Sustainable Production and Consumption 35 (2023) 55–71

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

One Framework to Rule Them All: An Integrated, Multi-level and Scalable Performance Measurement Framework of Sustainability, Circular Economy and Industrial Symbiosis

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A R T I C L E I N F O

Article history:
Received 25 July 2022
Received in revised form 14 October 2022
Accepted 15 October 2022
Available online 20 October 2022

Editor: Prof. K Tsagarakis

Keywords:
Sustainability
Circular Economy
Industrial Symbiosis
Performance Measurement System
Indicators

A B S T R A C T

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One framework to rule them all: an integrated, multi-level and scalable performance measurement framework of sustainability, circular economy and industrial symbiosis

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Abstract
There is an overall established agreement on the need for the industry to transition towards a more ecological and ethical approach to business. Numerous ways to engage into this transition exist, such as Sustainability, Circular Economy and Industrial Symbiosis; yet the proliferation of alternative paradigms creates confusion and generates limited applications in industries. The measurement of performance appears indispensable to foster the implementation of improving actions, benchmark results and effectively communicate them to different stakeholders. Despite the emerging interest, a proper system for the measurement of performance related to the ecological and ethical transition is still missing. By means of selection mechanisms specifically developed, indicators retrieved from the extant literature have been organized in a novel integrated, multi-level and scalable framework of performance measurement systems. The framework presents some features of great relevance, in particular: i) integration of Sustainability, Circular Economy and Industrial Symbiosis paradigms; ii) possibility to be applied at different levels of application, i.e. the single firm, the supply chain or the district; iii) adaptability to firms with different characteristics (firm size and awareness), thanks to the development of two different (full and core) scalable systems. The framework has been then validated in four manufacturing firms against its capacity to represent each paradigm, its usefulness, and its ease of use. Besides the positive feedbacks obtained considering the three axes of analysis, the framework was appreciated for its capability to overcome tensions among the three paradigms and encourage firms to consider performance beyond their own boundaries, including the supply chain or district, and its scalability as for different sizes. This research advances the knowledge on the ecological and ethical transition and on the related paradigms, contributing on theoretical and practical levels and offering several insights for future research, especially empirical ones.

Keywords
Sustainability; Circular Economy; Industrial Symbiosis; Performance Measurement System; Indicators.

Acronyms
CE: Circular Economy
SUST: Sustainability
IS: Industrial Symbiosis
PMS: Performance Measurement System
SC: Supply Chain
R&D: Research and Development
EHS: Environmental, Health and Safety
CEO: Chief Executive Officer
OHS: Occupational Health and Safety

1 Introduction

The industry is responsible for air pollution, resource consumption, environment depletion and damage (European Environment Agency, 2021; The European Commission, 2020) and negative social impacts (Govindan et al., 2021). The academic (Neri et al., 2018), managerial (Tonelli et al., 2013) and political debates (United Nations, 2015) stressed the need for the industry to engage in an ecological and ethical transition, towards a future thriving in harmony with the environment and the society. How firms can effectively implement such a transition is however still debated (International Energy Agency, 2021): indeed, many solutions are viable and desirable, as they would bring about great benefits in terms of industrial impact (Köhler et al., 2019). However, which one is best is still not clear (Alarcón et al., 2020).

The debate on the transition mainly revolves around three interrelated yet different paradigms, namely Sustainability (SUST), Circular Economy (CE) and Industrial Symbiosis (IS) (Salomone et al., 2020). The interest in the adoption of SUST within the industry grew greatly in recent years (Trianni et al., 2017a), with SUST being deemed as an interesting manner to conciliate targets and goals among economic, environmental, and social aspects (Carter and Rogers, 2008; Elkington, 1997). CE brings great potential for a mind-shift from a linear to a regenerative economy and production systems, by decoupling economic growth from the depletion of natural resources (Ellen MacArthur Foundation, 2021). IS focuses on cooperation within and across industrial systems to exchange waste and by-products, generating benefits for all the parts involved (Fraccascia and Giannoccaro, 2020). The three paradigms have been studied almost exclusively in a separate manner, yet important overlaps among them must be acknowledged, leading to both synergies (Geissdoerfer et al., 2017; Salomone et al., 2020) and tensions (Lee et al., 2021). As proof, all the paradigms focus on resource efficiency and waste elimination (Lieder and Rashid, 2016; Neves et al., 2019), but while IS addresses collaboration (Valenzuela-Venegas et al., 2016), responsibilities are not tackled by SUST, leading to a more competitive rather than collaborative approach (Geissdoerfer et al., 2017).

Theoretical and empirical research proved the numerous benefits of adopting the three paradigms (Ansari and Kant, 2017; Pandey and Prakash, 2019), yet industrial firms are still lagging in their implementation. SUST achievements are still absent and progress slow, with firms struggling to include environmental and social aspects in their daily decision-making (Trianni et al., 2019); firms are also still far from the foretold CE implementation levels (Kumar et al., 2019); successful application of IS are limited and carry considerable challenges (Neves et al., 2019).

The lack of implementation might originate from practical short-circuits. The richness and complexity of possible alternative paradigms create inaction (Scheibehenne et al., 2009). Additionally, despite the overlaps, the links among the paradigms remain overall implicit or unknown to firms, also due to the lack of adequate performance measurement systems (PMS) (Stewart and Niero, 2018). Practical tools to foster implementation and measure progress are fundamental for a broad understanding of the ecological and ethical transition (European Union, 2019; Eurostat, 2019), as well as for benchmarking and communicating with different stakeholders (Mishra et al., 2018). Performance measurement frameworks thus play a pivotal role, allowing the complexity of reality to be grasped (Simão et al., 2021), exploiting synergies among paradigms and providing guidance for decision-making. Current developments allow firms to focus on the performance of one selected paradigm, neglecting the others (Opferkuch et al., 2021) and not supporting their ecological and ethical transition adequately.

Focusing on this relevant gap in the extant knowledge, this research offers an integrated solution to measure the performance related to the ecological and ethical transition in industrial firms, exploring and exploiting synergies and trade-offs among SUST, CE and IS. In addition to the integration among the three paradigms, additional issues should be acknowledged while developing such a tool. First, the above-mentioned transition and the application of the three paradigms might happen both within a single firm (micro level) and within an industrial system (meso level), yet proper exploration of the relationships and integration between the two levels is overall missing in the available PMSs (Kristensen and Mosgaard, 2020). Despite the relevance of integrating different levels, additional efforts are needed to develop a multi-level measurement of performance. As proof, SUST should be considered as a collective and organized effort of the industrial system in which a firm operates, rather than an isolated effort (Massaroni et al., 2018; Neri et al., 2021a). Contributions to CE are disproportionately focused on the micro level, with lower attention to the meso one (Negri et al., 2021b) and limited research on their integration (Fehrer and Wieland, 2021). IS is mainly deployed at the meso (district) level, yet IS implementation should start at a micro level and with single-firms initiatives (Liu et al., 2015). Second, when addressing the measurement of performance, the influence of contextual factors cannot be overlooked (Trianni et al., 2019). Several different contextual factors can characterize firms (Neri et al., 2021b); among them, the size, the awareness and competencies towards a specific paradigm can considerably shape a firm's behaviour (García-Quevedo et al., 2020) and the way performance is gauged (Trianni et al. 2019). As proof, the size might influence the availability of resources such as money, staff and time to implement the transition (Mitchell et al., 2020), while competencies and awareness might influence a firm's decision-making process and the measurement of performance (Negri et al., 2021b). There is thus the need for a scalable PMS, so as able to adapt to the changing needs and maturity of firms, in a progressive approach to performance measurement (Correia et al., 2017).

To summarize, the adoption of interventions aimed at improving performance (Trianni et al., 2017b) and having appropriate tools for the measurement of such performance (Neri, 2021) is fundamental to enable the ecological and ethical transition. This applied both at the single firm and at a system level (Cagno et al., 2019; Neri et al., 2021a), entailing incremental degrees of depth and breadth (Oleinikova and Brovchenko, 2012).

Considering the above, this study proposes a new framework for the measurement of the performance related to the ecological and ethical transition. The framework addressed the three paradigms of SUST, CE and IS in an integrated manner, offering a multi-level and scalable approach. Specifically, the present study aims at answering the following research question:

"How can sustainability, circular economy, industrial symbiosis be measured in industrial contexts in an integrated, multi-level and scalable way?"

The remainder of the paper follows. Section 2 presents the literature review carried out to identify synergies and trade-offs among the paradigms, the performance measurement systems developed in the extant literature and relevant literature gaps. Section 3 presents the methodology used to develop the new performance measurement framework, leveraging on the gaps previously identified, and describes the methodology used for the empirical validation of the framework. Section 4 presents the novel performance measurement framework developed and the results of the empirical analysis. Section 5 discusses the results against the existing literature, while section 6 offers conclusions and paves the way for future research.

2 Literature review

In line with the aim of the study, the current section provides on the one hand an overview of the three concepts, underlying synergies and trade-offs; on the other hand, it discusses extant gaps and shortcomings in the measurement of the related performance in an integrated, multi-level and scalable manner.

2.1 Sustainability, circular economy and industrial symbiosis: Synergies and trade-offs

SUST is the eldest paradigm among the three (Nikolaou and Tsagarakis, 2021). SUST is about balancing environmental, social and economic aspects in the long term (Carter and Rogers, 2008). Although considerably investigated, the predominant focus is still on environmental aspects (Carter and Washispack, 2018). On this line, two understandings of SUST can be identified (Jacobs, 1999), namely weak SUST - valuing the economic pillar more than the other two - and strong SUST - considering the environmental pillar as overarching (Mulia et al., 2016).

Despite the numerous benefits deriving from the implementation of SUST in the industrial sector (Ansari and Kant, 2017) – such as better operational performance, reduced cost for non-compliance, better quality, lower lead times, improved resilience (Negri et al., 2022), SUST does not necessarily lead to rethinking current production and consumption modes and it does not provide a tangible alternative to the dominant economic and development model (Elkington, 2018; Salomone et al., 2020).

The CE paradigm proposes a regenerative economic system (Kirchherr et al., 2017; Salomone et al., 2020) aiming at protecting the environment by closing the material loop, reusing resources and ensuring resource efficiency (Kumar et al., 2019). CE may be as well divided between weak and strong ones (Johansson and Henriksson, 2020), depending on the degree of paradigm change considered (Nikolaou and Tsagarakis, 2021). Despite the undoubtful benefits it can bring, CE is accused to overlook social aspects, disregarding their relevance for a successful application of the paradigms – think, for example, about the importance of consumers behaviour dynamics (Corona et al., 2019); others blame CE to neglect economic aspects (Zink and Geyer, 2017), as possible related benefits might be offset by consumer behaviour or market dynamics.

