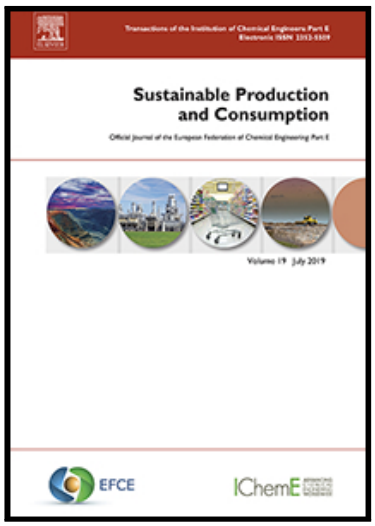

A triple bottom line balanced set of Key Performance Indicators to measure the sustainability performance of industrial supply chains

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A triple bottom line balanced set of Key Performance Indicators to measure the sustainability performance of industrial supply chains

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A triple bottom line balanced set of Key Performance Indicators to measure the sustainability performance of industrial supply chains

Abstract

The measurement of sustainability within industrial supply chains is becoming increasingly relevant, with both industry and academia calling for the development of a general and manageable set of key performance indicators (KPIs). With more than 2,000 performance measures already identified by the previous literature, the real challenge lays in the development of the right set of indicators. Stemming from a thorough literature review, we propose a novel set of KPIs, based on a Balance Score Card-Supply Chain Operations Reference integrated framework. Whilst including a limited number of KPIs, the proposed set: i) assures a balanced coverage of the sustainability pillars and related intersections; ii) addresses different decision-making levels, financial bases and components of performance; iii) simultaneously tackles the sustainability performance of an entire supply chain. We empirically validated the set in 3 supply chains and 7 focal firms, by assessing its completeness, usefulness and ease of use. The set resulted suitable for different contexts of application and appropriate for the evaluation of the sustainability performance of an overall supply chain. We conclude with remarks for academia, industry and policy-makers, also sketching directions for further research.

Keywords

Sustainability performance; Performance measurement; Performance indicators; Supply Chain; Industrial Sector.

1 Introduction

Current modes of production result in unsustainable socioeconomic and environmental consequences (Ansell and Cayzer, 2018; Freire, 2018): substantial long-term oriented changes are required and should be implemented through both sustainable products and sustainable industrial processes, from a technological, managerial, organizational and behavioural perspective (Blok et al., 2015). The role of sustainability in industrial supply chains (SCs) is central in the industry and management related debate (De Angelis et al., 2017; Tavassoli et al., 2020). Competition is nowadays occurring amongst

whole industrial systems rather than single firms (Massaroni et al., 2015; Shibin et al., 2017) and high advantages can be brought holistically addressing sustainability (Carter and Rogers, 2008; Taticchi et al., 2015).

Definitions of sustainable SC are thus focused on the creation of a bridge between sustainability and SC (Ahi and Searcy, 2013). A sustainable SC can be then addressed a systemic and strategic coordination and relationships among firm's functions and different firms (Carter and Rogers, 2008; Seuring and Müller, 2008), with the final aim of improving in the long - but finite (Babu and Mohan, 2018) - term the sustainability performance both of firms and SC firms (Stock and Boyer, 2009). The sustainability performance addressed should simultaneously consider and balance the three dimensions of sustainability, as well as their intersections (Cagno et al., 2019, 2018), particularly integrating the environmental and social ones with the economic criteria (Gualandris et al., 2015; Seuring and Müller, 2008).

The inclusion of sustainability within a SC, however, appears rather challenging (Jaehn, 2016). Sustainability measurement is the backbone (Howard et al., 2018) for many following activities such as improvement actions (Trianni et al., 2017), reporting (Katiyar et al., 2018), and benchmarking (Ferrari et al., 2019). Nevertheless, the required engagement and coordination among all tiers necessary for proper measurement of performance (Pagell and Shevchenko, 2014; Varsei et al., 2014) is hard to obtain (Marshall et al., 2016) and looks even more difficult when the metrics both within and across organizations are lacking (Carter et al., 2019). Recent research has highlighted two main challenges: the adoption of a standard but context-based set of performance indicators (PIs) (Rojas-lema et al., 2020) and the inclusion of SC tiers (Bové and Swart, 2016; Searcy, 2017). Measuring SC sustainability performance implies the consideration of all the players in the SC (Searcy, 2016) but identifying priorities and tracing impacts, aligning data collection and reporting systems can be extremely difficult, above all in SCs encompassing potentially several different tiers (Searcy and Ahi, 2014). Both academia and industry suggested the need for a concise set of general PIs, allowing different results to be compared with minimal level for reporting and with a long-term perspective (NAEM, 2019; Searcy and Ahi, 2014).

Reporting standards already exist, as ESG[1] and GRI[2] (EQUITA, 2020; KPMG, 2017). The ESG one is recognized to bring positive effect to the industrial world from a system perspective (Forbes, 2019), nevertheless few firms are using it within the scope of SC (Callan Istitute, 2019). As a large share of firms would need a more standardized approach toward ESG (EQUITA, 2020), firms practically mainly rely on the GRI Standard (KPMG, 2017). Nevertheless, the GRI still presents specific issues for its widespread applicability. Firstly, it presents a corporate perspective rather than an operative (Fuente et al., 2017; Sisco and Chorn, 2009) and process-oriented one (Raine and Ulrich, 2009), besides being recognized as difficult to assess (Sangwan et al., 2019); as for the last issue, many indicators considered in the GRI require information not easily to be collected and are challenging to evaluate, while no guidelines are provided on how to select the right indicators (Adams and Ghaly, 2006; Sangwan et al., 2019). Secondly, it is mainly adopted by large corporations (Chen et al., 2015; Dragu and Tiron-tudor, 2010), and the GRI itself recognized the urgency to modify the standard to reach Small and Medium Enterprises (SMEs) (GRI, 2018) as well as companies currently striving to

[1] The ESG (Environmental, Social Governance) is a Standard recognized to bring positive effects to the industrial world from a system perspective (Forbes, 2019).

[2] The GRI (Global reporting Initiatives) are the most worldwide adopted Standards for sustainability reporting (KPMG, 2017).

introduce sustainability in their daily activities (Cagno et al., 2019). Thirdly, specific shortcomings of GRI have been highlighted when trying to address the overall SC, with further issues arising for those sectors with strong relationships and dependencies among the different tiers (Chen et al., 2015; Isaksson and Garvare, 2003).

Therefore, despite thousands of PIs have been developed (Ahi and Searcy, 2013), research is still lacking the identification of the appropriate PIs (Bai and Sarkis, 2018; Taticchi et al., 2015) given the heterogeneity of firms within a SC in terms of contexts, industries, size and sustainability awareness. Furthermore, since PIs would not equally fit in all contexts (Rojas-lema et al., 2020), previous literature deems crucial to identify general key performance indicators (KPIs), representing a minimum set for the evaluation of sustainability performance and a common ground for firms characterized by different contextual factors, availability of resources and sustainability awareness. Such a set could then be complemented by specific PIs designed by individual firms and tailored to the unique needs of their own SCs (Ahi and Searcy, 2015; Searcy, 2017).

Starting from this main research gap, the present work aims at developing a balanced general set of KPIs for evaluating the sustainability-related performance in the context of industrial SCs, also providing an empirical validation of the set, as strongly suggested by Taticchi et al. (2015). The remainder of the paper is structured as follows. Stemming from the review of previous literature (Section 2), we defined the methods for the development of the new set of KPIs and its validation (Section 3). We then presented the set and the results from its validation, thoroughly discussing the theoretical foundations of our set of KPIs in light of the empirical validation (Section 4). We have further summarized the contributions of the study, acknowledging limitations of the study and sketching future research avenues in this domain (Section 5).

2 Literature Review

To get an understanding of previous models for measuring sustainability performance in an industrial SC, we opted for a narrative literature review, taking an in-depth but no systematic approach (Green et al., 2006; Robinson and Lowe, 2015). According to Carter and Washispack (2018), indeed, the wealth of systematic literature reviews on the specific topic under evaluation leaves room for just periodic updates.

To retrieve relevant contributions in the field, we identified an initial set of contributions considering literature reviews addressing sustainability-related performance in SCs published from 2015 onwards (Table 1). We then applied snowball method on this initial set: as suggested by Heckathorn and Cameron (2017) and applied by several scholars (Harris et al., 2021; Skolarus et al., 2017; Wohlin, 2014), the snowballing takes the form of identifying an initial set of contributions from which new contributions to analyse are retrieved using the references and the citations (Backward and Forward Snowballing). We are confident that previous literature reviews can provide an in-depth and complete overview on what was developed recently and so far (Carter and Washispack, 2018), allowing us to use them as a solid initial set.

Authors and Date	Journal	Years considered	Databases considered	Number of articles considered
Saeed and Kersten (2020)	Logistic Research	Up to 2019	Science-direct and EBSCO-host	72 (Full list)
Moreno-Camacho et al. (2019)	Journal of Cleaner Production	2015 - 2018	Scopus and WOS	113 (Details)
Tripathi and Gupta (2019)	Advances in Industrial and Production Engineering	2010 - 2017	Google Scholar	84 (Details)
Yun et al. (2019)	The International Journal of Logistics Management	2010 - 2016	Selected Journals	120 (Full list)
Bastas and Liyanage (2018)	Journal of Cleaner Production	2005 - 2017	EBSCO and publishers' database (peer-reviewed only)	93 (Full list) 37 on Sustainable Supply Chain Management
Maditati et al. (2018)	Resources, conservations & Recycling	Up to 2016	WOS	1523 (Details on the most influential)
Qorri et al. (2018)	Journal of Cleaner Production	2005 - 2018	Scopus	104 (Full list)
Tuni et al. (2018)	International Journal of Physical Distribution & Logistics Management	Up to 2015	Scopus and WOS	78 (Full list)
Dubey at al. (2017)	Benchmarking: An International Journal	1990 – 2016	Science Direct, Compendex, EBSCO, Emerald, Scopus, Google Scholar	248 (Details)
Rajeev et al. (2017)	Journal of Cleaner Production	2000 – 2015	EBSCO, Scopus and others	1078 (Full list) 15 on Sustainable Performance Measurement
Balfaqih et al. (2016)	Computers in Industry	1998 - 2015	Scopus and WOS	83 (Full list)
Ahi and Searcy (2015)	Journal of Cleaner Production	Up to 2012	Scopus (no conference papers)	445 (List and details not provided)
Beske-Janssen et al. (2015)	Supply Chain Management: An International Journal	1995 - 2015	EBSCO, Emerald, Science Direct, Wiley	149 (List and details not provided)
Tajbakhsh and Hassini (2015)	International Journal of Productivity and Performance Management	1994 - 2013	Google Scholar	140 (Full list)
Taticchi et al. (2015)	International Journal of Production Research	2000 - 2013	WOS	384 (Full list) 274 on Sustainable Supply Chain Management

Table 1. Recent literature reviews analysed. For each literature review analysed, the following are indicated: Authors and date, Journal, Years considered by the review, Databases considered by the review, Number of articles considered in the review.

Each contribution of the initial set was studied, paying attention to its references (Backward Snowballing) and to those contributions citing it (Forward Snowballing) (Wohlin, 2014). Starting from the initial set of 15 reviews reported in Table 1, we identified 69 relevant contributions (Table 2 and Table 3) proposing a model or framework for the evaluation of sustainability performance in SCs. These contributions have been addressed with a twofold perspective: on the one hand, we analysed the specific content and context of development and application; on the other hand, we analysed the indicators provided by all the contributions in the overall. The two analyses led to the identification of interesting open research gaps.

2.1 Analysis of the selected contributions – Content and Context

The selected contributions were analysed according to *General information* (Author, Year of publication), *Content* (Organization of indicators, Number of indicators, Characterization of Indicators, Perspective on sustainability, Intersections of sustainability areas), *Context* (Focus, Application in the overall SC, Theoretical development - Industry, Geographical area and size, Empirical application - Industry, Geographical area and size) – see also Maestrini et al. (2017), Neri et al. (2018)and Qorri et al. (2018). Our choice for the axes of analysis aims at better understanding, on the one hand, the features characterizing the models of indicators proposed in previous literature; on the other hand, the specific context of development and application of such models. The complete analysis is reported in Table 2 and Table 3 (contributions analysed according to *Content* and the *Context* respectively).

Regarding the organizations of the proposed indicators (Table 2), authors mainly chose a standard (Clift, 2003; Susanty et al., 2019) or slightly modified (Uysal, 2012) Triple Bottom Line (TBL) approach, or a Balanced Scorecard (BSC) framework (Brewer and Speh, 2000; Verdecho et al., 2020). Besides, a few authors used a classification based on the Supply Chain Operations Reference (SCOR) (Bai et al., 2012; Subramanian and Gunasekaran, 2015), developed their categorization (Beamon, 1999; Popovic et al., 2018), or just provided a list of indicators (Ahi and Searcy, 2015; Hassini et al., 2012). Some authors also further characterized the proposed indicators according to decision levels - tactical, strategical, operational (Baba et al., 2019; Liebetruth, 2017), financial base - financial, non-financial (Bhagwat and Sharma, 2007a; Gunasekaran and Kobu, 2007), measurement base - qualitative, quantitative (Chan, 2003; Shepherd and Günter, 2006) and components of performance - time, cost, quality, flexibility, asset (Sellitto et al., 2015; Stefanović and Stefanović, 2011). Some contributions focused on other specific characteristics (Narimissa et al., 2020; Said et al., 2020), but the majority did not provide any characterization.

