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Industry 4.0-based dynamic Social Organizational Life Cycle Assessment to target the social circular economy in manufacturing

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Abstract:	Nowadays in manufacturing, the topic of sustainability plays a key role. However, over the years, economic crises and the climate change debate have focused the attention of scholars, industrialists and policy makers mainly on environmental sustainability, putting social sustainability on the back burner. This is also evident in the scientific literature which highlights several knowledge gaps. The digital transition of factories and Industry 4.0 technologies have not yet been fully exploited to correlate production and social metrics. As a result, there is a lack of adequate tools for monitoring social performance in the factory environment. In this context, the social dimension of the circular economy is still an under-researched topic. This study aims to fill these gaps by integrating Social Organizational Life Cycle Assessment (SO-LCA) and Industry 4.0 technologies in a blended methodological approach designed to dynamically monitor the social performance of a major manufacturing industry. Using primary data, a set of site-specific social indicators and indexes were created to assess the organization's social impact against key stakeholder categories and subcategories. Finally, within that set, those social metrics that the organization considers essential to moving toward the circular economy were identified. Therefore, this study, has contributed to fill the literature gaps by demonstrating that the digitization of production processes, not only enables the assessment of environmental impact, but can also play a key role in knowing the social performance of a manufacturing organization and to identify the hidden social dimension in the circular economy.
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21th June, 2021

Dear Managing Guest Editor Prof. Dr. E. D.R. Santibanez Gonzalez,

Dear Guest Editors Prof. Dr. I. D'Adamo, Prof. Dr. P.Morone and Prof. Dr. P. Rosa.

Congratulations on your interesting Special Issue on *Green, Circular and Bioeconomy Practices and Strategies.* We are very grateful to you for inviting us to contribute our own research to your Special Issue. We believe that the manuscript we are submitting is consistent with the aims of the Special Issue.

We now hope that the paper entitled "*Industry 4.0-based dynamic Social Organizational Life Cycle Assessment to target the social circular economy in manufacturing*", will be suitable for your journal.

My colleagues and I conducted the research and coauthored the manuscript. We have all approved the paper for submission to *JCP* and I have been chosen as the corresponding author. Each of the authors confirms that this manuscript has not been previously published and is not currently under consideration by any other journal.

The paper represents a concrete result of the research project funded by the European Union under the LIFE program (LIFE16 ENV/IT/000307: LIFE Force of the Future; website: www.forture-life.eu), which aims to effectively integrate the three pillars of sustainability (environment, economy and society) into circular business models. Within this research framework, our article aims to identify social metrics that can be correlated with manufacturing performance; to this end, we envisioned an integration of the Social Organizational Life Cycle Assessment (SO-LCA) methodology with Industry 4.0 digital technologies. Thanks to this hybrid model, it is possible to conduct a dynamic social assessment of the organization by exploiting the acquisition of real-time primary data directly from the factory. In addition, we have identified those social metrics that directly contribute to the circularity of manufacturing, thus identifying the social dimension of the circular economy.

Believing that the topic is consistent with the goals of SI, we hope that readers of the journal will find interest in our article. Thank you for your interest and consideration.

Yours sincerely,

Davide Settembre Blundo

Corresponding Author

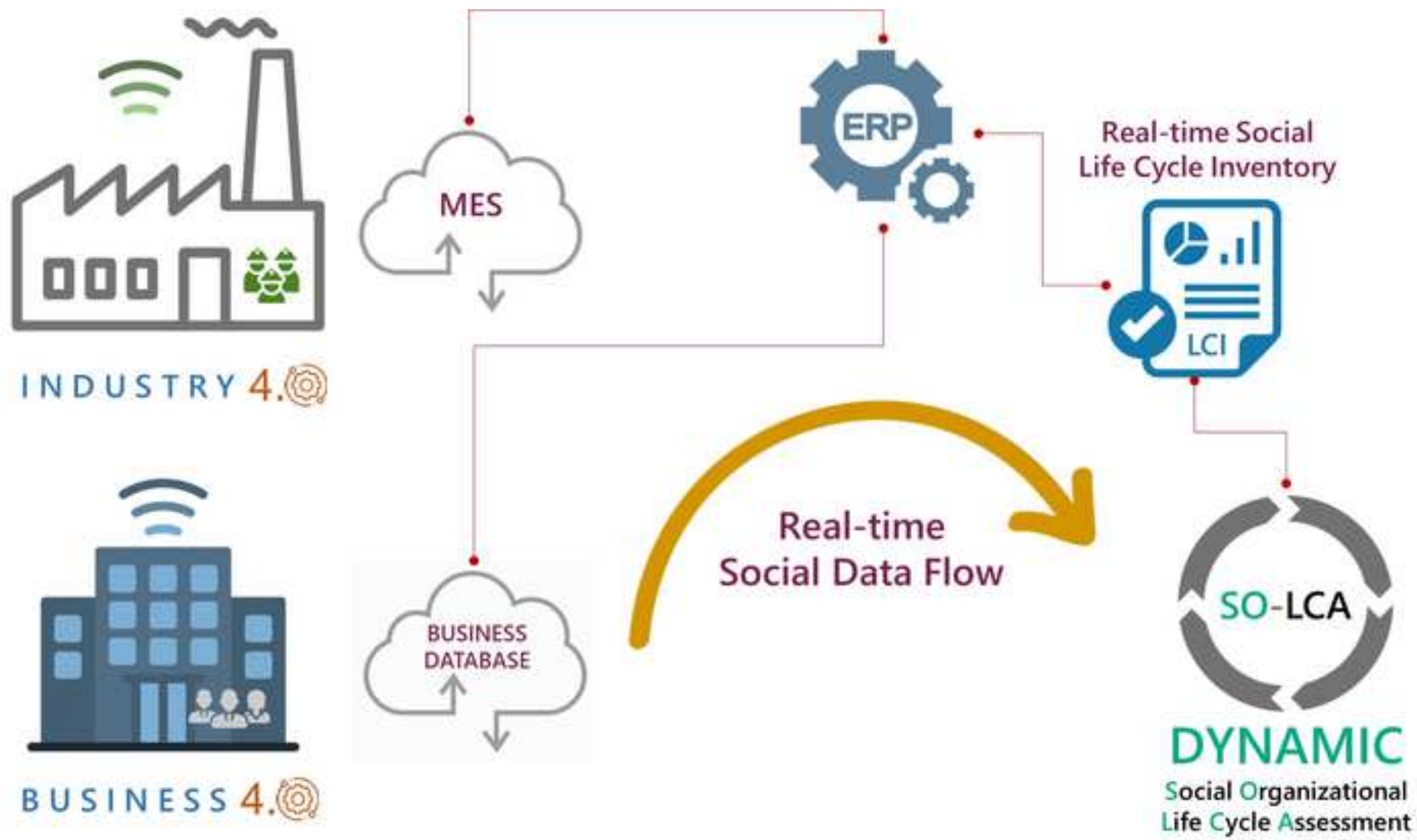
Industry 4.0-based dynamic Social Organizational Life Cycle Assessment to target the social circular economy in manufacturing

Highlights

- Social sustainability and the social dimension of circularity are still under-researched in manufacturing.
- Industry 4.0 technologies can enable dynamic social performance monitoring in the factory environment.
- A blended method integrating Social Organizational Life Cycle Assessment (SO-LCA) and Industry 4.0 has been pioneered.
- Organizational social impact with respect to stakeholders was assessed using only primary data.
- Social metrics that drive the manufacturing organization toward the circular economy were selected and validated.