IS relates to collective approaches for exchanging materials and resources. IS gained popularity as a possible solution to industrial waste (Salomone et al., 2020) and shares points of interest with CE. IS has a strong focus on cooperation among firms (Fraccascia and Giannoccaro, 2020; Parida et al., 2019) and it relates to several environmental and economic benefits, such as improved waste management (Ormazabal et al., 2018a) or reduced supply risk (Chertow, 2007), as well as benefits to the community (Pandey and Prakash, 2019). To be implemented effectively, IS requires a combination of technical, informational, political and economic factors (Mirata, 2004). Relevant issues thus relate to the handling of relationships among firms involved in its implementation, especially in case of changing and evolving needs (Lombardi and Laybourn, 2012), and to the increased vulnerability of the firms involved in case of high interdependencies (Li and Shi, 2015).

As stated above, most of the extant literature individually addresses the three paradigms. Nonetheless, some initial efforts to intertwine them emerge. One avenue of research focuses on the integration of the three paradigms as a way to overcome the single paradigm's specific limitations (Baldassarre et al., 2019). The literature focuses quite extensively on the connection between CE and SUST. Although several contributions frame CE within an overarching SUST-related stream of research, only a few of them encompass all three SUST dimensions when addressing CE (Kirchherr et al., 2017). Overall, although CE is often expected to provide practical implementation tools to achieve SUST (Ellen MacArthur Foundation, 2015a; Triguero et al., 2022), its implications for SUST remain unclear (Lee et al., 2021). According to recent literature (Geissdoerfer et al., 2017; Schöggl et al., 2020), the relationship between CE and SUST can lead to both synergies and trade-offs, with most of the tensions between CE and SUST originating from a limited understanding of the CE paradigm. In terms of synergies, both CE and SUST tend to stress inter-generational justice, global perspective and the need for deep business model innovations. Yet, while SUST is conceptualised as the intersection of economic, environmental and social aspects, CE prioritises economic issues leading to environmental benefits (Geissdoerfer et al., 2017). IS is recognized to potentially support the implementation of both CE and SUST (Fraccascia and Giannoccaro, 2020). CE and IS are often related (Kirchherr et al., 2017; Lieder and Rashid, 2016), with IS considered a tool for the successful adoption of CE (Ormazabal et al., 2018b; Rincón-Moreno et al., 2020). Particularly, IS is widely considered as the application of CE at an industrial district level (Kalmykova et al., 2018; Prieto-Sandoval et al., 2018), although this viewpoint might be limited compared to the actual possibilities offered by IS (Lombardi and Laybourn, 2012). Overall, CE and IS might strongly support each other: CE might give an economic grounding to the technical focus of IS, fostering the adoption of IS, whereas IS might provide a more technical perspective to CE, reinforcing the processes (Chertow, 2007). Differences among the two paradigms should be nonetheless underlined: as CE brings impacts on a societal level, IS might shift the focus on industrial systems (Parida et al., 2019); while IS uses an end-of-life approach to promote closed-loop resource flows, CE acts more on the design phase to draw considerations about resource reuse and value retention (Angioletti et al., 2017); whereas CE proposes a shift from a linear to a regenerative economy (Salomone et al., 2020), IS can support the transition towards a non-linear economy (Fraccascia and Yazan, 2019), in a "system-wide" manner (Parida et al., 2019). IS might also help achieve SUST-related targets (Fraccascia and Giannoccaro, 2020). Although not explicitly considering social aspects, IS leads to deep interactions among actors and stakeholders, bringing long-term cultural change, eventually benefitting communities (Lombardi and Laybourn, 2012). IS thus fosters the system change SUST might lack (Rizos et al., 2016). At the same time, SUST might benefit IS by enhancing industrial resilience (Balugani et al., 2020; Negri et al., 2021a). Table 1 provides and overview of the main characteristics of each paradigm as emerged in the extant literature, pinpointing trade-offs and synergies.

Table 1. Overview of the main characteristics of each paradigm as emerged in the extant literature. The identification of the characteristics is based on the following literature: [1] Angioletti et al. (2017); [2] Baldassarre et al. (2019): [3] Ellen MacArthur Foundation (2013); [4] Fraccascia and Giannoccaro (2020); [5] Geissdoerfer et al. (2017); [6] Korhonen et al. (2018); [7] Lombardi and Laybourn (2012); [8] Lozano (2015); [9] Parida et al. (2019); [10] Purvis et al. (2019); [11] Rincón-Moreno et al. (2020); [12] Rossi et al. (2020); [12] Salomone et al. (2020); [13] Schöggl et al. (2020). Legend. Sust: Sustainability; CE: Circular Economy; IS: Industrial Symbiosis.

Characteristic	Sust	CE	IS
Resources efficiency	✓	✓	✓
Avoidance of waste	✓	✓	✓
Different stakeholders' responsibilities	✓	✓	
Minimize or save raw materials		✓	✓
Requires high level cooperation		✓	✓
Local dimension of interactions or benefits		✓	✓
Intergenerational justice	✓	✓	✓
Global perspective	✓	✓	
Reliance on policy	✓	✓	
Need for innovation	✓	✓	
Economics improve by selling waste	✓		✓
Close the loops		✓	✓
Reference Literature	[5]; [8]; [10]; [12]	[1]; [3]; [5]; [6]; [9]; [11]; [12]; [13]	[2]; [4]; [7]; [9]; [11]

2.2 Performance measurement systems to measure sustainability, circular economy and industrial symbiosis

A PMS is a "*collection of indicators that conveys a broader purpose and significance to the individual indicator and provides a comprehensive picture of some entity*" (Saidani et al., 2019). An organized set of indicators is crucial for fostering any transition: it supports the decision-making process by providing an understanding of the current situation and suggesting actions to improve performance (Collins et al., 2016; Maranesi and De Giovanni, 2020). From this standpoint, to foster the ecological and ethical transition, an integrated framework of indicators is fundamental.

A framework of indicators should have specific characteristics for it to be considered appropriate (Garengo et al., 2005; Neri, 2021). It is thus interesting to assess these characteristics against the available PMSs for supporting the ecological and ethical transition.

First, a PMS should be integrated. This means the framework should manage to include all the concepts relevant for the decision-making (Bouckaert and Halligan, 2006), in an integrated and balanced way (Lieder and Rashid, 2016), recognising potential synergies among the concepts (Vegter et al., 2021). The extant literature provides complete and useful frameworks of indicators, yet efforts are overall still focused only on a single paradigm at a time, thus lacking integration.

Insightful efforts in this direction can be nonetheless acknowledged. Quite a considerable attention has been given to the integration of CE and SUST in PMSs. Contributions tried overall to categorize CE indicators according to the three pillars of SUST (Nikolaou and Tsagarakis, 2021) to ensure a link between circular practices and sustainable development (Saidani et al., 2022). Examples of this can be found in Rossi et al., (2020), that also stressed the need to use a set of indicators rather than cherry-picking them, so to avoid possible tensions among the indicators; Kravchenko et al. (2020), who developed a methodology to assess the SUST of CE initiatives, yet not providing a discussion on two paradigms' possible synergies; Vegter et al. (2021), who evaluated the SUST of CE practices, underlined the need for a representation of the interdependencies among the paradigms; Lee et al. (2021) underlined the presence of trade-offs between CE and SUST in the tyre industry, providing a more structured effort to integrate SUST and CE in performance measurement. During this integration between CE and SUST, the social aspect appears to be largely neglected, despite the implications of CE on numerous stakeholders (Kristensen and Mosgaard, 2020). Efforts in considering social implications of CE have been made recently (Mies and Gold, 2021; Padilla-Rivera et al., 2020), yet structured ones are still missing. The integration among the two paradigms was also addressed in the SUST's related literature. As proof, Kazancoglu et al. (2018) proposed a framework to measure the environmental SUST of firms with a CE perspective, including tangible and intangible indicators; Mesa et al. (2018) developed SUST indicators to measure the circularity of product families. Overall, despite the recognized relevance of linking CE and SUST in a performance measurement system (Martinho, 2021), little exploration of synergies has been so far carried out so far, particularly lacking a structured integration of them.

Focusing on IS literature, recent research developed indicators framing them within SUST (Lütje and Wohlgemuth, 2020; Martin and Harris, 2018) - or CE (Wen and Meng, 2015).

An interesting attempt to integrate the three paradigms was performed by Walker et al. (2021b), though they only focus on the social dimension of SUST and proposed more of a methodology rather than a structured system of indicators. Overall, an established approach to measuring the performance of SUST, CE and IS in an integrated manner is missing.

Second, a PMS should support the measurement of performance at different levels of application within an industrial system (Neri, 2021). Such a characteristic would prevent firms to cherry-pick the most convenient indicators for their communication purposes, especially at the micro level, which would lead to a suboptimal measurement of performance (Harris et al., 2021). As for the micro level, a direct link to the firm level can be established; as for the meso level, addressing the ecological and ethical transition, both supply chains (SCs) and industrial districts should be included (Asheim, 1996; Kennedy and Kundu, 2017). The relevance of a multi-level perspective, considering both the micro and the meso perspective, is largely shared in the literature (Fehrer and Wieland, 2021; Singh et al., 2016), especially considering SUST and CE (Harris et al., 2021). As proof, the performance of a SC and its tiers are strongly interrelated and mutually influenced and the same can be assumed for districts (Junaid et al., 2022; Neri, 2021). However, full disclosure from other actors – partners, suppliers, customers - within an industrial system is challenging (Oleinikova and Brovchenko, 2012) and still not addressed in most PMSs (Negri et al., 2021b). The multi-level perspective is fairly developed in SUST-related literature, with a specific focus on SCs (Alkhuzaim et al., 2021; Neri et al., 2021b); CE-related literature focuses mostly on the micro level (Harris et al., 2021); IS-related literature mostly focuses on the mere meso level in terms of industrial districts. Hence, an established approach to measuring the performance of SUST, CE and IS from a multi-level perspective is missing, even within single paradigms.

