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Improving environmental sustainability in agri-food supply chains: Evidence from an eco-intensity-based method application

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ABSTRACT

Focal companies in food supply chains face increasing pressure to produce food sustainably and lower the environmental impact across their supply chain (SC). Although governance mechanisms to manage suppliers and sub-suppliers have been established, focal companies in the food sector still lack effective tools to capture the actual environmental sustainability performance of their multi-tier SCs, which could support them to decrease the environmental impact associated to their products.

This work thus aims to showcase how assessing the environmental sustainability performance of a multi-tier food SC made up by SMEs can support decisions in order to drive evidence-based green improvements in the SC operations. A low-input eco-intensity-based multicriteria performance assessment method was applied to a bread SC, adopting a longitudinal case study design, to evaluate its applicability for decision-making in an operating context.

Following the identification of environmental hotspots along the SC, targeted green operational improvements were implemented within individual organisations, resulting in a decrease of the eco-intensity values both at the targeted SC tiers and at the overall SC level. These results demonstrated that the method was able to support the improvement of the SC environmental performance.

This work is the first longitudinal study in the multi-tier green supply chain management (GSCM) area. It contributes to the multi-tier food GSCM and GSCM performance assessment fields by demonstrating how the integration of environmental sustainability performance assessment methods and SC governance mechanisms can effectively support across time the deployment of GSCM within food SCs, while adopting an indirect SC management approach. Finally, the application of the method within a supply chain consisting of SMEs, inexperienced in sustainability assessment, demonstrates its potential to achieve SC-wide sustainability assessment and contributes to the wider GSCM field by providing insights on the implementation of GSCM in supply chains dominated by SMEs.

1. Introduction

Organisations face increasing pressure from stakeholders to include environmental considerations within their supply chain (Grimm et al., 2018). Focal companies, having a prominent role within the supply chain (SC) by providing the contacts with the final customers or designing the final product offered to the market (Seuring and Müller, 2008), are particularly under scrutiny by customers, who consider them liable for environmentally unsustainable behaviours within their SC (Hartmann and Moeller, 2014). Therefore, focal companies increasingly recognise the need for a multi-tier green supply chain management (GSCM) approach, realising the contribution of both suppliers and sub-suppliers to the overall environmental SC performance (Grimm et al., 2016).

Suppliers and sub-suppliers in the majority of SCs are small-and-medium enterprises (Tachizawa and Wong, 2014), which are more prone to lack resources to dedicate to sustainability and adequate environmental capabilities (Bourlakis et al., 2014; Lee and Klassen, 2008). 76 % of European organisations are small-and-medium enterprises (SMEs), which cumulatively account for 40–70 % of

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environmental impacts in the continent (Lee et al., 2012) and a holistic approach to multi-tier GSCM cannot exclude SMEs to broaden the understanding of GSCM and to obtain effective benefits for the environment (Shibin et al., 2020). Nevertheless, research on multi-tier GSCM addressing SMEs has been limited (Shibin et al., 2020). Existing research has either focused on the pre-determinants of GSCM for SMEs, including barriers (Mathiyazhagan et al., 2013), drivers (Lee, 2008; Lee and Klassen, 2008) and enablers (Lee and Klassen, 2008) or on the role of SMEs within SCs managed by larger focal companies (Ayuso et al., 2013), without advancing on SMEs-dedicated multi-tier GSCM approaches.

Food SCs are no exception, both in terms of SMEs' presence and in terms of their positioning within the SC. Food SCs "significantly depend on SMEs" and SMEs represent the majority of organisations within food SCs (Ali et al., 2017), calling for a multi-tier GSCM approach. Several focal companies in the industry have been stigmatised for being associated with environmentally unsustainable practices of their sub-suppliers leading to reputation damage (Dou et al., 2017). Additionally, customers show a high green awareness compared to other sectors (Beske et al., 2014), demanding sustainable food with a traceable origin (Bourlakis et al., 2014) and a low environmental impact across the entire SC (Wilhelm et al., 2016b). Furthermore, it is necessary to consider also farming and primary sector activities in the environmental assessment of food production in order to accurately assess the SC environmental performance and make an impact regarding environmental sustainability (Mena et al., 2013; Wilhelm et al., 2016a). In particular, agricultural operations alone account for 10.3 % of EU's GHG emissions (European Environment Agency, 2019) and threaten the natural capital in terms of loss of bio-diversity, land degradation and intensive water consumption (Wognum et al., 2011).

This call for a multi-tier GSCM approach within food SCs has been recently recognised, with multiple scholars looking into approaches that focal firms can adopt to manage lower-tier suppliers within food SCs (Grimm et al., 2016; Mena et al., 2013; Wilhelm et al., 2016b), including "direct", "indirect" and "work with third party" multi-tier GSCM approaches (Tachizawa and Wong, 2014). The role of 1st tier suppliers in disseminating the environmental sustainability requirements of the focal company in the upstream SC was also investigated (Wilhelm et al., 2016a). From the perspective of focal firms, this has been transposed in a renewed environmental sustainability SC leadership role (Jia et al., 2018), requiring an orchestration of environmental sustainability learning in multi-tier food SCs (Gong et al., 2018a; Gong et al., 2018b) and the identification of critical success factors for sub-suppliers' compliance with corporate sustainability standards (Grimm et al., 2018, 2014). This evolving stream of the literature captured the governance mechanisms to manage multi-tier GSCM food SCs; however, it has not specified how focal firms can adequately capture actions from lower-tier suppliers and assess their environmental sustainability performance in order to drive environmental sustainability-oriented improvements across their SCs (Villena and Gioia, 2018). The feedback loops emerging from lower-tier suppliers' actions can only be re-assessed over time, calling for the adoption of longitudinal research designs to capture the outcome of such actions in a dynamic context (Villena and Gioia, 2018).

Another stream of research tried to cover the need for more practice-oriented tools for food SC environmental performance assessment by developing a variety of frameworks, adopting various metrics, such as food miles and footprint indicators (Yakovleva et al., 2012) or developing case-specific indicators (Mintcheva, 2005). However, these frameworks took a snapshot perspective, lacking a demonstration of continuous implementation of environmental performance assessment methods (Gopal and Thakkar, 2012). As such, they failed to consider the time dimension to capture actions from organisations (Taticchi et al., 2014) and observe the sequential relationships of events, which is functional to gain in-depth insights (Luo et al., 2018). Alternatively, mathematical programming methods were also used to investigate how to simultaneously optimise economic and environmental objectives within the context of food SCs, either at the design stage (Allaoui et al., 2018) or at the operations stage (Mogale et al., 2020). However, both these approaches lacked in overcoming the trade-off between the range of environmental aspects and the extent of the SC considered, ultimately not adequately addressing the multi-tier dimension of most food SCs (Tuni et al., 2018).

On the contrary, life cycle assessment (LCA)-based methods have been able to assess the full lifecycle environmental performance of food products across their SC, with a plethora of products being investigated (Roy et al., 2009). However, LCA is typically inaccessible to SMEs due to resources constraint (Arzoumanidis et al., 2017) and suffers from three major drawbacks limiting its support for decision making. First, it typically limits the assessment with primary data to the focal company and adopts generic data for other organisations in the SC, thus not distinguishing between similar organisations and SCs with a similar design (Schöggl et al., 2016). Second, it assumes the existence of a central administration of the SC (Adhitya et al., 2011). Third, it adopts indicators that are usually different from those adopted for decision-making (Dong et al., 2018). LCA-based methods thus provide a high-level snapshot of the environmental performance of food products, but are unlikely to provide the focal company with sufficient information about suppliers and sub-suppliers without an appropriate supply chain management (SCM) orientation, thus limiting their support for decision making (Adhitya et al., 2011).

Therefore, a gap still exists in the multi-tier food SC literature. On the one hand, focal companies do not adequately capture the environmental sustainability performance of their multi-tier SC, and especially of lower-tier suppliers (Villena and Gioia, 2018), an aspect that is particularly critical in food SCs (Mena et al., 2013). On the other hand, within the GSCM performance assessment domain, a disconnection exists between the methods and indicators developed, and their actual implementation in reality for improved business decision making within multi-tier SCs, due to their limited integration with governance mechanisms (Ghadimi et al., 2019; Gong et al., 2018a; Gong et al., 2018b). Moreover, existing literature in the GSCM area did not adequately consider the time dimension to capture outcomes emerging from actions targeting environmental sustainability.

Based on the above, the following three research questions were formulated:

RQ1: Can an indirect multi-tier GSCM approach be applied to quantitatively assess the environmental sustainability performance of a multi-tier agri-food SC?

RQ2: Can an eco-intensity-based method be effectively applied by SMEs to assess the multi-tier SC environmental sustainability performance?

RQ3: How can an environmental sustainability performance assessment method be operationalised over time to guide green operational improvement in a multi-tier SC?

This work thus aims to showcase how assessing the environmental sustainability performance of a multi-tier food SC made up by SMEs, by using a low-input eco-intensity-based method, can support decisions in order to drive evidence-based green improvements in the SC operations. This is achieved by adopting a method based on a set of eco-intensity indicators that relate the environmental performance of the SC to its economic output in a weak sustainability perspective. The environmental sustainability performance assessment method, which is integrated with the indirect multi-tier SCM governance mechanism (Tachizawa and Wong, 2014), was applied to a multi-tier bread SC to evaluate its applicability for decision making in an operating context. A longitudinal case study served the purpose allowing to capture the feedbacks emerging from the assessment-action loops (Villena and Gioia, 2018) and the efficacy of the decisions on the resulting sustainability performance (Gong et al., 2018a; Gong et al., 2018b). The longitudinal case study is also functional to address the reported long-standing scarcity of longitudinal studies in the areas of SCM

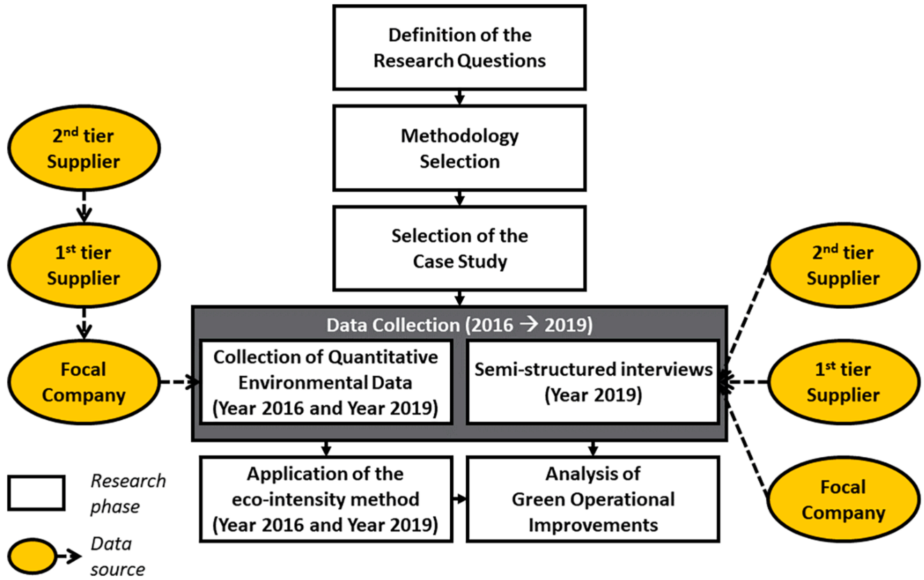

Fig. 1. Research Design.

performance assessment (Bititci et al., 2012), GSCM performance assessment (Carter and Rogers, 2008; Gopal and Thakkar, 2012; Taticchi et al., 2014), multi-tier GSCM (Villena and Gioia, 2018) and food SCs (Luo et al., 2018).

