31]. Several stakeholder identification and categorisation methodologies have been developed in academia:

Identification	Categorisation
〉 Basic stakeholder analysis [32]; 〉 Snowball sampling [33]; 〉 Radical transactiveness [34].	〉 Power-interest matrix [35]; 〉 Problem-frame matrix [36].

To complement the abovementioned methodologies, an effort should be made to understand the risks associated to managing stakeholders. Here is where the concepts of risk analysis and management enter the discussion. The Project Management Institute (PMI) argues that these practices ensure that the number of surprises that may occur is minimised whilst a project is ongoing. To materialise this, the impact that each stakeholder may have in the project, together with the probability of occurrence, p, of that exact impact, should be estimated resorting to the assignment of scores according to each combination of impact/risk [37]. Table 1 presents these scores.

Table 1 – PMI guidelines for risk assessment [37]

		Probability of occurrence, *p*			
		High $0,8 \le p \le 1$	Medium high $0,6 \le p < 0,8$	Medium low $0,3 \le p < 0,6$	Low $0 \le p < 0,3$
Impact	High (100)	Very High Exposure (100)	Very High Exposure (80)	High Exposure (60)	Moderate Exposure (30)
	Medium (50)	High Exposure (50)	Moderate Exposure (40)	Moderate Exposure (30)	Low Exposure (15)
	Low (10)	Low Exposure (10)	Low Exposure (8)	Low Exposure (6)	Low Exposure (3)

3.3.3. Ergonomics and ergonometrics

Industry 4.0 promises to bring new technologies into the shop floor and to change the way employees and machines interact [12]. With that, a rethinking of the human-centred design of work for the smart manufacturing age ought to be performed. Ergonomics enters here in the discussion while being the process of designing products, systems, or setting layouts for workplaces so that they fit the ones who use them. Ergonomics is a multiple factor concept that entails physical, cognitive, environmental, and organisational dimensions [24]. Compliance with ergonomics standards is one of the indicators of social sustainability in organisations and one that acquires higher importance in the age of smart manufacturing. Some indicators retrieved from the literature can be found below.

- 〉 Heart and breath rates;
- 〉 Oxygen consumption;
- 〉 Pupil dilatation;
- 〉 Brain activity;
- 〉 Fairness of workload distribution;
- 〉 Noise level;
- 〉 Workplace air quality;
- 〉 Intensity of light;
- 〉 Thermal amplitudes.

3.3.4. GRI indicators

The GRI offers a compilation of indicators segmented by category. Table 2 summarises some of these indicators that may be suitable to assess social sustainability within the industry 4.0 context due to their applicability to manufacturing industries [17].

Table 2 – Social indicators found in the literature [17]

GRI social category	Examples of indicators
Labour practices and decent work	〉 Fatalities per employee; 〉 Fatalities caused by large accidents; 〉 Frequency of accidents; 〉 Employee turnover; 〉 Fraction of hours of training relative to total hours worked.
Society	〉 Support to neighbouring educational institutions; 〉 Engagement in public and cultural activities; 〉 Level of acceptance by local community; 〉 Involvement of stakeholders.
Human rights	〉 Freedom of association between employees (formation of unions); 〉 Right to organise; 〉 Compliance to laws/regulations regarding child labour.
Product responsibility	〉 Number of customer complaints and claims; 〉 Product reliability and use of ecolabels; 〉 Amount of potentially imported fossil fuel avoided.

4. Methodology of work

Given the problem at stake, namely the need to find a way to quantitively and comprehensively assess the impacts of the introduction of industry 4.0 technologies in the shop floor in terms of the three dimensions of sustainability, as well as to assist and support decision-making processes in a smart manufacturing context, a generic tool to assess sustainability in a comprehensive manner was developed. The intended outputting tool – **Sustainability 4.0** – was developed to assess, by means of indicators and KPIs, sustainability issues in either of the following two contexts:

〉 **Context A** – Following the introduction of industry 4.0 technologies in the shop floor, in case the application of this tool is being performed after that moment, analysing the impacts and changes it prompted;
〉 **Context B** – During that technological shift, in case the application of this tool is being performed in any given point in time from the start to the end of the implementation phase, highlighting possible gaps between current and target situations.