Third, a PMS should adapt to the characteristics of the context under investigation (Garengo et al., 2005), leading to different requirements in terms of specific features such as the breadth and depth of investigation or the number of indicators included (Trianni et al. 2019). Among the different contextual factors influencing the needs of firms, size is recognized as a pivotal one. Particularly, Small and Medium Enterprises (SMEs) are usually characterized by resource constraints – time, staff, money (Ormazabal et al., 2018b), leading to objective difficulties in measuring performance

effectively (Dey et al., 2021), by properly selecting the right pool of indicators (Mengistu and Panizzolo, 2022a). The level of awareness (Malesios et al., 2020) and advancements and competencies about the transition (Negri et al., 2021b), might as well affect a firm's needs in terms of PMS. Extant efforts overall overlook the specific needs of firms according to their characteristics (Harris et al., 2021; Kristensen and Mosgaard, 2020). Scalability could represent the right solution from this perspective (Cagno et al., 2019), as a scalable framework would easily adapt to the specific characteristics and needs of firms, still maintaining a general structure and thus allowing it to be used in different contexts. A scalable system would be thus of extreme interest for firms to be supported during their path towards the ecological and ethical transition, as it would allow firms to use a unique system and adapt it according to their evolving needs (Garengo et al., 2005; Neri, 2021). Overall, an established scalable approach way to measuring the performance of SUST, CE and IS is missing.
Table 2 assesses selected literature contributions proposing a PMS for the ecological and ethical transitions against the above-discussed feature. In particular, the table includes only those contributions focusing at least on two paradigms simultaneously.

Table 2. Assessment of selected contributions against integration, multi-level and scalability features. Legend. PMS: Performance Measurement System; Sust: Sustainability; CE: Circular Economy; IS: Industrial Symbiosis; SC: Supply Chain.

Contribution	**Propose a PMS**	**Integration**			**Multi-Level**			**Scalability**
					Micro	**Meso**		
		Sust	**CE**	**IS**	**Firm**	**District**	**SC**	
Al-Thani and Al-Ansari, 2021			✓	✓	✓		✓	
Harris et al., 2021			✓		✓		✓	
Kazancoglu et al., 2018	✓	✓	✓		✓			
Kravchenko et al., 2020		✓	✓		✓			
Kristensen and Mosgaard, 2020		✓	✓		✓			
Lee et al., 2021	✓	✓	✓		✓			
Lütje and Wohlgemuth, 2020	✓	✓		✓		✓		
Martin and Harris, 2018	✓	✓		✓		✓		
Martinho, 2021		✓	✓	✓	✓			
Mesa et al., 2018	✓	✓	✓		✓			
Mies and Gold, 2021	✓	✓	✓		✓			
Padilla-Rivera et al., 2020	✓	✓	✓		✓			
Rossi et al., 2020	✓	✓	✓		✓			
Vegter et al., 2021		✓	✓		✓			
Walker et al., 2021b		✓	✓	✓	✓			
Wen and Meng, 2015			✓	✓		✓		

2.3 Literature gaps

Three main gaps emerged from the analysis of the extant literature:

- The integration among the three paradigms needs additional research, specifically for the assessment of possible synergies and trade-offs among them (Salomone et al., 2020), as to fostering the industrial transition.
- The relationship between the micro and the meso levels is not explored in depth as to the implications in terms of performance measurement. This is however fundamental, as single firms take decisions but are inserted in a broader industrial system and the two levels exert deep mutual influence. (Massaroni et al., 2018).
- Contextual factors, e.g., size or awareness, and their impact on the measurement of performance is yet not properly investigated and considered in the development of PMSs (Malesios et al., 2020). In particular, there is no indication of how firms can upgrade and scale up their performance measurement, once they proceed in their transition.

The overall shared interest in developing an integrated, multi-level and scalable method to measure performance related to the ecological and ethical transition has not so far translated into the development of an effective PMS (Vegter et al., 2021; Walker et al., 2021a).

3 Methods

The identified literature gaps have been tackled by developing a novel framework of performance measurement systems. The rationale for its development is detailed in Section 3.1, while the empirical validation methodology is presented in Section 3.2. This last step is required in order to corroborate the proposed framework with real case data, bridging theory and practice (Neri et al., 2021a), as commonly done in previous contributions (Sweeney et al., 2015).

3.1 Development of a novel integrated, multi-level and scalable framework of performance measurement systems

Stemming from the research gaps identified, this study proposes a novel framework of PMSs capable of considering a proper integration among the three paradigms, from a multi-level perspective and in a scalable manner.

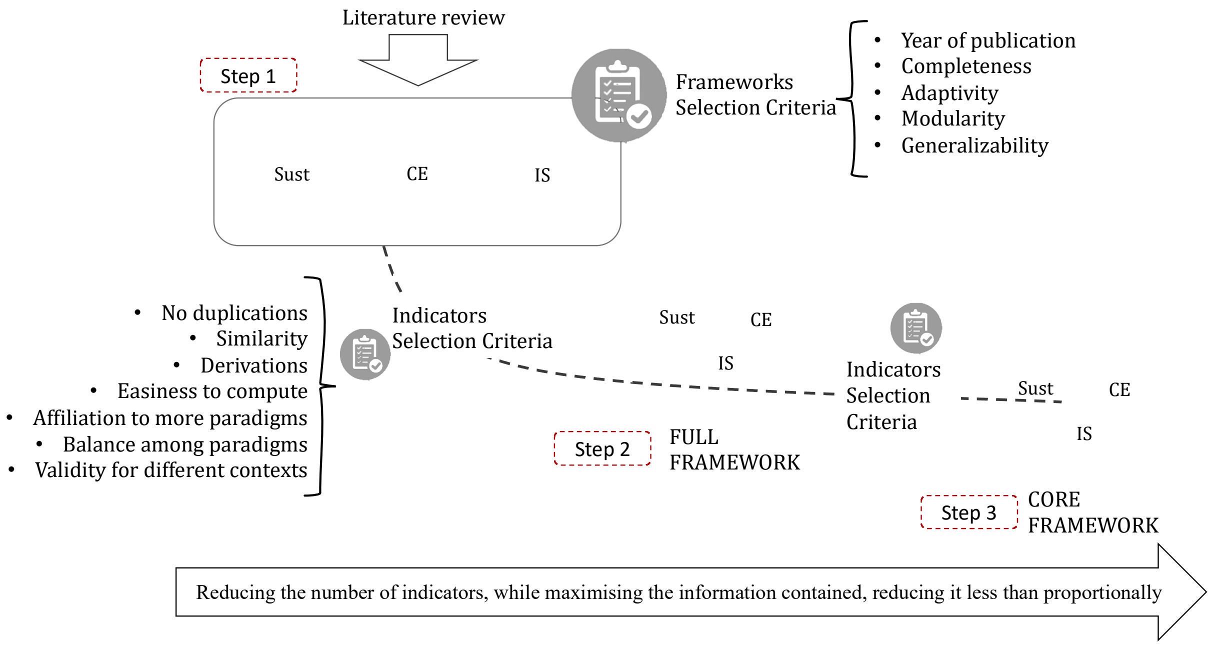
A considerable number of indicators have been developed so far by addressing the different paradigms. From this standpoint, the real challenge for the development of the framework lies in the non-biased selection of the right indicators among the available ones rather than in the development of new ones (Nikolaou et al., 2019; Singh et al., 2014). To tackle the issue, we developed a series of steps for developing the framework (Figure 1), building on previous literature (Ahmed et al., 2022):

- Step 1. We analysed systems of indicators, retrieved from recent literature reviews on single paradigms. Apart from some specific integration efforts as illustrated in Section 2, previous literature focused on single paradigms or levels. We thus used the existing PMSs to retrieve a list of indicators.
- Step 2. We analysed the retrieved indicators and selected those emerging as the most adequate to provide an integrated overview of the three paradigms according to a multi-level perspective. We then organized the selected indicators in a PMS, referring to it as the "Full system"
- Step 3. We further analysed the indicators included in the "Full system", aiming at streamlining it, that is to reduce as much as possible the number of indicators included, while limiting the information lost. This process led to the development of a second PMS named "Core system", ensuring adaptability to the firms' needs.

The two systems, the Full one and the Core one, constitute the integrated, multi-level and scalable framework for the analysis of performance related to the ecological and ethical transition.

In the flowing sub-sections, the different steps are illustrated in detail.

Figure 1. Process of frameworks and indicators selection. Legend. Sust: Sustainability; CE: Circular Economy; IS: Industrial Symbiosis.



3.1.1 *Step 1. Identification of indicators from the extant literature*

As mentioned, Step 1 consisted in the identification and selection of previous PMSs, leveraging on the procedure followed by previous contributions (Neri et al., 2021a). Indeed, the proliferation of studies on the paradigms, especially for sustainability, may justify having simple periodic updates (Carter and Washispack, 2018). Thus, relying on recent literature reviews was deemed sufficient to have an extensive knowledge on the performance measurement topic for the different paradigms.

The frameworks selection was based on some recent literature reviews, that analysed the topic of performance measurement for the different paradigms in a complete way (Martinho, 2021; Mengistu and Panizzolo, 2022b; Negri et al., 2021b). Based on the revised literature reviews, PMSs were selected considering the year of publication – giving priority to more recent contributions - completeness (ability to represent more aspects – SUST, CE and IS), adaptivity and modularity (possibility to adapt to different contexts, scaling up or down), generalizability (suitability to different industries and different actors). This step allowed to retrieve the most consolidated PMSs present in the extant literature, that are reported in Table 3.

Table 3. Contributions from which indicators were retrieved. Legend. SUST: Sustainability; CE: Circular Economy; IS: Industrial Symbiosis; SC: Supply Chain.