The remaining part of this paper is structured as follows. Section 2 exposes the research design, presents the environmental sustainability performance assessment method adopted in the case study and introduces the case study. Results are presented in Section 3. Finally, Section 4 discusses the contribution of this work against the relevant literature, while Section 5 concludes this paper and identifies directions for future research.

2. Materials and methods

This work presents an application of a quantitative multicriteria environmental sustainability performance assessment method in a multi-tier food SC through a longitudinal case study. Section 2.1 outlines the research design and methodology. Section 2.2 provides an overview of the method, which was applied to the case study, whose features are presented in Section 2.3.

2.1. Research design

The research design for this work, illustrated in Fig. 1, kicked-off with the definition of the research questions, outlined in Section 1, which informed the selection of the longitudinal case study methodology. Case study methodology was selected to evaluate the applicability of an environmental sustainability performance assessment method within SC operations in an operating context. Applicability is the relevance and appropriateness for the intended use (U.S. Environmental Protection Agency, 2009), which is, in this work, the extent the method is relevant and appropriate to assess the environmental performance of SCs and support decision-making.

Case study research is adopted in this work to empirically investigate a phenomenon within its real-life context (Genovese et al., 2013; Yin, 2003), that is, in this case, the environmental sustainability performance of a multi-tier food SC over a three-years timespan. A holistic single case study was selected in order to explore and showcase the applicability of an environmental sustainability performance assessment method in a specific and real situation (Genovese et al., 2013; Yin, 2003). The case study thus showcases the applicability of the method in an operating context using primary data sourced from actual practice and evaluates its potential to support decision-making within this context (Genovese et al., 2013; Yin, 2003). From a practical viewpoint, the case study is also functional to enhance the understanding of the usefulness of the results obtained in terms of environmental sustainability performance improvement for both the focal company and the other organisations part of the SC.

Longitudinal case studies are a particular type of case studies that enable accurate observation of changes occurring within a specific context, i.e. a supply chain, over time (Soundararajan and Brammer, 2018), by providing a "systematic way of observing the events, collecting data, analyzing information, and reporting the results" over a period of time (Silvestre, 2015). Longitudinal case studies allow "studying the same single case at two or more different points in time" and identifying how certain conditions, i.e. environmental performance, changed over time by identifying intervals at which such changes should reveal themselves (Yin, 2003). As such, longitudinal case studies, while not powerful enough to determine causal relationships, are tailored to observe the chronological order of events and the connection among them (Soundararajan and Brammer, 2018), that are, in this case, the green operational improvements introduced within the SC under observation and their impact on the eco-intensity indicators for longitudinal benchmarking purposes.

Food SCs are a major focus of sustainable SC research (Wilhelm et al., 2016a), yet the selection of the case study was guided by specific reasons. First, organisations part of the SC are SMEs, as Section 2.3 is going to further elaborate, which allows shedding light on the under-researched area of sustainable SCM implementation by SMEs (Ghadimi et al., 2019). Second, a long-established and stable relationship among SC companies exists, which, coupled with the open and trusting environment within the SC, represented a desirable feature to conduct a longitudinal case study (Grimm et al., 2014). Third, owing to the characteristics of the final product (bread), the selected SC allowed to cover within a three-tiers SC structure the whole SC, including the raw material production stage (Grimm et al., 2018, 2014; Mena et al., 2013), which is a highly relevant stage for food SCs (Grimm et al., 2016). The relatively simple design of the SC also allows to better track the assessment-action loops within the SC and to evaluate the support to decision-making and guidance towards green improvements offered by the method. Finally, all organisations along the SC show a strong sensitivity towards sustainability and a strong motivation to improve their environmental performance, thus ensuring committed support from the focal company as well as from its suppliers (Dou et al., 2017;

Grimm et al., 2014).

Data collection followed across a three-years timespan. While a constant communication was established between the researchers and the organisations within this timeframe, the bulk of the data collection took place in two separate moments, namely from September to December 2017, to collect environmental and economic data referring to year 2016, and from July to October 2020, to collect environmental and economic data referring to year 2019. A standardised spreadsheet for data collection was circulated among the organisations on both occasions. Furthermore, the second round of data collection was complemented by three semi-structured interviews with each of the owners of the organisations part of the SC, in order to capture qualitative information about the operational improvement introduced across the SC in the last three years as well as to evaluate the numerical results arising from the case study.

The quantitative environmental and economic data collected fed into the application of the environmental sustainability performance assessment method, which is illustrated in Section 2.2. The outputs emerging from the method, complemented by the information collected through the semi-structured interviews, provided the basis to analyse the green operational improvements implemented along the supply chain.

2.2. Overview of the environmental sustainability performance assessment method

The method adopted in the case study is based on an extended version of the method presented in Tuni and Rentizelas (2019), which aims to facilitate quantitative assessment of the environmental sustainability performance of multi-tier SCs, adopting a weak sustainability perspective. The social dimension of sustainability is outside the scope of this work. Five conceptual pillars model the environmental sustainability performance of the SC as well as its structure and dynamics:

- Eco-intensity: defined as the “environmental impact per unit of production value” (Huppes and Ishikawa, 2005), eco-intensity conceptualises the environmental sustainability performance, expressing the ‘use of nature’ divided by the economic benefit generated by an economic activity (European Environment Agency, 1999). Eco-intensity is thus a relative indicator, which better supports comparability of results and decision-making process compared to absolute indicators (Michelsen et al., 2006; Shokravi and Kurnia, 2014). Five environmental indicators are adopted at the numerator of the ratio: land occupation, water consumption, energy consumption, GHG emissions and solid waste. The denominator is the value of production, expressed in monetary units, which facilitates the application to any industry, irrespective of the physical properties of the products under analysis (Schaltegger et al., 2008). Moreover, the value of production is particularly suited for the SC environment as this data is not confidential and it does not undermine the competitive advantage of organisations (Brandenburg, 2015). Eco-intensity integrates the environmental and economic dimensions of sustainability in a single indicator, according to weak sustainability principles, which imply a perfect substitutability between the manufactured capital and the natural capital (Ukidwe and Bakshi, 2005).
- Cradle-to-gate and transformed resources system boundaries: the definition of the system boundaries is a necessary activity of any method as it determines the system of interest, which is modelled, and its surroundings, which are not modelled as part of the system (Oberkampf and Roy, 2010). The definition of system boundaries is also required to assess the performance of any system and to provide the comparability of results (Wiedmann et al., 2009). Two complementary approaches are used to define system boundaries. Cradle-to-gate approach defines the base boundaries of the SC, which includes all activities of the SC from raw material extraction (cradle) up to the point where the finished product leaves the organisation (gate) to reach the final customer (Nasir et al., 2017). The transformed resources approach defines the side boundaries of the SC, taking into consideration only “product-related suppliers” dealing with resources that will be treated, transformed or converted during the production processes and will be part of the final product (Kovács, 2008).
- Black-box approach: the definition of the level of granularity, i.e. the elementary sub-system into which the system is decomposed, is also required to conceptualise the system (Low et al., 2015). The independent and connected companies part of the SC are considered in this work as the elementary sub-systems (Koh et al., 2012; Mena et al., 2013). As such, each organisation is treated as a black box and the only aspect considered is the “global relationship between the inputs and the outputs of the system” both for the environmental and the economic dimensions (Oberkampf and Roy, 2010), thus requiring from each company a limited set of environmental and economic inputs and outputs. The black-box approach has been widely used in economic modelling (Sokolowski and Banks, 2010), as well as in the SC (Corsano and Montagna, 2011) and sustainability (Lozano, 2015) fields, owing to the reduced amount of information required, which can facilitate the applicability of models in operational contexts.
- Indirect multi-tier SCM approach: the pillar conceptualises how each company interfaces with its suppliers and sub-suppliers. As typical SCs are made by interconnected autonomous organisations (Mena et al., 2013), the relational dynamics of the SC are modelled according to the indirect approach (Tachizawa and Wong, 2014). This means that the focal company relies on 1st tier suppliers to establish contact with sub-suppliers (Meinlschmidt et al., 2018; Tachizawa and Wong, 2014), as the majority of focal companies do not have visibility of their SC beyond their 1st tier suppliers and lack control over their sub-suppliers (Grimm et al., 2014; Norris et al., 2021; Wilhelm et al., 2016a), calling for a decentralised approach where responsibilities are shared among different players (Jabbour et al., 2018) The indirect multi-tier SCM approach is formalised in the method into a bi-directional information-sharing mechanism (Tachizawa and Wong, 2014): focal firms require their 1st tier suppliers to convey the environmental requirements upstream to lower-tier suppliers (Tachizawa and Wong, 2014; Wilhelm and Villena, 2021); the requested data are then forwarded downstream to the focal company thanks to a recursive cascading mechanism (Schöggl et al., 2016).
- Transport: this work extends the method presented in Tuni and Rentizelas (2019), by including the environmental performance of the transport between SC tiers. Transported products are spatially transformed, but do not undergo any further physical transformation. Therefore, transport is not treated according to the black box approach as a separate tier within the SC, because no transformed resources enter the SC at the transport stage. Nevertheless, the environmental impact of the spatial transformation needs to be considered in a GSCM perspective (Azadi et al., 2015) and has to be incorporated within the method. This is conceptually modelled by the distance between the geographical locations of origin and destination in each dyadic transport link. Moreover, the key features of this spatial transformation, the mode of transport and the weight of goods moved, are also included, as the environmental impact of transport “depend on ton-miles and the mode of transportation” (Kannegiesser and Günther, 2013). Transport activities only impact two environmental categories, namely ‘Energy consumption’ and ‘GHG emissions’, in line with Harris et al. (2011). The environmental impact of transport activities is calculated using EcoTransIT online tool, which has already been used in the GSCM literature, as in Brandenburg (2015) and Tuni et al. (2020). EcoTransIT adopts factors per distance unit and weight unit to estimate the environmental impact of transport (EcoTransIT World Initiative, 2016). The indicators are calculated according to the tank-to-wheel option (TTW)

Table 1
Nomenclature.