Graphical Abstract

Click here to access/download;Figure;JCP_DYNAMIC_SO-LCA_Graphical-Abstract.jpg



Industry 4.0-based dynamic Social Organizational Life Cycle Assessment to target the social circular economy in manufacturing

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ABSTRACT

Nowadays in manufacturing, the topic of sustainability plays a key role. However, over the years, economic crises and the climate change debate have focused the attention of scholars, industrialists and policy makers mainly on environmental sustainability, putting social sustainability on the back burner. This is also evident in the scientific literature which highlights several knowledge gaps. The digital transition of factories and Industry 4.0 technologies have not yet been fully exploited to correlate production and social metrics. As a result, there is a lack of adequate tools for monitoring social performance in the factory environment. In this context, the social dimension of the circular economy is still an under-researched topic. This study aims to fill these gaps by integrating Social Organizational Life Cycle Assessment (SO-LCA) and Industry 4.0 technologies in a blended methodological approach designed to dynamically monitor the social performance of a major manufacturing industry. Using primary data, a set of site-specific social indicators and indexes were created to assess the organization's social impact against key stakeholder categories and subcategories. Finally, within that set, those social metrics that the organization considers essential to moving toward the circular economy were identified. Therefore, this study, has contributed to fill the literature gaps by demonstrating that the digitization of production processes, not only enables the assessment of environmental impact, but can also play a key role in knowing the social performance of a manufacturing organization and to identify the hidden social dimension in the circular economy.

Keywords: circular economy, social sustainability, social organizational life cycle assessment, manufacturing, industry 4.0

1. INTRODUCTION

Nowadays green economy and circular economy refer to the idea of an economic system based on resource efficiency, renewable energy sources, low CO_2 emissions and digital innovation. All this reflects the transition to a new economy of sustainability. In the large body of literature that covers the meaning of sustainability (Olawumi and Chan. 2018; Avesani, 2020), many researchers have pointed out that this concept is multidimensional, including environmental, economic and social aspects (Ranjbari et al., 2021). All definitions agree that sustainability should provide economic development consistent with social equity and the capability of natural resources to regenerate (Amrutha and Geetha, 2020), while maintaining a state of dynamic equilibrium (Dorsey and Hardy, 2018). However, the growing sensitivity on climate change and environmental issues (D'Amato et al., 2017), has focused the most recent discussion of scholars, political leaders, and public opinion, on environmental sustainability while neglecting social sustainability (Amankwah-Amoah and Syllias, 2020). In contrast, from a managerial perspective, social sustainability is as crucial as environmental and economic sustainability because by affecting the organizational model, it impacts the company's performance (Schönborn et al., 2019). Moreover, concrete social sustainability actions implemented by companies improve the trust of internal and external stakeholders towards the organization (Bruna and Nicolò, 2020).

Another relevant aspect of the social dimension of sustainability, is that there is still no unambiguous and accepted definition of the concept, both in the scientific community and in the policy debate (Weingaertner and Moberg, 2014; Woschnack et al., 2021). The direct consequence is the proliferation of a wide variety of tools and methods for assessing the social impact of economic activities (Molecke and Pinkse, 2017), an effect that is also due to the absence of international standards that establish an precise accounting system (Nekhili et al., 2017). However, despite these methodological and normative gaps, stakeholders increasingly demand firms to provide concrete evidence of their capability to create and share value (Diez-Cañamero et al., 2020). Among the social impact assessment methodologies, Social Return On Investment (SROI) attributes a monetary value to the social performance of an organization's activities that clearly cannot have a market value. The SROI is an efficiency index that measures the ability of an organization to generate value for each monetary unit invested (Watson et al., 2016). Shifting the perspective of analysis from the organization to projects, plans, and policies, another method to measure social impact is the Social Impact Assessment (SIA), (Bonilla-Alicea and Fu, 2019). The SIA must consider not only the social issues related to the planning and implementation of a project, but also the interactions with environmental impacts, integrating both quantitative and qualitative approaches and following the logic dictated by the SROI guidelines (Florman et al., 2016). The SIA should be integrated into all phases of a project's life cycle: from concept and identification through the preparation, approval, implementation, and completion phases (Vanclay, 2020).

A direct evolution of the SIA is the Social Life Cycle Assessment S-LCA, which applies the SIA approach to each stage of a product's life cycle, from sourcing raw materials to recycling and/or disposal after use (Grubert, 2018). The S-LCA is a technique developed within the concept of Life Cycle Thinking (LCT), which offers a holistic assessment of the impacts and social interactions created within the operating environment of an organization that produces and markets a product (Huarachi et al., 2020). The technique outlines ways to map and engage key stakeholders (Huertas-Valdivia et al., 2020), and also provides insight into how stakeholders involved in the process can exert both positive and negative pressure (Di Cesare et al., 2018).

The challenge of sustainability does not only affect individuals but also organizations, so in manufacturing, companies to be more sustainable should become more efficient by producing with less materials, stocks, and man hours (Bengtsson et al., 2018). Furthermore, from a sustainable development perspective and a social viewpoint, a production system should be able to meet the needs of both present and future workers (Taghavi et al., 2015). Despite the importance given to the social dimension even in manufacturing environments, the lack of managerial skills and the failure to involve operational staff are barriers to implementing appropriate social actions in factories (Awan et al., 2018; D'Adamo et al., 2020). Another impediment to implementing social sustainability in manufacturing firms is the lack of social performance measurement tools comparable to those already used to assess technological and operational performance (Lagun Mesquita et al., 2016). Existing tools are limited in their effectiveness by the lack of quantitative data linking social impacts to manufacturing operations (Sutherland et al., 2016). As a result, although many methods of assessing social sustainability have been proposed (Popovic et al., 2018; D'Eusanio et al. 2019; Rafiaani et al., 2020), the quantitative aspects of the social performance of manufacturing enterprises have not yet been sufficiently clarified, especially regarding the relationships between social impacts and corresponding technological performance (Shi et al., 2019), as well as the supply chain (Mani et al., 2020).

The rapid roll-out of digital technologies are offering the manufacturing sector great opportunities to become both more efficient in the use of resources (Santibanez-Gonzalez and Huisingh, 2015) and better performing in terms of environmental sustainability (Ghobakhloo, 2020). In fact, Industry 4.0 technologies make it possible to monitor a process by collecting information about resource consumption, material flows and emissions through sensors in production lines (Oláh et al., 2020). The processing of this data can take place in real time providing a dynamic environmental impact assessment (Ferrari et al., 2021). However, although tools and methodologies are available to measure the environmental sustainability of production processes, the era of Industry 4.0 has not yet provided digitized tools to assess social sustainability. It follows that the question of the new role of man in the factory environment raised by the digital transition is still to be investigated (Papetti et al., 2020). Thanks to the digitalization of factories, companies can reconfigure organizational models and production processes to develop new environmentally sustainable products made by minimizing environmental impacts and saving energy without wasting natural resources (Agrawal et al., 2021). Unlike previous industrial models, which were characterized by producing waste in a linear way (Santibanez-Gonzalez et al., 2019), the Industry 4.0 paradigm seeks to minimize or eliminate waste. And this characteristic can link Industry 4.0 with the principles of Circular Economy (CE) and sustainability (Garcia-Muiña et al., 2019).

The CE generates many expectations and is seen as a new development model that can create wealth, jobs and rational use of resources with environmental, economic and social benefits (Hartley et al., 2020). However, this framework still lacks a holistic view of the relationship between circularity and sustainability, which includes all three dimensions: environment, economy, and society (Kirchherr et al., 2017). Indeed, the literature points out that the similarities and differences between the concepts of sustainability and CE have not yet been sufficiently clarified (Geissdoerfer et al., 2017), although there seems to be a general consensus in seeing CE as a condition for being able to address the sustainability challenge and, with a broader view, sustainable development (Schöggl et al., 2020). On the other hand, CE strategies looking primarily at resource flows (Baleta et al., 2019) focus mainly on the positive effects of the environmental dimension of sustainability (Tomić and Schneider, 2020), considering as main beneficiaries the economic agents implementing these strategies (Pitkänen et al., 2020). As a result, the contribution of CE to the social dimension of sustainability is still underexplored (Murray et al., 2017; D'Adamo et al., 2021) or lacking in empirical evidence (Suárez-Eiroa et al., 2019). This precludes testing whether CE can promote the social welfare of current and future generations and whether the circular model is indeed more sustainable than the linear one (Padilla-Rivera et al., 2020). Walker et al. (2021A) also point out that in assessing the social impacts of CE practices, the literature focuses primarily, if not exclusively, on the "job creation" indicator. According to these authors, this approach contradicts the life-cycle perspective that, in CE, involves the collaboration of different firms in so-called circular networks (Walker et al., 2021B) for which it would be desirable to consider their social impacts. Finally, Reinales et al. (2020) point out that there are no relevant studies of social life cycle assessment of product value chains using a CE approach.