As for the type of the study (Table 3), based on Murillo-Luna et al. (2011) and Seuring (2013), the selected contributions are almost equally divided between only theoretical ones (Ortas et al., 2014; Schaltegger and Burritt, 2014) and theoretical ones with an empirical application (Erol et al., 2011; Govindan et al., 2013).

The proposed models and indicators were not developed to specifically address a given context, except for a few cases. As for sectors, contributions took up manufacturing in general (Thakkar et al., 2009), or a specific sector, among them food (Sufiyan et al., 2019), textile (Charkha and Jaju, 2015) and automotive (Gopal and Thakkar, 2015); regarding the geographical area, contributions mainly addressed Asia (Xu et al., 2016); about firms' dimension, only two contributions were specifically developed for Small-Medium Enterprises (SMEs) (Faisal, 2012; Thakkar et al., 2009).

From an empirical perspective, authors explored several contexts of applications. Specific industries were investigated, among them automotive (Büyüksaatçi Kiriş et al., 2020), textile (Verdecho et al., 2012), plastic (Xu et al., 2016), as well as the manufacturing sector in general (Chia et al., 2009); as for geographical area, authors conducted studies in single countries in Europe - among them Italy and Portugal (Ferreira et al., 2016; Marconi et al., 2017), Asia – among them India and Thailand (Malviya and Kant, 2019; Sopadang et al., 2017), and the Middle East (Tajbakhsh and Hassini, 2015); few contributions focused on a particular size, with examples on SMEs (Bhagwat and Sharma, 2007b; Faisal, 2012), Medium Enterprises (Erol et al., 2011) and Large Enterprises (Jalali Naini et al., 2011; Olugu and Wong, 2012).

Authors and Date	Organisation of Indicators	Number of indicators	Characterisation of Indicators	Perspective on sustainability	Intersections of sustainability areas
Beamon (1998)	Categorisation	9	-	-	-
Beamon (1999)	Categorisation	9	-	-	-
Brewer and Speh (2000)	BSC	16	-	-	-
Gunasekaran et al. (2001)	SCOR	40	Decision level; Financial base	-	-

Shah and Singh (2001)	List	11	-	-	
Chan (2003)	Categorisation	32	Measurement base	-	-
Clift (2003)	TBL	2	-	3 Pillars	Economic with environmental; Social
Hervani et al. (2005)	BSC; list	29	-	Environment	-
Shepherd and Günter (2006)	SCOR	129	Components of performance; Measurement base	-	-
Aramyan et al. (2007)	Categorisation	32	-	-	-
Bhagwat and Sharma (2007a)	BSC	54	-	-	-
Bhagwat and Sharma (2007b)	Decision level	34	Financial base	-	-
Gunasekaran and Kobu (2007)	List	26	BSC; SCOR; Components of Performance; Decision level; Financial base; Measurement base	-	-
Hwang et al. (2008)	SCOR	55	Components of Performance	-	-
Chia et al. (2009)	BSC	15	-	-	-
Sambasivan et al. (2009)	Categorisation	159	-	-	-
Thakkar et al. (2009)	BSC and SCOR	29	-	-	-
Xu et al. (2009)	Categorisation	10	-	-	-
Bigliardi and Bottani (2010)	BSC	28	-	-	-
Sloan (2010)	TBL	43	Categorization	3 Pillars	-
Erol et al. (2011)	TBL	36	-	3 Pillars	-
Hadiguna et al. (2011)	SCOR	23	Decision Level; BSC	-	-
Hsu et al. (2011)	BSC (modified)	25	-	General	-
Lauras et al. (2011)	Categorisation	10	-	-	-
Jalali Naini et al. (2011)	BSC	11	-	Environment	-
Stefanović and Stefanović (2011)	BSC	10	Components of performance	-	-
Bai et al. (2012)	Components of performance	59	-	Environment	-
Faisal (2012)	TBL	13	-	3 Pillars	No but interdependencies
Hassini et al. (2012)	List	157	-	3 Pillars	-
Olugu and Wong (2012)	Categorisation	49	-	Economic; Environment	
Uysal (2012)	TBL + Resources	30	-	3 Pillars	-
Verdechoet al. (2012)	TBL	12	-	3 Pillars (Financial pillar)	-
Yakovleva et al. (2012)	TBL	9	-	3 Pillars	No but relative importance
Zailani et al. (2012)	TBL + Operations	14		3 Pillars	No but interdependencies
Büyüközkan and Çifçi (2013)	TBL	12	-	3 Pillars	-
Govindan et al. (2013)	TBL	51	-	3 Pillars	-
Reefke and Trocchi (2013)	BSC, Categorisation	43	Resource dependence; Transaction costs; Resource-based view; Population ecology	General	-
Bhattacharya et al. (2014)	Categorisation	16	-	3 Pillars	-
Charkha and Jaju (2014)	Categorisation	52	-		
Schaltegger and Burritt (2014)	BSC	23	-	-	-

Shafiee et al. (2014)	BSC	144	-	-	-
Chardine-Baumann and Botta-Genoulaz (2014)	TBL	65	-	3 Pillars	-
Mishra and Sharma (2014)	Categorisation	20	-	-	-
Ortas et al. (2014)	List	27	-	-	-
Varsei et al. (2014)	TBL	10	-	3 Pillars	-
Ahi and Searcy (2015)	List	26	TBL, Types, frequency rate, other characteristics	3 Pillars	No, but impact of indicators on more than one pillar
Charkha and Jaju (2015)	BSC	35	-	-	-
Eskafi et al. (2015)	BSC	12	-	-	-
Gopal and Thakkar (2015)	TBL + Technological and Political	42	-	3 Pillars	-
Sellitto et al. (2015)	SCOR	17	Component of performance	-	-
Subramanian and Gunasekaran (2015)	SCOR	99	-	3 Pillars	-
Tajbakhsh and Hassini (2015)	TBL	16	According to SC's tiers	3 Pillars	-
Ferreira et al. (2016)	BSC	15	-	Environment	-
Xu et al. (2016)	TBL	14	-	3 Pillars	No but relative importance
Liebetruth (2017)	Categorisation; Decision level	73	-	General	-
Marconi et al. (2017)	Categorization	20	-	Environment (using traceability)	-
Sopadang et al. (2017)	TBL	14	-	3 pillars	-
Stindt (2017)	Categorization	28	-	Ecological; Social	-
Izadikhah and Saen (2018)	TBL	46	-	3 Pillars	-
Popovic et al. (2018)	Categorization	31		Social	
Baba et al. (2019)	TBL	113	Decision level	3 Pillars	-
Malviya and Kant (2019)	BSC Modified	26	-	Environmental	-
Sangwan et al. (2019)	TBL	121	-	3 Pillars	-
Sufiyan et al. (2019)	Categorization	18	-	-	-
Susanty et al. (2019)	TBL	11	-	3 Pillars	-
Büyüksaatçi Kiriş et al. (2020)	Categorization	29	SCOR modified	3 Pillars	-
Narimissa et al. (2020)	TBL	88	Categories	3 Pillars	-
Said et al. (2020)	Categorization	60	-	Social; Environment	-
Verdecho et al. (2020)	BSC modified	24	-	3 Pillars	-

Table 2. Details of the selected contributions - Content. For each contribution considered for the literature background analysis, the following are provided: Organization of indicators, Number of indicators, Characterization of Indicators, Perspective on sustainability, Intersections of sustainability areas.

Authors and Date	Focus	Application in the overall SC	Theoretical development	Empirical application
Beamon (1998)	SC design and analysis	Not clear	-	-
Beamon (1999)	Overall SC	Not clear	-	-
Brewer and Speh (2000)	Overall SC from single firm's perspective	Not clear	-	-
Gunasekaran et al. (2001)	Overall SC	Not clear	-	-
Shah and Singh (2001)	Internal SC	-	-	Paint industry
Chan (2003)	Overall SC	No, perspective of the manager of a specific firm within the SC	-	Electronic and delivery service
Clift (2003)	Impact of the SC meant as impact of the specific product	Not clear	-	-
Hervani et al. (2005)	Overall SC	Not clear Further research should focus on inter-organizational performance management and measurement, managing entire supply chains and not only the single dyadic relationship	-	-
Shepherd and Günter (2006)	Overall SC	Not clear Further research should consider developing measures of SC relationships and the SC as a whole	-	-
Aramyan et al. (2007)	Overall SC	SC members should have a common set of performance indicators helping to compare the performance, besides their own set The combination of different indicators into a performance function could represent a difficulty determining the performance of the entire SC.	Agri-food	Netherlands and Germany
Bhagwat and Sharma (2007a)	Single firm	Not clear, application in 3 different SMEs	-	Welding, Iron, Wheels; India; SMEs
Bhagwat and Sharma (2007b)	Logistic and SC (meant as extended enterprise)	Not clear, the application is performed in a single SME	-	India; SMEs
Gunasekaran and Kobu (2007)	SC and logistics	Not clear	-	-
Hwang et al. (2008)	Sourcing process	-	TFT-LCD; Taiwan	TFT-LCD; Taiwan
Chia et al. (2009)	Overall SC	Each tier applies the same BSC in order to obtain the overall evaluation	-	Diverse; Singapore; Diverse
Sambasivan et al. (2009)	Overall SC	Not clear, application in one manufacturing industry	-	Hard disk; Malaysia; Large
Thakkar et al. (2009)	Overall SC	No clear, application from the perspective of a single SME	Manufacturing; SMEs	Manufacturing; India; SMEs
Xu et al. (2009)	Overall SC	Not clear, application in 6 focal firms of as many SCs	-	Furniture; China
Bigliardi and Bottani (2010)	Overall SC	Not clear, application is single firms	Food	Food; Italy; Large
Sloan (2010)	Overall SC	Not clear Analyses of specific SCs should be addressed in future research, going beyond the mere development of analytical models	-	-
Erol et al. (2011)	Overall SC	Not clear, in the application entails the data are retrieved from the retailer.	-	Grocery retailer; Turkey; Medium
Hadiguna et al. (2011)	Overall SC	No clear	Automotive	
Hsu et al. (2011)	Single firm	-	Semiconductor	-
Lauras et al. (2011)	Overall SC	Inclusion of different tiers, but with a specific detail on the process "to make".	-	Pharmaceutical
Jalali Naini et al. (2011)	Overall SC (focal	-	-	Automotive; Iran;

	firm's perspective)			Large
Stefanović and Stefanović (2011)	Overall SC	Not clear in terms of measurement but using the proposed systems all parties in a SC can track the real-time flow of goods, money, information.	-	-
Bai et al. (2012)	Overall SC	No clear	-	-
Faisal (2012)	Overall SC	Not clear, application in single SMEs (manufacturer)	SMEs	Apparel, Food, Plastic; SMEs
Hassini et al. (2012)	Overall SC	Future research should develop principles considering the intricacies of SC structures that distinguishes them from individual firms.	-	-
Olugu and Wong (2012)	Closed- loop (single firm's perspective)	No clear, application in a single firm	Automotive	Automotive, Malaysia; Large
Uysal (2012)	Overall SC	Not clear, the application in 3 firms of the same SC is not completely detailed	-	-
Verdechoet al. (2012)	Overall SC	Not clear, but the importance of collaboration is highlighted. The local optimization lead to an overall optimization. The provided tool helps the single firms in critical elements of sustainability.	-	Automotive
Yakovleva et al. (2012)	Overall SC	No real application within firms (analysis performed on data at a National level). Moreover, no measurement of indicators, but evaluation of their relevance in the different processes of a SC.	Food	Chickens and potatoes; UK
Zailani et al. (2012)	Practices	No clear	-	-
Büyüközkan and Cifçi (2013)	Overall SC	Not clear, application from the logistic provider's perspective	-	Non-food logistic; Turkey; Large
Govindan et al. (2013)	Supplier selection	-	-	-
Reefke and Trocchi (2013)	Overall SC	Not clear	-	-
Bhattacharya et al. (2014)	Overall SC	Not clear, application in a single firm	-	Carpet manufacturing; UK
Charkha and Jaju (2014)	Overall SC	Not clear	Textile; India	-
Schaltegger and Burritt (2014)	Focal firm (influencing the design and actions of the overall SC)	-	-	-
Shafiee et al. (2014)	Overall SC	Not clear, the SC is divided in stages representing the for perspectives of BSC and specific indicators for each perspective are evaluated	Food	Food; Iran
Chardine-Baumann and Botta-Genoulaz (2014)	Practices	No clear	-	-
Mishra and Sharma (2014)	Overall SC	No clear, application from the perspective of the manufacturer	-	Paint industry; India
Ortas et al. (2014)	Sustainable SC practices' effect on financial indicators	Not clear The evaluation of sustainability in single firms can help considering the financial benefits of implement sustainability practices within a SC	-	-
Varsei et al. (2014)	Overall SC (focal firm's perspective)	The focal firms score the suppliers according to the different indicators	-	Raw material suppliers (no detail) in Asia
Ahi and Searcy (2015)	Overall SC	Further research should determine the level of impact/ contributions individual organizations or SC must make to be deemed sustainable or not	-	-
Charkha and Jaju (2015)	Overall SC	Not clear, application consider the evaluation of the SC from a single SME perspective	Textile	Textile; India; SMEs
Eskafi et al. (2015)	Focal firm	-	Food	Food; Iran; Large
Gopal and Thakkar (2015)	Overall SC	Not clear, application in a single firm	Automotive	Automotive; India
Sellitto et al. (2015)	Overall SC	3 tiers SC, each tier has specific indicators according to its role respecting the focal firm	Footwear	Footwear
Subramanian and Gunasekaran (2015)	Overall SC	Not clear	-	-
Tajbakhsh and Hassini (2015)	Overall SC	2 tiers SC, each tier has specific indicators according to its role respecting the focal firm	-	Beverage; Iran
Ferreira et al. (2016)	Overall SC	Not clear, the application is in the automotive sector as usually the sector is characterized by a	-	Automotive; Portugal