Abbreviation	Meaning
e	Environmental indicator
EI	Eco-intensity
EI_{ei}	Eco-intensity with respect to environmental indicator e of organisation i
EI_{eik}	Eco-intensity with respect to environmental indicator e of organisation i associated to its output product k
EI_{ejk}	Eco-intensity with respect to environmental indicator e of supplier j associated to its contribution to the output product k of their customer i
EP	Environmental performance
EP_{ei}	Environmental performance with respect to environmental indicator e of organisation i
EP^{tr}_{ejik}	Environmental impact of transport from supplier j to customer i with respect to environmental indicator e associated to the output product k of the customer i
i	Customer of each dyad for each iteration of the recursive mechanism
j	Supplier of each dyad for each iteration of the recursive mechanism
k	Products offered from an organisation to its customer for each iteration of the recursive mechanism
T	Turnover
T_i	Turnover of organisation i
T_{ik}	Turnover of organisation i generated by product k
T_{ijk}	Turnover of supplier j generated by organisation i through the purchase of intermediate products for the output product k of customer i
tr	Transport

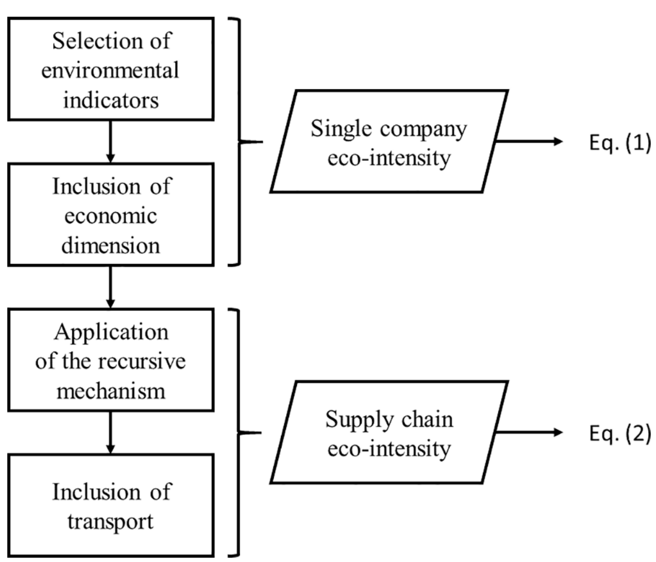

Fig. 2. Environmental sustainability performance assessment method flowchart.

for each dyadic transport activity along the SC, in accordance with the transformed resources system boundary adopted in this work.

The five conceptual pillars are transformed into mathematical formulations to calculate the outputs of the method, namely the eco-intensity results at the company level (Equation (1)) and at the SC level (Equation (2)). Calculations are performed according to an extended version of the mathematical model presented in Tuni and Rentizelas (2019), adopting a cascading assessment (Schöggl et al., 2016), which is materialised through a recursive mechanism, with the allocation of the environmental impact from the organisational level to the product level based on the economic output generated by each product (Tuni and Rentizelas, 2019). This is equal to the share of turnover generated by each product, obtained as the product of the quantities sold times their unitary price. The equations used to calculate the outputs follow the notation illustrated in Table 1. Equation (1) defines the eco-intensity EI of company i for the environmental indicator e, as the ratio of its absolute environmental performance EP_{ei} divided by the turnover of the company T_i. Equation (2) instead considers the SC contributions and defines the eco-intensity EI of company i including the environmental impact from the upstream supply chain of its product k for each environmental indicator e. This is achieved by summing three components: the internal absolute environmental performance EP_{ei} is allocated to the product k proportionally to the amount T_{ik} of turnover of company i generated by its product k compared to the organisational turnover T_i; the environmental impact of transport activities calculated as the sum of EP^{tr}_{ejik} from each supplier j to customer i with respect to environmental indicator e for the transport of intermediate products associated to the output product k; the environmental impact associated to the upstream supply chain, calculated by multiplying, for each supplier j, its eco-intensity EI_{ejk} with respect to environmental indicator e associated to its contribution to the output product k of the customer i with its turnover T_{ijk} generated by organisation i through the purchase of intermediate products for the output product k of customer i. The sum of these three terms is then divided by the amount of turnover T_{ik} of organisation i generated by the product k.

$$EI_{ei} = \frac{EP_{ei}}{T_i} \tag{1}$$

$$EI_{eik} = \frac{1}{T_{ik}}\left(\frac{T_{ik}}{T_i}EP_{ei} + \sum_j EP^{tr}_{ejik} + \sum_j EI_{ejk}T_{ijk}\right) \tag{2}$$

The method, comprising of the conceptual and mathematical model, is applied consistently with the method illustrated in Tuni and Rentizelas (2019), following the four steps depicted in Fig. 2:

1. Selection of the environmental indicators: indicators tackle both inputs withdrawn from the natural system and outputs released to the environment to achieve a balanced assessment of environmental performance.
2. Inclusion of economic dimension: the economic dimension of sustainability is used to relate the environmental performance to a single unit, in line with the concept of eco-intensity. The yearly turnover of an organisation is used as the single economic indicator. The first output of the method is calculated after this step. The single company eco-intensity for each environmental indicator defined at step 1, can be obtained at this stage.
3. Application of the recursive mechanism: the mechanism allows to move from the company level to the supply chain level, as each company adds the environmental performance and economic output of its upstream suppliers to its internal eco-intensity to calculate the cumulative environmental impact up to that point in the supply chain. Each organisation then forwards its eco-intensity information downstream to its customers until the system boundary is reached.
4. Inclusion of transport: the environmental impact associated to transport activities is added, allowing to calculate the second and main output of the method, which is the supply chain eco-intensity. A supply chain eco-intensity value is obtained for each environmental indicator defined at step 1.

2.3. Case study overview

The *Patto della Farina* SC is a collaborative regional SC operating in the 'Food products' industry according to the GICS classification scheme (MSCI, 2015) and the final product delivered to the customer is bread. The specific bread produced through the SC is identified to the final customer by the brand 'Pane del patto', which guarantees on its origin as well as on the traceability of the wheat used to produce bread and on the product transformation practices from the raw material stage

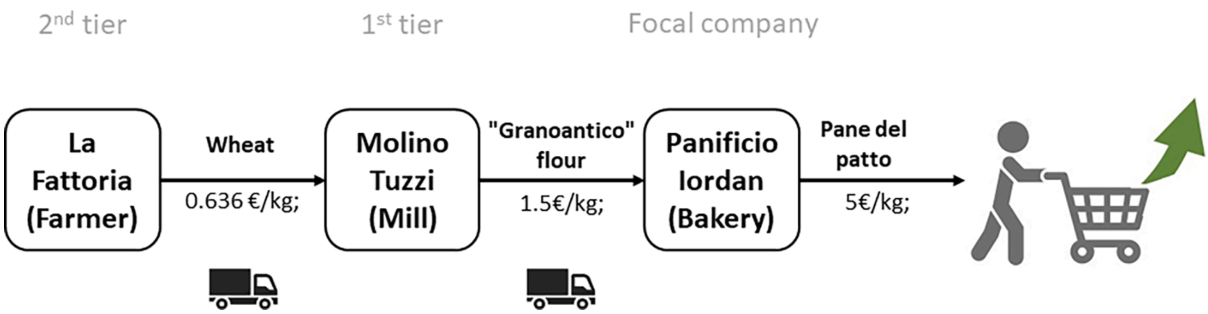

Fig. 3. "Patto della Farina" supply chain.

Table 2
Environmental and economic profile of the organisations.

Indicator		La Fattoria (LF) 2nd tier supplier			Molino Tuzzi (MT) 1st tier supplier			Panificio Iordan (PI) Focal company		
		2016	*2019*	Δ	*2016*	*2019*	Δ	*2016*	*2019*	Δ
Land occupation	[m^2]	805,000	870,000	8.07 %	368	368	0.00 %	204	204	0.00 %
Water consumption	[m^3/year]	42,000	39,375	−6.25 %	0	0	0.00 %	366	370	1.09 %
Energy consumption	[kWh/year]	79,687	46,667	−41.44 %	3,200	3,200	0.00 %	21,887	21,980	0.42 %
GHG emissions	[kg CO_2 e/year]	21,317	12,484	−41.44 %	3,418	3,109	−11.84 %	23,375	10,204	−55.77 %
Solid waste	[kg/year]	300	300	0.00 %	1,950	1,710	−12.31 %	3,465	2,421	−30.14 %
Turnover	[€/year]	98,000	83,000	−15.31 %	123,000	139,800	13.66 %	234,894	287,401	22.35 %
Supply chain share of turnover	[%]	1.9	1.9		2.9	2.1		6.0	4.2	
Contacted person		Owner			Owner			Owner		

Table 3
Single company eco-intensity indicators.

Eco-intensity indicators		La Fattoria (LF) 2nd tier supplier			Molino Tuzzi (MT) 1st tier supplier			Panificio Iordan (PI) Focal company		
		2016	*2019*	Δ	*2016*	*2019*	Δ	*2016*	*2019*	Δ
Land occupation	[m^2/€]	8.214	10.482	27.61 %	0.003	0.003	−12.02 %	0.001	0.001	−18.27 %
Water consumption	[m^3/€]	0.429	0.474	10.69 %	0.000	0.000	0.00 %	0.002	0.001	−17.38 %
Energy consumption	[kWh/€]	0.813	0.562	−30.85 %	0.026	0.023	−12.02 %	0.093	0.076	−17.92 %
GHG emissions	[kg CO_2 e/€]	0.218	0.150	−30.85 %	0.027	0.021	−22.43 %	0.098	0.036	−63.85 %
Solid waste	[kg/€]	0.003	0.004	18.07 %	0.016	0.012	−22.85 %	0.015	0.008	−42.90 %

throughout the final product.

Patto della Farina SC is a linear SC consisting of three tiers, as depicted in Fig. 3. The SC features a collaborative nature: organisations part of the SC have a transparent price policy with upstream and downstream organisations and are constantly sharing knowledge on best practices to improve the sustainability of the SC. The transportation between the SC tiers is made by truck. Although SC members have a strong motivation towards sustainability, this is the only viable transportation option due to the low volumes and short distances involved, as all products are locally sourced. Fig. 3 also includes additional information on the intermediate products that are shipped between SC members and the final product sold to the final customer, as well as on the price of such products.

According to the European Union enterprises classification, the focal company and the other organisations part of the SC could be defined as micro enterprises (European Union, 2003), as they employ fewer than 10 people and their annual turnover does not exceed EUR 2 million:

- Focal company: bakery 'Panificio Iordan'. The core business of the organisation is the production and distribution of bread, pastry and other bakery products. The bakery offers to the consumers (end users) the branded 'Pane del patto' bread, which is the final product under analysis.
- 1st tier supplier: mill 'Molino Tuzzi'. The mill transforms wheat purchased from farmers into flour and distributes it to several customers, including bakery 'Panificio Iordan'.
- 2nd tier supplier: farmer 'La Fattoria', producing wheat, which is the raw material necessary to produce bread and is delivered to the mill 'Molino Tuzzi'.

The key environmental and economic information on the organisations part of the SC are presented in Table 2. These are represented by five environmental indicators based on Tuni and Rentzelas (2019), which cover both environmental inputs withdrawn from natural capital as well as environmental outputs released to the environment. Energy consumption includes both electricity consumption and primary energy consumption due to fuel consumption, while GHG emissions captures scope 1 and scope 2 GHG emissions, which are converted to the common unit of measurement of kg CO2e. All figures are on a yearly basis and refer to years 2016 and 2019.

3. Results

The outputs obtained through the application of the method are presented in this section: the eco-intensity indicators at the company level (Section 3.1) and the eco-intensity indicators at the SC level (Section 3.2) Finally, Sections 3.3 and 3.4 discuss the value of such results, showcasing how the identification of environmental hotspots

Table 4
Supply chain eco-intensity indicators.