2. RESEARCH DESIGN

2.1 Gap-spotting and research questions

The analysis of the literature highlighted how the great attention given to environmental issues by public opinion, practitioners and the academic community has focused on environmental sustainability at the expense of social sustainability. In addition, the lack of a standard definition of social sustainability has led to a growth in assessment systems. Moreover, despite the growing interest in CE, the social dimension of circularity practices is still unexplored also due to the absence of appropriate metrics to assess social impacts. All this has raised a series of shortcomings related to the knowledge of social sustainability assessment both in theory and in practical application. Based on the gap-spotting identification framework provided by Sandberg and Alvesson (2011), the main shortcomings are identified below.

- **GAP 1**: there is a lack of social performance assessment tools to correlate social impacts with manufacturing metrics (Lagun Mesquita et al., 2016; Sutherland et al., 2016).
- **GAP 2:** the digital transition and Industry 4.0 have not yet been fully exploited as enablers to investigate the role of humans in the factory environment (Papetti et al., 2020).
- **GAP 3:** the social dimension of CE has not yet been sufficiently explored (Murray et al., 2017; Suárez-Eiroa et al., 2019; Padilla-Rivera et al., 2020).
- **GAP 4:** there is a general shortage of social metrics for CE from a life cycle perspective. (Walker et al., 2021 A and B).

The four GAPs circumscribe a neglected area in the existing literature on social sustainability assessment systems and give rise to the following research questions:

- **RQ 1**: How can Industry 4.0 digital technologies enable social impact assessment in a manufacturing environment?
- **RQ 2**: What metrics can help identify the contribution of social sustainability to CE from a life-cycle perspective?

2.2 Methodology

To answer the RQs stated in the previous paragraph, this study proposes a mixed method approach based on the integration of Social Life Cycle Assessment (S-LCA) methodology with Industry 4.0 technologies in a manufacturing context. The S-LCA was chosen over other social assessment methods because it adopts the same methodological procedure (analysis steps and life cycle approach) as LCA (Cespi et al., 2020), which is the basic tool for environmental impact assessment and provides useful indicators to define the circularity levels of an industrial process (Peña et al., 2021). In this analysis, S-LCA was applied following the guidelines provided by the United Nations Environment Program (UNEP) in the latest version published in 2020 (Achten et al., 2020). S-LCA shares the same ISO 14044 framework with LCA: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation (Martínez-Blanco et al., 2014). However, in comparison to the LCA, in the S-LCA the focus of the analysis shifts from the processes (Pohl et al., 2019) to realize the product (product-oriented approach), to the companies involved in the life cycle (business-oriented approach), evaluating their behaviour in relation to stakeholders' expectations (Sureau et al., 2018). This different perspective of analysis is also reflected in the type of data used: quantitative for LCA and qualitative or semi-quantitative for S-LCA (Opher et al., 2018). As a result, it is challenging to identify a Functional Unit (FU), i.e. the output-based quantity used as a reference for calculating and assessing impacts, that is satisfactory for both LCA and S-LCA (Arzoumanidis et al., 2020). The purpose of S-LCA is therefore to assess the consequences of social interactions created in the context of an organisation that manufactures and markets a product and to understand how the stakeholders involved in this process can exert both positive and negative pressure (Di Cesare et al., 2018). Unlike the environmental LCA, the data for assessment are not classified according to the different impact categories, but according to the stakeholders involved (Valdivia et al., 2013). The UNEP guidelines identify five main stakeholder groups (Workers, Local Communities, Consumers, Value Chain Actors and Society) involved in the life cycle of a product and for which social impacts are determined. S-LCA studies, while considering the life cycle, often exclude the use phase (Russo Garrido et al., 2018), as well as the "consumer" stakeholder category (Manik et al., 2013). This is since the indicators associated with them are very limited or in any case difficult to identify.

As mentioned above, the study of social evaluation in the manufacturing industry is still an unexplored line of research particularly in terms of metrics and indicators related to process variables. It was therefore decided to adopt the "single case study" methodology (Onghena et al., 2019), believing that this method was appropriate to circumscribe the context to a firm at the leading edge of digital transformation and adoption of the Industry 4.0 paradigm. For this purpose, an Italian company was chosen, which is among the top 10 Italian producers of ceramic tiles and among the top 5 for economic performance, already engaged as a case study by Ferrari et al. (2021) to develop a dynamic LCA system by integrating the environmental assessment tool with factory sensors through Enterprise Resource Planning (ERP). Therefore, this operational setting was deemed the most suitable to fill the GAPs in the literature and answer the RQs.

3. SOCIAL ASSESSMENT

This research follows the guidelines for S-LCA published by UNEP and described in section 2.2, which are based on the same four steps outlined for environmental LCA in the ISO 14040 series (ISO2006). In addition, for the specific case study, it was deemed more appropriate to apply the organizational version of the social assessment as outlined in the guidelines and called Social Organizational Life Cycle Assessment or SO-LCA (D'Eusanio et al., 2020). Therefore, the subsequent paragraphs will follow the same methodological framework. Subsequently, the social dimension of the circular economy was explored further on this basis.

3.1 Goal and scope definition

This SO-LCA study aims to assess the organizational social sustainability performance of a ceramic building tile manufacturer by mapping and identifying actual social impacts and employing primary data collected digitally in real time using Industry 4.0 technologies on the manufacturing site. Reporting organization was set as the reference unit of analysis and "cradle-to-grave" was defined as the system boundaries. Table 1 reports the mapping of the potential company stakeholders divided into subcategories ~~categories~~, and the respective attribution of a n impact a category and subcategory as required by the methodological sheets of the UNEP Guidelines for SO-LCA. In this study, not all potential stakeholders were considered, but only those for which primary quantitative data could be obtained.

STAKEHOLDER CATEGORIES	IMPACT CATEGORIES	STAKEHOLDER SUBCATEGORIES	IMPACT SUBCATEGORIES	STAKEHOLDER DETAILS
1.Workers	A.Human Capital	1.1 Staff Personnel	A1.Human Rights	1.1.1 Blue-collar Workers
				1.1.2 Employees
			A2.Health & Safety	1.1.3 Managers
				1.1.4 Top Management
		1.2 Trade Unions	A3.Working Conditions	1.2.1 Confederal Trade Unions
				1.2.2 Independent Trade Unions
2.Local Community	B.Social Capital	2.1 Local Institutions	B1.Local Expectations	2.1.1 Regional Governments
				2.1.2 Provincial Governments
				2.1.3 Municipalities
3.Society		3.1 Public and Private Organization	B2.Institutional Expectations	3.1.1 Regulatory Authorities
				3.1.2 Research Community
				3.1.3 National and International Public Institutions
				3.1.4 Civil Society Organizations
		3.2 Media	B3.Corporate Reputation	3.2.1 Newspapers
				3.2.2 Professional Magazines
				3.2.3 TV and Radio
				3.2.4 Internet
	C.Natural Capital	3.3 Environmental	C1.Environmental Footprint	3.3.1 Atmosphere
				3.3.2 Hydrosphere
				3.3.3 Lithosphere
				3.3.4 Biosphere
				3.3.5 Future Generations
4.Consumers	D.Economic Capital	4.1 Trade Channel Operators	D1.Customer Expectations	4.1.1 Resellers
				4.1.2 Trading Partners
				4.1.3 Business Customers
		4.2 Final Consumer		4.2.1 Private Customers
				4.2.2 Consumers Associations
5.Value Chain Actors	D.Economic Capital	5.1 Private Business	D2.Private Expectations	5.1.1 Company's Shareholders
				5.1.2 Association of Manufacturing and Service Companies
				5.1.3 Chambers of Commerce
		5.2 Suppliers	D3.Ethical Behavior	5.2.1 Large-Scale Suppliers (Key Suppliers)
				5.2.2 Small-Scale Suppliers
				5.2.3 Local Suppliers
		5.3 Partners		5.3.1 Practitioners and Professionals
		5.4 Competitors		5.4.1 Direct Competitors
				5.4.2 Indirect Competitors

Table 1: List of stakeholder categories, subcategories and details with their respective impact categories.