The goal is that sustainability aspects can be assessed with this tool and decision-makers can act upon any detrimental changes or insufficiently met KPIs resultant from the implementation of industry 4.0 technologies with the development of a SEP. This tool must also be suitable to be used in any case, regardless of the industry or sector it is being applied to, hence the need to develop a generic version of the tool. The methodology of work – which yields the desired outputs – comprises four steps, in which the first three correspond to the development of Sustainability 4.0 *per se* and an additional one corresponds to the development of a SEP. Overall, similar guidelines followed by the group of authors who developed their own SLCA methodology [31], namely the extension of their methodology to carry out an SLCA to the other two dimensions of sustainability, were taken into account. Each step is further described below.

The outputs of the first step of this methodology are the definition of the scope of the assessment and the description of the system under analysis. Here, the goal (or goals) of the study and its expected outputs should be clearly stated. The life cycle of the object under assessment and its boundaries, if applicable, should also be defined by adopting a systems-thinking philosophy that highlights the interconnections between the three dimensions of sustainability. To achieve this, the technique schematised in figure 1 is suggested [16].

The second step of this methodology is the selection of suitable sustainability indicators to be included in such an assessment. This can be accomplished by means of a literature review. In this work, the literature review was performed through the analysis of papers available in online publishers. Likewise, more indicators were obtained through an analysis of sustainability and other organisational reports. Moreover, if a generic tool that serves the purpose of assessing sustainability in an industry 4.0 context is to be developed, whilst there can be no *one-fits-all* indicator list, a criteria for the selection of indicators to be included in such an assessment ought to be defined. This step should, therefore, yield the selection of the indicators that are to be present in such an assessment.

The third step is to build the general framework and structure of Sustainability 4.0. Following the selection of indicators, the end user of the tool should decide how the results are going to be presented. Inspired by the works of a group of authors [31], a model for a dashboard, extended to the three dimensions of sustainability, essentially made up of columns and rows, was developed. It should present information regarding one indicator for each of the rows that compose it so that the end user can easily interpret it and act upon it accordingly. This can be materialised in whichever medium the end user finds best to work with.

The fourth stage is to develop an SEP to mitigate (or eliminate, whenever possible) the previously identified hotspots. A planned, well-defined, and successful engagement of stakeholders involves getting their support and develop collaborative tools to devise, plan, and develop new business solutions [38]. In this work, the proposed SEP development methodology is a hybrid between the works of two groups of authors [31,39], meaning that the methodology proposed by the first group of authors is used and the linkage to sustainability targets proposed by the second group of authors is added.

In order to validate both the scientific validity and the real-life applicability of Sustainability 4.0, a two-stage process took place. Firstly, the tool was validated through a focus groups with experts in the field. It is used in academia to generate knowledge and information, test innovative measures, or to clarify the goals and scope of a given project, for instance [40]. Then, in a secondary stage, presential and in-depth interviews with experts in the field, *i.e.*, more specifically, renowned academics from several Portuguese universities and individuals whose expertise and knowledge in the topic of industry 4.0 within the Portuguese industrial fabric and governmental agencies is widely acknowledged, were conducted to further validate the tool. This is essential to collect and analyse feedback from both a theoretical, and a more hands-on and pragmatic perspectives on the validity of the developed tool [41]. The main goals of the conduction of these in-depth interviews was to:

〉 Assess interviewees' perception of how industry 4.0 will impact an organisation in terms of sustainability;
〉 Evaluate if Sustainability 4.0 will, effectively, assist decision-makers in making more sustainable decisions;
〉 Assess the applicability of Sustainability 4.0 to a real-life context;
〉 Know how the interconnectivity and real time measurements, which are some of the premises of industry 4.0, enables Sustainability 4.0 to become a tool that can be used to assess sustainability issues in real time;
〉 Collect feedback on how can Sustainability 4.0 be further improved.

Prior to the conduction of the interviews, an interview script was developed, building the basis for the conduction of a semi-structured interview. This type of interview consists in enquiring interviewees with the previously scripted questions and adding hypothesis-directed, more technical, and probing ones on several other predetermined topics chosen by the interviewer whenever deemed appropriate and/or necessary [42].