Product: "Pane del Patto" bread		Supply chain eco-intensity			Difference compared to the focal company eco-intensity without environmental backpack
		2016	2019	Δ	2019
Land occupation	[m^2/€]	1.090	1.390	27.56 %	195,759 %
Water consumption	[m^3/€]	0.058	0.064	9.96 %	4,883 %
Energy consumption	[kWh/€]	0.209	0.157	−24.99 %	105 %
GHG emissions	[kg CO_2 e/€]	0.134	0.061	−54.75 %	71 %
Solid waste	[kg/€]	0.019	0.012	−37.45 %	42 %

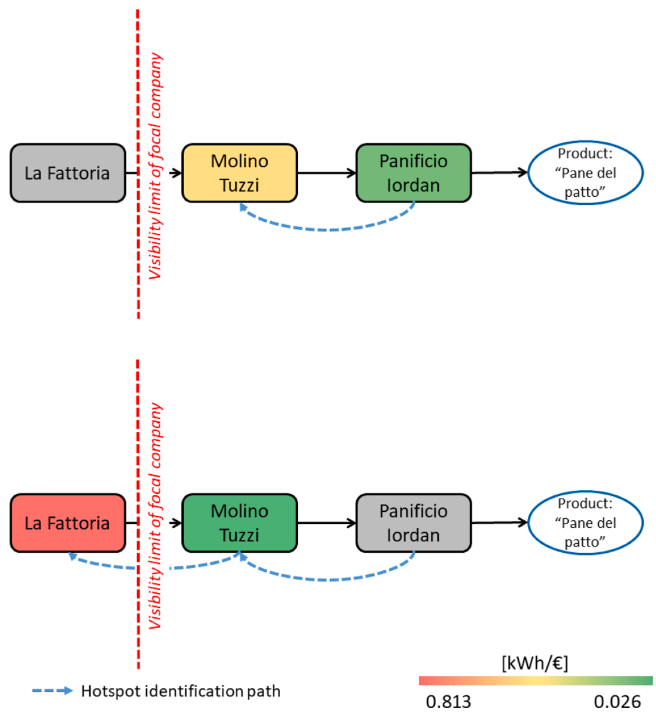

Fig. 4. Hotspot identification iterations for energy consumption eco-intensity: iteration at the focal company "Panificio Iordan" (a) and iteration at 1st tier supplier "Molino Tuzzi" (b).

through the method is functional to drive green operational improvement within the SC.

3.1. Single company eco-intensity

Although the investigated companies' core businesses differ, an initial analysis of the values presented in Table 3 demonstrates that the 2nd tier supplier 'La Fattoria' shows the worst eco-intensity indicator in four out of five environmental impact areas in both reported years, whereas the 1st tier supplier 'Molino Tuzzi' performs worst in the solid waste indicator. This finding demonstrates the need to adopt a multi-tier approach to assess the environmental performance of the SC, as a significant portion of the environmental impact would have been neglected if considering 1st tier supplier only, thus potentially underestimating the SC environmental impact. Despite the differences in the methodologies adopted and in the type of bread SC investigated, these findings confirm previous observations in the literature, which evidenced that the agricultural activities are responsible for the highest environmental impact within bread SC for both land occupation (Kulak et al., 2016, 2015) and GHG emissions (Câmara-Salim et al., 2020; Ingrao et al., 2018; Kulak et al., 2015). However, results using the eco-efficiency indicators show that energy consumption impact is primarily associated to the agricultural stage, whereas existing studies either associate energy consumption primarily to the focal companies' baking activities (Kulak et al., 2016) or offer a more balanced account among agricultural and baking activities (Notarnicola et al., 2017).

The results, calculated according to Eq. (1), also show an improvement of the eco-intensity performance in 2019 across all indicators for the focal company and the 1st tier supplier: this was achieved by either lowering or maintaining a stable absolute environmental impact (Table 2), while concurrently improving the economic performance. 2nd tier supplier 'La Fattoria' instead worsened its economic performance across time, which affected some eco-intensity indicators. 'La Fattoria' displays an improved eco-intensity performance only for energy consumption and GHG emissions, as its absolute environmental impact in these categories decreased more than proportionally than the turnover. Vice versa, the other three eco-intensity indicators show worse performance in 2019 compared to 2016, as its absolute environmental performance increased (land occupation), remained constant (solid waste) or decreased less than proportionally compared to the turnover (water consumption).

3.2. Supply chain eco-intensity

The supply chain results, calculated according to Eq. (2), represent the eco-intensity of the multi-tier SC with respect to each environmental impact and are the main output of the assessment of the SC environmental performance (Table 4). The SC results show an improvement of the environmental performance in three out of five environmental indicators, namely energy consumption, GHG emissions and solid waste, as eco-intensity values of these categories dropped from 2016 to 2019. On the other hand, land occupation and water consumption eco-intensity indicators have worsened across the three-years' time-span, largely as a consequence of the worse performance of 2nd tier supplier 'La Fattoria', as displayed in Table 3, and its effect on the SC performance.

Finally, the last column of the table points out the difference between the eco-intensity values at the SC level compared to the focal company eco-intensity values when omitting the environmental impact from the SC, i.e. the environmental backpack, for the year 2019. The values demonstrate that the eco-intensity would be significantly underestimated had the SC not been considered, potentially misleading decision-makers in the focal company on the environmental impact areas that are critical to tackle. The difference between the values appears particularly relevant due to the highest environmental impact being located at the 2nd tier supplier for four out of five environmental categories. The most significant variation is observed for the land occupation eco-intensity indicator due to the impact of the agricultural activities of 2nd tier supplier 'La Fattoria'. Vice versa, the impact is less significant in the solid waste eco-intensity indicator, due to the significant contribution of the focal company to this indicator.

3.3. Hotspot identification

The analysis of the values of eco-intensity allows identifying the hotspots along the SC, which is functional to plan targeted green operational improvement actions. The hotspot identification works following bilateral data exchanges, which are the common practice in multi-tier SCs, where focal companies rarely have the direct visibility of

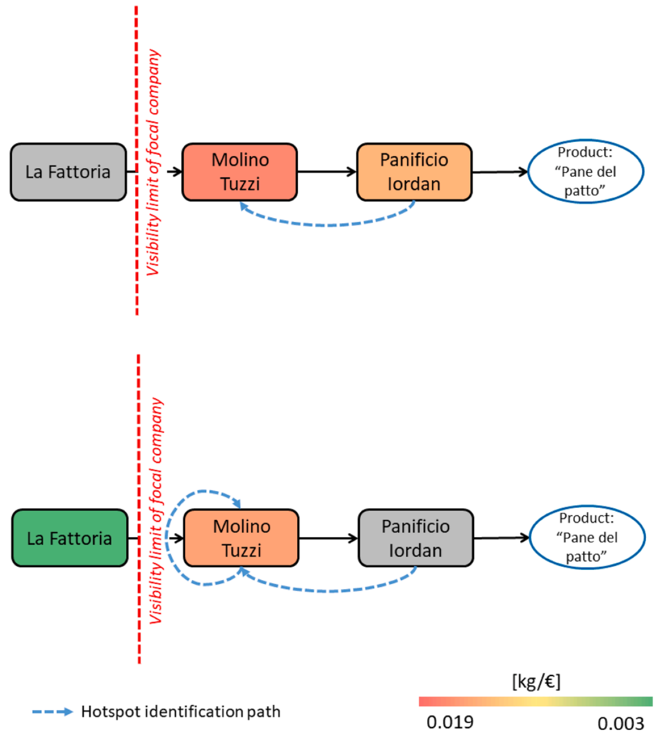

Fig. 5. Hotspot identification iterations for solid waste eco-intensity: iteration at the focal company "Panificio Iordan" (a) and iteration at 1st tier supplier "Molino Tuzzi" (b).

Table 5
GOI1 – Energy consumption.

Energy consumption eco-intensity [kWh/€]	2016	2019	Δ
2nd tier supplier/La Fattoria (single company)	0.813	0.562	−30.85 %
Supply chain	0.209	0.157	−24.99 %

their sub-suppliers (Gong et al., 2018a; Gong et al., 2018b; Schöggl et al., 2016; Villena and Gioia, 2018). This also allows protecting confidentiality and competitive advantage of every SC member (Schöggl et al., 2016).

The focal company can compare its internal organisational eco-intensity with the eco-intensity value (including the environmental backpack) that is cascaded by the 1st tier supplier downstream: if the internal figure is greater than the value passed by the supplier, the hotspot is located at the focal company. On the other hand, if the value passed by the supplier is greater than the focal company-one, the hotspot is located upstream along the SC. The backward mechanism can be iterated moving upstream along the SC by the 1st tier supplier until the hotspot is finally identified and does not require the focal company to have visibility of the multi-tier SC.

During the first environmental assessment in 2016, the case study application provided two different examples of positioning of the hotspots, with a different number of iteration stages. Environmental hotspots were located at the 2nd tier supplier 'La Fattoria', like in the case of energy consumption eco-intensity (Fig. 4), or at the 1st tier supplier 'Molino Tuzzi', like in the case of solid waste eco-intensity hotspot (Fig. 5), with no hotspot being identified at the focal company, thus reinforcing the need for adopting a multi-tier GSCM approach within food SCs.

The graphical visualisation of the eco-intensity values offers a user-friendly representation of the eco-intensity performance, which can be adopted by the users of the methods alternatively to the numerical outputs. In each figure, companies are represented in a relative colour scale based on their eco-intensity performance. At each iteration, the organisation involved in the process is represented according to its internal eco-intensity without environmental backpack, whereas its suppliers are represented according to their eco-intensity including the environmental backpack associated to their upstream SC, which is the actual value that is passed by each SC member to the next one. The eco-intensity is recalculated in a similar manner for each subsequent iteration at lower tier levels.

Two iterations of the backward mechanism were required to identify the energy consumption eco-intensity hotspot in 2016. First, focal company recognised that the eco-intensity indicator passed on by the 1st tier supplier including backpack is greater than the one internally recorded (excluding backpack), meaning that the hotspot is found in the SC (Fig. 4a). However, a similar pattern reappeared when the 1st tier supplier analysed the value, demonstrating that the hotspot was found at the 2nd tier supplier (Fig. 4b). Similarly, two iterations were required also for land occupation, water consumption and GHG emissions indicators, whose representations of the hotspot identification iterations are available in the Appendix.

On the other hand, Fig. 5 illustrates that the backward mechanism stopped after one iteration at Molino Tuzzi in the case of solid waste indicator. Panificio Iordan identified that the hotspot was located upstream in the SC in the first iteration as in the previous case (Fig. 5a), however the second iteration at Molino Tuzzi did not proceed the recursive mechanism further upstream as the 1st tier supplier identified itself as the hotspot for solid waste in 2016 (Fig. 5b).

3.4. Green operational improvements

The hotspot identification informed the owners of the organisations part of the SC on how to deploy the environmental strategy of the SC, by offering specific guidance on how to direct green operational improvements. Based on the results of the application of the method in the year 2016, each green operational improvement (GOI) was predominantly based on the hotspots identified in Section 3.3, targeting for each eco-intensity indicator the weakest tier in the SC. GOIs targeted three environmental categories, namely energy consumption (GOI1), GHG emissions (GOI2) and solid waste (GOI3). Such environmental categories were selected in accordance with the owners of the organisations responsible for the highest eco-intensity contribution in each category, in line with their overall environmental strategy and considering the feasibility of GOIs within each environmental category.

GOI1: Energy Consumption - La Fattoria (2nd tier supplier) – Agricultural machinery upgrade and improved conservative agriculture implementation.