		central strong firm with strong influence on the few present suppliers		
Xu et al. (2016)	Overall SC	Not clear, application in a single firm	Plastic film; China	Plastic film; china; Large
Liebetruth (2017)	Overall SC	Not clear	-	-
Marconi et al. (2017)	Overall SC	List of clear action to be undertaken by each actor, including data collection, monitoring and sharing. The application the downstream is not considered.	-	Shoes-maker; Italy
Sopadang et al. (2017)	Overall SC	Not clear. Different stakeholders have different indicators, but it is not clear who was investigated and from where the data were retrieved.	-	Sugar; Thailand
Stindt (2017)	Overall SC	Not clear. It is more a decision-making tool for increase corporate sustainability alignment along the SC	-	-
Izadikhah and Saen (2018)	Overall SC	Two-stage SC, but very little data are collected (10 indicators)	-	Pasta; Iran
Popovic et al. (2018)	Overall SC	3 tiers SC, data retrieved from reports		Industrial sector
Baba et al. (2019)	Overall SC	Not clear	Food; Malaysia	-
Malviya and Kant (2019)	Overall SC	Not clear, valuation of 4 single firms at different stages of automotive SC (not clear if from the same SC)	-	Automotive; India
Sangwan et al. (2019)	Overall SC	Not clear, application entails expert consultation	-	Cement
Sufiyan et al. (2019)	Overall SC	Not clear	Food	-
Susanty et al. (2019)	Overall SC	Not clear, the application is performed through the perspective of governmental representatives	Beef Production	Beef production; Indonesia
Büyüksaatçi Kiriş et al. (2020)	Suppliers evaluation and development (no selection)	-	-	Automotive
Narimissa et al. (2020)	Overall SC	Not clear	Oil company; Iran	-
Said et al. (2020)	SC disclosure level	Focus on the single firm that evaluate its SC	-	
Verdecho et al. (2020)	Suppliers selection	-	-	Agri-food

Table 3. Details of the selected contributions - Context. For each contribution considered for the literature background analysis, the following are provided: Focus, Application in the overall SC, Theoretical development -Industry, Geographical area and size, Empirical application - Industry, Geographical area and size.

2.2 Analysis of the selected contributions – Performance Indicators

From the selected contributions detailed in Table 2 and Table 3, 2,661 single sustainability performance measures were retrieved. Due to high heterogeneity, we classified the indicators in different "*performance areas*" and identified the specific "*performance*" related to each performance area. Furthermore, for each performance, different "*performance indicators*" can be related, in turn, gaugeable adopting different "*performance measures*". Performance areas and performance were deductively defined based on the reviewed contributions reported in Table 2 and Table 3, grounding on the approach of Saeed and Kersten (2017) and Stindt (2017). The retrieved indicators and measures were pigeonholed according to the identified performance areas and performance.

An example of the procedure followed for the classification of indicators is reported in detail for the performance area *costs*, that emerged as relevant for SC. The reviewed literature considers a wide and comprehensive spectrum of costs associated with the operating of a SC (Charkha and Jaju, 2014), and the total SC cost performance is considered by almost all contributions selected. A large share of contributions consider a general *minimization of cost* (Büyüközkan and Çifçi, 2013), or refer straightforwardly to *SC management cost* (Sangwan et al., 2019), while other provide a more detailed list of costs. As the single costs considered in the literature show a high heterogeneity, we decided to analyse them according to the direct/indirect classification (Xu et al., 2009), adding cost variance as a

third performance. Direct costs gather indicators spanning over the *source-make-deliver-return* SCOR structure, as *supply cost* (Tajbakhsh and Hassini, 2015), *production cost* - to which *labour cost* is strictly related (Hervani et al., 2005), *inventory cost* including obsolescence, opportunity and Stockout costs (Büyüksaatçi Kiriş et al., 2020), *distribution and transportation cost* (Bigliardi and Bottani, 2010), *disposal cost* (Bhattacharya et al., 2014) and *return cost* (Liebetruth, 2017). Indirect costs consider the importance of *transaction cost* (Aramyan et al., 2007), *information carrying cost* (Charkha and Jaju, 2015), *sales and advertisement cost* (Mishra and Sharma, 2014), *training cost* (Narimissa et al., 2020) and *other overhead costs* (Charkha and Jaju, 2014). Cost variance, lastly, includes *risk* (Bhagwat and Sharma, 2007b) and *variations against budget* (Sellitto et al., 2015).

Applying the same procedure on all the relevant performance areas and performance emerging from the literature, we retrieved 15 performance areas to which a total of 63 performance are related, with 326 PIs in the overall. More in-depth, the following performance areas with the related performance were deemed as relevant for measuring sustainability in SCs, according to the review literature:

- *Economic and Finance*. It measures the success of a firm's activities (Xu et al., 2016). The literature addressed this performance area considering market (Sangwan et al., 2019), financial performance (profitability) (Sopadang et al., 2017), economic performance (Hassini et al., 2012), context characteristics (Reefke and Trocchi, 2013) and corporate image (Subramanian and Gunasekaran, 2015).
- *Costs*. It relates to the costs associated with the operating of a SC (Charkha and Jaju, 2014). As the costs considered in the literature are rather heterogeneous: they were analysed according to the direct/indirect classification (Xu et al., 2009), adding cost variance as a third performance (Bai et al., 2012).
- *Management*. It plays a relevant role in the promotion (Gopal and Thakkar, 2016a; Marshall et al., 2015) and implementation (Luthra et al., 2018) of sustainability practices in a SC. The literature considered awareness (Hsu et al., 2011), procedures (Uysal, 2012), motivational effort (Olugu and Wong, 2012) and ethical conduct (Hsu et al., 2011).
- *Production*. The production performance area is fundamental for properly manage SCs (Bhagwat and Sharma, 2007b), and, if shared across the SC, can lead to improved sustainability (He et al., 2019). Production performance area addresses production performance (Malviya and Kant, 2019), process (Charkha and Jaju, 2014), schedule (Sambasivan et al., 2009), Research and Development (R&D) (Subramanian and Gunasekaran, 2015), Information Technology (IT) (Govindan et al., 2013) and production characteristics (Izadikhah and Saen, 2018).
- *Product*. The product performance area is fundamental for properly manage SCs (Olugu and Wong, 2012), and, if shared across the SC, can lead to improved sustainability (He et al., 2019). For this performance area, product characteristics (Ahi and Searcy, 2015), defectiveness (Tajbakhsh and Hassini, 2015), innovation (Thakkar et al., 2009), design (Schaltegger and Burritt, 2014) and responsibility (Varsei et al., 2014) are underlined as relevant.
- *Quality*. Quality refers to the standard of a product and service provided, linked to the customer satisfaction level and fitness to use (Chan, 2003; Charkha and Jaju, 2014). The quality performance area is tackled focusing on purchase quality (Shafiee et al.,

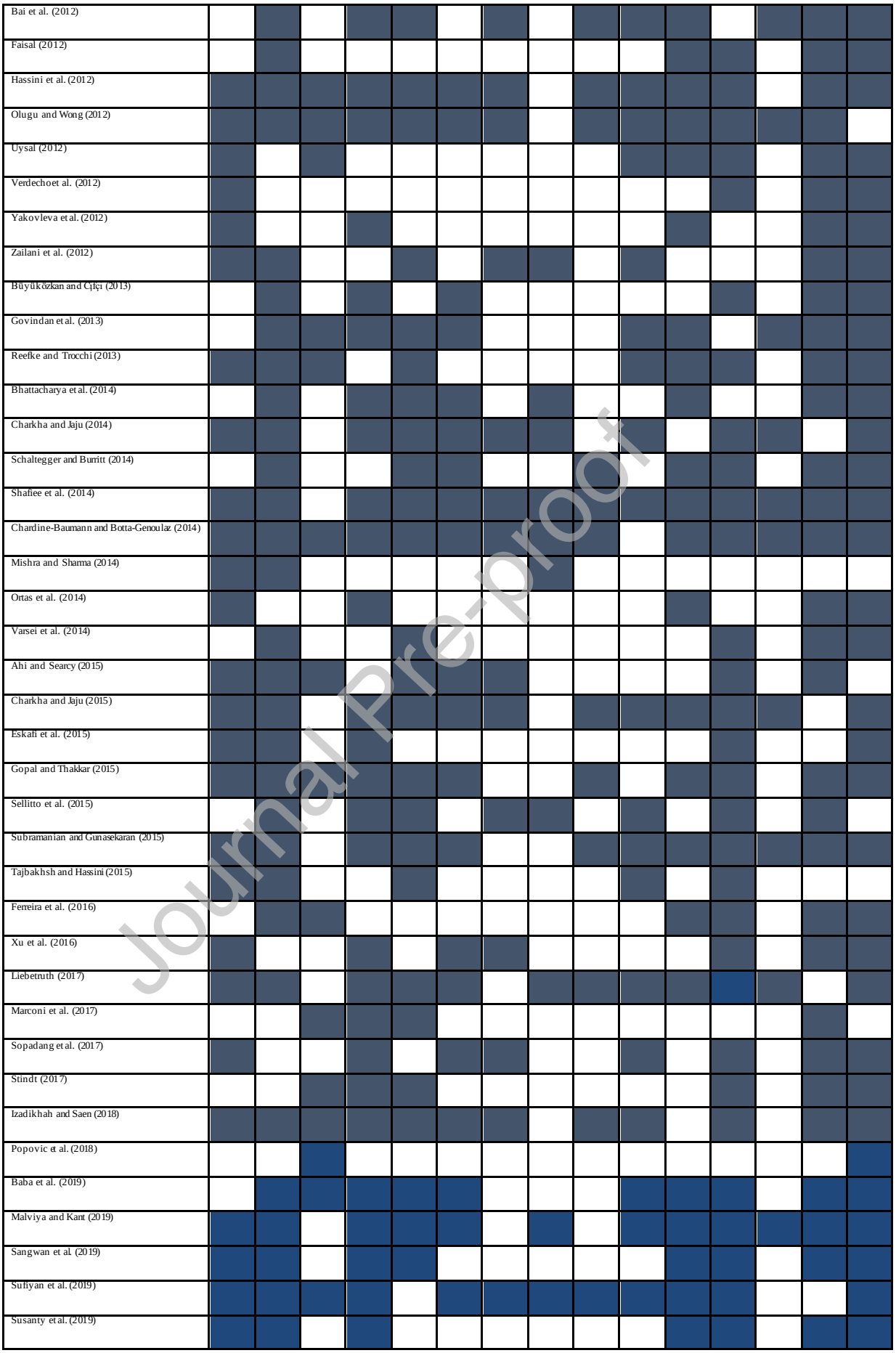
2014), product quality (Subramanian and Gunasekaran, 2015), returns service quality (Chia et al., 2009) and quality management (Sloan, 2010).

- *Flexibility*. Flexibility refers to the ability of the SC to respond to market changes or to gain and maintain a competitive advantage (Supply Chain Council, 2012). The performance identified are production flexibility (Sufiyan et al., 2019), SC flexibility (Stefanović and Stefanović, 2011) and operation flexibility (Chan, 2003).
- *Inventory*. Inventory in the SC ranges from raw materials to finished products (Shafiee et al., 2014). The effective management of inventory is critical, being related to customer service requirements (Bhagwat and Sharma, 2007b). The identified performance are inventory level (Sellitto et al., 2015), inventory coverage (Sambasivan et al., 2009), and inventory performance (Xu et al., 2016).
- *Information*. It relates to the data and knowledge flowing along the tiers of a SC (Sambasivan et al., 2009). Performance considered by the literature refers to the extent of sharing of information (Susanty et al., 2019), and to their characteristics (Narimissa et al., 2020).
- *Order procedures and delivery*. It relates to the soundness of order procedures and delivery (Bhagwat and Sharma, 2007b; Charkha and Jaju, 2014). This performance area addresses the order performance, invoice (Liebetruth, 2017), delivery performance (Büyüksaatçi Kiriş et al., 2020), timeliness of the delivery (Sopadang et al., 2017), and quality of the delivery (Chan, 2003).
- *Suppliers*. Suppliers are a force acting towards improved sustainability (Carter and Dresner, 2001; Gopal and Thakkar, 2016a), both in individual firms and SCs (He et al., 2019). As supplier performance evaluation is not enough anymore and the partnership should be considered as well (Bhagwat and Sharma, 2007b), suppliers performance area can be then addressed considering dependency (Yakovleva et al., 2012), suppliers' performance (Schaltegger and Burritt, 2014), suppliers' collaboration (Sambasivan et al., 2009), SC characteristics (Said et al., 2020), and reverse SC (Erol et al., 2011).
- *Customers*. Customers exert great pressure towards improved sustainability (Luthra et al., 2018) both in individual firms and SCs (He et al., 2019). The customer performance area includes satisfaction (Sopadang et al., 2017), service (Izadikhah and Saen, 2018) and characteristics (Baba et al., 2019).
- *SC response time*. The SC response time performance area is influenced by the total order lead time - the time elapsing between the customer's order and delivery of the goods (Gunasekaran et al., 2001) - and the order cycle time plays a relevant role in it (Bhagwat and Sharma, 2007b). Shepherd and Günter (2006) linked it to the ability of a SC to deliver high customer service. The performance identified is related to cycle time (Gunasekaran et al., 2001) and lead time (Subramanian and Gunasekaran, 2015).
- *Environment*. It assesses the environmental awareness of the SC (Sarkis and Dhavale, 2015). The environment performance area addresses resource consumption (Verdecho et al., 2020), recycling (Bhattacharya et al., 2014), emissions, waste (Chia et al., 2009), environmental management (Gopal and Thakkar, 2015), environmental cost (Ortas et al., 2014) and environmental ethical conduct (Izadikhah and Saen, 2018).