5. A hands-on guide to implement Sustainability 4.0

5.1. Step 1 – System definition

Here is where the scope of the study is defined. It involves describing the system under analysis. For that, the life cycle of the object under assessment should be depicted to better visualise it.

The end user should, then, portray the life cycle that corresponds to the organisation's needs. To depict the interactions between the three dimensions of sustainability, three types of flows can be defined:

〉 **Processual flows** – Represent the moving of materials and/or physical interactions (*e.g.* labour, movements of material and goods, *etc.*);
〉 **Monetary flows** – Represent the transfer of monetary quantities;
〉 **Externality flows** – Flows that highlight where externalities, either positive or negative, are generated, *i.e.*, if, when producing or consuming a good, an impact on third parties not directly related to the transaction is created (*e.g.* the extraction of raw material from the surrounding ecosystems is made at the cost of the generation of pollution).

The diagram should also distinguish, through four different geometrical shapes, the entities that intervene in the system:

〉 **Square** – Represents a phase of the life cycle. Should be linked to a physical process/activity;
〉 **Circle** – Represents an economic intervenient in the process. It can be either a specific department of the organisation or an external entity that has economic influence over the system;
〉 **Diamond** – Represents the stakeholders;
〉 **Cross** – Represents the surrounding ecosystems and natural systems, namely air, land, water, and biosphere.

Stakeholders are either people, groups of people, or organisations, meaning their intrinsic social nature is present by definition. However, some of them play a major role in the economic ecosystem that surrounds the life cycle. Therefore, stakeholders such as, for instance, suppliers, competitors, and workers are considered borderline intervenient in both the economic and social layers. One stakeholder that belongs solely in the social layer is the local community for not having a strong and direct influence in the economic dimension of the organisation.

The life cycle should be the centrepiece of the diagram, as it is the common denominator between all interactions with the three dimensions of sustainability. Additionally, the flows that depict the interactions between the three layers ought to be numerated so that they can be easily identified.

5.2. Step 2 – Indicator selection

This step constitutes the centrality of the tool. As mentioned, indicators should be retrieved from the literature and their suitability to assess a subject like the context of smart manufacturing should be, subsequently, evaluated. Any selected indicator must, however, be clearly characterised by means of a clear definition, have its relevance to the analysis stated and sustained, and a mathematical formulation, stating how to perform its computation. Additionally, an indicator, in order to acquire the effective properties of one, must be [43,44]:

- **Accessible** – Information regarding any indicator can be verified by accessible data;
- **Quantifiable** – Any indicator must be numerically measured, meaning that qualitative indicators are left out;
- **Relevant** – Any indicator must show relevant information about a system, *i.e.*, the object of analysis, meaning that its presence in the assessment is able to be sustained;
- **Reliable** – The information provided by an indicator must be trustworthy and verifiable;
- **Understandable** – The definition of an indicator must be clearly, unequivocally, and easily understandable by all stakeholders.

Since a generic version of the tool is being presented, and as there can be no *one-fits-all* indicator list for all cases, a criteria for the selection of indicators to be analysed needs to be defined. Therefore, the selected indicators are to be categorised into three types, according to the criteria presented in table 3:

Table 3 – Criteria for the categorisation of indicators to be used in Sustainability 4.0 according to their type (source: author)

Primary	〉Use whenever possible; 〉Essential to a comprehensive and robust assessment of the impacts the introduction of industry 4.0 technologies entails; 〉Generally related to the changes bound to occur when making the shift to industry 4.0; 〉Look for changes in cost structure, productivity, employee structure and benefits, and LCIA midpoints; 〉Analyse from an investment point of view.
Complementary	〉Use if possible; 〉Those whose presence in the assessment are accessory and, at times, difficult to obtain, but complement the analysis to sustain it; 〉Look for microeconomic indicators, socio-demographic characteristics of employees, and accessory environmental indicators such as the ones suggested by the GRI.
Sector-dependant	〉Those whose presence in the assessment depend on the type of industry, company, or market it is being used in; 〉They are case study dependant.