3.2 Dynamic inventory analysis

In this phase of the social assessment, data collection was done ~~following the criterion of~~ using only site-specific quantitative data derived from primary sources. To comply with this condition of analysis, the potential of digital technologies that characterize the Industry 4.0 production model was exploited. Underpinning inventory analysis is the cloud-based integration of social factory data with social business data (Figure 1). The digital technologies of the Industry 4.0 environment, in fact, allow the real-time collection, not only of production performance data but also of social data closely related to production processes, especially concerning workers. In a similar way, outside the factory and in the company's headquarters, social data related to employees and other categories of stakeholders (shown in Table 1) are collected. Production data is transmitted to the ERP through a Manufacturing Execution Systems (MES) which has the function of interfacing the factory with the management system. Similarly, the other corporate data are transferred to the ERP using a Business Data Base with functions similar to the MES but designed exclusively to collect non-productive information non-productive information.

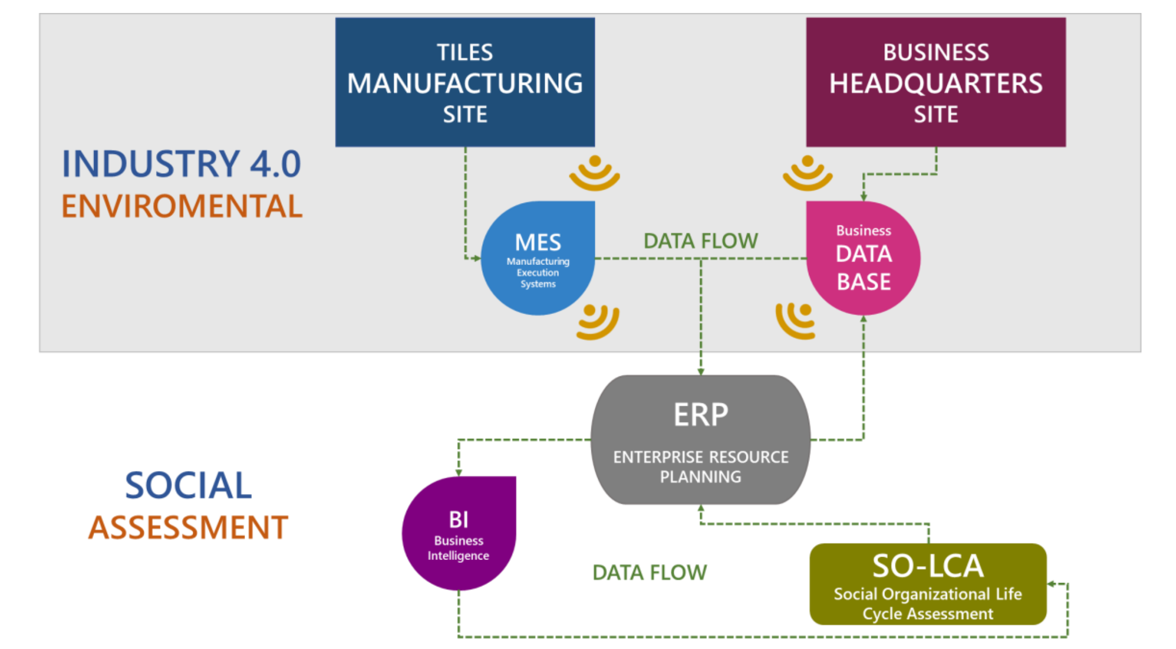

Figure 1: Cloud-based integration between Industry 4.0 and Business information systems, with the SO-LCA tool.

Therefore, thanks to Industry 4.0 digital technologies and the ERP, a dynamic cloud-based inventory analysis can be achieved, thanks to the data collected and made available in real time. Finally, a Business Intelligence system (BI) connects the ERP with the SO-LCA tool to share the Dynamic Inventory Analysis (DIA) and perform a real-time social assessment.

STAKEHOLDER CATEGORIES	IMPACT CATEGORIES	STAKEHOLDER SUBCATEGORIES	IMPACT SUBCATEGORIES	DYNAMIC SOCIAL INDICATORS		INDICATORS DESCRIPTION	SOCIAL POSITIVE INFLUENCE
1.WORKERS	A.Human Capital	1.1 Staff Personnel	A1.Human Rights	DSI-A1.1	Gender Equality	(N° of women) / (Total workforce)	INCREASE
				DSI-A1.2	Childhood Workforce	(N° of children) / (Total workforce)	DECREASE
				DSI-A1.3	Forced Labour	(N° of forced labour workers) / (Total workforce)	DECREASE
				DSI-A1.4	Migrant Worker	(N° of migrant workers) / (Total workforce)	INCREASE
			A2.Health & Safety	DSI-A2.1	Lost Time Injury Frequency Rate (LTIFR)	(N° of injuries x 1,000,000) / (Hours worked)	DECREASE
				DSI-A2.2	Personal Protective Equipments (PPEs)	(N° of PPEs) / (Total workforce)	INCREASE
		1.2 Trade Unions	A3.Working Conditions	DSI-A3.1	Collective Bargaining Agreement (CBA)	(N° CBA) / (Total workforce)	INCREASE
				DSI-A3.2	Overtime Working Hours	(Man-Hours overtime) / (Man-Hours worked)	DECREASE
				DSI-A3.3	Full-time Staff	(Full-time staff) / (Total workforce)	INCREASE
				DSI-A3.4	Local Workforce	(Local workforce) / (Total workforce)	INCREASE
				DSI-A3.5	Training	(Training hours) / (Hours worked)	INCREASE
2.LOCAL COMMUNITY	B.Social Capital	2.1 Local Institutions	B1.Local Expectations	DSI-B1.1	Stakeholders Engagement	(Stakeholders engaged / Stakeholders mapped)	INCREASE
				DSI-B1.2	Public Engagement	(Local governments engaged / N° local governments)	INCREASE
3.SOCIETY		3.1 Public and Private Organization	B2.Institutional Expectations	DSI-B2.1	University Engagement	(Man-Hours of scientists) / (Man-Hours into R&D&I)	INCREASE
				DSI-B2.2	Regulatory Authorities Engagement	(Authorities engaged) / (N° of Regulatory Authorities)	INCREASE
		3.2 Media	B3.Corporate Reputation	DSI-B3.1	Corporate Social Media Engagement	(Corporate Followers / Corporate Likes)	INCREASE
				DSI-B3.2	B2B Social Media Engagement	(B2B Followers / B2B Likes)	INCREASE
				DSI-B3.3	B2C Social Media Engagement	(B2C Followers / B2C Likes)	INCREASE
	C.Natural Capital	3.3 Environmental	C1. Carbon Footprint	DSI-C1.1	Global Warming Potential (GWP)	(Company GWP / Industry GWP)	DECREASE
4.CONSUMERS	D.Economic Capital	4.1 Trade Channel Operators	D1.Customer Expectations	DSI-D1.1	B2B Non-compliance	(N°. of B2B non-compliance) / (N°. of B2B warnings)	DECREASE
		4.2 Final Consumer		DSI-D1.2	B2C Non-compliance	(N°. of B2C non-compliance) / (N°. of B2C warnings)	DECREASE
5.VALUE CHAIN ACTORS		5.1 Private Business	D2.Private Expectations	DSI-D2.1	HR-based R&D Workforce	(Researchers staff) / (Total workforce)	INCREASE
				DSI-D2.2	HR-based Innovation Workforce	(Innovators staff) / (Total workforce)	INCREASE
				DSI-D2.3	R&D & Innovation	(R&D&I. Invest.) / (Total invest.)	INCREASE
		5.2 Suppliers	D3.Ethical Behavior	DSI-D3.1	Order Approval Manager	(N°. of approved orders / N°. of total orders)	INCREASE
				DSI-D3.2	Ethical Key Suppliers	(Ethical Key Suppliers / Total Key Suppliers)	INCREASE
				DSI-D3.3	Local Suppliers	(Local Suppliers / Total Suppliers)	INCREASE
				DSI-D3.4	Local Suppliers Turnover	(Local Suppliers Turnover / Key Suppliers Turnover)	INCREASE

Table 2: Description of Dynamic Social Indicators (DSI) and their contribution to social sustainability.