- *Social.* It assesses the social consequences of the firm's activity on its stakeholders (Chardine-Baumann and Botta-Genoulaz, 2014). Social performance includes external stakeholders (Zailani et al., 2012), community (Faisal, 2012), employees (Popovic et al., 2018), social management (Stindt, 2017), social related cost (Subramanian and Gunasekaran, 2015) and ethical conduct (Hsu et al., 2011).

The detail of the performance areas considered by each contribution is reported in Table 4. The detail of the specific PIs for each performance with the full list of references is reported in Appendix I.

	Performance areas addressed by the literature														
	finance	*Costs*	*Management*	*Production*	*Product*	*Quality*	*Flexibility*	*Inventory*	*Information*	*and delivery*	*Suppliers*	*Customers*	*SC response time*	*Environment*	*Social*
Beamon (1998)	■	■		■				■		■		■			
Beamon (1999)	■	■						■		■		■	■		
Brewer and Speh (2000)	■	■		■	■		■			■		■	■		
Gunasekaran et al. (2001)	■	■		■	■	■	■	■		■	■	■	■		
Shah and Singh (2001)	■	■						■							
Chan (2003)		■		■	■		■	■	■	■		■	■	■	
Clift (2003)				■											■
Hervani et al. (2005)	■	■				■	■				■	■		■	■
Shepherd and Günter (2006)	■	■		■	■	■	■	■	■	■	■	■	■	■	■
Aramyan et al. (2007)	■	■				■	■	■		■		■	■	■	■
Bhagwat and Sharma (2007a)	■	■		■	■	■	■	■		■	■	■	■		
Bhagwat and Sharma (2007b)	■	■		■	■		■		■	■	■	■	■		
Gunasekaran and Kobu (2007)	■	■	■	■	■	■	■			■		■	■		
Hwang et al. (2008)	■	■	■		■		■	■		■	■		■		
Chia et al. (2009)	■	■				■				■		■		■	■
Sambasivan et al. (2009)	■	■		■	■		■	■	■	■	■	■	■		
Thakkar et al. (2009)	■	■		■	■	■	■	■		■	■	■			■
Xu et al. (2009)	■	■					■			■			■		■
Bigliardi and Bottani (2010)	■	■		■	■	■	■	■		■	■	■	■		
Sloan (2010)	■	■	■	■	■	■					■	■	■	■	■
Erol et al. (2011)	■		■	■						■	■	■		■	■
Hadiguna et al. (2011)	■	■		■	■	■				■	■	■	■	■	
Hsu et al. (2011)	■		■	■	■						■	■		■	■
Lauras et al. (2011)		■		■		■		■			■		■		
Jalali Naini et al. (2011)		■					■		■		■			■	
Stefanović and Stefanović (2011)	■	■					■			■	■		■		



Büyüksaatçi Kiriş et al. (2020)		■	■	■	■	■				■			■		■	
Narimissa et al. (2020)		■		■	■	■	■		■	■	■	■	■	■	■	
Said et al. (2020)		■	■			■					■	■			■	
Verdecho et al. (2020)	■	■			■					■	■	■		■	■	

Table 4. Detail of the performance areas addressed by the selected contributions.

2.3 Emerging gaps

Analysing the extant literature, the lack of a general set of KPIs able to address all the aspects related to the measurement of sustainability in industrial SC emerged. The literature background analysis allowed in particular to highlight more specific additional open issues.

1. *Holistic perspective on sustainability*: literature contributions still do not provide a holistic and balanced perspective on the three TBL pillars (Taticchi et al., 2015; Xu et al., 2016) (see Table 2).
    - The economic pillar has been so far investigated more than the other two (Shepherd and Günter, 2006; Stindt, 2017), focusing particularly on the financial indicators (Chia et al., 2009). The environmental pillar has been largely investigated as well (Babu and Mohan, 2018), having acquired recently prominence with the concept of "green" SC (Marshall et al., 2015; Varsei et al., 2014). The social pillar is the weakest link of the chain, calling for additional research efforts (Cole and Aitken, 2019; Munny et al., 2019) that started to be carried out recently. These two specific insights can be appreciated in Table 4, with more detail provided in Appendix I.
    - Industrial sustainability-related literature largely underlined the necessity to address the pillars of sustainability in a holistic and integrated manner (Cagno et al., 2019). This aspect seems to be still absent in the specific SC discussion. Some contributions recently started investigating the relationships among different pillars (Macchion et al., 2017; Marshall et al., 2015), while also the impact of specific indicators on different pillars (Ahi and Searcy, 2015; Zailani et al., 2012). However, none develops a holistic and balanced perspective on sustainability, not accounting for intersections and interrelations among the different pillars (see Table 2).
2. *Long-term strategy and sustainability orientation*: The success of a strategy formulation depends on the alignment and balance of the operational, tactical and strategical decision levels (Gunasekaran et al., 2001; Gunasekaran and Kobu, 2007; Thakkar et al., 2009). The developed models for PIs, however, seem to lack a connection with a long-term strategy (Shepherd and Günter, 2006), as only a few contributions consider the different decision level (see Table 2). The lack of such an approach also negatively impacts on the addressing of a strong long-term sustainability perspective (Carter and Rogers, 2008; Morali and Searcy, 2013).
3. *Balance of the performance indicators*: the concept of balance is particularly relevant (Gunasekaran et al., 2001). Besides the abovementioned balance among TBL pillars and decision levels, models should consider the balance between financial and non-financial indicators and among the different SCOR processes and linked components of performance (Supply Chain Council, 2012). These aspects were already highlighted by Gunasekaran and Kobu (2007), and the review of the literature confirmed they are

subsistent. Although balancing financial and non-financial indicators may help reach higher performance (Said et al., 2003) and an exclusive focus on financial indicators may produce a misleading picture of actual SC performance (Chen and Paulraj, 2004; Shepherd and Günter, 2006), many contributions have not considered this aspect as a base for the development models (see Table 2). As the balance among SCOR locations of measures and components of performance, could facilitate the integration of various functional areas within a SC (Kocaoğlu et al., 2013), some contributions developed their proposal on the SCOR model (Hwang et al., 2008; Sellitto et al., 2015), but too many still do not (see Table 2). Lastly, interesting to note, none of the reviewed models was simultaneously covering all the performance areas identified from the literature, as it can be inferred by Table 4.

4. *Number of performance indicators*: different voices raised the issues of how many indicators a model should entail (Searcy and Roca, 2012). As largely suggested, a model should propose a manageable number of indicators (Bhagwat and Sharma, 2009; Sambasivan et al., 2009), possibly allowing firms to start with a limited set of indicators, moving then to a larger one (Eckerson, 2009; Searcy and Ahi, 2014), as too many indicators could distract from pursuing a focused strategy (Epstein and Widener, 2010). There is no agreement in the literature about the threshold number of the "trivial few" (Thakkar et al., 2009) - see (Collins et al., 2016; Krajnc and Glavič, 2003; Siskos, 2014): trade-off arises then between an outright view of sustainability performance – for which a considerable amount of indicators is required, and the slenderness of the decision-making process (Gunasekaran et al., 2001; Medini et al., 2015) - maximum effectiveness and minimum operating cost (Gunasekaran and Kobu, 2007). For the analysed contributions PIs range from a minimum of 2 to a maximum of 159 (see Table 2). The issue of the number of indicators becomes even more crucial by considering the massive presence of SMEs within SCs (Faisal, 2012), usually typified by limited available of resources (as, money, staff and time) to measure performance in an appropriate and effective manner (Borga et al., 2009).
5. *Focus on the overall SC*: contributions are still way too much focused on local optimization (mainly addressing focal firm), rather than on the optimization of the entire SC (Masi et al., 2018), which should also comprehend a multi-tier perspective (Maestrini et al., 2017), leading to the still open point on how the indicators should be measured along the SC (Qorri et al., 2018). As an example, the routing flexibility PI (Chan, 2003) proposes a local and internal optimization, rather than a systemwide one (Lambert and Pohlen, 2001; Taticchi et al., 2013). Despite the ambitious objective of almost all contributions to assess the performance of the overall SC, the empirical applications are still conducted from the perspective of focal firms, not clearly discussing how to apply the proposed PIs along the overall SC (see Table 3). Some authors, however, provide some first example, as Chia et al. (2009) through the application of the same BSC to all the tiers of a SC, or Sellitto et al. (2015) analysing three-tiers of a SC, although proposing specific PIs to each tier (see Table 3).
6. *Appropriate for application in different contexts:* too little attention has been paid so far on developing a model of PIs applicable in different contexts. Indeed, as many models were developed for a general context, their validation or application took place in limited

and specific ones, as Sangwan et al. (2019) (see Table 3). Such model of PIs would allow for a cross-sectoral analysis with a side policy-making purposes, considering the great heterogeneity of SCs in different sectors, geographical locations and firm sizes (Grimm et al., 2014; Plambeck, 2012; Sarkis, 2012).

To tackle the research gaps, the aim of the present paper is to propose a set of KPIs for evaluating the sustainability performance in a SC, suitable for application in SCs with different characteristics, integrating into a single set the aforementioned issues deemed crucial by previous literature.

3 Methods

The rationale for the development of the proposed set of KPIs was based on two steps: first, the identification of an appropriate structure for the set; second, the definition of a method for the identification and selection of the most appropriate KPIs to be included in the set. The set has been then tested against a theoretical and empirical validation. As for the empirical validation, we assured to cover, from a literature perspective, the gaps identified after the literature review; this process goes hand in hand with the identification and selection of the most appropriate KPIs to be included in the set. By taking inspiration from previous literature (Voss et al., 2002), we then assessed the capability of the set to survive the test of empirical data and real-cases confrontation. The empirical validation was assessed through case studies – the preferred method for theory testing (Hillebrand et al., 2001) – also allowing to effectively corroborate insights from different actors in the SC, a relevant aspect for understanding the real usefulness and applicability of the proposed set of KPIs (Maestrini et al., 2018).

A graphical representation of the methods adopted is reported in Figure 1, while the following paragraphs offer details on the different steps.

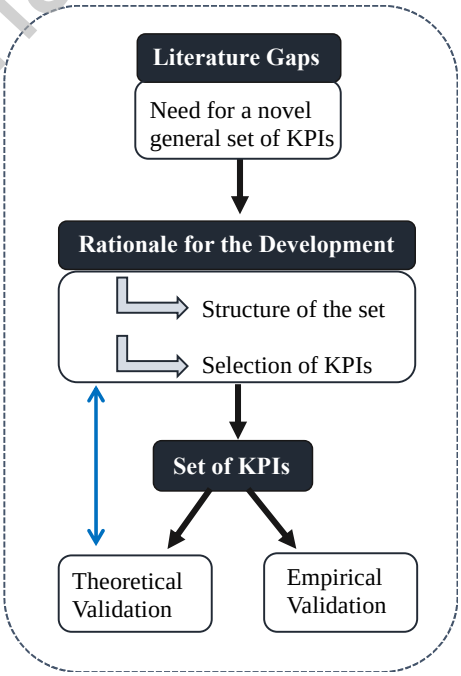


Figure 1. Methods employed in the present research.

3.1 Rationale for the development

The present section introduces the rationale for the development of the set of KPIs to measure sustainability along the SC proposed in the present work. In the following, we highlighted the structure of the set of KPIs (Section 3.1.1) and the rationale for the selection of specific KPIs, offering an example of application (Section 3.1.2).

3.1.1 Structure of the set of KPIs

The first step was to identify a structure for the set of KPIs. As for previous literature (Table 2), the BSC and the SCOR resulted highly used as theoretical frameworks.