5.3. Step 3 – Framework development

Once the indicators are selected, the end user should decide how the information is going to be presented. A very straightforward way to accomplish it is through a dashboard. A proposed layout for such a dashboard – one for each of the three dimensions of sustainability – is presented in figure 2. As mentioned, the materialisation of this tool can be executed resorting to whichever medium the end user finds most appropriate to work with. For this work in particular, the materialisation of this tool was achieved resorting to MS Excel®. The following subsections describe, in detail, each set of columns.

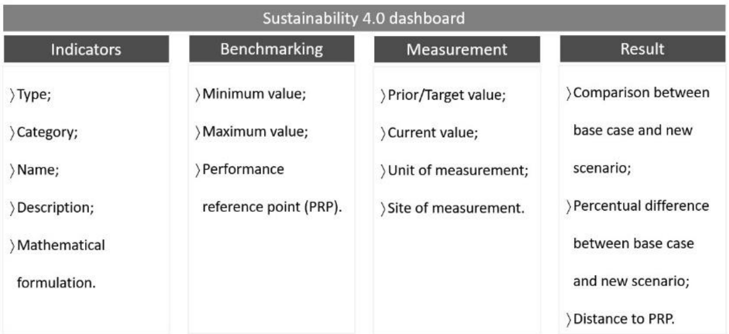

Figure 2 – Generic layout for the dashboard of Sustainability 4.0 (source: author)

5.3.1. Indicators

Here is where the previously selected indicators are itemised. Each indicator should contain information regarding:

- Its **type**, *i.e.*, whether it is a primary, complementary, or sector-dependant one;
- To which **category** it belongs, *i.e.*, the subject the indicator aims to evaluate (*e.g.* if it is related to productivity issues, if its related to labour practices and decent work, *etc.*);
- An identifiable **name** – preferably short –, to be univocally recognised;
- A **description**, so that anyone who uses the tool recognises its relevance and what it is measuring;
- Its **mathematical formulation**, when applicable, by means of an equation, for instance, so that its computation is clear.

For the sake of simplicity and to underwhelm the dashboard, all information, apart from the name, can be remitted to an annex document as long as it can be accessible to the end user.

5.3.2. Benchmarking

Lower and upper bound values are defined for each indicator, setting a range of values that build the basis for a comparative analysis. These values can be set through the following means:

- The organisation's own objectives and managerial goals, meaning they are defined internally;
- Existing regulations and legislation;
- Information available in the literature;
- Data from other organisations whose operations are similar to the ones that are under assessment and are located, preferably, in the same geographic regions [31].

A performance reference point (PRP) can be defined to assess whether the current level is in line with this reference value. One way to compute the PRP is to take the arithmetical average between the lower (minimum) and upper bound (maximum) values [31]. This can be understood as a conversion of the minimum and maximum values to a scale of 0% (worst possible) to 100% (best possible), respectively. The PRP will, therefore, be the figure for which the system obtained a value of 50%. This approach is particularly useful to evaluate whether the positive differences that may be identified between prior values and current values, for instance, are in line with what was defined as satisfactory.

5.3.3. Measurement

Here is where the actual measurement and consequent computation, when applicable, of the numerical values of each of the indicators ought to be displayed. This is, essentially, the cornerstone of Sustainability 4.0, since it is fundamental to understand the effects of the introduction of industry 4.0 technologies. Two measurements are required to make a comprehensive assessment:

- 〉 **Prior value** – The numerical value of an indicator in a point of time prior to the introduction of industry 4.0 technologies. It must be present if the tool is to be applied after the implementation of these technologies on the shop floor level, *i.e.*, in a context A situation. The moment in time immediately prior to this implementation is recommended. However, if either the data availability and/or its quality, in any other moment in time before that one, is superior, it should then be considered;
- 〉 **Target value** – The numerical value of an indicator whose goal is to attain or surpass it. It must be present if the tool is to be applied during the implementation of these technologies on the shop floor level, *i.e.*, in a context B situation, as another benchmarking reference to keep track of the success of the implementation. Again, this value can be obtained in the same way as the benchmarking ones;
- 〉 **Current value** – The numerical value of the same indicator at the present time. It must be present in either of the tool's applicability contexts.

Additionally, the unit of measurement must be specified, as well as the location, in the life cycle, where the measurement took place. The end user should, for that purpose, resort to the life cycle depiction, namely the names of the entities or the numbered flows, so that the information about the data provenience is clear.