The DIA is based on a selection of 46 organisation-specific social metrics, which combined have enabled a comprehensive framework of Dynamic Social Indicators (DSI) represented in Table 2. Each DSI is correlated to the categories and sub-categories of stakeholders and to the corresponding categories and sub-categories of social impact. In addition, for each indicator, the contribution to social sustainability was defined, specifying whether a positive social influence corresponds to an increase or decrease in its value. To test the model, the values of the 46 metrics recorded by the organization in the years 2018, 2019 and 2020 were dynamically collected through the ERP+BI interaction (Table 1).

3.3 Site-specific dynamic social impact assessment

Recent studies have shown that the use of organisation-specific data gathered directly from the company's operating environment is not a commonly adopted approach in S-LCA analysis (Tsalidis et al., 2021), especially in the manufacturing sector (Zamani et al., 2018). Presumably because data collection is costly and time-consuming (Cadena et al., 2019). However, site-specific data increases the quality of social analysis (Prasara-A & Gheewala, 2018) compared to available databases, such as the Social Hotspots Database (Norris et al., 2014), which are still limited to a few sectors (Moltesen el al., 2018).

(A)

DYNAMIC SOCIAL INDICATORS		2018		2019		2020	
		Value	Rating	Value	Rating	Value	Rating
DSI-A1.1	Gender Equality	0,39	0,80	0,39	0,80	0,40	0,80
DSI-A1.2	Childhood Workforce	1,00	1,00	1,00	1,00	1,00	1,00
DSI-A1.3	Forced Labour	1,00	1,00	1,00	1,00	1,00	1,00
DSI-A1.4	Migrant Worker	0,01	0,80	0,02	1,00	0,03	1,00
DSI-A2.1	Lost Time Injury Frequency Rate (LTIFR)	1,00	1,00	0,92	1,00	0,82	1,00
DSI-A2.2	Personal Protective Equipments (PPEs)	0,72	0,80	0,72	0,80	0,72	0,80
DSI-A3.1	Collective Bargaining Agreement (CBA)	1,00	1,00	1,00	1,00	1,00	1,00
DSI-A3.2	Overtime Working Hours	0,98	1,00	0,98	1,00	0,97	1,00
DSI-A3.3	Full-time Staff	0,99	1,00	0,99	1,00	0,99	1,00
DSI-A3.4	Local Workforce	1,00	1,00	1,00	1,00	1,00	1,00
DSI-A3.5	Training	0,01	0,20	0,01	0,20	0,01	0,20
DSI-B1.1	Stakeholders Engagement	0,77	0,80	0,79	0,80	0,78	0,80
DSI-B1.2	Public Engagement	1,00	1,00	1,00	1,00	1,00	1,00
DSI-B2.1	University Engagement	0,53	0,60	0,53	0,60	0,93	1,00
DSI-B2.2	Regulatory Authorities Engagement	0,50	0,60	0,80	0,80	1,00	1,00
DSI-B3.1	Corporate Social Media Engagement	0,00	0,20	1,03	1,00	1,09	1,00
DSI-B3.2	B2B Social Media Engagement	0,00	0,20	0,00	0,20	1,37	1,00
DSI-B3.3	B2C Social Media Engagement	0,00	0,20	0,23	0,40	0,14	0,20
DSI-C1.1	Global Warming Potential (GWP)	0,83	0,80	0,80	0,80	0,82	1,00
DSI-D1.1	B2B Non-compliance	0,83	0,80	0,85	1,00	0,87	1,00
DSI-D1.2	B2C Non-compliance	0,87	1,00	0,88	1,00	0,90	1,00
DSI-D2.1	HR-based R&D Workforce	0,05	0,60	0,06	0,60	0,07	0,80
DSI-D2.2	HR-based Innovation Workforce	0,01	0,20	0,02	0,40	0,03	0,40
DSI-D2.3	R&D & Innovation	0,64	0,60	0,67	0,80	0,70	0,80
DSI-D3.1	Order Approval Manager	0,05	1,00	0,03	1,00	0,04	1,00
DSI-D3.2	Ethical Key Suppliers	0,50	0,60	0,67	0,80	0,57	0,60
DSI-D3.3	Local Suppliers	0,95	1,00	0,95	1,00	0,95	1,00
DSI-D3.4	Local Suppliers Turnover	0,83	1,00	0,78	0,80	0,78	0,80

DYNAMIC SOCIAL INDICATORS		RATING				
		0,2	0,4	0,6	0,8	1
DSI-A1.1	Gender Equality	0,0 ÷ 0,1	0,1 ÷ 0,2	0,2 ÷ 0,3	0,3 ÷ 0,4	0,4 ÷ 0,5
DSI-A1.2	Childhood Workforce	< 0,99	/	/	/	1,0
DSI-A1.3	Forced Labour	< 0,99	/	/	/	1,0
DSI-A1.4	Migrant Worker	0,0	< 0,01	0,0 ÷ 0,01	0,01 ÷ 0,1	> 0,1
DSI-A2.1	Lost Time Injury Frequency Rate (LTIFR)	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-A2.2	Personal Protective Equipments (PPEs)	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-A3.1	Collective Bargaining Agreement (CBA)	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-A3.2	Overtime Working Hours	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-A3.3	Full-time Staff	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-A3.4	Local Workforce	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-A3.5	Training	0,0 ÷ 0,01	0,01 ÷ 0,02	0,02 ÷ 0,03	0,03 ÷ 0,04	0,04 ÷ 0,05
DSI-B1.1	Stakeholders Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-B1.2	Public Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-B2.1	University Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-B2.2	Regulatory Authorities Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-B3.1	Corporate Social Media Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-B3.2	B2B Social Media Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-B3.3	B2C Social Media Engagement	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-C1.1	Global Warming Potential (GWP)	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D1.1	B2B Non-compliance	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D1.2	B2C Non-compliance	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D2.1	HR-based R&D Workforce	0,01 ÷ 0,02	0,02 ÷ 0,04	0,04 ÷ 0,06	0,06 ÷ 0,08	0,08 ÷ 0,10
DSI-D2.2	HR-based Innovation Workforce	0,01 ÷ 0,02	0,02 ÷ 0,04	0,04 ÷ 0,06	0,06 ÷ 0,08	0,08 ÷ 0,10
DSI-D2.3	R&D & Innovation	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D3.1	Order Approval Manager	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D3.2	Ethical Key Suppliers	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D3.3	Local Suppliers	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0
DSI-D3.4	Local Suppliers Turnover	0,0 ÷ 0,2	0,2 ÷ 0,4	0,4 ÷ 0,6	0,6 ÷ 0,8	0,8 ÷ 1,0

(B)