		Paradigm		
		CE	**IS**	**SUST**
Level	**Firm**	Rossi et al., 2020 Cayzer et al., 2017	-	Cagno et al., 2019 Mengistu and Panizzolo, 2022a
	SC	Howard et al., 2019	-	Neri et al., 2021a
	District	-	Fraccascia and Giannoccaro, 2020 Felicio et al., 2016a Valenzuela-venegas et al., 2016	Valenzuela-venegas et al., 2016

3.1.2 *Step 2. Development of the Full System*

The previous step allowed retrieving 239 indicators. To develop the Full System, the following criteria were used for selecting the indicators to be included:

- Duplications were removed. As proof, “waste recycled” was mentioned both in CE-related (Rossi et al., 2020) and SUST-related literature (Cagno et al., 2019); “reduction of raw material” was mentioned both in IS (Fraccascia and Giannoccaro, 2020) and SUST- related frameworks.
- Several indicators appeared multiple times with slightly different names. This happened within a single paradigm and across paradigms. As proof, focusing on SUST-related indicators “R&D investment” was present in (Cagno et al., 2019) and “R&D capacity” in (Neri et al., 2021a); these were merged into one single indicator.
- Similar indicators were merged. For instance, “by-product utilization” (Valenzuela-Venegas et al., 2016) and “inbound by-products” (Felicio et al., 2016b) were merged into “inbound by-products”.
- Indicators that could be derived from others were eliminated. For instance, “reduction in input purchase thanks to IS” (Fraccascia and Giannoccaro, 2020) was incorporated into “supply cost” (Liakos et al., 2019; Neri et al., 2021a), as the savings deriving from the application of IS might be easily evaluated comparing the “supply cost” value in different periods of time.
- Indicators that could be easily understood or calculated by firms were prioritized (Howard et al., 2019). As proof, “customer satisfaction” (Feil et al., 2019) was prioritized over “community relationship” (Neri et al., 2021a), as the former is usually well understood by firms and often already monitored. Conversely, including complex or non-straightforward indicators may hinder the process of performance measurement.
- Indicators pertaining to more than one paradigm were prioritized. For example, indicators related to renewable energy, air pollutant, use of water and origin of resources were kept - as “restorative or regenerative sources”, “renewable energy use for production”, “water for production”, “CO_2 emissions”, “restorative or regenerative sources”, since of interest for all the paradigms.
- A special attention was given to maintaining the balance among the paradigms and the levels.
- Indicators suitable for different products and types of industries have been prioritized over not suitable ones (Saidani et al., 2017). For instance, very specific indicators addressing NO_x, SO_2, metal emissions were excluded, as not applicable to all firms.

In addition, the following assumptions were made for specific indicators.

- “Energy efficiency investment”: it is not cited as a main indicator of CE, but since CE principles promote energy efficiency (Ellen MacArthur Foundation, 2015b), it is reasonable to include it.
- “Mindset, cultural change”: it is developed for CE and not mentioned in the IS and SUST related literature, but it is reasonable to extend its importance also to the two concepts (Lombardi and Laybourn, 2012; Trianni et al., 2017b).

3.1.3 Step 3. Development of the Core System

Firms with limited resources or awareness might struggle with the use of the Full system. We thus deemed it necessary to propose a Core system, allowing the scalability of the framework according to the specific firms’ needs. Leveraging on the procedure presented by (Cagno et al., 2019), the Core system was derived from the Full one by reducing the number of indicators while diminishing the information in the system in a less than proportional manner (Figure 2). The information contained in each indicator of the Full system was thus assessed against the information provided by each of the other indicators. To reduce biases, this step was performed independently by each author and followed by a joint discussion leading to an agreement over the inclusion or exclusion of each indicator. Indicators that are able to cover more than one paradigm were prioritized; nonetheless, some indicators specific to a single paradigm were kept so as not to lose important information. For instance, “Cost variation due to IS practices implementation” (Fraccascia and Giannoccaro, 2020) is only referable to IS but it has been kept. In the selection, operativity was prioritized, so indicators such as “bill of energy”, “bill of waste” and “bill of material” (Valenzuela-Venegas et al., 2016) were eliminated from the set for being complex and less informative. Other indicators were removed because considered more complex or not straightforward to be evaluated as "gender discrimination" (Cagno et al., 2019), "waste treatment carbon footprint" (Valenzuela-Venegas et al., 2016) or "health of surrounding area" (Howard et al., 2019).

3.2 Empirical validation of the proposed framework

To assess the theoretical framework against empirical data, the framework was validated by means of semi-structured interviews (Adams, 2015), an interesting method to complement theoretical backgrounds when the related empirical literature appears fragmented (Kallio et al., 2016).
Semi-structured interviews are considered a suitable methodology in explorative contexts, as they allow collecting a great variety of data (Cooper and Schindler, 2014) and better understanding the topic under analysis by relying on experts' insights (Kallio et al., 2016). Indeed, semi-structured interviews allow asking immediate follow-up questions when issues arise (Adams, 2015), thus benefitting from the emerging free dialogues (DiCicco-Bloom and Crabtree, 2006).

3.2.1 Sample selection

We adopted purposive sampling (Acharya et al., 2013; Hibberts et al., 2012) by designing a heterogeneous sample, in terms of sector and size to intentionally improve external validity and the results robustness (Baškarada, 2014). Possible firms to be included in the investigation were selected using the AIDA database and by looking at secondary information on their SUST, CE or IS strategy or activities in place, as these could be the most suitable actors for this research. As sector and size are contextual factors that impact the type and number of the performance indicators being measured (Ahmad et al., 2019; Govindan et al., 2020; Trianni et al., 2019), the firms were selected to maximize sector and size diversity. Among the industrial settings, we focused on the manufacturing industry as one of the most relevant for the European industrial sector and economy (Eurostat, 2020) and with substantial impacts on ecosystems (Acerbi and Taisch, 2020). Therefore, the manufacturing sector traditionally experienced relevant pressures (Neri et al., 2018) from various stakeholders to engage in the ecological and ethical transition, constituting an interesting focus for this study.
We conducted five interviews in four manufacturing firms. The firms belonged to different sectors, have different sizes, awareness levels on performance measurement and the three paradigms -SUST, CE and IS. This number of semi-structured interviews conciliates the necessity to go in-depth during the interviews and the requirement to build robust and testable theory (Barratt et al., 2011; Voss et al., 2002). The characteristics of the sample are reported in Table 4.

Table 4. Characteristics of the interviewed firms

Firm	**A**	**B**	**C**	**D**
NACE rev.2	2932	3102	2733	2370
Activity description	Manufacturing of parts and accessories for motor vehicles and their engines	Manufacturing of kitchen furniture	Production and trade of electrical, civil and industrial materials	Trade in and working of marble, granite and related products
Employees	3.152	499	293	34
Contact(s)	Chief environment and energy officer	Chief Executive Officer (CEO) Quality, safety and environment manager	Chief Executive Officer (CEO)	Chief Executive Officer (CEO)

3.2.2 Data collection and analysis

Interviews were conducted with knowledgeable experts inside the selected firms and lasted approximately two hours. Secondary sources of data – newspapers, firms' website, reports - were used for triangulation to confirm the information retrieved from the interviewees (Woodside and

Wilson, 2003; Zainal, 2007). An interview protocol (Adams, 2015), was developed to ensure reliability (Baškarada, 2014). The empirical validation protocol is reported in Appendix A.
The interview was divided in two parts.
In the first part, the interviews focused on a general description of the firm, followed by the interviewees' definition and understanding of the three paradigms (SUST, CE and IS).
In the second part, firms were presented the version of the framework (full or core system) according to the firm's profile in terms of awareness, size, resources spent in performance measurement as emerged during the first part of the interview (Cagno et al., 2019). Based on the gathered material, firms A, B and C were presented with the Full system, while firm D with the Core one. The interviewers went through the indicators included in the system explaining them to the respondents. Interviewees were then asked to comment on indicators' clarity, usefulness, and possible issues. Interviewees were then asked to comment on the capacity of representation, easiness of use and usefulness of the system (Trianni et al., 2017b). The capacity of representation investigated the ability of the system to represent all relevant performances of the three paradigms; the easiness of use investigated the system's user-friendliness; finally, the usefulness investigated whether the system allowed facilitating the firms' decision-making process. The evaluation was performed using a 4-point Likert-like scale (from 1 as the lowest value, 4 as the highest). As for the Likert-like scale, an even scale was used to minimize the number of neutral answers (Nowlis et al., 2002). This allowed to synthesize the data from the interviews as done in previous research (Trianni et al., 2017b). The answers were then commented to gain additional insights and to identify potential issues and necessity to amend the system. Additionally, interviewees were also asked to indicate possible issue with any of the proposed indicators.
Interviews were recorded and transcribed for data analysis (Kohlbacher, 2006). The data retrieved from the transcriptions were categorized in a dataset, in order to facilitate comparisons and organize information (Rowley, 2012). This step was performed by two researchers independently to reduce bias (Miles et al., 2014). The interviewees' answers were thus contextualised based on the comments and more quantitative responses were triangulated with the comments received (Thurmond, 2001).

4 Results

This Section is divided as follows. First (Section 4.1), the novel framework, consisting of a Core and a Full PMS, is presented, and the indicators are assessed against the three paradigms, namely SUST, CE and IS. Second (Section 4.2), the rationale for selecting the most suitable PMS (i.e., the Core or the Full) to disclose to each sampled firm for the empirical validation is offered. Third (Section 4.3), the findings of the empirical validation are introduced.

4.1 Novel integrated, multi-level and scalable framework of performance measurement systems

After applying the criteria mentioned in Section 3.1, we obtained a list of 91 indicators. To provide an organized set of indicators, and thus meeting the main requirement for a PMS, we organized the indicators into categories of performance. The dimensions used to classify indicators are elaborated from (Cagno et al., 2019; Neri et al., 2021a; Rossi et al., 2020). This was deemed important also to provide operability to the framework and clearly identify areas that need improvement, thus facilitating the implementation of the practices.
Table 5 presents the framework, in particular the Full system is reported in column 3 and the Core system in column 4. Details of indicators are presented in Table 6.
The Core system is reported in the fourth column of Table 5. It includes 53 indicators - so almost half the number of indicators of the Full one. However, the information the Core system can provide is not halved, as the selected indicators better grasp the intersections among the paradigms and levels.

Table 5. The novel integrated, multi-level and scalable framework.