The BSC is largely recognized as a management system facilitating the implementation of a strategy (Beske-Janssen et al., 2015; Hoque, 2014); as it goes beyond the traditional accounting system (Reefke and Trocchi, 2013), also considering non-financial aspects, it maintains a balance between short and long-term objectives (Bhagwat and Sharma, 2007b; Shafiee et al., 2014). The traditional Kaplan and Norton (1992)'s BSC is organized around four perspectives, namely: Financial, Customer, Internal processes, Learning and growth (Bigliardi and Bottani, 2010; Shafiee et al., 2014). As sustainability started to be incorporated in management tools, three different approaches were discussed for framing sustainability within the BSC (Hsu et al., 2011): incorporate environmental and social aspects within the already present perspectives (Ferreira et al., 2016); add a fifth non-market aspects related perspective (Reefke and Trocchi, 2013); add fifth and sixth perspectives related to social and environmental aspects (Verdecho et al., 2012). As the inclusion of environmental and social aspects in the traditional four perspectives may not sufficiently represent them (Reefke and Trocchi, 2013), the latter approach is deemed suitable for strategically coordinating and controlling relevant environmental and social aspects (Figge et al., 2002). Traditionally developed to be applied in firms, the BSC can also provide foundations for a strategic SC management system (Bhagwat and Sharma, 2007b). To include considerations of SC management, aspects related to coordination, instructional and partnership have been included in the BSC (Brewer and Speh, 2000; Liebetruth, 2017; Verdecho et al., 2012), or the same BSC had been applied to different entities of the SC (Chia et al., 2009), but the need for an adaptation of the traditional perspectives to apply the BSC at a SC decision level is still vivid (Liebetruth, 2017; Reefke and Trocchi, 2013).

The SCOR model, on the other side, is a standard framework enabling effective and collaborative SC management (Gulledge and Chavusholu, 2008) along the SC activities (Sellitto et al., 2015). The SCOR model indeed considers five business process types - Plan, Source, Make, Deliver and Return, while also addressing five strategic SC performance - traditionally Reliability, Responsiveness, Flexibility, Cost and Asset (Supply Chain Council, 2012), then adapted by specific contributions (Bai et al., 2012). Despite the SCOR importance for achieving operational improvements, it is not appropriate for the development of a comprehensive operations strategy, aligned with the firm's overall strategy (Stewart, 1997).

Considering the advantages and limitations of the BSC and the SCOR, a combination of the two could pursue the firm's strategy, allowing a balance among the different phases of a SC. A combined framework could help to focus on a long-term SC strategy, seeking a two-fold

aim: due to the SCOR foundation, it is a structured framework able to cover the entire SC (Balfaqih et al., 2016b); due to its BSC structure, it can align strategy and performance (Brewer and Speh, 2000), while also providing a balanced approach to the TBL pillars (Eskafi et al., 2015) – see (Epstein and Roy, 2003; Figge et al., 2002; Sloan, 2010).

An open issue still needs to be tackled as BSC and SCOR were mainly developed for use in medium and large firms, not taking into consideration the specific needs of smaller enterprises (Thakkar et al., 2009). Perforce, the set of KPIs should be simple to understand and easy to use, focusing on few but critical indicators (Chia et al., 2009; Thakkar et al., 2009). As previous literature suggests from 5 (Collins et al., 2016; Krajnc and Glavič, 2003) up to 60 (Globerson, 1985) indicators as the right number of PIs a model should entail, we deem a number between 20 and 40 to be an appropriate one, relying on the theoretical and empirical insights by Cagno et al. (2019) and Trianni et al. (2019).

3.1.2 Rationale for the selection of the KPIs

Identified the frame for the set, we proceeded to the selection of KPIs to include, so to provide a handy set of indicators, i.e. straightforward, easy-to-use and communicable (Faisal, 2012; Thakkar et al., 2009), while also covering the identified gaps. In doing so, we relied on Gunasekaran and Kobu (2007) for their structured and broadly valued approach (Ahi and Searcy, 2015; Balfaqih et al., 2016b; Taticchi et al., 2015), adding the environmental and social PIs emerged from the literature. Furthermore, during the overall selection process, we also considered the suggestions by Chia et al. (2009) and Reefke and Trocchi (2013) for the development of indicators for sustainability in SCs.

The rationale for the selection of indicators to include was based on different but parallel reasonings:

(i). We considered as a proxy of relevance the frequency of occurrence in the literature (Cagno et al., 2019; Veleva and Ellenbecker, 2001) and the prioritisation of indicators performed by several authors - please consider, for example (Aramyan et al., 2007; Chia et al., 2009; Stindt, 2017) - thus focusing on indicators acknowledged by previous literature as the most relevant ones (Ahi and Searcy, 2015).

(ii). We addressed the gaps that emerged from the conducted revision of the literature, particularly:

   a. To tackle the SC in the overall, as abovementioned, we considered the traditional SCOR processes, namely *plan*, *source*, *make*, *deliver* and *return* (Chehbi-Gamoura et al., 2019; Supply Chain Council, 2012), deeming a KPI able to foster integration and cooperation along the entire SC if able to cover more than one process, while also focusing on the coverage of the components of performance, namely *time*, *cost*, *quality*, *flexibility* and *asset* (Bai et al., 2012; Shepherd and Günter, 2006).
   b. To provide a balanced set of KPIs, we focused on the coverage of (b_1) the three TBL pillars and their intersections (Cagno et al., 2019; Trianni et al., 2017); (b_2) the different decision levels (Björklund et al., 2012); (b_3) and the diverse financial bases (Gopal and Thakkar, 2016b).

During the selection, we acknowledged that an indicator can be related to more than

one SCOR process, components of performance, TBL pillar, decision level or financial base.

An example is here reported for the selection of the KPIs *Inventory cost*.

(i). *Selection of relevant indicators*. Firstly, the literature reviewed allowed (see Table 2) to identify and retrieve 28 different performance measures related to inventory management (see Table 2). Among these performance measures, the most frequent one is *Inventory cost*. We pigeonholed the 28 performance measures according to 21 PIs. Among these, *Inventory cost* remains the most frequently cited. We also reorganized the 21 PIs in 3 performance, namely *Inventory cost*, *Inventory level* and *Inventory performance*. Among the three performance, since *Inventory cost* is still the most frequently cited, we thus deemed it to be a proper KPI for the proposed set. The steps and related details for the selection of the KPI are reported in Table 5. Secondly, we sought confirmation of our selection in previous literature: in this case, Gunasekaran et al. (2001) deemed *Inventory cost* as a KPI of fundamental importance to evaluate the cost associated with the inventory. Additionally, we also found confirmation of this in grey and industry-related literature (Kaçan, 2019; Stackpole, 2020).

(ii). *Addressing of the literature gaps.* We considered the capability of the selected KPI to cover the performance and performance areas presented in Section 2.2 (Table 4). The *Inventory Cost* KPI results able to cover the performance Direct cost; Inventory level; Inventory performance and the performance areas Cost and Inventory. This procedure is crucial to evaluate the coverage of the *Inventory Cost* KPI concerning the SCOR process and components of performance, as well as to identify which sustainability pillar in the TBL is most addressed by the KPI. In this case, *Inventory cost* is relevant in all the SCOR processes (Bigliardi and Bottani, 2010). Notably, addressing both the *cost* and *flexibility* components of performance (Gunasekaran and Kobu, 2007; Sellitto et al., 2015), it can impact the *financial* (Hadiguna et al., 2011), *internal process* (Shafiee et al., 2014) and *learning and growth* (Eskafi et al., 2015) BSC's perspectives. When considering sustainability pillars, *Inventory cost* is largely targeted as a financial indicator (Bhagwat and Sharma, 2007b). As a general KPI, more detailed aspects can be evaluated by focusing on specific inventories (Gunasekaran et al., 2001) - as raw material, finished goods of WIP (Shafiee et al., 2014), on the obsolescence cost (Gunasekaran and Kobu, 2007), and on costs related to the control of inventory (Shepherd and Günter, 2006), given the service level (Giannakis and Papadopoulos, 2016). The KPI straightforwardly affects the TBL's economic dimension (Xu et al., 2016), but can also impact the environmental one, as better inventory management could lead to lower space utilisation, emissions and waste level (Stindt, 2017; Xia and Li-Ping Tang, 2011). Finally, authors also noted that *Inventory cost* spans from the strategical to the operational decision levels (Liebetruth, 2017; Subramanian and Gunasekaran, 2015).

Performance (own organization)	*Performance indicator (own organization)*	Performance measures (as retrieved the literature)

Performance	Occurrence in the reviewed literature	Occurrence in the reviewed literature *	Performance indicator	Occurrence in the reviewed literature	Occurrence in the reviewed literature *	Performance measure	References	Occurrence in the reviewed literature	Occurrence in the reviewed literature *
Inventory cost	26.1%	58.1%	*Inventory cost*	26.1%	58.1%	Inventory cost	(Baba et al., 2019; Bai et al., 2012; Bhagwat and Sharma, 2007b; Bigliardi and Bottani, 2010; Chan, 2003; Charkha and Jaju, 2015, 2014; Eskafi et al., 2015; Faisal, 2012; Gunasekaran and Kobu, 2007; Liebetruth, 2017; Mishra and Sharma, 2014; Narimissa et al., 2020; Olugu and Wong, 2012; Sambasivan et al., 2009; Shafiee et al., 2014; Shepherd and Günter, 2006; Subramanian and Gunasekaran, 2015)	26.1%	58.1%
						Warehouse cost	(Chan, 2003; Charkha and Jaju, 2014; Sambasivan et al., 2009; Shepherd and Günter, 2006)	5.8%	12.9%
						Storage cost unit per volume	(Shepherd and Günter, 2006)	1.4%	3.2%
						Cost of storage (3rd part),	(Liebetruth, 2017)	1.4%	3.2%
			Inventory cost - WIP	1.4%	3.2%	Inventory cost WIP	(Shafiee et al., 2014)	1.4%	3.2%
			Inventory cost – Finished goods	1.4%	3.2%	Inventory cost finished goods in transit	(Shafiee et al., 2014)	1.4%	3.2%
			Inventory cost - Scrap	6.7%	12.9%	Inventory cost scrap	(Baba et al., 2019; Narimissa et al., 2020; Sambasivan et al., 2009; Shafiee et al., 2014)	6.7%	12.9%
			Inventory cost – Stock holding expenses	1.4%	3.2%	Opportunity cost	(Bhagwat and Sharma, 2007b)	1.4%	3.2%
			Inventory cost – Obsolescence	1.4%	3.2%	Obsolescence cost	(Gunasekaran and Kobu, 2007)	1.4%	3.2%
Inventory level	*11.6%*	*25.8%*	*Inventory level*	7.2%	16.1%	Inventory level	(Beamon, 1998; Bhagwat and Sharma, 2007a; Gunasekaran et al., 2001; Malviya and Kant, 2019; Sellitto et al., 2015)	7.2%	16.1%
			Inventory level- Incoming	2.9%	6.5%	Incoming stock level	(Sambasivan et al., 2009; Shafiee et al., 2014)	2.9%	6.5%
			Inventory level- incoming Finished products	4.3%	9.7%	Finished products inventory level	(Mishra and Sharma, 2014; Sambasivan et al., 2009; Shafiee et al., 2014)	4.3%	9.7%
			Inventory level- Raw material	4.3%	9.7%	Raw material inventory level	(Gunasekaran et al., 2001; Mishra and Sharma, 2014; Sambasivan et al., 2009)	4.3%	9.7%
			Inventory level- WIP	2.9%	6.5%	WIP inventory level	(Gunasekaran et al., 2001; Sambasivan et al., 2009)	2.9%	6.5%
			Inventory level- Semi-finished	2.9%	6.5%	Semi-finished inventory level	(Gunasekaran et al., 2001; Mishra and Sharma, 2014)	2.9%	6.5%
Performance	*24.6%*	*54.8%*	*Performance - Obsolescence*	7.2%	16.1%	Inventory obsolescence	(Beamon, 1998; Liebetruth, 2017; Sambasivan et al., 2009; Shafiee et al., 2014; Shepherd and Günter, 2006)	7.2%	16.1%
			Performance - Utilization	14.5%	32.3%	Inventory utilisation	(Shepherd and Günter, 2006)	1.4%	3.2%
						Inventory turnover ratio	(Bigliardi and Bottani, 2010; Charkha and Jaju, 2014; Liebetruth, 2017; Shepherd and Günter, 2006; Sufiyan et al., 2019; Thakkar et al., 2009; Zailani et al., 2012)	10.1%	22.5%
						Inventory days of supply	(Charkha and Jaju, 2014; Hwang et al., 2008; Mishra and Sharma, 2014; Sambasivan et al., 2009; Shepherd and Günter, 2006; Zailani et al., 2012)	8.7%	19.4%
						Inventory flow-time	(Shepherd and Günter, 2006)	1.4%	3.2%
			Performance - Stock out	14.5%	32.3%	Stock out	(Beamon, 1999; Chan, 2003; Charkha and Jaju, 2014; Sambasivan et al., 2009; Shepherd and Günter, 2006)	7.2%	16.1%
						Stock out cost	(Bhagwat and Sharma, 2007b; Gunasekaran and Kobu, 2007; Liebetruth, 2017; Sangwan et al., 2019; Shafiee et al., 2014)	7.2%	16.1%
			Performance - Accuracy	4.3%	9.7%	Inventory accuracy	(Liebetruth, 2017; Sambasivan et al., 2009; Shafiee et al., 2014)	4.3%	9.7%
Miscellaneous	7.2%	16.1%	*Inventory – General*	2.9%	6.5%	Inventory	(Aramyan et al., 2007; Liebetruth, 2017)	2.9%	6.5%
			Inventory control	1.4%	3.2%	Inventory control	(Hassini et al., 2012)	1.4%	3.2%

			Minimum inventory	1.4%	3.2%	Minimum inventory	(Bhattacharya et al, 2014)	1.4%	3.2%
			Inventory range	1.4%	3.2%	Inventory range	(Shepherd and Günter, 2006)	1.4%	3.2%
			Toxic release	1.4%	3.2%	Toxic release	(Schaltegger and Burritt, 2014)	1.4%	3.2%

Table 5. Example of the selection procedure for the KPI *Inventory Cost.* The Table reports all the performance measures identified in the literature related to the inventory management. Basin on own elaboration the performance measures have been pigeonholed according to performance indicators and performance. For each performance measure, performance indicator and performance, the occurrence in the reviewed literature is reported. The occurrence is evaluated both on the total number of contributions reviewed (see Table 2) and on the total number of the contributions reviewed considering the inventory management (*).