5.3.4. Result

Lastly, the fourth set of columns is a compilation of results stating whether there was an improvement or a deterioration of each indicator, the respective percentual difference between prior and current values (or current and target values), and the difference to the specified PRP, when applicable. Bar charts and/or tornado charts are the recommended graphical mediums to showcase the percentual differences and the absolute values for the indicators, respectively. Cases which either fail to surpass the respective PRP, or in which the percentual difference displays a negative value, meaning deterioration has occurred, are considered a system hotspot.

It is important to note that there is a group of indicators that, despite being a central part of the analysis, ought to be handled in a different way since no comparison between prior and current values is possible. These are the investment analysis indicators. Making the shift to industry 4.0 involves a great effort from the investment point of view but that investment is made (or is considered to be made) in a single point of time, making no sense to compare it to any other value. Achieving economic sustainability in such a context implies that investment analysis indicators attain satisfiable levels. However, these can be interpreted without any basis of comparison, meaning its evaluation is made simply by looking at its values. Investment analysis indicators must then be present in this analysis as primary type indicators but should be kept aside from the remaining ones.

Moreover, whilst being fundamental to identify the system's hotspots, the definition of improvement and deterioration of an indicator may vary according to the organisation's objectives. Some indicators such as accident frequency, for example, have this task relatively simplified as an increase in the number of accidents is always considered to be a bad thing. However, in some indicators such as percentage of employees who work in a part-time regime, this assessment becomes somewhat subjective. Therefore, the distinction between good and bad should be made by taking into account the scope of the assessment, as well as the organisation's strategy.

5.4. Step 4 – Stakeholder engagement plan

The fourth step is the development of an SEP to mitigate (or eliminate) the previously identified hotspots. Firstly, the stakeholders are to be identified. Here, the aforementioned stakeholder identification techniques should be applied. Hybrid versions of the many available stakeholder identification methodologies validated by the literature are also acceptable for as long as a congruent output is obtained.

Following the identification of stakeholders, these ought to be classified according to, for instance, their power, interest, and their supportiveness towards change so that the end user can better manage them individually. This can be accomplished using the abovementioned power-interest matrix [35] and the problem-frame matrix [36], for instance. Again, other stakeholder categorisation techniques that the end user may find more suitable to be applied in a given case are also valid as long as a consistent output is obtained.

Then, the requirements of the stakeholders who are associated to a given hotspot ought to be identified and linked to appropriate sustainability targets [31,39]. For each of the identified hotspots, a stakeholder requirement table ought to be constructed, *i.e.*, there should be as many of these tables as the number of the identified hotspots. The purpose of this table is to list the stakeholder's requirements (*e.g.* increase in wages, *etc.*), which are then linked to the organisation's own sustainability targets/goals. The stakeholders should be ticked to their respective requirements.

The last step before the definition of the SEP *per se* is to determine any impacts, negative and positive, that will result from the defined actions to mitigate/eliminate the hotspots. For that, an impact table should be constructed – again, one table for each of the identified hotspots. For each of these, a list of the positive and negative impacts that the proposed actions to mitigate/eliminate the hotspots will prompt, with regard to a given stakeholder, should be stated. Ideally, an impact-risk score should be assigned to each impact. This can be achieved resorting to the abovementioned risk management methods, namely, the attribution of a score according to the criteria defined and presented in table 1 (which can be inputted between brackets, for instance).

The SEP should, ultimately, establish an involvement strategy for each stakeholder, stating the mechanisms of interaction, *i.e.*, the way the organisation should communicate with stakeholders during the application process, in order to mitigate/eliminate the previously identified system's hotspot, providing, whenever possible, a time schedule for each of them, *i.e.*, to state when the actions present in the SEP should be triggered. All these steps allow for the end user of Sustainability 4.0 to acquire much needed knowledge regarding stakeholders, which is crucial when designing an SEP. For instance, the greater the power and interest a given stakeholder has towards the results of the application of Sustainability 4.0, the more intense should the engagement mechanisms be [31]. These authors also list, as examples of engagement mechanisms, the conduction of interviews and surveys, personal and frequent meetings, group workshops, surveys, and even social media engagement.