Level	Category of performance	Full System	Core System
Firm	Product and production process	Reuse-product	Reuse – product
		Product longevity	Product longevity
		Remanufacturing	Remanufacturing
		Refurbishment	Refurbishment
		Product quality	
		Lead time	-
		Scrap	
		Throughput	Throughput
	Material	Hazardous or toxic substances use	Hazardous or toxic substance use
		Reuse-manufacturing	Reuse – manufacturing
		Reduction of raw material	Reduction of raw materials
	Waste	Hazardous solid waste	Hazardous waste
		Hazardous liquid waste	
		Manufacturing waste management	
	Energy	Renewable energy use for production	Renewable energy use for production
		Non-renewable energy use for production	
		Reused energy	Reused energy
		Bill of energy	
	Water	Recycled water use	Recycled water use
	Air emission	CO_2 emissions	CO_2 emissions
		Toxic emission	Toxic emissions
	Employees	Work satisfaction	
		Job creation	Job creation
		Gender discrimination	
		Safety training	Safety training
		Education and training in waste minimization	Education and training in waste minimization
		Employee participation	Employee participation
	Occupational Health and Safety	Accidents	Accidents
		Injuries	
		Fatalities	
		Absenteeism	
	Other	Mindset-cultural change	Mindset – cultural change
	Investment	Research and development investment	
		Environment investment	
		Energy efficiency investment	Energy efficiency investment
		Safety investment	Safety investment
		Circular innovation investment	Circular innovation investment
	Cost	Production cost	
		Inventory cost	
		Labour cost	
		Maintenance cost	
		Cost variation	Cost variation
		Environmental, Health and Safety (EHS) fines	Environmental, Health and Safety (EHS) fines
	Incomes	Revenues	Revenues
		Profit	Profit
Supply chain	Management	Dematerialization possibility	Dematerialization possibility
		Take-back scheme availability	Take-back scheme availability
		Deliver reliability	
		Supply chain flexibility	Supply chain flexibility
	Lead time	Supplier lead time	
		Distribution lead time	
	Material	Material use	
		Restorative or regenerative sources	
		Risk, scarce or vulnerable material sources	Risk, scarce or vulnerable material sources
		Total technical products and materials recovered and recirculated	Total technical products and materials recovered and recirculated
		Reduction in materials used as input by industrial processes	
		Bill of materials	
	Waste	Waste recycled	Waste recycled

		Biological materials returned to the biosphere	
	Energy	Energy use	
	Air emission	Transportation	
	Customer	Customer satisfaction	Customer satisfaction
		Client mindset	Client mindset
		Communication – client values	
	Stakeholders	Supply chain partners structure and diversity	Supply chain partners structure and diversity
		Involvement of supply chain partners	Involvement of supply chain partners
		Information	
		Fair trade	Fair trade
	Cost	Supply cost	Supply cost
		Distribution cost	Distribution cost
		Return cost	Return cost
		Disposal cost	Disposal cost
District	Management	Quantity match	Quantity match
		Volume flexibility	
		Industrial symbiosis indicator	
	Material	Inbound by-products	Inbound by-products
		Outbound by-products	
	Waste	Waste disposed reduction	Waste disposed reduction
		Waste treatment carbon footprint	
	Energy	Energy for production	Energy for production
	Water	Water for production	Water for production
	Community	Community complaint	Community complaint
		Involvement in community projects	Involvement in community projects
		Health of surrounding area	
	Stakeholders	District partners structure and diversity	
		Involvement of district partners	
		Information	
	Cost	By-products transportation costs	
		Additional industrial symbiosis costs	Additional industrial symbiosis costs
		Relationships maintenance	
	Incomes	Additional industrial symbiosis revenues	Additional industrial symbiosis revenues

Table 6. Details of indicators included in the framework. Supporting references for the indicators and their description. [1] Rossi et al. (2020); [2] Howard et al. (2019); [3] Cayzer et al. (2017); [4] Felicio et al. (2016b); [5] Valenzuela-Venegas et al. (2016); [6] Fraccascia and Giannoccaro (2020); [7] Cagno et al. (2019); [8] Neri et al. (2021); [9] Ellen MacArthur Foundation (2015c); [10] Feil et al. (2019); [11] Chertow (2000); [12] Pandey and Prakash (2019); [13] Liakos et al. (2019); [14] Molla et al. (2019); [15] Lin and Mills (2001). The unit comes from the literature and the authors' own elaboration. The indicators have been classified according to the paradigm(s) they refer to. "**" refers to the authors' elaboration. Legend. SUST: Sustainability; CE: Circular Economy; IS: Industrial Symbiosis.

Level	Category of performance	Performance indicator	Description	Proposal of unit	CE	SUST	IS
Firm	Product and Production process	Reuse-product	Percentage of reused material in the product	%	[1], [9]		
		Product longevity	Quantity of time added in the lifespan of the product	Unit of time	[1], [3], [9]		
		Remanufacturing	Quantity of remanufactured products	#	[1], [9]		
		Refurbishment	Quantity of parts of the product recovered without necessarily going through all stages of the remanufacturing	#	[1], [9]		
		Product quality	Qualitative consideration of returned products quality, in order to determine whether it can be upcycled rather than downcycled	Qualitative	[1], [3], [9]		
		Lead time	Quantity of time the production process needs to manufacture an item	Unit of time		[7], [8], [10]	
		Scrap	Quantity of items generated by the production process with no economic value, or only the value of its basic materials	Unit of mass		[7], [10]	[11]
		Throughput	Productivity of the production process	Pieces/unit of time		7], [8], [10]	
	Material	Hazardous or toxic substances use	Quantity of materials/substances used in the production process which may pose a threat to health and safety and that is listed as corrosive, harmful, irritant, reactive or toxic	Unit of mass	[9], [13]	[7], [10]	
		Reuse-manufacturing	Quantity of materials reused within the production process, also among different functions of the firm	Unit of mass	[1], [2], [9]		[6], [11]
		Reduction of raw material	Quantity of raw material used in the production process	Unit of mass	[1], [2], [9]	[7], [10]	
	Waste	Hazardous solid waste	Quantity of solid materials/substances which may pose a threat to health and safety and that is listed as corrosive, harmful, irritant, reactive or toxic and which do not have any economic value	Unit of mass	[1], [9]	[7], [10]	
		Hazardous liquid waste	Quantity of liquid materials/substances which may pose a threat to health and safety and that is listed as corrosive, harmful, irritant, reactive or toxic and which do not have any economic value	Unit of volume	[1], [9]	[7], [10]	
		Manufacturing waste management	Presence of a bill of waste and how it is disposed	Qualitative	[3]	[14]	
	Energy	Renewable energy use for production	Quantity of renewable energy used in the production process	Unit of energy	[1], [9], [13]	[7], [10]	
		Non-renewable energy use for production	Quantity of non-renewable energy used in the production process	Unit of energy	[1], [9], [13]	[7], [10]	
		Reused energy	Energy reused within the firm processes and not wasted	Unit of energy			[6]
		Bill of energy	Presence of a complete bill of energy (both firm and supply chain)	Qualitative		[3], [14]	
	Water	Recycled water use	Quantity of water recycled within the process	Unit of volume		[7], [10]	[5], [12]
	Air emission	CO2	Quantity of CO_2 emitted by production process	Unit of volume	[9]	[7]	
		Toxic emission	Quantity of gas emission produced by production process that is considered harmful for the environment and the human health	Unit of volume	[9]	[7]	
	Employees	Work satisfaction	Qualitative assessment of the employees' satisfaction	Qualitative		[7], [8], [10]	
		Job creation	Quantity of job created each year	#	[1], [13]	[7], [8], [10]	[5], [6], [12]
		Gender discrimination	Qualitative assessment of discrimination due to gender characteristics within the firm	Qualitative (or # or %)		[7], [10],[14]	
		Safety training	Quantity and quality of training for employees to increase their awareness of safety measures and protocols	#, qualitative		[7]	
		Education and training in waste minimization	Quantity and quality training for employees to increase their waste minimization awareness and to facilitate practices of IS or CE	#, qualitative	**		[5]
		Employee participation	Qualitative assessment of the awareness and involvement of employees in CE practices	Qualitative	[1], [13]		
	Occupational Health and Safety	Accidents	Number of accidents happening yearly	#		[7], [15]	
		Injuries	Number of injuries happening yearly	#		[7], [15]	
		Fatalities	Number of fatalities happening yearly	#		[7], [15]	
		Absenteeism	Average hours of absenteeism of employees	#		[7], [15]	
	Other	Mindset-cultural change	Qualitative assessment of the firm board awareness and care of environment and social challenges, and of the presence of long-term strategies to address them, including the use of CE and IS available practices	Qualitative	[1]	**	**
	Investment	Research and development investment	Investments in research and development	Unity of currency		[7], [10]	
		Environment investment	Investments in support of environmentally friendly practices, services and products	Unity of currency		[7], [10]	
		Energy efficiency investment	Investments in energy efficiency practices	Unity of currency	**	[7], [10]	