3.2 Methods for the empirical validation of the proposed set of KPIs

After the theoretical validation, we have assessed the proposed set of KPIs against its capability of addressing sustainability within a whole SC and its applicability in SCs with different characteristics. The aim was to understand whether the theoretically developed set of KPIs was also effectively helpful and adequate for an empirical application (Denzin and Lincoln, 2011; Ketokivi and Choi, 2014). Particularly, the set of KPIs was tested for its: (i) capability to represent – adequately taking into consideration all the PIs addressing sustainability in a SC; (ii) usefulness - being meaningful if applied; and (iii) ease of use - evaluating the effort (resources and possible difficulties) required for the application of the set.

As multiple case studies are recommended for theory testing purposes (Voss et al., 2002), the overall sample investigated includes 3 SCs - 2 three-tiers and one dyadic - and 7 focal firms, for a total of 15 firms. Indeed, the perspective of the investigation is two-fold: on the one hand, we aim to evaluate the applicability of the proposed set of KPIs on the whole SC - thus on all the firms within a SC; on the other hand, we required a response by focal firms on the views of their suppliers on the proposed set of KPIs.

Each case study has then been treated and examined as a single case (Handfield and Melnyk, 1998; Voss et al., 2002). The level of investigation adopted is the single firm, belonging to the manufacturing sector, located in Italy. We thus focused on a sample heterogeneous by activity and size, but alike as for country (Morioka and Carvalho, 2014; Osagie et al., 2016), as reported in Table 6. Our sample finds justification as: on the one hand, Northern Italy is a strongly industrialised Italian region, particularly relevant for the European manufacturing sector (European Commission, 2018; Eurostat, 2018); on the other hand, the possibility for the manufacturing sector to improve and enhance its industrial sustainability-related performance is largely highlighted (European Agency for Safety and Health at Work, 2009; European Commission, 2017; Meng et al., 2018).

We selected the firms from "AIDA" (https://aida.bvdinfo.com/), a database displaying containing Italian firms' information according to the EU's industrial activities classification (European Commission, 2008). About two-thirds of the firms contacted accepted to take part in the research (Firms A2, B2, C2, D, E, F, G, H, I, J). We asked these firms to extend the invitation to members of their SC. Firms A2, B2 and C2 accepted the request, and other 5 firms were included in the sample investigated, allowing for 3 SCs and 7 single firms. The final sample includes therefore 15 firms. The size of the sample is judged adequate for the

aim of the empirical validation with a replication logic (Meredith and Vineyard, 1993; Voss et al., 2002). Moreover, a less qualitative description may be involved, with a relatively slight narrative for all sites, but a more thorough depiction for a few cases (Meredith and Vineyard, 1993).

Supply Chain / Single Firm	Firm	NACE	Description of the activity	Size - As in European Union (2003)	Interviewee
Supply Chain A (Metalworking)	Firm A1	25.62	Machining	Micro	Managing Director
	Firm A2	25.73	Manufacture of tools	Medium	Production Manager
	Firm A3	28.14	Manufacture of other taps and valves	Small	Managing Director
Supply Chain B (Automotive)	Firm B1	22.19	Manufacture of other rubber products	Medium	Quality Manager
	Firm B2	22.19	Manufacture of other rubber products	Medium	Quality Manager Health Safety and Environment Manager
	Firm B3	46.47	Wholesale of furniture, carpets and lighting equipment	Large	Quality Manager
Supply Chain C (Plastic)	Firm C1	28.00	Manufacture of machinery and equipment	Medium	Production Manager
	Firm C2	22.29	Manufacture of other plastic products	Small	Plant Manager
Single firm	Firm D	13.91	Manufacture of knitted and crocheted fabrics	Medium	Commercial Manager
Single firm	Firm E	31.09	Manufacture of other furniture	Micro	Co-owner
Single firm	Firm F	28.11	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	Small	CEO
Single firm	Firm G	26.20	Manufacture of computers and peripheral equipment	Small	Production and Purchasing Manager
Single firm	Firm H	25.99	Manufacture of other fabricated metal products	Medium	General Director
Single firm	Firm I	28.14	Manufacture of other taps and valves	Medium	Plant Manager
Single firm	Firm J	14.10	Manufacture of wearing apparel, except fur apparel	Small	CEO

Table 6. Information on firms investigated. For each firm investigated the table reports: whether it belongs to a supply chain or it has been investigated as a single firm; the NACE code; a description of the activity; the number of employees; the size; the person(s) interviewed.

The collection of both primary and secondary the data relied on five different sources of evidence, detailed in Appendix II.

For the 15 firms participating, we collected secondary data on firms' structure and processes, as well as reports, projects, initiatives and similar related to sustainability.

The source of primary data is the investigation within the firms. As the main source of data in the present research comes from the investigation, we have selected as interviewees industrial decision-makers knowledgeable of aspects related to sustainability and all the processes of the firm (Meredith and Vineyard, 1993). The investigation within the firms took place with the use of semi-structured interviews and a questionnaire, using a protocol as a guide (Patton, 1990) while also collecting any further comments emerging during the interview (Dicicco-

Bloom and Crabtree, 2006). We have divided the investigation into two parts, lasting a total of 2 hours on average. In the first part, employing semi-structured interviews, interviewees were asked to describe the firm in terms of the sector, production processes, the number of employees, SC characteristics and attitude towards sustainability. Interviewees were asked to focus their attention on the sustainability of the SC and to identify the KPIs currently used for evaluation of SC performance within their SC. To facilitate this process, we asked the interviewees to recall recent sustainability interventions implemented within their firms and within the SC, and to focus on the performance reached and measured after the implementation in the overall SC. In the second part of the investigation, employing a questionnaire, we introduced the set of KPIs to interviewees, describing each single KPI, asking them to evaluate the set with the help of a questionnaire based on a 3-points Likert-like scale. As a part of the investigation, the interviewers involved also visited the production plant to directly observe and better understand the context under investigation and took field notes.

We transcribed the interviews promptly after the investigation, so to maximise recall (Voss et al., 2002). We analysed the data using a content analysis approach. The transcriptions were independently coded manually by the investigators and the results were then discussed together reaching a common understanding of them. We adopted an emergent coding, developing categories based on the research questions (Kohlbacher, 2006; Kolbe and Burnett, 1991). Detailed, we applied a Structural code, appropriate for semi-structured interviews (Saldaña, 2009), succeeded by an Axial code, relating codes to each other (Voss et al., 2002). The analysis conducted for SC A and SC B is reported in Appendix III, by way of example. We corroborated the information obtained through the different sources and in case of misalignments we requested a second meeting with the interviewees for additional clarification.

Figure 2 reports an overview of the different steps of our empirical validation with the main aspects of each step.

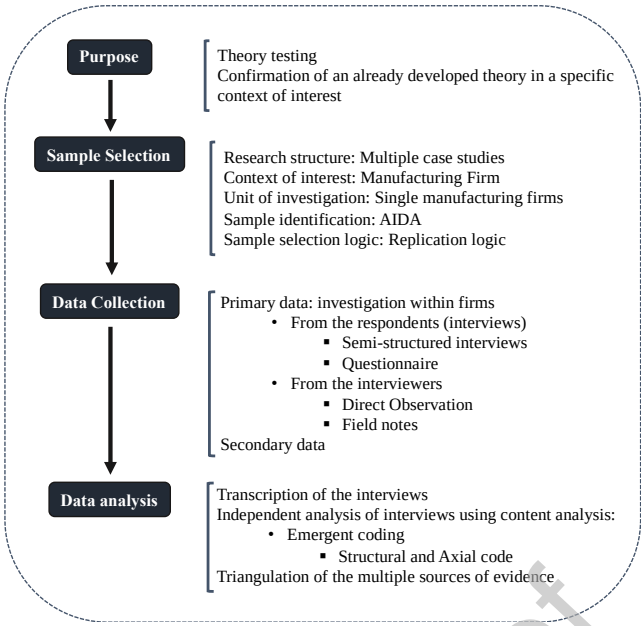


Figure 2. Overview of the different steps of the empirical validation.

As for methodological rigor, Table 7 reports how we assessed the four design test suggested by Yin (2009), namely construct validity, internal validity, external validity and reliability according to what reported in Figure 2 and previously detailed.

Test	Tactics	References
Construct validity	- Triangulation sources of evidence - Creation of a chain of evidence - electronic folder containing all the data for each case	(Baškarada, 2014; Benbasat et al., 1987; Beverland and Lindgreen, 2010; Rowley, 2002)
Internal validity	- Multiple sources of evidence	(Hays, 2004; Voss et al., 2002; Yin, 2009)
External validity	- Specification of the population - Replication logic - Multiple case studies	(Beverland and Lindgreen, 2010; Meredith and Vineyard, 1993)
Reliability and research bias	- Multiple case studies - Case study protocol - Multiple interviewers	(Barratt et al., 2011; Eisenhardt, 1989; Voss et al., 2002)

Table 7. Assessment of methodological rigor.

4 Theoretical and empirical validation: results and discussion

In this section, we propose the final set of KPIs, followed by the presentation of the findings for the theoretical and empirical validation.

4.1 The set of KPIs for sustainability in Supply Chains

The final set proposes 33 KPIs, organized according to six perspectives. Based on the considerations in Section 3.1.1, we adopted a six perspectives BSC: to the traditional *Financial, Internal process, Learning and Growth, Customer* perspectives (Bigliardi and Bottani, 2010; Shafiee et al., 2014), we added *Environment* and *Social* perspectives (Figge et al., 2002; Verdecho et al., 2012).

The KPIs are selected according to the rationale discussed in Section 3.1.2. In the following, we offer an overview of the six perspectives and the 33 KPIs, whilst further details related to the selection of each specific KPIs are reported in Appendix IV.

Financial perspective

- *Return on investment*. ROI measures the economic efficiency of invested resources (Ahi and Searcy, 2015), which influences the organisation profitability.
- *Return on sales*. ROS is considered a proxy of profitability addressing only operational activities (Bottazzi et al., 2008), indicating the ability to control expenses related to sales (Chopra and Wu, 2016).
- *Return on assets*. ROA describes the profitability of a SC to its total assets (Gomes et al., 2015).
- *SC total cost*. It is the total cost of fulfilment, associated with the operation of the SC (Charkha and Jaju, 2014; Thakkar et al., 2009).
- *Inventory cost*. Inventory cost along the entire SC is considered highly relevant (Gunasekaran et al., 2001).
- *Cash-to-cash cycle time*. It is the time it takes for every tier of the SC to obtain a profit from its activities, indicating how working capital is managed (Supply Chain Council, 2012).

Internal process perspective

- *Capacity utilisation*. It measures how intensively the resource is used for the production process (De Treville et al., 2005; Supply Chain Council, 2012).
- *Recycling*. This measures the level of consumption of recycled parts (Supply Chain Council, 2012), capturing the ability of the SC to close the loop (Sellitto et al., 2015), decreasing the environmental impact (Bhattacharya et al., 2014).
- *Certifications*. It indicates if and to what extent the SC is certified.
- *SC responsiveness*. It describes the ability of a SC to adapt to market variations, making available the products/services to meet the individual customers' demand (Gunasekaran et al., 2001).
- *SC cycle time*. It is the time required for fulfilling a customer's order (Ahi and Searcy, 2015).
- *SC process time*. It quantifies the time required by the SC from the time the product began its manufacture to the time it is completely processed (Chan, 2003).

Learning and growth perspective

- *Labour productivity*. It is the productivity of the workforce along the different tiers of the SC (Stindt, 2017; Yakovleva et al., 2012).
- *New product development time*. It accounts for time elapsing from the projects' conception and definition until the new product's launch into the market (Griffin et al., 2019).
- *Investments*. It represents the amount of investments allocated to R&D related to the SC operations (Hadiguna et al., 2011).
- *Integration with SC partners*. It measures the level and extent of collaboration and partnership along the entire SC (Yenipazarli, 2017).

- *Use of new technology*. It measures the level of new technologies adopted (Shepherd and Günter, 2006).