DYNAMIC SOCIAL INDICATORS		INDICATOR WEIGHT		IMPACT SUBCATEGORIES	DYNAMIC SOCIAL INDEXES 2018	2019	2020	INDEX WEIGHT		IMPACT CATEGORIES	2018	2019	2020
DSI-A1.1	Gender Equality	100%	20%	A1.Human Rights	0,94	0,96	0,96	100%	30%	A.Human Capital	0,91	0,91	0,91
DSI-A1.2	Childhood Workforce		35%										
DSI-A1.3	Forced Labour		35%										
DSI-A1.4	Migrant Worker		10%										
DSI-A2.1	Lost Time Injury Frequency Rate (LTIFR)	100%	80%	A2.Health & Safety	0,96	0,96	0,96		30%				
DSI-A2.2	Personal Protective Equipments (PPEs)		20%										
DSI-A3.1	Collective Bargaining Agreement (CBA)	100%	30%	A3.Working Conditions	0,84	0,84	0,84		40%				
DSI-A3.2	Overtime Working Hours		10%										
DSI-A3.3	Full-time Staff		20%										
DSI-A3.4	Local Workforce		20%										
DSI-A3.5	Training		20%										
DSI-B1.1	Stakeholders Engagement	100%	60%	B1.Local Expectations	0,88	0,88	0,88	100%	30%	B.Social Capital	0,48	0,65	0,78
DSI-B1.2	Public Engagement		40%										
DSI-B2.1	University Engagement	100%	60%	B2.Institutional Expectations	0,60	0,68	1,00		20%				
DSI-B2.2	Regulatory Authorities Engagement		40%										
DSI-B3.1	Corporate Social Media Engagement	100%	25%	B3.Corporate Reputation	0,20	0,49	0,64		50%				
DSI-B3.2	B2B Social Media Engagement		30%										
DSI-B3.3	B2C Social Media Engagement		45%										
DSI-C1.1	Global Warming Potential (GWP)	100%	100%	C1. Carbon Footprint	0,80	0,80	1,00	100%	100%	C.Natural Capital	0,80	0,80	1,00
DSI-D1.1	B2B Non-compliance	100%	50%	D1.Customer Expectations	0,90	1,00	1,00	100%	40%	D.Economic Capita	0,79	0,88	0,89
DSI-D1.2	B2C Non-compliance		50%										
DSI-D2.1	HR-based R&D Workforce	100%	20%	D2.Private Expectations	0,52	0,68	0,72		30%				
DSI-D2.2	HR-based Innovation Workforce		20%										
DSI-D2.3	R&D & Innovation		60%										
DSI-D3.1	Order Approval Manager	100%	30%	D3.Ethical Behavior	0,92	0,91	0,91		30%				
DSI-D3.2	Ethical Key Suppliers		20%										
DSI-D3.3	Local Suppliers		25%										
DSI-D3.4	Local Suppliers Turnover		25%										
					0,76	0,82	0,89				0,75	0,81	0,90

Table 3: Rating of dynamic social indicators DSI (A) and weighting of dynamic social indexes DSX (B).

Through direct measurement of the 46 social metrics, it was possible to calculate DSIs, which are expressed as social-rate ratios. At this stage of the analysis, it was necessary to standardize the numerical value of the rate ratios because positive social contribution can be described by a high or low value depending on the case. To this end, following the UNEP guidelines for S-LCA, a rating was constructed for each indicator through a unique reference scale (Table 3A): 0.2 (starkly below compliance level); 0.4 (slightly below compliance level); 0.6 (compliance with local and international laws and/or basic societal expectations); 0.8 (beyond compliance) and 1.0 (ideal performance, best in class). To correlate the social-rate ratios to the five values on the scale, a panel of experts was deployed, selecting twenty-one top positions from among the board of directors and the top and middle management of the company under study. The semi-structured expert panel interview technique has already been successfully applied to the same case study to conduct a sustainability-based risk assessment and adaptive life cycle costing (Medina Salgado et., 2021). The experts associated each of these rating values with a range in which the social-rate ratios fall: 0.2 (0.0÷0.2); 0.4 (0.2÷0.4); 0.6 (0.4÷0.6); 0.8 (0.6÷0.8) and 1.0 (0.8÷1.0).

In some cases, the best performance was not set at a value of 1 but was different: 0.5 (Gender Equality), > 0.1 (Migrant Worker), 0.05 (Training) and 0.1 (R&D Workforce and Innovation Workforce). In the case of child and forced labor, only best performance is allowed, i.e. a social-rate ratio of 1.

From a managerial perspective, the rating, attributed to each social-rate ratio, was collected for each expert and the final rating value attributed to the indicator was calculated by applying the formula (1) below:

$$(r)_i = \frac{\sum_{i=1}^{n}(e)_i}{n} \qquad (1)$$

where $(r)_i$ is the final social-rate ratio i obtained by summing the rating values given by the experts $(e)_i$, and n is the number of experts. Therefore, by rating the social-rate ratio values, it was possible to obtain a set of indicators (DSIs) that were normalized and mutually comparable. Next in line with the methodological approach of Naghshineh et al. (2020) applying the S-LCA to a manufacturing setting, it was necessary to implement a mathematical model to weight and aggregate the values of the DSIs into partial and final Dynamic Social Indexes (DSX) scores corresponding to the impact subcategories and categories. The literature points out that one of the main limitations of S-LCA studies, especially in the absence of site-specific data, is the use of equal weights for social indicators/ratios (Singh and Gupta, 2018). In contrast, in this study, having primary data from the organization, it was decided to give different weights to the indicators and indices by adopting a managerial perspective (Table 3B). To this end, the same panel of experts from the company was asked to assign a percentage weight to each indicator to aggregate them into social indices associated with the impact subcategories and categories, applying equation (2) below:

$$(s)_i = \sum_{i=1}^{m}(r)_i \times w_i \qquad (2)$$

where $(s)_i$ is the DSX aggregated for subcategory or category impact i, $(r)_i$ is the social-rate ratios i, w_i is the percentage weight given to $(r)_i$ by experts, and m is the number of impact subcategories and categories . Through this aggregation, We obtain a dynamic social index for each impact subcategory or category that reflect stakeholder expectations from the managerial perspective provided by corporate experts. Finally, by performing the simple mathematical average of these indices, the total social dynamic index could be determined (Table 3B).

3.4 Interpretation of results and discussion

Table 4 provides an overview of the organization's social assessment over the three-year period 2018-2020.

DYNAMIC SOCIAL INDEXES									
STAKEHOLDER CATEGORIES	IMPACT CATEGORIES	2018	2019	2020	STAKEHOLDER SUBCATEGORIES	IMPACT SUBCATEGORIES	2018	2019	2020
1.Workers	A.Human Capital	0,91	0,91	0,91	1.1 Staff Personnel	A1.Human Rights	0,94	0,96	0,96
						A2.Health & Safety	0,96	0,96	0,96
					1.2 Trade Unions	A3.Working Conditions	0,84	0,84	0,84
2.Local Community	B.Social Capital	0,48	0,65	0,78	2.1 Local Institutions	B1.Local Expectations	0,88	0,88	0,88
3.Society					3.1 Public and Private Organization	B2.Institutional Expectations	0,60	0,68	1,00
					3.2 Media	B3.Corporate Reputation	0,20	0,49	0,64
	C.Natural Capital	0,80	0,80	1,00	3.3 Environmental	C1.Carbon Footprint	0,80	0,80	1,00
4.Consumers	D.Economic Capital	0,79	0,88	0,89	4.1 Trade Channel Operators	D1.Customer Expectations	0,90	1,00	1,00
					4.2 Final Consumer				
5.Value Chain Actors					5.1 Private Business	D2.Private Expectations	0,52	0,68	0,72
					5.2 Suppliers	D3.Ethical Behavior	0,92	0,91	0,91
					5.3 Partners				
					5.4 Competitors				
		0,75	0,81	0,90			0,76	0,82	0,89

Table 4: Representative overview of social indices by impact categories, impact subcategories and totals.

