DATA-DRIVEN SOCIAL LIFE CYCLE ASSESSMENT (S-LCA) AS A NEW OBJECTIVE APPROACH TO DECISION-MAKING IN CERAMIC MANUFACTURING

Andrés Fernández-Miguel[1,2], Fernando E. García-Muiña[1], Davide Settembre-Blundo[1,4], Maria Pia Riccardi[3], Valerio Veglio[2]

[1] Department of Business Administration, Rey Juan Carlos University, Paseo de los Artilleros, s/n - 28032 Madrid, Spain
[2] Department of Economics and Management, University of Pavia, Via S. Felice Al Monastero, 5 - 27100 Pavia, Italy
[3] Department of Earth and Environmental Sciences, University of Pavia, Via Ferrata, 1 - 27100 Pavia, Italy
[4] Gruppo Ceramiche Gresmalt, 41049 Sassuolo, Italy

ABSTRACT

Social sustainability, a critical concern within the manufacturing industry, poses assessment challenges due to the lack of standardized metrics and the complex nature of social data. To address this, Social Life Cycle Assessment (S-LCA) is emerging as a globally recognized methodology that is being widely used to assess social sustainability. S-LCA uses a life cycle framework to measure the social impacts of an organization or product across all stages of the life cycle, including key issues such as worker welfare, community welfare, and human rights. In response to subjectivity issues in traditional social assessment methods, this study introduces an innovative data-driven S-LCA model that uses Exploratory Factor Analysis (EFA) - Principal Component Analysis (PCA) to assign weights to social impact indicators. EFA-PCA, a statistical tool, simplifies data complexity by identifying uncorrelated variables that explain most of the variability. This model has been validated by applying it to a case study of an Italian ceramic tile company. The results showed that EFA-PCA based weighting of social impact indicators significantly improves the accuracy and objectivity of social sustainability assessments, outperforming the traditional subjective expert weighting approach. This innovative approach paves the way for more streamlined S-LCA applications, increasing the objectivity of social sustainability assessments in the ceramic manufacturing sector and providing decision makers with effective tools to guide corporate social sustainability efforts and firm strategy.

1. INTRODUCTION

In today's dynamic manufacturing landscape, the concept of social sustainability has evolved from a footnote on corporate agendas to a critical pillar of success (Ferreira et al., 2023). Companies have come to understand that prioritizing social sustainability is not just about profits and environmental responsibility: it is about building resilient, forward-thinking organizations with a profound impact on society (Rai et al., 2021). This paradigm shift underscores a broader concept of corporate responsibility. It goes beyond profit margins and environmental stewardship to include the creation of nurturing and inclusive environments, the cultivation of stronger and more diverse stakeholder relationships, and an unequivocal commitment to improving the well-being and prosperity of the communities in which these companies operate (Missimer and Mesquita, 2022). This new perspective marks a pivotal moment in the manufacturing industry, where social sustainability is no longer an afterthought, but a core determinant of long-term success (Asha'ari et al., 2023).

However, as the importance of social sustainability in manufacturing is recognized, so too are the challenges associated with assessing and measuring it (Govindan et al., 2021). The hurdles to overcome are significant, underscoring the urgent need to develop valid and reliable methodologies that can effectively quantify and assess social sustainability. One of the most glaring challenges is the lack of standardized international measures and guidelines for assessing social sustainability. Unlike environmental sustainability, which benefits from well-established frameworks and metrics, the social sustainability landscape remains devoid of universally accepted benchmarks. This deficiency complicates the task of evaluating and comparing the social performance of different organizations, especially those operating on a global scale (Afshari et al., 2022). The lack of standardized measures makes it extremely difficult to accurately quantify and qualify the social impacts and contributions of companies (Walker et al., 2021).

Adding to this complexity is the inherently qualitative and quantitative nature of social data. Unlike financial or environmental metrics, which can be precisely quantified, social data encompasses a wide range of variables that cannot be easily reduced to numerical values (Saxena et al., 2020). The facets of social sustainability are diverse, including but not limited to human rights, employee well-being, community well-being, diversity and inclusion, and ethical practices. These multiple dimensions require nuanced assessment methodologies (Bai et al., 2022). To address these complex challenges and pave the way for a more socially sustainable manufacturing industry, the field of Social Life Cycle Assessment (S-LCA) has emerged as a powerful methodology (Tokede and Traverso, 2020). This internationally recognized approach uses a life cycle framework to comprehensively examine the social impacts associated with an organization or product throughout its entire life cycle. S-LCA casts a wide net, examining various facets such as working conditions, community engagement, labor rights, and human rights (Huarachi et al., 2020). By providing a holistic understanding of social impacts, S-LCA serves as a powerful decision-making tool, enabling organizations to adopt sustainable and socially responsible manufacturing practices (Bouillass et al., 2021).