As Fig. 4 highlighted, the hotspot in terms of energy consumption is located at the 2nd tier supplier, suggesting to take actions to improve the environmental performance at La Fattoria. The whole energy consumption of the organisation is due to primary energy consumption, caused by fuel consumption of the agricultural machinery in use. As a result, this was the main focus of the operational improvement for the 2nd tier supplier, leading to the purchase of a more fuel-efficient tractor, which was introduced in 2017. Moreover, a secondary action was taken to decrease energy consumption: soil disturbance was reduced in line with the principles of conservative agriculture, which prescribes only minimum tillage of the land (Life HelpSoil Project, 2014). This had a

Table 6
GOI2 – GHG emissions.

GHG emissions eco-intensity [kg CO_2 e /€]	2016	2019	Δ
2nd tier supplier/La Fattoria (single company)	0.218	0.150	−30.85 %
1st tier supplier/Molino Tuzzi (single company)	0.027	0.021	−22.43 %
Focal company/Panificio Iordan (single company)	0.098	0.036	−63.85 %
Supply chain	0.134	0.061	−54.75 %

Table 7
GOI3 – Solid waste.

Solid waste eco-intensity [kg/€]	2016	2019	Δ
1st tier supplier/Molino Tuzzi (single company)	0.016	0.012	−22.85 %
Focal company/Panificio Iordan (single company)	0.015	0.008	−42.90 %
Supply chain	0.019	0.012	−37.45 %

direct impact on the absolute use of agricultural machinery and, as a consequence, on the energy consumption associated to fuel consumption. The results reflect the environmental benefits of such operational improvements (Table 5), with a decrease of the energy consumption equal to −30.85 % at the organisational level and −24.99 % at the SC level, confirming that the potential for energy reduction is usually larger at the agricultural level than at the manufacturing level in food SCs (Wilhelm et al., 2016a).

GOI2: GHG emissions

GOI2.1 GHG emissions - La Fattoria (2nd tier supplier) – Agricultural machinery upgrade and improved conservative agriculture implementation

The GOI tackling energy consumption at the 2nd tier supplier benefited also the GHG emissions eco-intensity indicator, another eco-intensity indicator whose hotspot was located at 2nd tier supplier 'La Fattoria' in 2016. The reduced energy consumption of agricultural operations led to a concurrent decrease of the GHG emissions eco-intensity of −30.85 % (Table 6). This was the result of a decrease in absolute GHG emissions of −41.44 %, which was however hampered by the decrease of the organisation-wide turnover. The enhanced understanding of the GHG emissions eco-intensity provided by the method, led to additional GOI within this environmental category beyond the organisation recognised as the hotspot in 2016. GOIs in the GHG emissions performance were deemed strategic across the SC, since green customers are more familiar with this indicator, which is often used as a proxy of the overall environmental performance (Tuni et al., 2018).

GOI2.2: GHG emissions – Molino Tuzzi (1st tier supplier) - water mill restoration

Although Molino Tuzzi is the least emission-intensive organisation within the SC, the 1st tier supplier in line with its motivation to improve the environmental sustainability, completed a long-term plan to restore the water mill existing on its premises, aiming to use renewable hydropower instead of electricity from the grid for the milling operations under certain hydrological conditions. The energy requirements of the company remained stable throughout the years, however the water mill covered provided 250kWh in 2019, which accounts for 8 % of the energy demand of Molino Tuzzi. While the energy consumption eco-intensity has remained unchanged, the water mill restoration impacted the GHG emissions as scope 2 emissions were reduced. An absolute reduction of −11.84 % in the GHG emissions (Table 2) combined with the increase of the turnover of the company led to a –22.43 % in the GHG emissions at the organisational level (Table 6).

GOI2.3: GHG emissions – Panificio Iordan (Focal company) – Renewable energy self-production

Additionally, the focal company, also driven by its proactiveness towards environmental sustainability, tackled its internal GHG emissions eco-intensity, by installing solar panels to cover part of its internal energy requirements. Moreover, given the high energy consumption at the bakery, the owner aimed to achieve a win–win situation between the economic and environmental dimensions of sustainability. Although the absolute energy demand of the bakery slightly increased by 0.42 % across the years (Table 2), 11,857 kWh out of the total of 21,980 kWh were internally self-produced through the solar panels in 2019, meaning that over half of the energy requirements were covered by directly produced renewable energy. While this did not have an impact on the energy consumption eco-intensity, it significantly impacted the GHG emissions indicator. The absolute value of GHG emissions dropped by −55.77 % (Table 2), which, coupled with the increase in the yearly turnover, led to a decrease of the GHG emissions eco-intensity of −63.85 % at the organisational level (Table 6).

The combined implementation of these three actions led to a decrease of 54.75 % of the GHG emissions eco-intensity at the SC level (Table 6), demonstrating the effect that the environmental performance of each tier has on the performance of the entire SC.

GOI3: Solid waste

GOI3.1 solid waste - Molino Tuzzi (1st tier supplier) – Flour bin installation

As Fig. 5 highlighted, the hotspot in terms of solid-waste is located at the 1st tier supplier, suggesting to take actions to improve the environmental performance at Molino Tuzzi. A sizeable amount of solid-waste generated at Molino Tuzzi in 2016 was due to the paper packaging. While wheat had long been shipped to Molino Tuzzi in bulks, the flour received from different producers to offer blended mixes of flour to the customers was then received in 25 kg packages. Therefore, the identified solution was to improve the mill premises by expanding the flour bin facilities to store incoming flour, in order to increase the share of flour received in batches and reduce the paper packaging waste, similarly to the practices already in use for wheat supplies. The effect of the installation of flour bin containers in 2018 led to an absolute reduction of the solid waste generated at Molino Tuzzi of around 200 kg on a yearly basis, which, coupled with the increasing turnover at the company, led to a decrease of 22.85 % of the solid waste eco-intensity at the organisational level in 2019, compared to 2016 (Table 7). This determined the hotspot for this environmental category to move from the 1st tier supplier to the focal company and a re-appraisal of the situation was required leading to the decision on further action at the focal company, in a similar vein to Villena and Gioia (2018).

GOI3.2: Solid waste – Panificio Iordan (Focal company) – Bulk supplies

According to the complementary information provided by the owner, Panificio Iordan produces solid waste largely due to the packaging of products associated to the ingredients required to produce oven-baked products, different from bread, which are also part of the product mix offered by the bakery. The focal company, aiming to reduce its organisational solid waste eco-intensity, tried to shift from individually packaged supplies to bulk supplies, wherever this was an option in line with the sourcing policies of the bakery. The operational improvement led to a decrease of 42.90 % of the solid waste eco-intensity at the organisational level in 2019, compared to 2016, as illustrated in Table 7.

The combined implementation of these two actions led to a decrease of 37.45 % of the solid waste eco-intensity at the SC level (Table 7), demonstrating the effect that the environmental performance of each tier has on the performance of the entire SC.

4. Discussion

This work contributes to the multi-tier GSCM literature by providing insights on the deployment of the indirect GSCM approach to assess the environmental sustainability performance of SCs in an operating context and by demonstrating the value of information-sharing mechanisms in the management of suppliers and sub-suppliers to guide green operational improvements across time. This was achieved by presenting the first longitudinal case study in the field, allowing to capture the outcomes of actions taken by the focal company and its upstream SC (Eggert and Hartmann, 2021). The longitudinal case study presented in this work addresses the long-standing call for longitudinal studies in the performance assessment literature within the SCM field (Bititci et al., 2012; Carter and Rogers, 2008; Gopal and Thakkar, 2012) and more specifically the lack of longitudinal studies within GSCM performance assessment (Taticchi et al., 2014) and multi-tier GSCM performance assessment (Villena and Gioia, 2018). The following paragraphs discuss the outcomes of this work against the guiding research questions.

4.1. Research question 1

RQ1: Can an indirect multi-tier GSCM approach be applied to quantitatively assess the environmental sustainability performance of a multi-tier agri-food SC?

The case study provides evidence of an application within an operating context of a method specifically designed for multi-tier GSCM performance assessment based on the indirect multi-tier GSCM approach, demonstrating the suitability in achieving a decentralised assessment, according to the cascading assessment logic (Schöggl et al., 2016), and relying on first-party audit, i.e. self-assessment processed by the supplier and forwarded to the customer (Grimm et al., 2016).

Consequently, this work advances the literature in the area of multi-tier GSCM within food SCs. Previous research in this field has either focused on governance mechanisms to manage sustainability for multi-tier SCs, most noticeably through the work of Grimm et al., (2014), Mena et al., (2013) and Wilhelm et al. (2016a), Wilhelm et al. (2016b), or adopted a strictly technical approach, mostly based on LCA, thus neglecting the need to deal with complex SC dynamics arising with interconnected organisations (Adhitya et al., 2011). This work demonstrates how the integration of environmental sustainability performance assessment methods and SC governance mechanisms can support effectively the deployment of multi-tier GSCM within food SCs. This integration is functional to simultaneously achieve sustainability-oriented sub-supplier management in food SCs and guide GOIs to improve the food SC environmental performance.

4.2. Research question 2

RQ2: Can an eco-intensity-based method be effectively applied by SMEs to assess the multi-tier SC environmental sustainability performance?

The case study demonstrated that the eco-intensity-based method adopted in this work, thanks to the data collection at the organisational level and the simplified rule for the allocation of environmental impacts, is accessible for companies inexperienced in sustainability assessment, including SMEs, which is a key requirement to achieve SC-wide sustainability assessment (Schöggl et al., 2016). With this respect, the case study also demonstrated that the method only requires limited support from organisations along the SC to their suppliers for the environmental performance assessment process, which was previously identified as a major obstacle to a wider implementation of multi-tier GSCM within SMEs SCs (Dou et al., 2017; Grimm et al., 2014). The eco-intensity-based method also proved effective in identifying the hotspots of environmental impact within the SC.

As a result, this work contributes to the wider GSCM field, by providing insights on the implementation of GSCM performance assessment methods within SMEs, which have traditionally been overlooked by GSCM literature (Bourlakis et al., 2014), owing to the lack of information and resources available to SMEs to dedicate to GSCM (Bourlakis et al., 2014). This is of particular value in the food sector, as food SCs are typically dominated by the presence of SMEs (Manzini and Accorsi, 2013). The case study is also particularly interesting as it tackles a SC made up entirely by SMEs that take a proactive approach to GSCM, differently from the predominant narrative of SMEs reacting to the external pressures of larger focal companies located downstream in the SC (Centobelli et al., 2021).

4.3.

RQ3: How can an environmental sustainability performance assessment method be operationalised over time to guide green operational improvement in a multi-tier SC?

The eco-intensity-based environmental sustainability performance assessment method provided an enhanced understanding of the contribution of each organisation to the overall SC environmental performance for each of the environmental categories considered, and allowed the identification of environmental hotspots, guiding individual organisations in the implementation of GOIs. The evidence from the longitudinal study proved that the improvements that resulted from the understanding of the hotspots led to a significantly improved eco-intensity performance in the three targeted environmental categories, namely energy consumption, GHG emissions and solid waste within the 3-years timescale of the study. It should be noted that these improvements took place in different tiers of the multi-tier SC. The method, supported from a clear SC governance mechanism, as detailed in Section 4.1, couples a SC-wide assessment with individual responsibility for operational improvements within each organisation identified as a hotspot for each environmental indicator, thus respecting the independency of each organisation (Mena et al., 2013) and leaving flexibility to each organisation to implement GOIs.