Customer perspective

- *Market share*. It represents the percentage of the total sales earned over a specific time and acquiring the market share of each tier can allow a deeper insight into single firms.
- *Customer satisfaction*. It indicates the overall level to which customers are satisfied with the product/service, also including evaluation of the customers' complaints (Aramyan et al., 2007).
- *Product quality*. It measures the product's conformance with quality characteristics (Hadiguna et al., 2011), focusing also on reliability and safety and health (Aramyan et al., 2007; Marconi et al., 2017).
- *Product/service variety*. IT measures the depth and breadth of products and services offered (Gong and Yan, 2015).
- *Order fulfilment*. It accounts for the capability of the SC to fulfil an order (Croxton, 2003), and it can be easily related to the fill rate (Beamon, 1998; Charkha and Jaju, 2014).
- *Delivery reliability*. It measures the reliability of delivery in terms of product, place, time, quantity, condition and customer (Charkha and Jaju, 2014).

Environmental perspective

- *Energy use*. It quantifies the energy used to perform the SC operations (Aramyan et al., 2007); it is easily translatable into the energy cost given the energy price (Giannakis and Papadopoulos, 2016).
- *Water use*. It quantifies the water used to perform SC operations; it is easily translatable into the water cost given the water (Balfaqih et al., 2017; Varsei et al., 2014).
- *Material use*. It quantifies the material used to perform SC operations; it can be easily transformed into material cost through the material price (Balfaqih et al., 2017; Varsei et al., 2014).
- *Environmental impacts*. It quantifies the main environmental impacts of the overall SC (Balfaqih et al., 2016a).
- *Waste*. It addresses the waste produced to perform SC operations and can be easily transformed into waste cost through the waste price (Balfaqih et al., 2017; Varsei et al., 2014).

Social perspective

- *Stakeholders relationships*. It involves aspects related to the relationship of the SC with external stakeholders (Hilsdorf et al., 2017).
- *Philanthropic investments*. It represents investments aimed at improving the general condition of society (Carter and Jennings, 2002; Sutherland et al., 2016).
- *OHS performance*. It addresses the aspects related to Occupational Health and Safety (OHS) (Trianni et al., 2019).
- *Labour turnover*. It measures the rate of rotation of employees by tackling the stability of work positions and the capability of SC firms to invest in career development (Erol et al., 2011).

- *Employee satisfaction.* It measures the employees' satisfaction regarding different aspects such as wages, diversity, well-being, involvement and benefits (Cagno et al., 2019).

4.2 Results of the validation

4.2.1 Theoretical Validation

According to the rationale for the development of the set, the selection should have met specific requirements (reported in Section 3.1.2), particularly guaranteeing the relevance of the selected KPIs and their adequacy to address the literature gaps. Table 8 reports the analysis of the selected KPIs according to several significative axes for the present research.

			Financial Base		TBL Pillars			SCOR Processes					Components of Performance				Decision Level			Traditional BSC's perspectives			
		Relevance	*Financial*	*Non-financial*	*Economic*	*Environment*	*Social*	*Plan*	*Source*	*Make*	*Delivery*	*Return*	*Time*	*Cost*	*Quality*	*Flexibility*	*Asset*	*Strategical*	*Tactical*	*Operational*	*Financial*	*Internal process*	*Learning and Growth*	*Customers*
Financial	Return on investment	[2]; [10]; [34]; [50]	[2]; [6]; [7]; [8]; [55]		[34]; [39]; [42]; [50]			[2]; [4]; [8]; [13]; [16]	[13]; [39]	[13]	[13]	[13]		[4]; [8]				[2]; [6], [7]; [16]			[6]; [8]; [11]; [16]; [31]; [55]			
	Return on sales	[x8]	[42]		[42]			•	•	•	•	•		•				•			•			
	Return on assets	[1]	[42]; [55]		[42]			[2]; [4]						[4]			[9]; [19]	[2]			[11]; [55]			
	Total SC cost	[2]; [10]	[2]; [55]		[32]; [26]; [34]; [37]; [39]; [40]; [42]; [46]; [47]; [53]			[4]; [13]	[3]; [13]; [39]	[2]; [3]; [13]; [39] [xxv]	[3]; [13]	[3]; [13]	[8]	[8]; [12]; [27]; [53]	[8]			[39]		[2]; [6]; [7]; [16]	[3]; [11]; [28]; [55]	[8]; [31]	[8]	
	Inventory costs	[2]	[2]; [6]; [8]		[39]; [42]	[x]	[x]	[8]; [13]	[3]; [13]; [16]; [38]	[2]; [3]; [6]; [13]; [16]; [38] [xxv]	[8]; [13]	[8]; [13]		[4]; [8]; [38]; [43]		[8]		[39]	[49]	[2]; [6]; [7]; [16]; [43]; [49]	[8]; [16]	[6]; [8]; [31]	[36]	
	Cash-to-cash cycle time	[2]; [35]		[2]; [6]; [7]	[42]			[2]; [4]; [13] [xxvi]	[13]	[13]	[13]	[13]	[4]	[4]			[9]; [19]	[2]; [6], [7]			[11]; [43]	[6]; [31]		
Internal process	Capacity Utilization	[2]; [35]		[2]; [6]; [7]	[29]; [39]	[xiv]	[xiv]			[2]; [4]; [8]; [13]; [16]				[4]; [8]				[39]	[8]	[2]; [6]; [8]; [16]; [43]		[6]; [8]; [16]; [31]	[6]; [8]; [31]	
	Recycling	[34]; [46]		•	[37]; [49]	[15]; [21]; [22]; [23]; [25]; [29]; [34]; [37]; [39]; [47]		[16]; [39]	[16]; [39]	[16]		[38]			[20]; [38]			[16]; [39]		[49]	[3]; [16]; [18]	[3]; [16]		
	Certification	[34]; [54]		[8]	[14]; [25]; [34]	[14]; [15]; [22]; [23]; [25]; [27]; [32]; [34]; [37]; [42]; [39]; [47]; [49]	[14]; [15]; [26]	[8]; [13]	[8]; [16]; [39]	•	•	•			[8]; [27]			[8]; [16]				[8]; [28]	[8]; [28]	[17]; [18]
	Supply chain responsiveness	[2]; [5]; [54]		[2]; [6]; [8]	[25]; [32]; [54]		[25]	[4]; [8] [xxvi]	[x8]	[8]		[2]; [13]	[8]	[4]; [8]	[8]	[4]; [9]; [8]; [19]; [20]		[2]; [6]; [7]; [8]	[8]	[8]		[6]; [8]; [31]	[8]; [18]	[6]; [11]; [31]
	Supply chain cycle time	[2]		[2]; [7]	•	[xv]	•	[2]; [8] [xxvi]	[2]	[16]	[16]; [53]	[16]	[4]			[53]		[2]; [7]	[16]			[3]; [6]; [31]		[16]
	Process cycle time	[36]		[8]	•		•	[8]		[4]; [8]	[8]		[4]; [8]			[8]			[8]	[8]		[8]	[36]	•

Learning and growth	Labour efficiency	[24]		[8]	[24]; [39]		[24]	[8]		[8]				[8]; [20]				[39]	[8]	[8]	[28]	[43]	[8]	
	New product development time	[2]; [50]		[2]; [6]; [7]	[2]; [50]	[38] *[ix]; [xi]*	*[ix]*	[2]; [8]; [16]; *[vi]*	[8]	[4]; [16]			[4]; [8]			[20]	[20]		[2]; [6]; [7]; [16]			[6]; [8]; [16]; [31]	[6]; [8]; [31]	
	Investments	[17]; [50]	•		[50]	[39]	[39]	[16]	[16]	•	•	•		•	•	•	•	[16]; [39]			[16]; [41]	•	•	
	Integration with SC partners	[2]; [51]; [54]	[2]; [6]; [7]		[22]; [54]	[20]; [54] *[xx]*	*[xx]*	[4]	[2]; [13] *[vi]; [xxv]*	•	•	•	[4]	[4]	[4]; [20]	[4]		[2]; [6]; [49]	[7]	[2]	[6]	[31]	[6]; [11]; [18]; [31]	[18]; [31]
	Use of new technology	[36]; [50] *[xxiii]*		•	[27]; [47]; [50]	*[xiii]*	*[xiii]*	[4]	[4]	[4]	[4]	[4]		[31]			[4]; [20]	*[xxiii]*					[31]; [55]	
Customer	Market share	[10]; [34]	•		[14]; [24]; [25]; [34]	[37]	[25]; [49]	•	•	•	•	•		•				*[ii]*			[11]			[55] *[ix]*
	Customer satisfaction	[10]; [35]; [50]; [51]; [54]		[2]; [6]; [7]	[32]; [34]; [50]; [54]		[22]; [23]; [34]; [37]; [42]; [45]; [48]; [49]; [54]	[4]; [16]			[38]	*[xxv]*		[4]	[4]; [27]; [30]; [38]			[16]; [49]	[49]	[43]				[28]; [31]; [35]; [36]; [43]; [55] *[ix]*
	Product quality	[10]; [34]; [51]		[2]; [8]	[14]; [23]; [26]; [27]; [32]; [34]; [42]; [39]; [47]; [49]	[34]	[34]		[39]	[16]	[8]; [16]	[4]; [8]; [16]			[4]; [8]	[8]		[39]	[16]	[2]; [8]; [16]		[28]	[16]	[6]; [8]; [11]; [16]; [28]; [31]
	Product/service variety	[10]; [35]		[2]; [8]	[13]	[39]	*[xv]*	[2]; [31]	[38]	[8]; [13]; [38]	[2]; [4]; [8]; [13]; [38]	[38]			[8]	[8]; [20]; [38]		[2]; [8]				[8]; [31]	[6]; [8]; [18]; [31]	[6]; [8]; [31]
	Order fulfilment	[25]; [53] *[xi]*		[2]	[14]; [25]; [47]		[25]			[53]	[2]; [16]	[16]	[19]; [20]		[9]; [19]; [53]			[2]; [8]		[16]; [43]	[31]	[16]; [31]		[6]; [31]
	Delivery reliability	[2]; [51]; [53]; [54]	[2]	•	[27]; [39]; [47]; [54]		[36] *[xii]*		[8]; [38]	[38]; [53]	[2]; [4]; [8]; [13]; [38] *[xxv]*	[8]; [38]	[8]; [20]; [19]		[4]; [8]; [20]; [53]			[2]; [7]; [39]		[43]	[6]; [31]	[8]; [11]; [43]		[6]; [8]; [11]; [31]
Environment	Energy use	[26]; [34]; [50]; [52]	•	•	[29]; [37]; [49]	[14]; [15]; [22]; [24]; [26]; [27]; [32]; [33]; [34]; [37]; [42]; [47]; [52]; [54]; [55]; [52]		*[xvii]; [xxvi]*	[39]	[16]; [39]	[16]	*[xvii]; [xxvi]*		[20]	[49]			[39]	[16]	[49]	[28]	[3]; [16]; [41]	[3]	
	Water use	[34]; [50]; [52]	•	•	[29]; [49]	[14]; [15]; [24]; [27]; [32]; [33]; [34]; [37]; [42]; [47]; [50]; [49]; [49]; [52]		•	[39]	[39]				[20]	[49]			[39]	[16]	[49]	[28]	[41]	[3]	
	Key material use	[46]; [50]	•	•	[21]; [40]; [49]	[14]; [21]; [27]; [32]; [37]; [42]; [50]; [49]		•	[39]	[39]				[20]; [49]				[39]	[16]; [49]	[49]	[28]	[41]	[3]	

	Environmental impacts	[26]; [34]; [46]; [50]; [54]		•	[28]	[14]; [22]; [26]; [27]; [29]; [32]; [33]; [34]; [40]; [42]; [47]; [50]; [54]	[xxii]	[xxii]; [xxii]	[39]	[39]	[16]	[xxii]; [xxii]		[20]	[20]			[39]			[28]	[3]; [41]		
	Waste	[10]; [21]; [22]; [46]; [50]; [54]	•	•	[25]; [29]; [37]	[14]; [15]; [21]; [22]; [23]; [24]; [25]; [26]; [32]; [33]; [34]; [37]; [39]; [42]; [44]; [45]; [46]; [47]; [50]	[37]	[16]		[16]; [39]				[20]	[20]			[39]	[16]		[3]	[1]; [10]; [17]; [18]; [31]; [41]		
Social	Community relationships	[46]; [50]		•	[25]		[21]; [22]; [23]; [25]; [26]; [27]; [32]; [33]; [37]; [42]; [39]; [47]; [48]; [50]; [49]	•	[39]	•	•			[1]; [xxi]	[49]	[49]		[39]					[3]	[17]
	Philanthropic investments	[xxiii]	•	•	[42]		[21]; [22]; [27]; [32]; [37]; [39]	•						•				[39]			•			•
	OHS performance	[46]; [50]; [54]		•	[xxiv]	[xxv]; [xxii]	[14]; [15]; [21]; [22]; [24]; [26]; [27]; [32]; [33]; [37]; [42]; [39]; [47]; [48]; [50]; [49]; [54]			[39]				[49]	[49]			[39]					[3]	
	Labour turnover	[10]; [46]; [52]		•	[xxiv]		[15]; [52]	•	•	•	•	•		•				[xiii]		[49]			[31]; [ix]	
	Employee satisfaction	[10]; [17]; [50]; [54]		•	[22]		[23]; [24]; [27]; [32]; [37]; [42]; [39]; [47]; [48]; [50]; [54]	•	•	[39]	•	•		•				[ii]	[49]			[iii]	[31]; [ix]	

Table 8. Analysis of the coverage of the characteristics selected for the development of the novel set of KPIs. The table reports the different characteristics considered for the development of the set of KPIs, namely: Relevance; Financial base (financial; non-financial); TBL pillars (Economic, Environment, Social); SCOR Processes (Plan, Source, Make, Delivery, Return); Components of performance (Time, Cost, Quality, Flexibility, Innovation); Decision level (Strategical, Tactical, Operational); Traditional BSC's perspectives (Financial, Internal process; Learning and growth; Customer). For each characteristic, the coverage by each of the 33 selected KPIs is reported. The coloured box indicates that the considered KPI (row) is addressing specific characteristic (column). When applicable, references are also provided: numbers from [1] to [47] refer to references analysed in the literature review (please refer to Table 2 and Table 3); numbers from [ii] to [xxiv] refer to additional references.