However, despite the immense potential of S-LCA, recent studies have highlighted a pressing issue - the subjectivity inherent in the construction of social impact indices (García-Muiña, et al., 2021). This subjectivity often takes the form of expert judgement, where variable weights are assigned based on the knowledge and experience of individuals (Pollok, et al., 2021). Alternatively, it manifests itself as equal weighting of variables, assuming equal importance across the board (Naghshineh, et al., 2020). This subjectivity introduces biases and limitations that undermine the objectivity and reliability of sustainability indicators, a challenge that urgently needs to be addressed (Gompf, et al., 2021). To overcome this hurdle and strengthen the objectivity of sustainability indicators, this study boldly proposes a novel approach to S-LCA. The cornerstone of this approach is the application of Exploratory Factor Analysis (EFA) - Principal Component Analysis (PCA), a statistical technique known for its ability to reduce data complexity (Asante-Okyere, et al., 2020). EFA-PCA accomplishes this by identifying uncorrelated variables that collectively explain most of the variability within the original data set. By using EFA-PCA, this methodology aims to reduce the subjectivity associated with assigning weights to social impact indicators.

To test this groundbreaking methodology and demonstrate its real-world applicability, the study conducted an empirical investigation of an Italian ceramic tile company (Medina-Salgado, et al., 2021). This study attempts to shed light on the paramount importance of social sustainability in the manufacturing industry. It illustrates how the transformative role of social sustainability extends far beyond profit margins and into the realm of societal well-being and sustainable success. It also highlights the inherent complexities and challenges associated with assessing and measuring social sustainability, and the urgency of addressing these challenges head-on. By introducing this methodology of applying EFA-PCA to S-LCA, this research contributes to a more accurate and objective assessment of social sustainability. It provides decision makers with innovative tools to guide their strategies toward greater corporate social responsibility, promoting a manufacturing sector that is not only economically sound and environmentally responsible, but also socially equitable, inclusive and accountable.

2. METHODOLOGY AND PRELIMINARY FINDINGS

Social Life Cycle Assessment (S-LCA) and Social Organizational Life Cycle Assessment (SO-LCA) are emerging methodologies (Pollok et al., 2021) that extend the environmental assessment inherent in Life Cycle Assessment (LCA) (Ferrari et al., 2021), to assess both the social impacts of products and organizations.

S-LCA/SO-LCA is still under development and follows the United Nations Environmental Programme (UNEP) Guidelines for the Social LCA of Products and Organizations (Achten et al., 2020), while LCA is well established and based on international ISO standards (Toniolo et al., 2020).

S-LCA assesses the social aspects and potential positive or negative impacts of products throughout their life cycle, including extraction, production, distribution, use, recycling and disposal.

SO-LCA addresses the challenge of identifying social indicators at the product level by taking an organizational perspective (D'Eusanio et al., 2022). However, both approaches are unable to determine social sustainability in an absolute sense and are primarily aimed at companies seeking to monitor their social impact.

The manufacturing industry faces two methodological gaps:

1. Identifying social indicators at the product level, as social impacts are often organizational;
2. Eliminating or at least reducing the subjective component when assigning weights to social metrics, given the mixed qualitative and quantitative nature of social data.

This study aims to fill the second gap, already highlighted by the authors in a recent SO-LCA analysis of a ceramic tile manufacturing company (García-Muiña, et al., 2022), by proposing an innovative methodology based on a mixed method approach aimed at trying to reduce the level of subjectivity in the estimation of dynamic social sustainability indicators adopted by Italian companies operating in the ceramics sector. This approach arises as an evolution of Social Life Cycle Analysis, which is mainly based on subjective estimations and thus more susceptible to biased estimates.

Subjective estimations based on the opinion of a committee of experts, although very promising, could be inaccurate, especially in today's competitive landscape characterized by a high level of uncertainty and a growing emphasis on data-driven approaches. As such, the development of a mixed methodology is becoming one of the main challenges for companies, which want to pursue a high level of social sustainability and remain competitive in the global marketspace.

Our methodology has been tested on a three-years' time series database ranging from 2020 to 2022. The database analyzed is based on the stakeholder categories (workers, local community, society, consumers, and value chain actors) identified by the UNEP. Then, the committee of experts integrated these categories with different impact categories (human capital and social capital) by identifying a new category of impact defined as natural capital category. In addition, the committee of experts assigned specific stakeholder subcategories to each impact category to which correspond different impact subcategories and, for each impact subcategories, the relative social indicators have been identified. The final database includes 28 social sustainability indicators that refer, respectively, to 10 impact subcategories and 10 stakeholder categories that, in turn, make up 4 impact categories. Table 1 shows a description of the database used to test this novel methodology. The analysis of the database was performed with R version 4.3.1. The main function used was "prcomp" for Principal Component Analysis, which is included in the base package "stats", adjusted to the particularities of the study.