		Safety investment	Investments in how the firm manages risk, protects employees and works towards introducing changes which increase the safety level of the working environment	Unity of currency		[7],	
		Circular innovation investment	Investment in CE and IS practices	Unity of currency	[1]		**
	Cost	Production cost	Costs incurred from manufacturing a product or providing a service. It includes labour cost, raw material cost, general overhead	Unity of currency		[7]	
		Inventory cost	Expenses related to holding and storing unsold goods	Unity of currency		[7]	
		Labour cost	Sum of employees' wages, cost of benefits and payroll taxes paid	Unity of currency		[7]	
		Maintenance cost	Costs to keep the firm assets in good condition and operative	Unity of currency		[7]	
		Cost variation	Variation of production cost	Unity of currency	[1], [3]	[7]	[6], [11]
		Environmental, Health and Safety (EHS) fines	Environmental health and safety fines	Unity of currency		[7], [15]	
	Incomes	Revenues	Total revenues	Unity of currency		[7], [10]	
		Profit	Total profit	Unity of currency	[1]	[7], [10]	
Supply chain	Management	Dematerialization possibility	Qualitative assessment of the presence of practices at the "(re)use" product life cycle. This includes the possibility of on-demand orders and of product-as-service, as well as the promotion of sharing economy	Qualitative	[2], [3]		
		Take-back scheme availability	Presence of schemes which enable consumers to dispose of their unwanted products and recapture their value	Qualitative	[2], [3]		
		Deliver reliability	Percentage of orders delivered correctly and on time	%		[8]	
		Supply chain flexibility	Qualitative assessment of volume and mix flexibility of both downstream and upstream supply chain	Qualitative		[8]	
	Lead time	Supplier lead time	Average time of suppliers to respond to an order request and to deliver the order	Unit of time		[8]	
		Distribution lead time	Average time of receiving an order, schedule it, organize it and deliver the items	Unit of time		[8]	
	Material	Material use	Quantity of material used along the supply chain	Unit of mass		[8]	
		Restorative or regenerative sources	Quantity of biological raw materials entering as input in the firm, which are considered to come from restorative or regenerative sources	Unity of mass* (%)	[2]	**	
		Risk, scarce or vulnerable material sources	Quantity of technical raw materials entering as input in the firm, which are classified scarce or which come from risk or vulnerable sources	Unity of mass (%)	[2]	**	
		Total technical products and materials recovered and recirculated	Quantity of materials and/or products which have left the firm boundaries and are recaptured and recirculated in the firm	Unity of mass	[1], [3]		
		Reduction of amount of materials used as input by industrial processes	Quantity of material that is no longer needed in input for the industrial process, thanks to IS practices	Unity of mass			[6]
		Bill of materials	Assessment of the presence of a complete bill of material which account for the sources and the final destination of materials	Qualitative	[3]		
	Waste	Waste recycled	Quantity of waste produced in the production process that is recycled	Unity of mass	[1]		
		Biological materials returned to the biosphere	Quantity of biological materials returned to the biosphere in a safe and harmless way (e.g. not contaminated).	Unity of mass	[2]	**	
	Energy	Energy use	Quantity of energy used in the supply chain	Unity of energy		[8]	
	Air emission	Transportation	Toxic and greenhouse gas emissions due to transportation	Quantity of volume	[2]	[7], [8], [10]	
	Customer	Customer satisfaction	Qualitative assessment of the customer satisfaction	Qualitative		[8], [10]	
		Client mindset	Client characterization (e.g. social level, geographical regions, age group if B2C, or size, mission, values if B2B)	Qualitative		[8], [10]	
		Communication – client values	Collection of data or information from customer surveys, customer service and other channels. The indicators account for the capacity of identifying correlations with information of adoption by the clients of circular practices or sustainability	Qualitative	**	[8], [10],[14]	
	Stakeholders	Supply chain partners structure and diversity	Map of the stakeholders and their diversity in geographical disposition, values, material treated, service offered, etc	Qualitative	[1]	[8]	[5],[6]
		Involvement of supply chain partners	Qualitative assessment of stakeholders who participate in the general business model and those who effectively participate in the organization's decision making	Qualitative	[1]		[5],[6]
		Information	Qualitative assessment of the availability, accuracy and timeliness of information exchanged with the stakeholders. It also accounts for the quality of information and the transparency of the sources	Qualitative			**
		Fair trade	Qualitative assessment of the fairness towards the suppliers. It also checks the "fair trade" certifications	Qualitative		[8], [14]	
	Cost	Supply cost	Costs derived from all supply activities	Unity of currency	[13]	[7], [8]	[6]
		Distribution cost	Costs derived from distribution activities	Unity of currency		[7], [8]	
		Return cost	Costs derived from reverse logistic	Unity of currency	[13]		
		Disposal cost	Costs derived from disposal activities	Unity of currency		[7], [8]	[6]
District	Management	Quantity match	It verifies that the quantity of by-products (including materials, energy, water) required and supplied by a symbiotic partner coincide	Unit of mass, #			[4],[5];[6],[11]
		Volume flexibility	Capability of symbiotic partners of change the volume of material flow both in input and in output	Qualitative			[5]
		Industrial symbiosis indicator	Level of development of symbiosis of the firm. It is a qualitative indicator computed in this way: (Weighted sum of the different inbound by-products)/(1+weighted sum of outbound by-products). The weight is given qualitatively by the firm, depending on the importance of the material exchanged	Absolute number			[4], [11]
	Material	Inbound by-products	Sum of the amount of materials (by-products, energy, water) exchanged with a symbiotic partner. It accounts both for the materials supplied and received	Unit of mass, #			[4], [6], [11]

		Outbound by-products	Sum of the amount of materials (by-products, energy, water) that could have been exchanged with a symbiotic partner and thus exploited but that are disposed	Unit of mass, #			[4], [6], [11]
	Waste	Waste disposed reduction	Quantity of materials considered to have no economic value which are disposed, reaching their end-of-life. The indicator accounts for the ways the waste is disposed (e.g. landfill, incineration)	Unit of mass		[7], [12]	[5], [11]
		Waste treatment carbon footprint	Emission caused during the treatment process of the wasted generated	Unit of volume	[9]	[7]	[5], [11]
	Energy	Energy for production	Quantity of energy used in the production process. It specifically accounts for the energy savings due to IS practices	Unit of energy		[7], [10]	[5], [6], {11]
	Water	Water for production	Quantity of water used in the production process. It specifically accounts for the water saved due to IS practices	Unit of volume		[7], [10]	[5],[6], [11]
	Community	Community complaint	It verifies that the firm collects and considers the complaints coming from the district and its community	Qualitative		[7], [10]	[6], [11]
		Involvement in community projects	It verifies the firm involvement in community projects and qualitatively accounts for the type of projects developed and their impact	Qualitative		[2], [10]	[6], [11]
		Health of surrounding area	Measurement of the quantity of air pollutants, water pollutants and waste discharged into surrounding area	Qualitative		[2], [12]	[6], [12]
	Stakeholders	District partners structure and diversity	Map of the stakeholders and their diversity in geographical disposition, values, material treated, service offered, etc.	Qualitative	[1]		[5],[6]
		Involvement of district partners	Qualitative assessment of stakeholders who participate in the general business model and those who effectively participate in the organization's decision making	Qualitative	[1]	[8]	[5], [6]
		Information	Qualitative assessment of the availability, accuracy and timeliness of information exchanged with the stakeholders. It also accounts for the quality of information and the transparency of the sources	Qualitative			**
	Cost	By-products transportation costs	Costs generated by the transportation of the by-products in the district	Unity of currency		**	[6]
		Additional industrial symbiosis costs	Additional costs coming from buying by-products from symbiotic partners	Unity of currency			[6]
		Relationships maintenance	Cost of maintaining good quality relationships with the stakeholder of the district	Unity of currency		**	[6], [11]
	Incomes	Additional industrial symbiosis revenues	Additional revenues coming from selling by-products to symbiotic partners	Unity of currency			[6]

4.2 Selection of the right system

The investigated sample showed a good understanding of the SUST paradigm, albeit to different extents. Conversely, the understanding of CE and IS was overall quite poor. CE was mainly related to recycling and reusing material, whereas not all the respondents were familiar with IS (Firm B and C). The level of understanding of the paradigms varied among the interviewed firms:

- *Firm A*. The firm has a good knowledge of the SUST paradigm, and the interviewee referred several times to inter-generational justice: "*we embrace the concept of a broader SUST, which means guaranteeing the next generations the same availability of resources we had. This classical concept […] is reflected well in our activities: we have a SUST department, and long-, medium- and short- term objectives*". The respondent also stressed the need for "*a proper legislative infrastructure to enable the implementation of SUST before one can start talking about measurement*", underlying that individual firms' initiatives alone might not be enough to achieve the ecological and ethical transition. However, they also pinpointed the difficulty of involving the SC in its performance measurement, although "*it is more correct to think to what happens outside the firm as well*". As for CE and IS, the respondent perceived a strong overlap "*I consider them the same thing but from different viewpoints, an economic one for CE and an industrial one for IS*". The respondent underlined strong synergies among the three paradigms: "*for a firm to be sustainable, it is mandatory to pass from CE and IS, and vice-versa […] I cannot see three separate concepts, because the firm is one. I think separating the concepts may create confusion inside the firm and measuring three performances is a lot harder*". Considering the above and the firm's characteristics (Table 4), Firm A was presented with the full system.
- *Firm B*. The firms focused on SUST in terms of efficiency in resources use and waste reduction with an attention to social aspects, beyond the legal requirements: "*it is not just about being compliant with legislation. We seek to go beyond […], We obtained environmental certifications, and we are in the process of obtaining social and safety ones. We sustain our community by sponsoring the local football team, the local book fair, making available internships and work opportunities for the local people and we have programs to improve our employees' well-being*." (CEO). Firm B intended CE as a closed-production loop, by "*using scraps as raw materials*" (CEO), while a full awareness as for IS did not emerge. Considering the relationships among paradigms, the firm underlined that "*CE is one of the streams of SUST*" (CEO) and affirmed that fostering CE could help achieve SUST. Difficulties in implementing a collaborative approach within the district were underlined, with most of the interactions being "*destructive or competitive*" (CEO); although recognizing this approach "*is wrong and it slows down innovation*", they added "*it is how it works nowadays*" (Quality, safety and environment manager). Considering the above and the firm's characteristics (Table 4), Firm B was presented with the full system.
- *Firm C*. For Firm C being sustainable means to "*be less invasive as possible both in terms of occupied area and resources use, and control of water and energy consume and impact on the community*". CE is intended as "*using and reusing materials as long as possible and minimize the final waste*", and Firm C implemented some practices at the intersection of CE and IS, sending back to the supplier production scraps – dust and little pieces of material, and the supplier then sells Firm C the re-processed scraps at a convenient price. However, it emerged that the practice is more a "*gentlemen's agreement*" rather than a structured practice. The respondent showed an interesting understanding of possible synergies among paradigms: "*I think the synergies can be defined as a single word: rationality. If we apply all paradigms, we will reach a certain rationality in the use of materials and resources, that will provide benefits*." Considering the above and the firm's characteristics (Table 4), Firm C was presented with the full system.

- *Firm D*. The firm considers SUST as a journey, during which "*everyone has a responsibility towards the world and must balance economic, environmental and social aspects*." As for CE, Firm D focused on aspects such as the "*usage and creation goods that can be recycled or reused*", while was not aware of the IS paradigm. Firm D operates in a small district, quite lagging as for ecological and ethical solutions implemented, although Firm D stressed the responsibility of firms to reduce their impact. Considering the above and the firm's characteristics (Table 4), Firm D was presented with the core system.

4.3 Validation of the framework

According to the sampled firms, the framework covers all the main aspects of the three paradigms, highlighting their synergies. The framework was appreciated for its ability to make the nuances of the three concepts understandable and manageable by the industrial-decision maker, without too much hassle in selecting specific indicators related to one paradigm or the other one.

4.3.1 Full system

The firms agreed on the representation capacity of the Full system. Firm C especially underlined that, covering the three concepts, the system allows better grasping the synergies among them, while including "*everything that is relevant*". Firm B appreciated the structure of the system, stating it would help them defining goals. Firm B perceived few overlaps among the proposed indicators, but still recognized that "*summarising is not easy and* [the system] *is a great job of simplification*" and that the need for monitoring performance related to the three paradigms calls for the presence of slightly overlapped indicators.
As for the ease of use, the system received overall positive judgments. Firm C and Firm A underlined that the system would have been even easier to employ if fewer indicators were included. Specifically, Firm A stated that "*for a framework aiming at providing direction on a daily basis to SMEs, the number of indicators should be reduced*". The comment is of extreme interest: although the interviewee mentioned only SMEs, it underlines also larger firms may face difficulties in handling the amount of information entailed in the full system, making the core one suitable to increase the tool operativity.
Concerning usefulness, the system was judged positively as it allows understanding synergies among the paradigms at different levels of application. Specifically, Firm B stated they "*are not structured and the system can help in defining goals, also considering that they are not currently using indicators*".
Table 7 reports the judgment provided according to the three axes of evaluation.