In order to visualise what the outputting SEP should look like (and also to help the end user to keep track of its progression), a SEP table should be constructed. A mock-up of this table is depicted in table 4. Here, for each of the stakeholders that are linked to hotspots (in this case, *n* stakeholders), a list of actions to mitigate/eliminate the hotpot that should be carried out with a given stakeholder are presented, as well as their respective engagement mechanisms.

Table 4 – Mock-up of the outputting SEP (based on [31])

Stakeholders			
Stakeholder 1	Stakeholder 2	…	Stakeholder *n*
〉 Action 1.1; 〉 Action 1.2; 〉 …	〉 Action 2.1; 〉 Action 2.2; 〉 …	…	〉 Action *n*.1; 〉 Action *n*.2; 〉 …
Engagement mechanism (EM)			
EM_1	EM_2	…	EM_n

6. Validating Sustainability 4.0: insights and recommendations

6.1. Preliminary validation via focus group

The first step was to select the participants of the focus group. The choice fell on three experts in the field, all from the Department of Engineering and Management of the university the author of this work belongs to. The author of this work played the role of facilitator.

The second step was to define the way the focus group was going to be carried out so that a productive discussion was generated. Here, the facilitator plays a major role, since it is her/his responsibility to define the topics of the focus group and make sure the discussion is as relevant as possible, guaranteeing that every topic and subject of interest is covered. The topics were presented and discussed in the following order:

- Contextualisation of the problem and explanation of the motives that led to the development of Sustainability 4.0 in the first place;
- Showing of the methodology for the development of Sustainability 4.0;
- Definition of the criteria for the selection of indicators to be present in the dashboard of Sustainability 4.0;
- Suitability of Sustainability 4.0 to assess sustainability issues in a smart manufacturing context.

The third and last step was to collect every piece of feedback from all participants and turn that information into knowledge. As the issues that were brought to the conversation were being discussed, several remarks and improvements were suggested, which were later implemented. The version of Sustainability 4.0 heretofore presented is, therefore, a fine-tuned version of the tool following the validation from the academic point of view through the focus group.

6.2. Further validation via in-depth interviews

Taking into consideration the research question presented in the first chapter, the purpose and objectives for the application of this validation technique presented in chapter 4, and the steps for the development of Sustainability 4.0 presented in the chapter 5, a semi-structured interview script was elaborated.

The selection of interviewees favoured fifteen experts in the field, more specifically, six renowned academics from several European universities, as well as nine individuals whose expertise and knowledge in the topic of industry 4.0 within the Portuguese industrial fabric is widely acknowledged. Their anonymity was guaranteed.

Overall, the interviewees' reaction and receptivity to Sustainability 4.0 was overpoweringly positive whilst considering it makes a very strong case for the acclamation of Sustainability 4.0 as a tool to assess sustainability impacts in a smart manufacturing context, despite, of course, some remarks having been suggested. Moreover, interviewees' general perception is that industry 4.0 will, undoubtedly, be the cause of impacts that will affect all dimensions of sustainability. Table 5 aims to summarise the main conclusions that were drawn from the interviews, as well as suggestions that were made, divided by aspect.

Table 5 – Summary of conclusions collected from the interview process (source: author according to the interviewees' feedback)