STAKEHOLDER CATEGORIES	IMPACT CATEGORIES	STAKEHOLDER SUBCATEGORIES	IMPACT SUBCATEGORIES	SOCIAL INDICATORS	
1.WORKERS	**A.Human Capital**	**1.1 Staff Personnel**	**A1.Human Rights**	**SI-A1.1**	Gender Equality
				SI-A1.2	Childhood Workforce
				SI-A1.3	Forced Labour
				SI-A1.4	Migrant Worker
			A2.Health & Safety	**SI-A2.1**	Lost Time Injury Frequency Rate (LTIFR)
				SI-A2.2	Personal Protective Equipments (PPEs)
		1.2 Trade Unions	**A3.Working Conditions**	**SI-A3.1**	Collective Bargaining Agreement (CBA)
				SI-A3.2	Overtime Working Hours
				SI-A3.3	Full-time Staff
				SI-A3.4	Local Workforce
				SI-A3.5	Training
2.LOCAL COMMUNITY	**B.Social Capital**	**2.1 Local Institutions**	**B1.Local Expectations**	**SI-B1.1**	Stakeholders Engagement
				SI-B1.2	Public Engagement
3.SOCIETY		**3.1 Public and Private Organization**	**B2.Institutional Expectations**	**SI-B2.1**	University Engagement
				SI-B2.2	Regulatory Authorities Engagement
		3.2 Media	**B3.Corporate Reputation**	**SI-B3.1**	Corporate Social Media Engagement
				SI-B3.2	B2B Social Media Engagement
				SI-B3.3	B2C Social Media Engagement
	C.Natural Capital	**3.3 Environmental**	**C1. Carbon Footprint**	**SI-C1.1**	Global Warming Potential (GWP)
4.CONSUMERS	**D.Economic Capital**	**4.1 Trade Channel Operators**	**D1.Customer Expectations**	**SI-D1.1**	B2B Non-compliance
		4.2 Final Consumer		**SI-D1.2**	B2C Non-compliance
5.VALUE CHAIN ACTORS		**5.1 Private Business**	**D2.Private Expectations**	**SI-D2.1**	HR-based R&D Workforce
				SI-D2.2	HR-based Innovation Workforce
				SI-D2.3	R&D & Innovation
		5.2 Suppliers	**D3.Ethical Behavior**	**SI-D3.1**	Order Approval Manager
				SI-D3.2	Ethical Key Suppliers
				SI-D3.3	Local Suppliers
				SI-D3.4	Local Suppliers Turnover

***Tabla 1**: Social Inidicators Database*

The mixed method methodology is based on three main steps. Firstly, we rescaled our data through a Sigmoid Standardization to minimize the likelihood of obtaining biased estimations. Secondly, we applied statistical analyses, specifically, the Exploratory Factor Analysis (EFA) - Principal Component Analysis (PCA) to each impact subcategories to obtain an objective score for each social sustainability indicator. Sigmoid normalization was chosen for its ability to provide a balanced, mean-centered representation of the data and its resistance to outliers, which is desirable in sustainability analysis contexts with small data sets. Instead, the EFA-PCA allows assigning coefficients to the indicators based on the variability or information that each one of them contributes, thereby facilitating an objective weighting of the indicators to obtain the indexes of the social impact categories. In our analysis, we identified certain indicators that remained constant throughout the time series, leading to zero coefficients in the EFA-PCA. This occurs because they don't introduce variability to the set of indicators. A potential solution could be to increase the database with indicators from other companies. Therefore, to overcome this obstacle, to obtain a more objective score of the sustainability indicators, we matched the objective score resulting from the EFA-PCA with the subjective score resulting from the expert committee. Third, we matched the subjective score assigned from the committee of experts with the objective score obtained from the EFA-PCA. The final score is an average between the score assigned by the committee of experts and those resulting from the statistical analysis based on the EFA-PCA. An example of the application of our method is shown in Table 2.

SOCIAL INDICATORS	IMPACT SUBCATEGORIES	INDICATOR SCORE		
		EXPERT SCORE	STATISTICAL SCORE	MIXED METHOD SCORE
Gender Equality	**Human Rights**	20%	50.0%	35.0%
Childhood Workforce		35%	0.0%	17.5%
Forced Labour		35%	0.0%	17.5%
Migrant Worker		10%	50.0%	30.0%
Lost Time Injury Frequency Rate (LTIFR)	**Health & Safety**	80%	50.0%	65.0%
Personal Protective Equipments (PPEs)		20%	50.0%	35.0%
Collective Bargaining Agreement (CBA)	**Working Conditions**	30%	0.0%	15.0%
Overtime Working Hours		10%	25.5%	17.7%
Full-time Staff		20%	24.2%	22.1%
Local Workforce		20%	25.1%	22.6%
Training		20%	25.1%	22.6%

Experts Score: the score has been obtained through subjective techniques (e.g. experts committees assign a subjective way based on their opinions).
Statistical Score: the score has been obtained through the Exploratory Factor Analysis (EFA) - Principal Component Analysis (PCA).
Mixed Score: the score has been obtained through the combination of both subjective and statistical methodologies.