By operationalising the method over time, the case study addresses the paucity of sustainability performance assessment methods adopted into practice for enhanced integration of decisions across the SC (Beske-

Janssen et al., 2015; Ghadimi et al., 2019). The case study also contributes to the debate in the field of SC performance assessment by confirming and contradicting factors functional to the operationalisation of SC performance assessment methods. Confirmed enabling factors were the easiness of sharing environmental and economic indicators among SC partners (Gopal and Thakkar, 2012) and the adoption of indicators, such as eco-intensity that can capture the performance of lower-tier suppliers and focal company alike (Villena and Gioia, 2018), as well as the collaborative nature of the SC, which resulted in effective information-sharing mechanisms across multiple SC tiers (Gopal and Thakkar, 2012).

Additional intangible enabling factors for the operationalisation of the method were the long-term collaboration among SC organisations and the resulting open and trustful environment among the organisations, with high levels of trust between both the focal company and the 1st tier supplier and between the 1st tier and the 2nd tier supplier. These aspects differ from the dominant emphasis on power asymmetries in green multi-tier SC, as in Dou et al. (2017), highlighting that different approaches may be adopted by SMEs, due to their reliance on more informal methods to manage their SC (Cagliano et al., 2001). This is further substantiated by the role of locality in the network. The deep relationship with the local context and the geographical proximity of all SC members facilitated the collaboration and information-sharing mechanism required to successfully operationalise the recursive mechanism (Bourlakis et al., 2014; Centobelli et al., 2021; Gopal and Thakkar, 2012), an aspect potentially being SMEs-specific (Bourlakis et al., 2014; Centobelli et al., 2021).

5. Conclusions

This work aimed to showcase how assessing the environmental sustainability performance of a multi-tier food SC made up by SMEs can support decisions in order to drive evidence-based green improvements in the SC operations. This was achieved by applying a quantitative multicriteria environmental sustainability performance assessment method in a bread SC, dominated by SMEs, and demonstrated through a longitudinal single case study. Five eco-intensity indicators were adopted to track the environmental performance of the SC, covering both environmental inputs withdrawn from natural capital as well as environmental outputs released to the environment.

The method offers a tool for practitioners in focal companies to adopt a systemic approach to develop environmentally efficient SCs. The outputs obtained through the application of the method can effectively guide multi-tier SCs on their path towards sustainability, by prioritising areas of intervention for each environmental impact, i.e. environmental hotspots, and supporting them in evaluating the efficacy of the operational improvements on the SC environmental performance, even when such improvements do not arise in the hotspots but are operationally and economically feasible and can contribute to a reduction of the SC environmental impact. The case study presented in this work assessed the effect of GOIs on environmental sustainability performance; however, the method can be functional also in a forward perspective to set environmental targets both at the company and at the SC level. Finally, practitioners may be interested to adopt results arising from the method as part of their external reporting, in order to use evidence-based communication to the customers in a green marketing perspective.

As with every piece of research, this work is not immune to limitations. First, it was limited to a holistic single case study in a food SC. Some limitations of this research design are thus embedded in this work. Operational details within the SC were not investigated (Yin, 2003) and the results of the application of the method were affected by the data fed into the mathematical model as input. As first-party audit was into place and each company was in charge for its internal self-assessment, a reliable mechanism to verify the quality of environmental data provided by suppliers needs to be identified in the future. Second, the case study relies on the environmental performance assessment method developed in Tuni and Rentizelas (2019) and, as such, shares some of the limitations embedded in the method, like the potential impact of price fluctuations on the turnover and, consequently, on eco-intensity results. Such fluctuations can be the outcome of internal or external price dynamics. In the former case, the focal company may be able to generate additional value with less environmental impact, contributing towards a sustainable future by balancing environmental and economic pillars of sustainability, according to weak sustainability principles. In the latter case, the price fluctuations may be the result of variations in the general market demand, a “domino effect” of prices due to increased cost of raw materials or a general increase of the level of prices within the economy, i.e. inflation, which are not linked to any organisational economic improvement. Therefore, the method needs to be used with care for longitudinal benchmarking in contexts featuring high volatility of prices. Third, all organisations part of the case study are micro enterprises: additional research in food SCs dominated by larger enterprises and broader geographical scope is recommended in order to strengthen the external validity of the case study through replication logic (Yin, 2003). With this respect, it would be particularly interesting to perform a cross-case analysis with an industrial bread SC displaying a broader geographical scope. Moreover, it would also be interesting to explore the effectiveness of the indirect SCM approach and of the cascading assessment where a large organisation coordinates the SC acting as the focal company and asymmetric power relationships may exist between the focal company and its suppliers. Finally, it would be interesting to explore the applicability of the method in a SC characterised by a more unstable supply base, unlike the long-lasting relationships among SC organisations in the presented case study, to evaluate the adaptability of the method to a more dynamic and competitive context.

Nevertheless, the case study illustrated that the method is a powerful tool, that can be adopted both from the focal company and from its suppliers and sub-suppliers, to longitudinally benchmark the environmental sustainability performance of operations both at the organisational level and at the SC level, offering guidance for GOI and enhanced support to decision making within the environmental sustainability domain to drive the transition towards a more sustainable food industry.

Declaration of Competing Interest

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

Acknowledgement

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Appendix

Figs. A1 to A3.

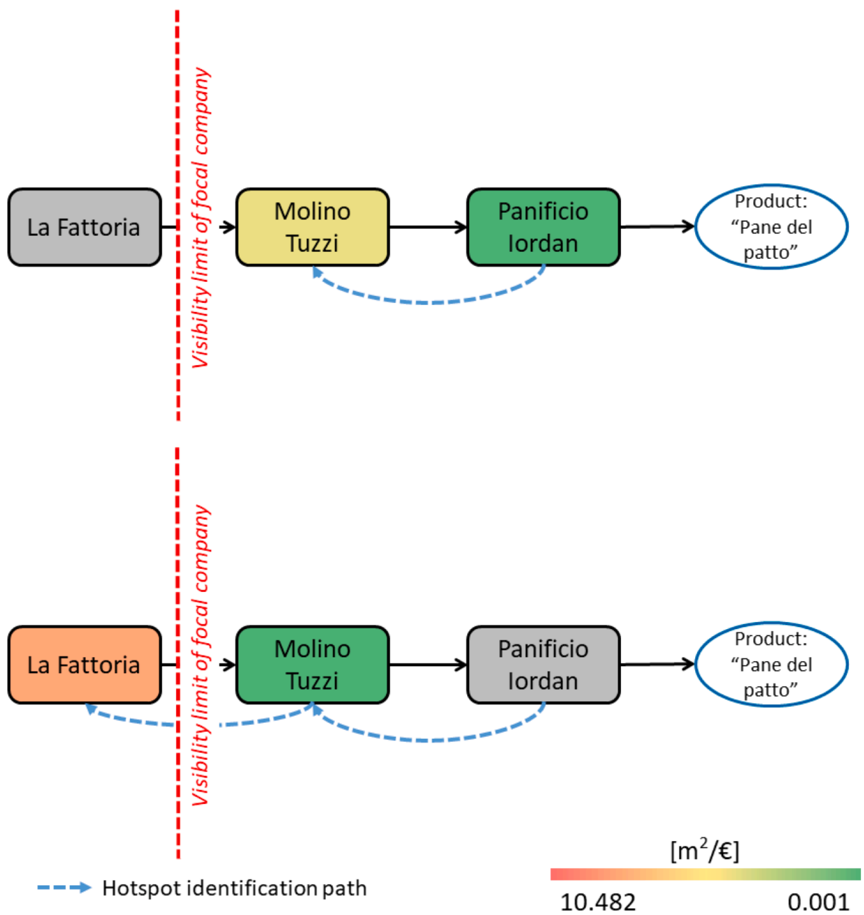

Fig. A1. Hotspot identification iterations for land occupation eco-intensity: iteration at the focal company "Panificio Iordan" (a) and iteration at 1st tier supplier "Molino Tuzzi" (b).

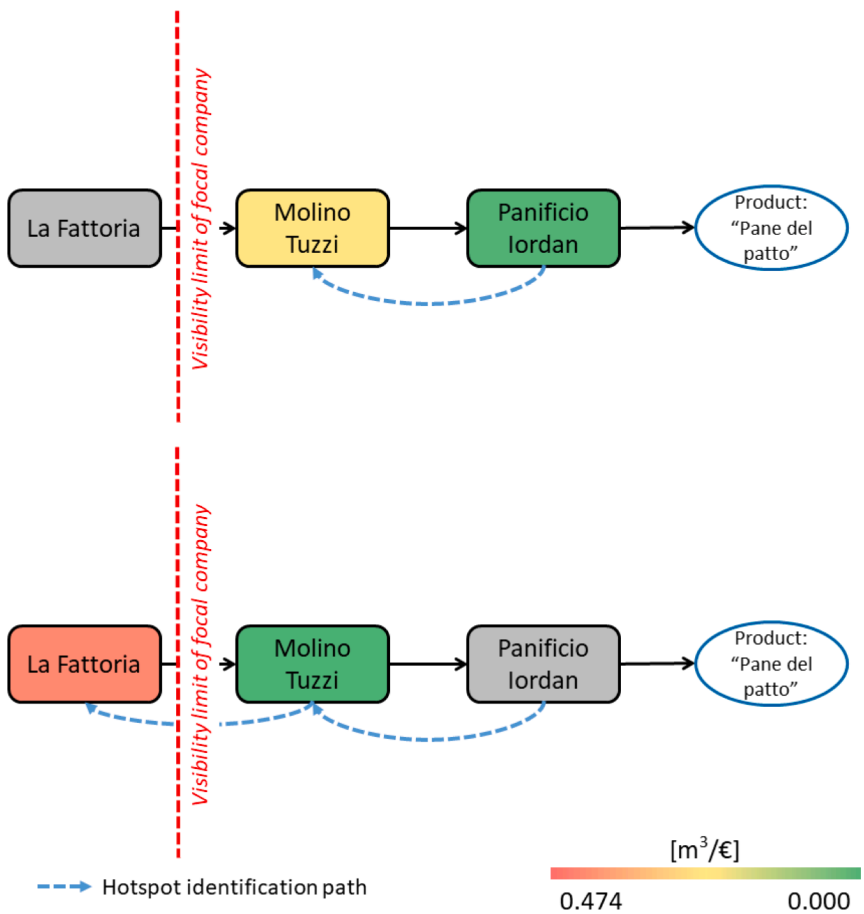

Fig. A2. Hotspot identification iterations for water consumption eco-intensity: iteration at the focal company "Panificio Iordan" (a) and iteration at 1st tier supplier "Molino Tuzzi" (b).