Engagement plan	〉 Use of operations research techniques, namely multi-objective optimisation techniques, in order to obtain an optimal set of actions whose maximisation is assured; 〉 Employment of the Delphi method to mediate any possible conflicts that may arise when defining the SEP in order to generate consensus within stakeholders.
Indicators	〉 Development of a comprehensive and collaborative sustainability indicator database for the context of industry 4.0 to minimise the necessary time for the indicator retrieval and selection phases; 〉 Development of a version of Sustainability 4.0 that resorted solely to GRI indicators and standards in order to assure the standardisation of the assessment and to ensure a solid comparison basis between organisations; 〉 Inclusion of a metric that would assess the reliability of the data that is collected in order to obtain and/or compute the indicators; 〉 Development of a methodology that would allow to rank indicators, within the same dimension, by importance, assigning weights to them; 〉 Assignment of each indicator to an indicator-owner, *i.e.*, a specific individual who would become responsible for its continuous measurement and for updating the dashboard with information regarding that specific indicator.
Applicability	〉 The application of the tool was considered to be dependent on the use of external consultancy services in order to ensure its correct application; 〉 Conversion of Sustainability 4.0 into an inspection tool that would allow to identify organisations that don't comply with regulations; 〉 The tool can be extrapolated outside the context of industry 4.0 and be applied in any process of organisational change, from any point A to any point B in time; 〉 Conversion of Sustainability 4.0 into a dashboard that would allow to implement gamification strategies in the shop floor; 〉 Use of Sustainability 4.0's framework in order to identify organisations whose practices in the field of sustainability are notorious to either award them or learn from the best-in-class; 〉 Possibility of defining the PRP with a different value rather than the arithmetic average between the maximum and minimum values defined in the benchmarking section whilst maintaining the analogy of assigning 0% to the minimum value and 100% to the maximum value; 〉 Development of a weighted approach of Sustainability 4.0, meaning the three dimensions of sustainability would become ranked; 〉 Employment of Hoshin Kanri and Balanced Scorecard frameworks to guarantee the attainment of the project's objectives.
Further implementation stages	〉 Dematerialisation of Sustainability 4.0, *i.e.*, implementation of the tool in a platform that can be accessible to all (*e.g.* server) rather than in one single file saved in one's computer and only accessible to some, allowing its continuous improvement and updating process; 〉 Listing of which indicators are to be measured in real time and definition of how this real time measurement of data is to be attained from the technological point of view.

7. Conclusions and future work outlook

The industrial fabrics of the world's most developed economies are becoming increasingly and successively more digital due to the democratisation and wide-spread diffusion of internet-based systems, creating the perfect ecosystem for another industrial revolution to occur. Industry 4.0 is, therefore, the current trend in automated and interconnected systems and also the climax of the three previous industrial revolutions. These new technologies and consequent conjunctural transformations and disruptions will, undoubtedly, change the relationships between employers and employees, business models pursued by companies, and trigger new strains on both the environmental and social systems in which organisations are embedded. However, the conducted literature review stressed the lack of research regarding suitable and tailored sustainability indicators, assessment methodologies, and metrics for the introduction of these disruptive technologies on the shop floor level. Additionally, since the assessment of sustainability itself equally lacks standardisation and clear definition, there was a need to find appropriate and suitable sustainability indexes for a smart manufacturing context.

As such, the methodology for the development of a tool that allowed to measure and track sustainability indicators, in each of its three dimensions and in an industry 4.0 context, was presented. This tool – **Sustainability 4.0** – starts by assessing, for each selected indicator, two values: a prior value and a current value, in a case where the technological shift is considered complete, or the current value and a target value, if the application of this tool is being performed in the midst of that shift. This allows the end user to identify what is going well and what is going wrong in this process. The hotspots of the systems, *i.e.*, the indicators whose figures have worsened or have failed to surpass the predetermined PRP, are to be mitigated (or, if and whenever possible, eliminated) through the development of an SEP.

Research in the field of sustainability *per se* is, fundamentally, an everlasting quest as societies evolve continuously. Furthermore, future prospects indicate that sustainability will be an even more relevant topic within policymakers and, in particular, European policymakers as the results of the 2019 European elections have substantiated. As to what research in the field of industry 4.0 *per se* is concerned, due to the novelty of this thematic, a lot is yet to be studied and, as industry 4.0 enters, effectively, in the shop floor, more consolidated data can be retrieved. However, this is the first industrial revolution in which much of the knowledge that surrounds this topic is being generated before its effective occurrence. These facts should motivate and empower both decision-makers and policymakers to take advantage of this generated knowledge so that this transition runs more smoothly and is performed in a more sustainable way. This is, precisely, one of the strongest reasons why the development of frameworks and tools – such as the one Sustainability 4.0 is – are crucial to ensure that exact smooth transition.

The aforementioned reasons provide sufficient and valid motives to pursue further research in the field of sustainability in the context of industry 4.0. In particular, despite the exposition and development of the building blocks of the tool, Sustainability 4.0 has yet so much unravelled potential. In fact, one key feature of Sustainability 4.0, which was pointed out in more than one interview, is its suitability to assess and track sustainability standards in any organisational modification or paradigm change, *i.e.*, from any point A to any point B in time. It would be extremely interesting to extrapolate this framework to other contexts of organisational change rather than just the case of the shift to industry 4.0. As such, the development of a tool that, despite having both similar guidelines and implementation methodology as Sustainability 4.0, could track and assess sustainability, and identify the system's hotspots, in any given context of organisational/paradigm change, would be very beneficial.