Table 7. Validation of the system as provided by the interviewees. Scores are based on a 4-point Likert scale.

Firm	Capacity of representation	Ease of use	Usefulness
A	3	4	4
B	3	3	3
C	4	3	4

Focusing on the proposed indicators, firms confirmed they cover the main aspects of SUST, CE, and IS. Most of the indicators resulted of extreme interest for the sampled firms and already considered for the evaluation of performance. This is the case, for example, of "reuse of raw materials or products"; "reduced energy consumption"; "reduced waste and toxic emissions"; and their economic corresponding. Notably, the economic assessment still plays a major role in shaping firms' decision making, and the measurement of other indicators is mainly due to legislative requirements, as safety-related ones. SUST indicators resulted generally more adopted, while indicators pertaining more to CE and IS appeared, respectively, less and not adopted. As for CE, some indicators (e.g. "manufacturing waste management", "mindset – cultural change", "dematerialization possibility")

were identified as too broad and therefore difficult to compute, albeit interesting; others (e.g. "bill of material") were deemed difficult to apply at the SC level, since the quantity of information is considerable.
Some indicators were not currently evaluated but considered of relevance, especially for exploring the adoption of the three paradigms beyond the firm's boundaries; an example is "product longevity", for which however a strong collaboration with SC partners is however advisable.
Specific indicators were also considered as missing. As proof, Firm A emphasised the lack of "product innovativeness"; yet, the perspective might be influenced by the characteristics of Firm A, as large firms tend to have more structured and functioning innovation processes, with more formalized partners evaluation (Chiambaretto et al., 2020). Firm A was indeed the most advanced in terms of knowledge and adoption of indicators.

4.3.2 Core system

The capacity to represent was considered optimal. Indeed, despite some "*overlaps due to the overlaps of the concepts* [...] *indicators are overall distinct*". The ease of use was also judged positively. Firm D yet stressed that SMEs – as itself - might have more difficulties in implementing the system, because of the lack of resources to allocate to performance measurement. The system resulted useful as it allows for the identification of synergies among the paradigms and the different levels of application. Overall, the system was considered clear and possible difficulties attributed to the complexity of the topic addressed.
Table 8 shows the judgment provided according to the three axes of evaluation.

Table 8. Validation of the system as provided by the interviewees. Scores are based on a 4-point Likert scale

Firm	Capacity of representation	Ease of use	Usefulness
D	4	4	3

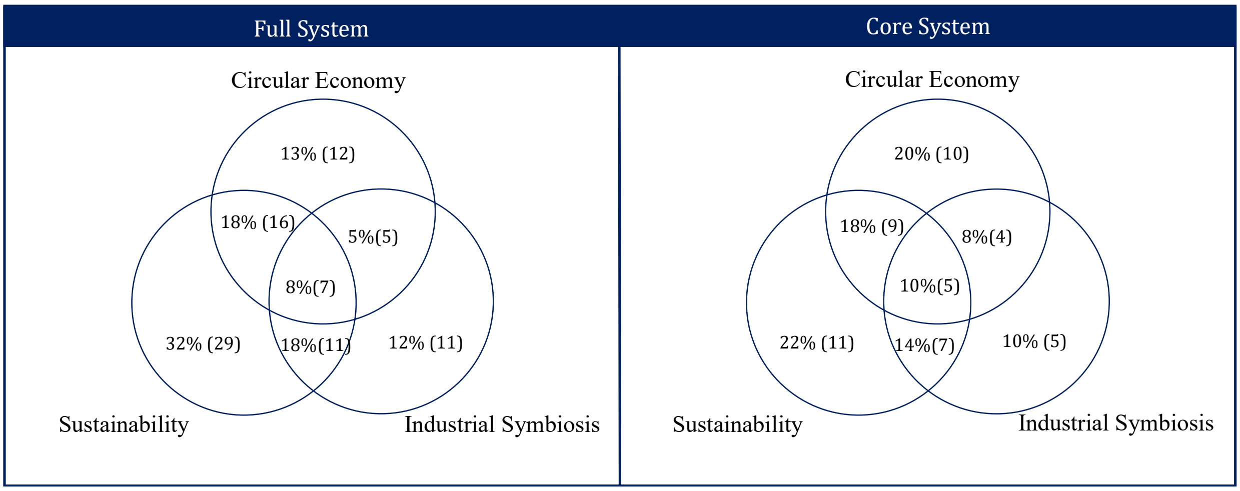
Concerning the indicators per se, their completeness and clarity were appreciated. Firm D mainly measures indicators exclusively on the micro level and related to cost and waste, or to legislative obligations, such as "hazardous waste" or "toxic emissions", while specific CE and IS indicators emerged as lagging. The reason is twofold. On the one hand, the firm has never implemented any practice related to these paradigms and thus has not been interested in monitoring the related performance. On the other hand, the firm finds it hard to appreciate the applicability of some indicators to its specific sector: for instance, "refurbishment" was reported to make little sense for the marble industry in which the firm operates. Yet, the process of repairing and cleaning products (i.e. refurbishment) to make them as new may be applied to this sector too, and this may be a more ecological alternative to simply substituting the product once deteriorated (Ellen MacArthur Foundation, 2022). In line with previous literature, firms tend to apply only few practices and mostly related to recycling products (García-Quevedo et al., 2020), which translates in a narrower selection of performance indicators. The presented framework could be used to expand the vision of firms, SCs and districts to advance their SUST, CE and IS thinking. This once again demonstrates the importance of having a scalable framework.

5 Discussion

The integrated, multi-level and scalable framework being proposed is of great relevance in advancing the academic and managerial debates related to the ecological and ethical transition, particularly on the integration of SUST, CE and IS (Salomone et al., 2020) and the related performance measurement (Maranesi and De Giovanni, 2020). Indeed, the presence of different paradigms to engage in the transition, as well as the lack of adequate performance measurement frameworks, has prevented firms from engaging in important changes (Kumar et al., 2019; Trianni et al., 2019).

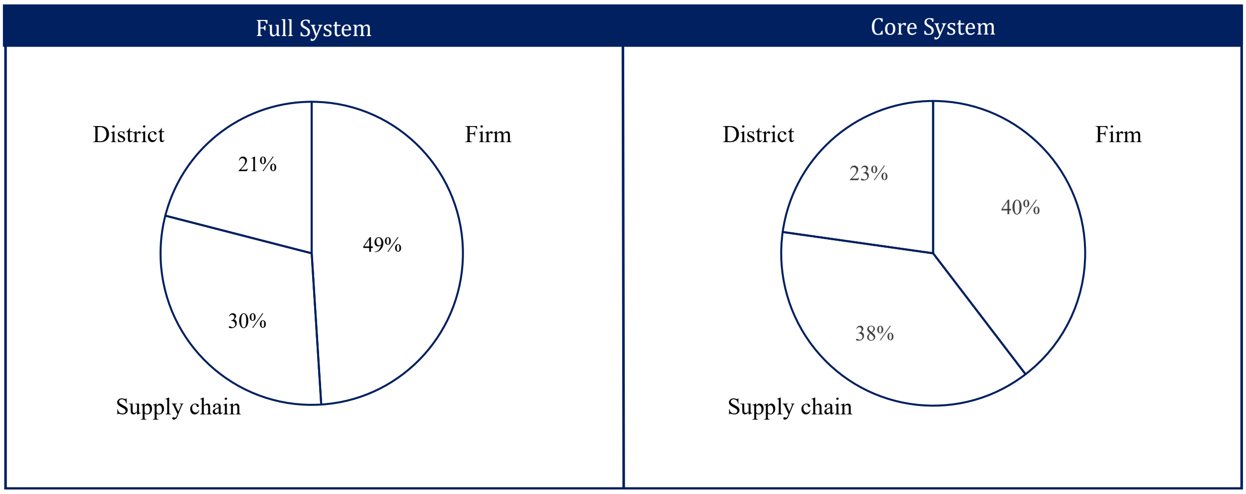
The extant literature lacked an integrated framework that includes all relevant paradigms for the ecological and ethical transition. We proposed a framework that covers three of the most relevant paradigms in the recent literature, namely SUST, CE and IS.
The division of indicators according to their coverage of the SUST, CE and IS paradigms is reported in Figure 2. Such division is obtained considering how each indicator covers the three paradigms, as reported in Table 6. As it emerges, some indicators cover only one paradigm, several cover two paradigms, and a good number of them cover all three. For instance, “scrap” measures both SUST and IS performance (Cagno et al., 2019; Feil et al., 2019); “reduction of raw material” measures both CE and SUST performance (Cagno et al., 2019; Howard et al., 2019; Rossi et al., 2020); “job creation”, “mindset/cultural change”, “supply cost” refer to all three paradigms (Cagno et al., 2019; Rossi et al., 2020; Valenzuela-Venegas et al., 2016). Moving from the Full to the Core system, it can be noted that the share of indicators covering two or three paradigms increases, while the indicators measuring only one paradigm decrease in number. This reflects the methodology with which the framework – and, in particular, the Core system - was built, as indicators covering more paradigms were preferred over more specific ones. This indeed may help firms focus on the most important aspects of the ecological and ethical transition at first, leaving room for deepening more specific aspects on single paradigms with specific indicators once their awareness, skills or resources increase.