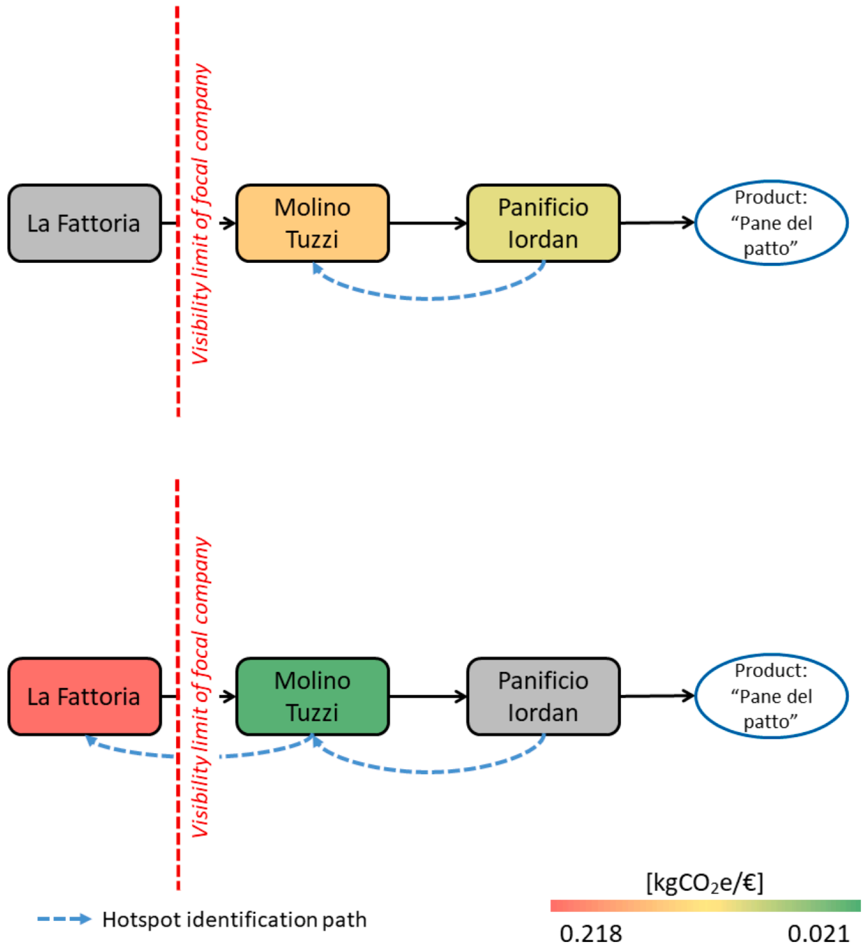

Fig. A3. Hotspot identification iterations for GHG emissions eco-intensity: iteration at the focal company "Panificio Iordan" (a) and iteration at 1st tier supplier "Molino Tuzzi" (b).

References

Adhitya, A., Halim, I., Srinivasan, R., 2011. Decision support for green supply chain operations by integrating dynamic simulation and LCA indicators: Diaper case study. Environ. Sci. Technol. 45, 10178–10185. https://doi.org/10.1021/es201763q.

Ali, A., Bentley, Y., Cao, G., Habib, F., 2017. Green supply chain management–food for thought? Int. J. Logist. Res. Appl. 20, 22–38. https://doi.org/10.1080/13675567.2016.1226788.

Allaoui, H., Guo, Y., Choudhary, A., Bloemhof, J., 2018. Sustainable agro-food supply chain design using two-stage hybrid multi-objective decision-making approach. Comput. Oper. Res. 89, 369–384. https://doi.org/10.1016/j.cor.2016.10.012.

Arzoumanidis, I., Salomone, R., Petti, L., Mondello, G., Raggi, A., 2017. Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools. J. Clean. Prod. 149, 406–425. https://doi.org/10.1016/j.jclepro.2017.02.059.

Ayuso, S., Roca, M., Colomé, R., 2013. SMEs as "transmitters" of CSR requirements in the supply chain. Supply Chain Manag. An Int. J. 18, 497–508. https://doi.org/10.1108/SCM-04-2012-0152.

Azadi, M., Shabani, A., Khodakarami, M., Farzipoor Saen, R., 2015. Planning in feasible region by two-stage target-setting DEA methods: An application in green supply chain management of public transportation service providers. Transp. Res. Part E Logist. Transp. Rev. 70, 324–338. https://doi.org/10.1016/j.tre.2014.12.009.

Beske, P., Land, A., Seuring, S., 2014. Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature. Int. J. Prod. Econ. 152, 131–143. https://doi.org/10.1016/j.ijpe.2013.12.026.

Beske-Janssen, P., Johnson, M.P., Schaltegger, S., 2015. 20 Years of performance measurement in sustainable supply chain management – what has been achieved? Supply Chain Manag. An Int. J. 20, 664–680. https://doi.org/10.1108/SCM-06-2015-0216.

Bititci, U., Garengo, P., Dörfler, V., Nudurupati, S., 2012. Performance measurement: challenges for tomorrow. Int. J. Manag. Rev. 14, 305–327. https://doi.org/10.1111/j.1468-2370.2011.00318.x.

Bourlakis, M., Maglaras, G., Aktas, E., Gallear, D., Fotopoulos, C., 2014. Firm size and sustainable performance in food supply chains: insights from Greek SMEs. Int. J. Prod. Econ. 152, 112–130. https://doi.org/10.1016/j.ijpe.2013.12.029.

Brandenburg, M., 2015. Low carbon supply chain configuration for a new product – a goal programming approach. Int. J. Prod. Res. 53, 1–23. https://doi.org/10.1080/00207543.2015.1005761.

Cagliano, R., Blackmon, K., Voss, C., 2001. Small firms under MICROSCOPE: International differences in production/operations management practices and performance. Integr. Manuf. Syst. 12, 469–482. https://doi.org/10.1108/eum0000000006229.

Câmara-Salim, I., Almeida-García, F., González-García, S., Romero-Rodríguez, A., Ruíz-Nogueiras, B., Pereira-Lorenzo, S., Feijoo, G., Moreira, M.T., 2020. Life cycle assessment of autochthonous varieties of wheat and artisanal bread production in Galicia, Spain. Sci. Total Environ. 713, 136720 https://doi.org/10.1016/j.scitotenv.2020.136720.

Carter, C.R., Rogers, D.S., 2008. A framework of sustainable supply chain management: moving toward new theory. Int. J. Phys. Distrib. Logist. Manag. 38, 360–387.

Centobelli, P., Cerchione, R., Esposito, E., Passaro, R., Shashi, 2021. Determinants of the transition towards circular economy in SMEs: A sustainable supply chain management perspective. Int. J. Prod. Econ. 242 https://doi.org/10.1016/j.ijpe.2021.108297.

Corsano, G., Montagna, J.M., 2011. Mathematical modeling for simultaneous design of plants and supply chain in the batch process industry. Comput. Chem. Eng. 35, 149–164. https://doi.org/10.1016/j.compchemeng.2010.06.008.

Dong, Y., Miraglia, S., Manzo, S., Georgiadis, S., Sørup, H.J.D., Boriani, E., Hald, T., Thöns, S., Hauschild, M.Z., 2018. Environmental sustainable decision making– The need and obstacles for integration of LCA into decision analysis. Environ. Sci. Policy 87, 33–44. https://doi.org/10.1016/j.envsci.2018.05.018.

Dou, Y., Zhu, Q., Sarkis, J., 2017. Green multi-tier supply chain management: An enabler investigation. J. Purch. Supply Manag. 1–13 https://doi.org/10.1016/j.pursup.2017.07.001.

EcoTransIT World Initiative, 2016. Ecological Transport Information Tool for Worldwide Transports: Methodology and Data Update. EcoTransIT World Initiaitive (EWI).

Eggert, J., Hartmann, J., 2021. Purchasing's contribution to supply chain emission reduction. J. Purch. Supply Manag. 27 https://doi.org/10.1016/j.pursup.2021.100685.

European Environment Agency, 1999. Making sustainability accountable: Eco-efficiency, resource productivity and innovation, Proceedings of a workshop on the occasion of the Fifth Anniversary of the European Environment Agency (EEA).