Another variation of Sustainability 4.0 that was mentioned by most of the interviewees from the business dimension is the development of a weighted approach on the assessment, whether at the indicator level, meaning some indicators are more important than others, or at the dimensional level, *i.e.*, the three dimensions of sustainability become prioritised. To develop such a would be of great value, especially to compare and prioritise actions since the identified hotspots were ranked by order of importance.

In chapter 5, it is mentioned that one of the contexts for the application of this tool is in a case where the process of implementation of industry 4.0 in an organisation is considered to be complete. Effectively, this raises several questions:

To what extent has the organisation adopted industry 4.0 technologies in their operations?
What defines a complete implementation of industry 4.0?

One way to answer to these questions is with some sort of a digitalisation index. The literature review highlighted that there are, to this date, no records of a standardised, well-established and widely acknowledged indicator to assess, precisely, the degree of digitalisation or industry 4.0 implementation that a given organisation has attained. The development of such an index would contribute to enrich Sustainability 4.0 and remove some subjectivity off the table, as the results provided by the indicators could be correlated with this value, allowing a much more comprehensive assessment.

Despite the vertical and horizontal integrations which are some of the premises of industry 4.0, one limitation of the tool is that it focuses merely on the shop floor level and the organisations' operations rather than the supply or value chain as a whole, restricting the scope of the assessment. This comes as a direct inheritance of the characteristics of industry 4.0, since these technologies are focused, precisely, on the shop floor level. However, an assessment of sustainability in the value chain as a whole, rather than in just one echelon, adds much more value to all intervenient entities. As such, a version of Sustainability 4.0 with a scope of assessment wide enough to entail the whole value chain, resorting to the premise of more data centralisation, should also be developed.

As mentioned by several interviewees, this tool can be used as an inspection tool by governmental entities such as the Authority for Work Conditions, the Portuguese Environmental Agency, or even the Portugal 2020 programme, responsible to allocate European funds to organisations, to check whether or not the organisation complies with existing regulations or if the funds are being properly employed.

Another thing that was mentioned in more than one interview was the development of a skeuomorphic software version of Sustainability 4.0 that could route users through the step-by-step process of its application, allowing to decrease hypothetical training times. Additionally, this software version should be equipped with a comprehensive sustainability indicator database from which end users could select the indicators that ought to be present in the assessment, alongside with information on how to obtain and/or compute a given indicator. This software version should also promote the centralisation and accessibility of the information, meaning that anyone should be able to consult or update it whenever deemed necessary.

Finally, the last presented suggestion for further research work is the real-life application of Sustainability 4.0. Despite having been validated with fifteen interviews with the most diverse panel of experts, only a case study approach would offer the best results in order to determine whether or not this tool is applicable in an organisation and its consequent viability. Additionally, an effort should be made in transforming this tool in a way that it is more sellable and marketable. As suggested by most of the interviewees, the application of this tool in an organisation is more likely to be successful through the use of external consultancy services. Organisations would only hire these services if they saw and understood the full potential of the tool. Therefore, to market Sustainability 4.0 as a comprehensive and straight-forward decision-making tool should be a logical step to take.

The topics of sustainability and industry 4.0 are, undoubtedly, intimately related, as this work demonstrated. Making the shift to industry 4.0 will impact each of the three dimensions of sustainability in different extents. Whether those impacts are mostly negative or predominantly positive is up to decision-makers and policymakers, but if they possess decision-aiding tools, *i.e.*, tools that provide them with solid and trustworthy information on which they can sustain their decisions, this will empower them to make better decisions. As such, the ultimate goal of this work is to provide decision-makers with a tool for the assessment of sustainability in industries that have implemented (or are in the process of implementing) industry 4.0 technologies. With this, the topic of sustainability, in all of its three dimensions, might finally take a prominent spot in any policymaking and decision-making processes that take place.

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