Each subcategory and impact category has a DSX index that photographs the level of social performance achieved by the organization on a scale of 0.00 (below compliance level) to 1.00 (best in class). The organization shows excellent results in all impact sub-categories, almost always reaching the highest level in the three-year period (0.80 ÷ 1.00), except in the case of sub-category B3 (Corporate Reputation) where the DSI indicators, which make up the DSX indices, measure the impact of presence on social networks. The company opened its B2B and B2C social channels between 2018 and 2019, so there is a fast increase in the index from 0.20 to 0.64. Again, just below the maximum level is sub-category D2 (Private Expectations), in this case the DSIs that compose the DSX, measure the incidence of personnel dedicated to R&D&I compared to total employees, as well as investment in R&D&I equipment. Since this is an organization with a strong manufacturing footprint, obviously blue-collar workers outnumber white-collar workers, however, this imbalance is partially offset by investments to innovate industrial equipment and facilities. The weighted aggregation of DSX indices provides a set of four indices that measure the organization's performance against the impact categories identified as capital (human, social, natural, and economic). This type of approach help to assess the sustainability of an organization's development and growth according to its capability to acquire, manage and transfer intergenerationally the four forms of capital mentioned above. These four capitals are essential for the functioning of the organization to manufacture and sell products and to preserving the quality of the environment in which it operates. The capital perspective also shows an organization with excellent social sustainability performance. Finally, by aggregating the DSX indices of the impact categories and subcategories, a Total Social Sustainability Index can be obtained for each year.

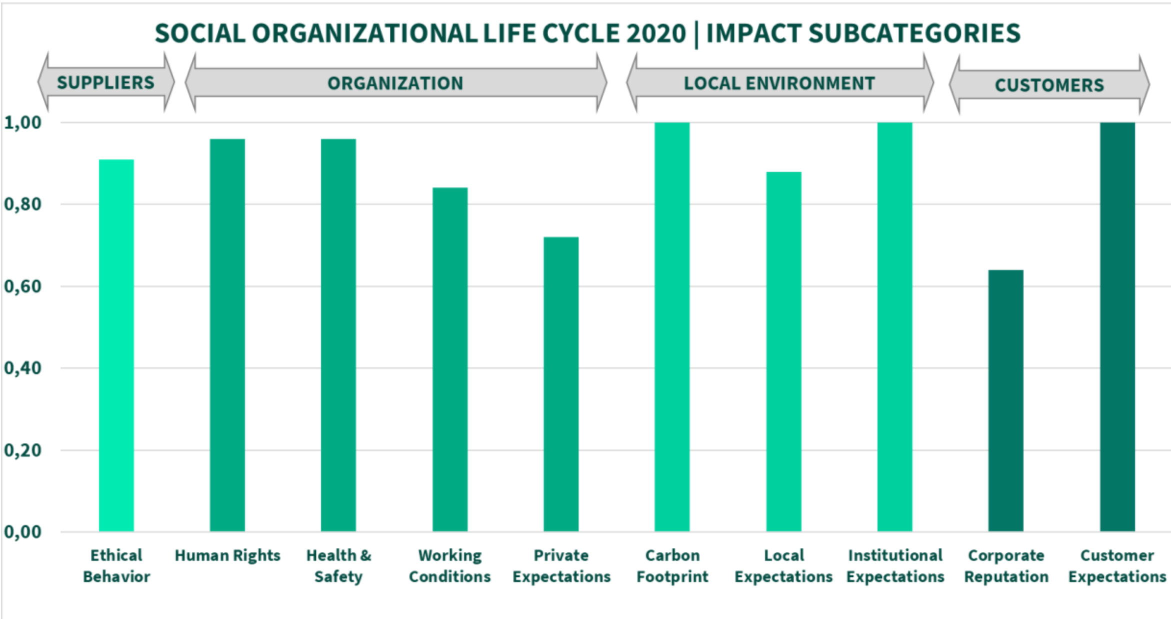

Figure 2: Trend of social sustainability along the value chain in line with the life cycle approach for the year 2020.

In order to depict the social impact of the organization following the life cycle approach, the DSX index data for each impact sub-category have been ordered following the sequential logic of the value chain as shown in the bar chart in Figure 2. In addition to highlighting the good results achieved in terms of social sustainability, the diagram also points out the areas of improvement where the organization should be active to excel socially: Private Expectations and Corporate Reputation.

Upon completion of the social sustainability assessment and in accordance with the guidelines for SO-LCA provided by UNEP, we can conclude that the study was conducted in compliance with the criterion of completeness. All the data collected in the inventory analysis contributed to the objective of assessing the organization's social performance over a three-year period. Likewise, the data collected and processed complied with the criterion of consistency. In fact, for each social indicator, the positive or negative effect they have on social sustainability has been addressed; moreover, the adoption of a scale for rating the values assumed has made it possible to normalize the indicators, making them comparable and aggregable among themselves. Regarding the degree of uncertainty of the analysis, the study also had the aim of constructing a useful benchmark for comparing the social performance collected in real time with the annual values. Finally, the materiality of social indicators has been considered from a managerial perspective through the attribution of a percentage weight to each indicator, taking into account the expectations of the corresponding stakeholders.

3.5 Social dimension of circular economy

As highlighted in the literature, the social impact of the Circular Economy (CE) is still unexplored especially at the micro level of companies (Aranda-Usón et al., 2020). The reason for this shortcoming is that CE primarily provides insight into the degree of efficiency of resource flows through a production and consumption process and supply chain (Wang et al., 2020) that can be easily quantified in a predetermined time frame.

DYNAMIC SOCIAL INDICATORS		IMPACT SUBCATEGORIES	SUSTAINABLE DEVELOPMENT GOALS (SDGs)		
DSI-A1.1 DSI-A1.2 DSI-A1.3 DSI-A1.4	Gender Equality Childhood Workforce Forced Labour Migrant Worker	A1.Human Rights	5 GENDER EQUALITY	8 DECENT WORK AND ECONOMIC GROWTH	10 REDUCED INEQUALITIES
DSI-A2.1 DSI-A2.2	Lost Time Injury Frequency Rate (LTIFR) Personal Protective Equipments (PPEs)	A2.Health & Safety	3 GOOD HEALTH AND WELL-BEING		
DSI-A3.1 DSI-A3.2 DSI-A3.3 DSI-A3.4 DSI-A3.5	Collective Bargaining Agreement (CBA) Overtime Working Hours Full-time Staff Local Workforce Training	A3.Working Conditions	8 DECENT WORK AND ECONOMIC GROWTH	1 NO POVERTY	4 QUALITY EDUCATION
DSI-B1.1 DSI-B1.2	Stakeholders Engagement Public Engagement	B1.Local Expectations	17 PARTNERSHIPS FOR THE GOALS	11 SUSTAINABLE CITIES AND COMMUNITIES	16 PEACE, JUSTICE AND STRONG INSTITUTIONS
DSI-B2.1 DSI-B2.2	University Engagement Regulatory Authorities Engagement	B2.Institutional Expectations	17 PARTNERSHIPS FOR THE GOALS	11 SUSTAINABLE CITIES AND COMMUNITIES	16 PEACE, JUSTICE AND STRONG INSTITUTIONS
DSI-B3.1 DSI-B3.2 DSI-B3.3	Corporate Social Media Engagement B2B Social Media Engagement B2C Social Media Engagement	B3.Corporate Reputation	17 PARTNERSHIPS FOR THE GOALS		
DSI-C1.1	Global Warming Potential (GWP)	C1. Carbon Footprint	13 CLIMATE ACTION	7 AFFORDABLE AND CLEAN ENERGY	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
DSI-D1.1 DSI-D1.2	B2B Non-compliance B2C Non-compliance	D1.Customer Expectations	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	17 PARTNERSHIPS FOR THE GOALS	
DSI-D2.1 DSI-D2.2 DSI-D2.3	HR-based R&D Workforce HR-based Innovation Workforce R&D & Innovation	D2.Private Expectations	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	4 QUALITY EDUCATION	
DSI-D3.1 DSI-D3.2 DSI-D3.3 DSI-D3.4	Order Approval Manager Ethical Key Suppliers Local Suppliers Local Suppliers Turnover	D3.Ethical Behavior	16 PEACE, JUSTICE AND STRONG INSTITUTIONS	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	

Table 5: Framework for association between DSI indicators, impact subcategories, and SDGs.