European Environment Agency, 2019. Annual European Union greenhouse gas inventory 1990–2017 and inventory report 2019.
Genovese, A., Lenny Koh, S.C., Kumar, N., Tripathi, P.K., 2013. Exploring the challenges in implementing supplier environmental performance measurement models: a case study. Prod. Plan. Control 25, 1198–1211. https://doi.org/10.1080/09537287.2013.808839.
Ghadimi, P., Wang, C., Lim, M.K., 2019. Sustainable supply chain modeling and analysis: Past debate, present problems and future challenges. Resour. Conserv. Recycl. 140, 72–84. https://doi.org/10.1016/j.resconrec.2018.09.005.
Gong, Y., Jia, F., Brown, S., Koh, L., 2018b. Supply chain learning of sustainability in multi-tier supply chains: A resource orchestration perspective. Int. J. Oper. Prod. Manag. 38, 1061–1090. https://doi.org/10.1108/MRR-09-2015-0216.
Gong, M., Simpson, A., Koh, L., Tan, K.H., 2018a. Inside out: The interrelationships of sustainable performance metrics and its effect on business decision making: Theory and practice. Resour. Conserv. Recycl. 128, 155–166. https://doi.org/10.1016/j.resconrec.2016.11.001.
Gopal, P., Thakkar, J., 2012. A review on supply chain performance measures and metrics: 2000–2011. Int. J. Product. Perform. Manag. 61, 518–547.
Grimm, J.H., Hofstetter, J.S., Sarkis, J., 2014. Critical factors for sub-supplier management: A sustainable food supply chains perspective. Int. J. Prod. Econ. 152, 159–173. https://doi.org/10.1016/j.ijpe.2013.12.011.
Grimm, J.H., Hofstetter, J.S., Sarkis, J., 2016. Exploring sub-suppliers' compliance with corporate sustainability standards. J. Clean. Prod. 112, 1971–1984. https://doi.org/10.1016/j.jclepro.2014.11.036.
Grimm, J.H., Hofstetter, J.S., Sarkis, J., 2018. Interrelationships amongst factors for sub-supplier corporate sustainability standards compliance: An exploratory field study. J. Clean. Prod. 203, 240–259. https://doi.org/10.1016/j.jclepro.2018.08.074.
Harris, I., Naim, M., Palmer, A., Potter, A., Mumford, C., 2011. Assessing the impact of cost optimization based on infrastructure modelling on CO2 emissions. Int. J. Prod. Econ. 131, 313–321. https://doi.org/10.1016/j.ijpe.2010.03.005.
Hartmann, J., Moeller, S., 2014. Chain liability in multitier supply chains? Responsibility attributions for unsustainable supplier behavior. J. Oper. Manag. 32, 281–294. https://doi.org/10.1016/j.jom.2014.01.005.
Huppes, G., Ishikawa, M., 2005. Eco-efficiency and its terminology. J. Ind. Ecol. 9, 43–46. https://doi.org/10.1162/108819805775247891.
Ingrao, C., Licciardello, F., Pecorino, B., Muratore, G., Zerbo, A., Messineo, A., 2018. Energy and environmental assessment of a traditional durum-wheat bread. J. Clean. Prod. 171, 1494–1509. https://doi.org/10.1016/j.jclepro.2017.09.283.
Jabbour, C.J.C., de Sousa Jabbour, A.B.L., Sarkis, J., 2018. Unlocking effective multi-tier supply chain management for sustainability through quantitative modeling: Lessons learned and discoveries to be made. Int. J. Prod. Econ. 217, 11–30. https://doi.org/10.1016/j.ijpe.2018.08.029.
Jia, F., Gong, Y., Brown, S., 2018. Multi-tier sustainable supply chain management: The role of supply chain leadership. Int. J. Prod. Econ. 217, 44–63. https://doi.org/10.1016/j.ijpe.2018.07.022.
Kannegiesser, M., Günther, H.-O., 2013. Sustainable development of global supply chains—part 1: sustainability optimization framework. Flex. Serv. Manuf. J. 26, 24–47. https://doi.org/10.1007/s10696-013-9176-5.
Koh, L.S.C., Gunasekaran, A., Tseng, C.S., 2012. Cross-tier ripple and indirect effects of directives WEEE and RoHS on greening a supply chain. Int. J. Prod. Econ. 140, 305–317. https://doi.org/10.1016/j.ijpe.2011.05.008.
Kovács, G., 2008. Corporate environmental responsibility in the supply chain. J. Clean. Prod. 16, 1571–1578. https://doi.org/10.1016/j.jclepro.2008.04.013.
Kulak, M., Nemecek, T., Frossard, E., Chable, V., Gaillard, G., 2015. Life cycle assessment of bread from several alternative food networks in Europe. J. Clean. Prod. 90, 104–113. https://doi.org/10.1016/j.jclepro.2014.10.060.
Kulak, M., Nemecek, T., Frossard, E., Gaillard, G., 2016. Eco-efficiency improvement by using integrative design and life cycle assessment. The case study of alternative bread supply chains in France. J. Clean. Prod. 112, 2452–2461. https://doi.org/10.1016/j.jclepro.2015.11.002.
Lee, S., 2008. Drivers for the participation of small and medium-sized suppliers in green supply chain initiatives. Supply Chain Manag. An Int. J. 13, 185–198. https://doi.org/10.1108/13598540810871235.
Lee, S.M., Kim, S.T., Choi, D., 2012. Green supply chain management and organizational performance. Ind. Manag. Data Syst. 112, 1148–1180. https://doi.org/10.1108/02635571211264609.
Lee, S., Klassen, R.D., 2008. Drivers and Enablers That Foster Environmental Management Capabilities in Small- and Medium-Sized Suppliers in Supply Chains. Prod. Oper. Manag. 17, 573–586. https://doi.org/10.3401/poms.1080.0063.
Life HelpSoil Project, 2014. LIFE HELPSOIL and Conservation Agriculture [WWW Document].
Low, J.S.C., Tjandra, T.B., Lu, W.F., Lee, H.M., 2015. Adaptation of the Product Structure-based Integrated Life cycle Analysis (PSILA) technique for carbon footprint modelling and analysis of closed-loop production systems. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2015.09.095.
Lozano, R., 2015. A holistic perspective on corporate sustainability drivers. Corp. Soc. Responsib. Environ. Manag. 22, 32–44. https://doi.org/10.1002/csr.1325.
Luo, J., Ji, C., Qiu, C., Jia, F., 2018. Agri-food supply chain management: Bibliometric and content analyses. Sustain. 10, 1–22. https://doi.org/10.3390/su10051573.
Manzini, R., Accorsi, R., 2013. The new conceptual framework for food supply chain assessment. J. Food Eng. 115, 251–263. https://doi.org/10.1016/j.jfoodeng.2012.10.026.
Mathiyazhagan, K., Govindan, K., NoorulHaq, A., Geng, Y., 2013. An ISM approach for the barrier analysis in implementing green supply chain management. J. Clean. Prod. 47, 283–297. https://doi.org/10.1016/j.jclepro.2012.10.042.
Meinlschmidt, J., Schleper, M.C., Foerstl, K., 2018. Tackling the sustainability iceberg: A transaction cost economics approach to lower tier sustainability management. Int. J. Oper. Prod. Manag. 38, 1888–1914.
Mena, C., Humphries, A., Choi, T.Y., 2013. Toward a theory of multi-tier supply chain management. J. Supply Chain Manag. 49, 58–77. https://doi.org/10.1111/jscm.12003.
Michelsen, O., Fet, A.M., Dahlsrud, A., 2006. Eco-efficiency in extended supply chains: A case study of furniture production. J. Environ. Manage. 79, 290–297. https://doi.org/10.1016/j.jenvman.2005.07.007.
Mintcheva, V., 2005. Indicators for environmental policy integration in the food supply chain (the case of the tomato ketchup supply chain and the integrated product policy). J. Clean. Prod. 13, 717–731. https://doi.org/10.1016/j.jclepro.2004.01.008.
Mogale, D.G., Cheikhrouhou, N., Tiwari, M.K., 2020. Modelling of sustainable food grain supply chain distribution system: a bi-objective approach. Int. J. Prod. Res. 58, 5521–5544. https://doi.org/10.1080/00207543.2019.1669840.
MSCI, 2015. Global Industry Classification Standard.
Nasir, M.H.A., Genovese, A., Acquaye, A.A., Koh, S.C.L., Yamoah, F., 2017. Comparing linear and circular supply chains: A case study from the construction industry. Int. J. Prod. Econ. 183, 443–457. https://doi.org/10.1016/j.ijpe.2016.06.008.
Norris, S., Hagenbeck, J., Schaltegger, S., 2021. Linking sustainable business models and supply chains — Toward an integrated value creation framework. Bus. Strateg. Environ. 1–15 https://doi.org/10.1002/bse.2851.
Notarnicola, B., Tassielli, G., Renzulli, P.A., Monforti, F., 2017. Energy flows and greenhouses gases of EU (European Union) national breads using an LCA (Life Cycle Assessment) approach. J. Clean. Prod. 140, 455–469. https://doi.org/10.1016/j.jclepro.2016.05.150.
Oberkampf, W.L., Roy, C.J., 2010. Modeling and computational simulation. In: Verification and Validation in Scientific Computing. United Kingdom, Cambridge, pp. 83–144.
Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., Shiina, T., 2009. A review of life cycle assessment (LCA) on some food products. J. Food Eng. 90, 1–10. https://doi.org/10.1016/j.jfoodeng.2008.06.016.
Schaltegger, S., Martin, B., Burritt, R.L., Jasch, C., 2008. Environmental Management Accounting for Cleaner Production.
Schöggl, J.P., Fritz, M.M.C., Baumgartner, R.J., 2016. Toward supply chain-wide sustainability assessment: A conceptual framework and an aggregation method to assess supply chain performance. J. Clean. Prod. 131, 822–835. https://doi.org/10.1016/j.jclepro.2016.04.035.
Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 16, 1699–1710. https://doi.org/10.1016/j.jclepro.2008.04.020.
Shibin, K.T., Dubey, R., Gunasekaran, A., Hazen, B., Roubaud, D., Gupta, S., Foropon, C., 2020. Examining sustainable supply chain management of SMEs using resource based view and institutional theory. Ann. Oper. Res. 290, 301–326. https://doi.org/10.1007/s10479-017-2706-x.
Shokravi, S., Kurnia, S., 2014. A step towards developing a sustainability performance measure within industrial networks. Sustainability 6, 2201–2222. https://doi.org/10.3390/su6042201.
Silvestre, B.S., 2015. Sustainable supply chain management in emerging economies: Environmental turbulence, institutional voids and sustainability trajectories. Int. J. Prod. Econ. 167, 156–169. https://doi.org/10.1016/j.ijpe.2015.05.025.
Sokolowski, J.A., Banks, C.M., 2010. Modeling and Simulation Fundamentals. Wiley.
Soundararajan, V., Brammer, S., 2018. Developing country sub-supplier responses to social sustainability requirements of intermediaries: Exploring the influence of framing on fairness perceptions and reciprocity. J. Oper. Manag. 58–59, 42–58. https://doi.org/10.1016/j.jom.2018.04.001.
Tachizawa, E.M., Wong, C.Y., 2014. Towards a theory of multi-tier sustainable supply chains: a systematic literature review. Supply Chain Manag. An Int. J. 19, 643–663. https://doi.org/10.1108/SCM-02-2014-0070.
Taticchi, P., Garengo, P., Nudurupati, S.S., Tonelli, F., Pasqualino, R., 2014. A review of decision-support tools and performance measurement and sustainable supply chain management. Int. J. Prod. Res. 53, 1–22. https://doi.org/10.1080/00207543.2014.939239.
Tuni, A., Rentzelas, A., 2019. An innovative eco-intensity based method for assessing extended supply chain environmental sustainability. Int. J. Prod. Econ. 217, 126–142. https://doi.org/10.1016/j.ijpe.2018.08.028.
Tuni, A., Rentzelas, A., Duffy, A., 2018. Environmental performance measurement for green supply chains. Int. J. Phys. Distrib. Logist. Manag. 48, 765–793. https://doi.org/10.1108/IJPDLM-02-2017-0062.
Tuni, A., Rentzelas, A., Chinese, D., 2020. An integrative approach to assess environmental and economic sustainability in multi-tier supply chains. Prod. Plan. Control 31, 861–882. https://doi.org/10.1080/09537287.2019.1695922.
U.S. Environmental Protection Agency, 2009. Guidance on the Development, Evaluation, and Application of Environmental models. USEPA Publication.
Ukidwe, N.U., Bakshi, B.R., 2005. Natural versus economic capital in industrial supply networks – implications for outsourcing and sustainability. Environ. Sci. Technol. Technol. 39, 9759–9769.
Union, E., 2003. Commission Recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises. Off. J. Eur. Union 124, 36–41. https://doi.org/10.1017/CBO9781107415324.004.
Villena, V.H., Gioia, D.A., 2018. On the riskiness of lower-tier suppliers: Managing sustainability in supply networks. J. Oper. Manag. 64, 65–87. https://doi.org/10.1016/j.jom.2018.09.004.

Wiedmann, T.O., Lenzen, M., Barrett, J.R., 2009. Companies on the scale comparing and benchmarking the sustainability performance of businesses. J. Ind. Ecol. 13, 361–383. https://doi.org/10.1111/j.1530-9290.2009.00125.x.

Wilhelm, M., Blome, C., Bhakoo, V., Paulraj, A., 2016a. Sustainability in multi-tier supply chains: Understanding the double agency role of the first-tier supplier. J. Oper. Manag. 41, 42–60. https://doi.org/10.1016/j.jom.2015.11.001.

Wilhelm, M., Blome, C., Wieck, E., Xiao, C.Y., 2016b. Implementing sustainability in multi-tier supply chains: Strategies and contingencies in managing sub-suppliers. Int. J. Prod. Econ. 182, 196–212. https://doi.org/10.1016/j.ijpe.2016.08.006.

Wilhelm, M., Villena, V.H., 2021. Cascading sustainability in multi-tier supply chains: when do Chinese suppliers adopt sustainable procurement? Prod. Oper. Manag. 30, 4198–4218. https://doi.org/10.1111/poms.13516.

Wognum, P.M., Bremmers, H., Trienekens, J.H., Van Der Vorst, J.G.A.J., Bloemhof, J.M., 2011. Systems for sustainability and transparency of food supply chains – current status and challenges. Adv. Eng. Informatics 25, 65–76. https://doi.org/10.1016/j.aei.2010.06.001.

Yakovleva, N., Sarkis, J., Sloan, T., 2012. Sustainable benchmarking of supply chains: the case of the food industry. Int. J. Prod. Res. 50, 1297–1317. https://doi.org/10.1080/00207543.2011.571926.

Yin, R.K., 2003. Case Study Research: Design and Methods, Sage Publications. Sage Publications, Thousand Oaks. 10.1097/FCH.0b013e31822dda9e.