Tabla 2: *Social Indicators Score*

Table 2 highlights differences in scores based on the method adopted. The mixed method approach provides different scores compared to the subjective (opinion of a committee of experts) and the statistical one (EFA-PCA technique). For example, in the context of "Human Rights", in the case of "Childhood Workforce" the committee of experts assigned a high score to this indicator, while the statistical method assigns it a null weight due to its lack of variability. To overcome the limitation of these contrasting results, the mixed method approach, which considers both the subjective and the objective components, becomes essential to obtain a more objective score. Another difference emerges from the indicator of "Gender Equality". The statistical approach assigns a higher score to this indicator than the subjective method. Generally, some indicators yield similar results as observed in the case of working conditions, where both the committee of experts and the analytical method assign similar weights to the indicators. Despite the validity of both subjective and statistical methods, the mixed method could provide a more precise score for the estimation of the social sustainability indexes because it is based also on scientific algorithms able to guarantee a certain level of accuracy.

The mixed method approach guarantees a high level of accuracy because it also considers the experience of experts that could represent one of the main strategic drivers for the success of companies in today's competitive landscape. Relying solely on a single method, whether it is subjective, or objective, could lead to biased scores that could lead decision makers to make wrong strategic choices with a subsequent negative impact on the companies' performance.

3. CONCLUSION

The core objective of this research is to introduce a data-driven Social Organizational Life Cycle Assessment (SO-LCA) model for assessing social sustainability levels within the ceramic manufacturing sector. To achieve this, we have developed a mixed-methods methodology with the specific aim of mitigating subjectivity in the assignment of weights to social metrics. This approach includes not only input from a panel of experts, but also objective evidence derived from statistical analyses such as EFA-PCA.

Our results clearly show that the use of EFA-PCA to determine the weighting of social impact indicators results in a more accurate and objective assessment of social sustainability, outperforming traditional subjective methods such as SLCA and Social Organizational Life Cycle Assessment (SO-LCA). In addition, this study presents SO-LCA as a straightforward yet scientifically robust methodological framework for conducting social impact assessments within manufacturing organizations, particularly those in sectors such as ceramics.

The use of site-specific social metrics and the collection of primary data directly from the factory environment streamline the analysis process and make it accessible to individuals without specialized training in these areas. In the current business environment of heightened uncertainty, the quest for objectivity has become paramount.

Our research underscores the critical importance of social sustainability indicators in the ceramics manufacturing sector and highlights the inherent complexities associated with their assessment and measurement. It highlights the urgent need for standardized and objective methodologies. By introducing EFA-PCA as a tool to reduce subjectivity in SO-LCA, our study contributes to ongoing efforts to improve the accuracy and objectivity of social sustainability assessments.

Ultimately, our research provides decision-makers with invaluable tools to steer their organizations toward greater corporate social sustainability, thereby fostering a more inclusive, supportive, and socially responsible manufacturing sector. In today's corporate landscape, characterized by an increased emphasis on social and environmental responsibility, objective social sustainability assessments have become paramount.

This growing importance of objective social sustainability ratings is in line with the European Non-Financial Reporting Directives, which require certain large companies to disclose information about their social impacts. This reflects a growing recognition of the link between social sustainability and broader sustainability goals. Such objective ratings are of particular importance to ESG expert committees, whose recommendations and assessments have a significant impact on investment decisions, stakeholder relations and corporate reputation.

In addition, these objective social sustainability ratings encourage companies to be more transparent in sharing both financial and non-financial reports with the public and stakeholders. This increased transparency fosters trust and accountability, which are essential elements in today's socially conscious business environment.

In conclusion, the synergy between objective social sustainability assessments and evolving regulatory guidelines not only benefits individual companies, but also advances the overarching goal of fostering a more inclusive, supportive, and responsible business sector. In addition, by introducing the use of statistical techniques, this research contributes to the ongoing discourse surrounding the development of standardized metrics for assessing corporate social sustainability. The mixed-methods methodology provides a powerful tool for decision makers to develop more accurate business strategies.

However, despite the encouraging results, our study has certain limitations that provide avenues for further research. We conducted our tests on a limited database consisting of only a three-year time series. To strengthen the validity of our methodology, it should be tested on a larger database. In addition, our data are cross-sectional and pertain to a single firm. Subsequent research could explore the applicability of this methodology by testing it on panel databases, possibly including multiple firms within the same industry. Finally, future research could extend this methodology to cross-country databases to understand potential differences in the weight given to each social sustainability indicator across countries.

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