In contrast, the social dimension of sustainability has a very different time perspective than a production process. Recently, some scholars have proposed to estimate the contribution of the social dimension of sustainability to CE through the association of social indicators with the Sustainable Development Goals

(Belmonte-Ureña et al., 2021; El Wali et al., 2021) while also providing easily replicable methodological frameworks (Padilla-Rivera et al., 2021). It has been shown that the Circular Economy can fully or partially support the achievement of certain sustainability targets or can aggravate the achievement of others conditioned by the industry concerned, the multiple stakeholders or the regional interactions (El Wali et al., 2021). Therefore, it is necessary to develop an implementation framework to help clarify these issues.

Following this approach and consistent with UNEP's guidelines for SO-LCA, site-specific social indicators were associated with the impact subcategories and SDGs (Ronzon and Sanjuán, 2020) as shown in the framework in Table 5. To identify which social topics and SDGs are relevant to achieve the CE targets, the managerial perspective was adopted by still making use of the same panel of experts within the organization, already involved to carry out the social assessment. Managers were asked which of the social impact subcategories and SDGs presented in the Table 5 framework were essential or otherwise highly relevant to the EC. The experts selected SDGs 8, 9, 12, and 13. This result is consistent with what was found in the study by Belmonte-Ureña et al. (2021), Dantas et al. (2021) and the survey by Padilla-Rivera eta l. (2021), such convergence of evaluations carried out even in very different contexts, demonstrates the validity of the methodological approach chosen. Again, the experts were asked to provide an index of relevance expressed in a percentage weight of the selected SDGs with respect to the aims of the CE and the results are represented in Table 6. The indices of subcategories of social impact shown in Table were balanced with the weights attributed to them by the experts.

DYNAMIC SOCIAL INDICATORS		IMPACT SUBCATEGORIES	SDGs	WEIGHT	2018	2019	2020
DSI-A1.1 DSI-A1.2 DSI-A1.3 DSI-A1.4	Gender Equality Childhood Workforce Forced Labour Migrant Worker	A1.Human Rights	8 DECENT WORK AND ECONOMIC GROWTH	20%	0,19	0,19	0,19
DSI-A3.1 DSI-A3.2 DSI-A3.3 DSI-A3.4 DSI-A3.5	Collective Bargaining Agreement (CBA) Overtime Working Hours Full-time Staff Local Workforce Training	A3.Working Conditions			0,17	0,17	0,17
DSI-C1.1	Global Warming Potential (GWP)	C1. Carbon Footprint	13 CLIMATE ACTION	30%	0,24	0,24	0,30
DSI-D1.1 DSI-D1.2	B2B Non-compliance B2C Non-compliance	D1.Customer Expectations	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	35%	0,32	0,35	0,35
DSI-D2.1 DSI-D2.2 DSI-D2.3	HR-based R&D Workforce HR-based Innovation Workforce R&D & Innovation	D2.Private Expectations	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	15%	0,08	0,10	0,11
					0,20	0,21	0,22

Table 6: Social contribution of the organization to the targets of the Circular Economy.

Using the site-specific social indices (DSI) and the managerial perspective, the results show that the organization contributes to the achievement of the aims of the CE with an almost constant value of 0.2 expressed on the same scale (0÷1) used for the SO-LCA. Obviously, to reach the maximum target of 1.0, it will be necessary to add to the social contribution also that of the environmental and economic dimension to be conducted by other specific assessments.

4. CONCLUSION

Circular economy is a model that can help find solutions to today's societal challenges and facilitate the achievement of Sustainable Development Goals, although this model may be conditioned by various factors such as the industry or the region involved (El Wali et al., 2021). However, research has traditionally focused on environmental and economic objectives. Therefore, more research is needed on the methodologies that would allow the fulfillment of social objectives. In this study, the Social Organizational Life Cycle Assessment (SO-LCA) methodology was applied to a manufacturing industry that produces ceramic tiles for building. For this purpose, the latest guidelines provided by UNEP for Social Life Cycle Assessment (S-LCA) were followed using site-specific social metrics and primary data sources. The results obtained showed that a digitized organizational environment in line with the Industry 4.0 paradigm, allows to automate phase 2 of the SO-LCA, namely the inventory analysis. In fact, the huge database created by the organization over time within the ERP, served as the primary data source for the social assessment. This data is provided in real time using a Business Intelligence interface between the factory and business environment and the analytical tool used to perform the SO-LCA. The dynamicization of data collection from primary sources realized in real time, demonstrates that Industry 4.0 digital technologies can enable the social assessment of a manufacturing organization, thus responding affirmatively to RQ1. In addition, the use of only organization-specific data without relying on more general external databases significantly contributes to improving the overall quality of the analysis. The proposed assessment framework is based on specific social metrics adapted to a production reality such as that of the case study considered in this research. Thanks to the adoption of a managerial approach that included the participation of a panel of experts from the organization, it was possible to construct social indicators that were then aggregated into social indices, all correlated to categories and subcategories of stakeholders and the corresponding categories and subcategories of social impact, also following the logic of the life cycle. This approach, with the support of experts, also allowed the identification of which social metrics are essential for the achievement of circular economy (CE) targets, quantitatively determining the organization's contribution to the social dimension of CE. This result therefore responded positively to RQ2.

From a theoretical perspective, this research helps to fill several gaps that have emerged in the literature. The proposed SO-LCA framework correlates social impact categories and subcategories with organization-specific social metrics (GAP1). The SO-LCA/ERP interfacing allowed leveraging Industry 4.0 technologies for a dynamic social sustainability assessment (GAP2). Finally, organization-specific metrics, aggregated into indicators and indices, allowed highlighting the social contribution to CE thanks to the managerial perspective and life cycle approach, contributing to the knowledge of the social dimension of CE (GAP3 and GAP4).

The results also provide promising operational implications for practitioners. The framework of metrics, indicators and indices on which this dynamic SO-LCA has been developed is easily replicable to other manufacturing companies or easily transferable to organizations that produce goods or deliver services. In addition, a relatively simple tool is provided to include and consider the social dimension of a manufacturing context.

Finally, this example of applying SO-LCA to a fully digitized organization provides potential implications for public policy and decision makers as it may represent a best practice for measuring how Industry 4.0 may change organizational models from a societal perspective. This is consistent with the Commission's White Paper on the Future of Europe, which sets out the challenges that Europe must overcome by 2030, when Industry 4.0 is fully established in European society. In fact, the Commission calls for the achievement of a "*highly competitive social market economy*." To move in this direction, public and private actors must cooperate, and private companies can anticipate organizational innovations, including in terms of social sustainability and circularity, to stimulate change in public organizations as well.

This research also has some limitations. The first concerns the analysis approach adopted. In fact, the authors believe that the organizational perspective (SO-LCA) is fundamental for building a methodological and preparatory framework for a more general social assessment that also includes the product perspective (S-LCA), which was not considered in this study. The criteria for rating indicators will have to be improved to decrease the subjective component when assigning their weight. The authors believe that the annual evaluation carried out over several years can build a more solid benchmark for constructing classification scales adapted to the evaluation carried out in real time thanks to the digitization of the system. Finally, the challenge of constructing a social circularity metric remains partially unresolved because the proposed solution is based on indirect estimation. However, the authors believe that the social circularity metric can be identified after a reasonable time of testing the SO-LCA model at the organization, to see how it responds and to gain experience and new knowledge.

CRediT authorship contribution statement

Fernando García-Muiña: Investigation, Writing-original draft. **María Sonia Medina-Salgado**: Methodology, Project administration. **Rocío González-Sánchez:** Formal analysis, Validation. **Irene Huertas-Valdivia**: Resources. **Anna Maria Ferrari**: Supervision. **Davide Settembre-Blundo**: Conceptualization, Writing-original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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