Figure 2. Balance among the paradigms



The extant literature lacked a PMS entailing multiple levels of analysis and thus appropriate to be implemented at different levels of application (Negri et al., 2021b). The proposed framework demonstrated the capability to encourage firms to think beyond their boundaries and start considering the performance of the SC or district in which they operate. This attitude could be extremely useful to foster collaborative approaches to engage in the ecological and ethical transition (Tuni et al., 2020), possibly helping in overcoming the significant barriers in the evaluation of performance along the SC (Maestrini et al., 2017). As the influence of SCs and districts on the firm’s performance cannot be overlooked (Fehrer and Wieland, 2021), this framework provides a way to systematize information related to different levels, to ultimately improve the overall industrial system. Keeping micro and meso level indicators together is interesting also to re-align global and local challenges. For instance, the measurement of CO_2 emissions may be local but the problem should be solved at global level; or again, the enhanced circularity of a SC may create job opportunities at the local level (Kristensen and Mosgaard, 2020). The division of the proposed framework indicators into the levels of application is reported in Figure 3, and it is based on the information provided in Table 5. Both the Full and the Core systems show an overall equal distribution between the micro (i.e. firm) and the meso (i.e. district and SC) levels in terms of numerosity of indicators. Considering the three levels separated, i.e. firm, supply chain and district, the indicators related to the single firms appear to be higher in number. This reflects the fact that the decisions are often taken internally to the firm, and firms find it easier to monitor indicators that relate to their own performance (Kristensen and Mosgaard, 2020). Yet, the share of firm level indicators is reduced moving from the Full to the Core system, again underlying how the Core system is focusing on those indicators that can maximize the overall information from all the considered perspectives.

Figure 3. Balance among the levels of the framework



The scalability of the framework allows it to be tailored according to firms' contextual factors and levels of awareness, while keeping a common structure for the two developed systems, as strongly recommended by previous literature (Arena and Azzone, 2012; Negri et al., 2021b). By making the framework scalable, we provide guidance on the measurement process in an adaptable way, responding to important needs highlighted by previous contributions (Singh et al., 2016). Furthermore, the proposed framework allows SMEs and firms with limited awareness of the ecological and ethical transition (Negri et al., 2021b) to gain knowledge and expand their performance measurement habits, while also better understanding and comprehending the possible relationships among the three paradigms. For instance, Prieto-Sandoval et al. (2018) and Rizos et al. (2016) underlined how the exploration of IS paradigm could help SMEs in being more circular, thanks to a system change that SUST might not stress enough. In confirmation of this, the CEO from Firm B stated that "firms in this district do not have constructive interactions but destructive ones, although we all know that this slows downs the innovation process", highlighting that a more symbiotic relationship could foster the adoption of innovative practices.

Interestingly, the Chief environment and energy officer of Firm A mentioned that the number of indicators of the Full system may be excessive to allow for an efficient use of this tool in SMEs. This empirically confirmed that a scalable framework is necessary to adapt to the different needs of firms (Bititci et al., 2015), whether these necessities are due to daily and operative requirements or necessities linked to awareness or availability of resources to perform a measurement of performance (García-Quevedo et al., 2020). Although from this standpoint the Core system provides an interesting solution, further efforts could be dedicated in further elaborations to streamline the number of indicators even more, perhaps providing a third system (Cagno et al., 2019).

The proposed framework thus responds to several needs pointed out by the previous literature. First, it is an adequate tool to measure the performance related to the ecological and ethical transition in an integrated manner (Domenech et al., 2019), and can properly support the industrial decision-makers (Taticchi et al., 2015). Second, the framework demonstrated its capability to enable a proper monitoring of relevant SUST, CE and IS performance by means of an integrated assessment, fostering the exploitation of synergies among paradigms (Morales and Belmonte-Urena, 2021), yet permitting a distinction among the specific nuances of each paradigm (Salomone et al., 2020). The relevance of such a tool emerged also from the empirical validation, with respondents stating that the "framework is complete and allows to comprehensively measure our performance" and that the firms "do not distinguish among the paradigms, it would be impossible" (Chief environment and energy officer, Firm A). Overall, having one unique system to measure the performance, firms showed to better understand the synergies and overlaps among the paradigms.

Despite the overall positive feedbacks received on the framework, some issues emerged as well from the empirical confrontation with firms. These issues were carefully considered, as they offer the possibility to further discuss and reason on the applicability of the proposed framework, paving the way for possible future developments.

Although appreciating the general structure, Firm A's Chief environment and energy officer raised the attention to the lack of indicators related to innovation. This can be explained by the fact that Firm A is a large and very innovative player in its reference market, and thus it pays particular attention to the theme. The other firms, instead, did not put as much emphasis on innovation indicators. Furthermore, this information is included in two different indicators present in the framework, namely the process cycle time (Neri et al., 2021a), and R&D investment (Feil et al., 2019). The issue was arisen only by one firm in the sample, which led us conclude that the information grasped by the two indicators present in the framework are sufficient. However, additional tailoring of the indicators can be considered for specific needs, considering for example also the increasing relevance of digital innovation strategy in the current industrial scenario (Kumar et al., 2022). On the other way round, Firm D considered some of the indicators included in the systems not relevant for its sector. As proof, the interviewee mentioned "reuse product" as not applicable, claiming that marble products are not really reused. Also in this case, additional tailoring of the indicators can be considered for specific needs, and the scalable structure of the framework makes the procedure relatively easy. However, as for the specific indicator mentioned by Firm B, it is our opinion that also basic materials could live a second life, if a proper reuse market were in place and incentivised. From this line, the issue seems to be more related to the awareness of the firms with reference to the ecological and ethical transition, rather than to the specific indicator itself.

Indeed, the firms' awareness towards performance measurement is another factor strongly influencing the framework validation. Interestingly to note, Firm B was the only one assigning a score of 3 out of 4 to all the axes of analysis considered, namely capacity of representation, ease of use and completeness. Interestingly, Firm B' Quality, safety and environment manager stated they do not measure any indicator, as it would be a "waste of money". Such an attitude might be highly problematic for an effective measurement and improvement of performance, limiting the understanding and interest in the process (Trianni et al. 2019).

Another issue arose as for the actual possible measurement of the indicators is related to the SC and industrial district levels, above all if compared to the indicators at a firm's level. Such a situation was expected, as firms generally find it easier to measure their internal performance rather than those related to the industrial system in which they operate (Kristensen and Mosgaard, 2020). Nonetheless, the value of expanding the scope of measurement was valued by all interviewees, and intended as an interesting and important step towards this direction. Surely, additional efforts should be dedicated in understanding how to foster the measurement of performance beyond the boundaries of the single firm.

6 Conclusions

This study provides several contributions. On the practical side, practitioners are provided with a novel integrated, multi-level and scalable framework to measure their performance, which can boost the adoption of SUST, CE and IS practices in an integrated manner, strongly advancing the ecological and ethical transition. The framework resulted useful for industrial firms and industrial decision-makers, as it summarizes in a structured manner the indicators needed to monitor to track progress and undertake possible corrective actions. The framework was designed to be easily understandable, which reduces frictions and encourages firms to measure their SUST, CE ad IS related performance.

In addition, the framework supports firms to look outside their boundaries, monitoring their SC or their district's performance as well. This will provide additional information for decision making and, once again, to foster the ecological and ethical transition in the SCs and the districts. Finally, this framework provides guidance for firms with limited skills or awareness on the three paradigms, adapting then to their changing needs.
On the theoretical side, this paper contributes to the discussion on the three paradigms of SUST, CE and IS. Indeed, synergies are indirectly highlighted by selecting similar indicators. This study could represent an initial step towards a more exhaustive elaboration on the synergies among SUST, CE and IS.
Despite the contributions brought by the novel framework, it is not exempt from caveats which nonetheless offer great opportunities for future research. The framework was validated in four manufacturing firms, and future resources are encouraged to enlarge the sample also to possibly refine the framework. Indeed, as emerged from the empirical validation, the framework could still be too complex for firms with limited resources or awareness. Future developments are encouraged to better understand how to adapt the framework to specific situations.
We encourage future streams of research to further explore the synergies among SUST, CE and IS paradigms, from both a theoretical and an empirical perspective. Additionally, we suggest the collection of empirical evidence on the measurement of performance through the proposed framework, ideally involving SCs and districts, by adopting a long-term perspective.

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Appendix A – Empirical validation protocol

This section contains the protocol used for the empirical analysis. The protocol contains both the structure of the interview questions, which constitute the primary data collection method, and the secondary data collected.

Primary data	**Source of evidence 1: semi-structured interview**	
	General questions	Interviewee's introduction: role within the firm, work experience, background, interests
		Firm's description: number of employees, turnover, sector, certifications
	Products and processes	What products do you produce?
		What production process activities do you perform?
	Supply chain	How do you position the firm in the supply chain? How much do you care about the ethic and environmental values of your stakeholders?
	District	How would you describe your role within the district and the community? (How is the relation with other near companies? Are you involved in community projects?)
	Sustainability	What is your definition of sustainability?
		To stimulate discussion: do you think is important to look outside firm's boundary to measure the real impact of the firm?
		How do you think a firm can develop a systemic sustainability?
		How do you measure your sustainability performance?
	Circular economy	What is your definition of circular economy?
		Do you think circular practices can help to achieve industrial sustainability? Which practices did you adopt towards circularity?
		How do you measure circular performance?
	Industrial symbiosis	What is your definition of industrial symbiosis?
		What do you think of industrial symbiosis as a tool to fulfil circular economy and sustainability objectives?
		Did you adopt any actions/intervention towards industrial symbiosis? If yes, how do you measure the performance?
	Referring to the proposed framework, after explanation	
	Capacity of representation	Do you think the proposed framework represents all the relevant indicators for an ethical and ecological transition? Do you think the concepts of sustainability, CE and IS are well represented?
		Are the indicators clear and distinct?
		On a scale from 1 to 4, how would you rate its capacity of representation?
	Easiness of use	Do you think it would be easy for you to apply the proposed set?
		Would the proposed framework be worth the effort of being adopted?
		On a scale from 1 to 4, how would you rate its easiness of use?
	Usefulness	Could the framework help you in identifying new indicators?
		Could the framework lead you to better reorganize your indicators?
		Does the framework
		On a scale from 1 to 4, how would you rate its usefulness?
	Features	What are the features you appreciated the most? Which less?
	Additional comments	Are there any other comments and opinions you would like to share about the proposed framework? If yes, what?
	Source of evidence 2: direct observations	
	Plant tour (if applicable)	Direct observation of the production plant during working hours, with the possibility to contextually ask additional questions to interviewees.
	Source of evidence 3: field notes	
	Taken during the interview	Field notes collected during the conduction of the semi structured interviews and questionnaire (descriptive and reflective)
	Taken during plant tour (if applicable)	Field notes collected during the production plant tour (descriptive and reflective)
Secondary data	**Source of evidence 4: secondary materials**	
	Firm website	General firm information; firm attention to CE; sustainability report; description of interventions; description of products and technologies
	Online newspapers	News related to the firm, especially referred to circular economy and activities within the district as sustainability
	National database	Economic reports and balance sheets