[1] Brewer and Speh (2000); [2] Gunasekaran et al. (2001); [3] Hervani et al. (2005); [4] Shepherd and Günter (2006); [5] Aramyan et al. (2007); [6] Bhagwat and Sharma (2007a); [7] Bhagwat and Sharma (2007b); [8] Gunasekaran and Kobu (2007); [9] Hwang et al., 2008); [10] Chia et al. (2009); [11] Thakkar et al. (2009); [12] Xu et al. (2009); [13] Bigliardi and Bottani (2010); [14] Sloan (2010); [15] Erol et al. (2011); [16] Hadiguna et al. (2011); [17] Hsu et al. (2011); [18] Jalali Naini et al. (2011); [19] Stefanović and Stefanović (2011); [20] Bai et al. (2012); [21] Faisal (2012);[22] Uysal (2012); [23] Verdecho et al. (2012); [24] Yakovleva et al. (2012); [25] Zailani et al. (2012); [26] Büyüközkan and Çifçi (2013); [27] Govindan et al. (2013); [28] Reefke and Trocchi (2013); [29] Bhattacharya et al. (2014); [30] Charkha and Jaju (2014) ; [31] Shafiee et al. (2014); [32] Chardine-Baumann and Botta-Genoulaz (2014); [33] Varsei et al. (2014); [34] Ahi and Searcy (2015); [35] Charkha and Jaju (2015); [36] Eskafi et al. (2015); [37] Gopal and Thakkar (2015); [38] Sellitto et al. (2015); [39] Subramanian and Gunasekaran (2015); [40] Tajbakhsh and Hassini (2015); [41] Ferreira et al. (2016); [42] Xu, Jiang, and Wu (2016); [43] Liebetruth (2017); [44] Marconi et al. (2017); [45] Sopadang et al. (2017); [46] Stindt (2017); [47] Izadikhah and Saen (2018); [48] Popovic et al. (2018); [49] 49 et al. (2019); [50] Sangwan et al. (2019); [51] Sufiyan et al. (2019); [52] Susanty et al. (2019); [53] Büyüksaatçi Kiriş et al. (2020); [54] Narimissa et al. (2020); [55] Verdecho et al. (2020).

[i] Maurer (1971);[ii] Buzzell et al. (1975); [iii] Butler et al. (1997); [iv] Figge et al. (2002); [v] Croxton (2003); [vi] Huan et al. (2004); [vii] Bottazzi et al. (2008); [viii] Ton and Huckman (2008); [ix] Johnsen (2009); [x] Xia and Li-Ping Tang (2011); [xi] Ashby et al. (2012); [xii] Gimenez and Tachizawa (2012); [xiii] Triguero et al. (2013) ; [xiv] Martínez-Jurado and Moyano-Fuentes (2014); [xv] Gong and Yan (2015); [xvi] De Villiers et al. (2016); [xvii] Garza-Reyes et al. (2016); [xviii] Mandal and Bagchi (2016); [xix] Trianni et al. (2017); [xx] Ahmed Khamis al Naqbi et al. (2018); [xxi] Batista et al. (2018); [xxii] Cagno et al. (2018); [xxiii] Morais and Silvestre (2018); [xxiv] Cagno et al. (2019); [xxv] Kottala and Herbert (2019).

4.2.2 Empirical validation

The results of the empirical evaluation of the proposed set of KPIs are reported in Table 9. Regarding *capability to represent*, notably, the completeness of the set was largely confirmed, focusing in particular on the integration of the TBL pillars. Regarding the distinction among the proposed KPIs, the interviewees spotted no overlapping, also meaning the interviewees identified a practical application for all the KPIs. A2 and A3 lie in the small set of firms that partially disagreed. The Production Manager of A2, during the investigation, underlined that they often perceived logistics to be one of the most important aspects for a SC, given also the high number of suppliers and customers of A2. Since, as they stated, "*the first point is to find suppliers as close as possible*", distribution is considered notably important for the development of sustainability in a SC, while other aspects are left behind as *"I can't tell you about social aspects: there are more stringent issues"*. The same reasoning can be applied to A3, whose Managing Director perceived SC sustainability as being related mainly to lead time and quality. The answers obtained for A2 and A3 could thus represent bias by the priorities of both firms.

Focusing on *usefulness*, the overall results were positive. Some interviewees seemed to be aware of (some of) the proposed KPIs, but, as a shared opinion, the model helped them to better reorganise what they had already in mind, while also being a valid and quick help for the evaluation of the sustainability performance of the SC. Particularly, the Plant Manager of C2 recognised the proposed set of KPIs as a useful instrument to align each tier within the SC, adding that: "*if a SC is aligned, the performance of every tier improves, and, as a consequence, the performance of the overall SC improves*". The Commercial Manager of Firm D and the Co-owner of Firm E also pinpointed this aspect. Both, indeed, deemed the improvement in the performance of one tier to bring about benefits overall, but "*there is the need for perfect alignment in terms of actions and evaluation of effects*" (Co-owner, Firm E). Some interviewees stated they were already aware of the proposed KPIs: this does not represent a flaw of the study since we did not aim to identify new KPIs but rather to reorganise in a balanced manner the PIs already available. We expected more proactive or sustainability-aware firms to have a broad knowledge of the topic. This turned out to be correct as firms B2 and D, both holding quality and environmental certifications, had a proper perspective on sustainability - *"*[sustainability] *is the necessity, for all the tiers, to broadcast the message that sustainable means to keep the same performance* [price and quality], *having a more ethical perspective"* (Commercial Manager of D); *"Sustainability is something for rich: first of all you need the economic availability, after that, you need foresight […] it would be good to extend the* [sustainability time] *horizon because it would allow taking completely different decisions"*(Health Safety and Environment Manager of B2) - and considered various SC PIs, spanning among the different pillars, also addressing Safety and Environment performance areas.

Ease of use was confirmed by the vast majority of interviewees. The few deeming the model a bit complex, offered nonetheless a positive evaluation, pinpointing its worth of use. Notably, the interviewees seemed to appreciate the low number of KPIs, as underlined by the Plant Manager of C2, as: *"it is very important to select manageable performance indicators, so to check them steadfastly"*. Moreover, the interviewees showed interest in the possible use of the set during the decision-making process, so to help them in evaluating possible measures and practices to be adopted.

Supply Chain / Single Firm	Firm	Capacity to represent		Usefulness			Ease of use	
		Completeness	*Distinction*	*New KPIs*	*Reorganization*	*Valid and Quick Help*	*Ease of use*	*Worth the effort*
Supply Chain A (Metalworking)	Firm A1	✓	✓	✗	✓	✓	✓	✓
	Firm A2	✓	✓	✓	✓	✓	✓	✓
	Firm A3	✓	✓	✓	✓	✓	✓	✓
Supply Chain B (Automotive)	Firm B1	✓	✓	✓	✓	✓	✓	✓
	Firm B2	✓	✓	✓	✓	✓	✓	✓
	Firm B3	✓	✓	✓	✓	✓	✓	✓
Supply Chain C (Plastic)	Firm C1	✓	✓	✓	✓	✓	✗	✓
	Firm C2	✓	✓	✓	✓	✓	✓	✓
Single firm	Firm D	✓	✓	✗	✓	✓	✓	✓
Single firm	Firm E	✓	✓	✓	✓	✓	✓	✓
Single firm	Firm F	✓	✓	✓	✓	✗	✓	✓
Single firm	Firm G	✓	✓	✓	✓	✓	✓	✓
Single firm	Firm H	✓	✓	✓	✓	✓	✓	✓
Single firm	Firm I	✓	✓	✓	✓	✓	✓	✓
Single firm	Firm J	✓	✓	✗	✓	✓	✓	✓

Table 9. Results of the empirical validation of the novel set of KPIs according to the three performances investigated.

Legend: ✓: Yes ✓: Partially ✗: No

4.3 Discussion

The present section discusses the set of KPIs proposed with respect to the research gaps addressed in the present work, in light of both theoretical and empirical validation.

First, from a theoretical perspective, a major challenge and element of novelty was represented by the need to encompass the previous literature with the newly proposed set of KPIs. We can see that the selected KPIs cover all the performance areas, the performance and related indicators identified in the prior literature. Focusing on previous literature (see Table 4) any contribution was covering all the performance areas identified in the literature, for example, Marconi et al. (2017) focused almost exclusively only on Product, Production and Environmental areas; Chardine-Baumann and Botta-Genoulaz (2014) spanned on all the performance areas identified, but missed aspects related to Orders procedures and delivery. Looking at the specific KPIs encompassed in the present set, not all the previous contributions were considering them, despite their relevance (see Table 8 and Appendix I for details), for example, ROI was not considered by Narimissa et al. (2020), who however provided quite a numerous set of indicators; Inventory Cost, whose importance has been underlined in Section 3.1, is not mentioned by Ferreira et al. (2016), who nonetheless recommended a strategy-oriented approach based on BSC; Waste, a fundamental aspect of the environmental pillar of the TBL, is not directly tackled by Verdecho et al. (2020) despite the focused on a TBL perspective; Employees' satisfaction, strongly related to customer satisfaction

and operational performance Fernández-Muñiz et al. (2012) is not addressed by Said et al. (2020) who focused mainly in Social and Environmental aspects.

Second, the set of KPIs has been assessed against its capability to effectively measure sustainability issues according to the TBL pillars without the common unbalance towards economic (or financial) issues, thus neglecting the environmental and social dimensions. In this regard, the proposed encompasses 8 financial based KPIs, e.g. ROA (Xu et al., 2016), with 18 non-financial based KPIs, e.g., labour efficiency (Gunasekaran and Kobu, 2007), plus 6 KPIs that can are not economic/financial but have of course economic/financial implications such as e.g., deliver reliability (Gunasekaran et al., 2001). By a closer look to the TBL pillars, 14 out of 33 KPIs address all the three of them, thus in line with remarks of previous literature about the need to focus on the intersection of all pillars (Biely et al., 2018; Mulia et al., 2016). Another 14 address the socio-economic and economic-environmental pillars, whilst only 5 are focused exclusively on the economic pillar. As several of the previous contributions address sustainability according to the TBL concept, to our knowledge any of them evaluated the balance of the proposed set in terms of TBL pillars and above all in terms of TBL pillars' intersections (see Table 2). Three contributions, however, started moving in this direction, still showing some limitations as for the area of interest of the present study: Faisal (2012) proposed a theoretical methodology for evaluating the relationship among different variables of sustainability; Zailani et al. (2012) applied factor analysis to understand the outcomes related to specific and limited in number performance– for example, they do not consider employees' related performance; Ahi and Searcy (2015) evaluated the impact of specific indicators on the three pillars of the TBL, yet indicators are provided without a categorization and mainly address environmental aspects.

Third, in response to previous studies (Ahi and Searcy, 2015; Searcy and Ahi, 2014), the limited number of selected KPIs represents a major strength of the present set, as also appreciated during the empirical investigation. The importance of a limited number of indicators has been remarked by extant research (Isaksson and Garvare, 2003; Vanleer et al., 2016), and could result particularly useful when applied to firms with limited resources to be devoted to measuring sustainability performance and managing related issues (Borga et al., 2009; Tremblay and Badri, 2018). By having a manageable number of indicators (Epstein and Widener, 2010; Medini et al., 2015), enterprises and SCs can effectively measure the overall sustainability performance, still capturing relevant operational elements and viable for empirical application. The present study, by presenting this set of KPIs, seems to allow overcoming the issues emerged in previous approaches, as for example the ones by Sambasivan et al. (2009) and Sangwan et al. (2019), either too broad or too burdensome for companies and SCs, either lacking the operational dimension, or too onerous for an effective deployment on the field. Furthermore, contributions focused on TBL and entailing around 30 indicators, do not covered all the performance areas, as Sopadang et al. (2017), Susanty et al. (2019) and Xu et al. (2016).

Moreover, the proposed set presents a strong integration between three different decision-making levels, (i.e., strategical, tactical and operational), with about two-thirds of KPIs addressing the strategical decision level that can be turned into tactical and operational decisions. Such capability of entailing a long-term orientation about sustainability is deemed as crucial by previous studies (Carter and Rogers, 2008; Morali and Searcy, 2013). Additionally, the proposed set of KPIs is meant to offer a guideline of the most important ones to be considered but could always be complemented by more specific ones tailored to the unique needs of their own SC. Furthermore, the proposed set considers in the development and consequently offers an appropriate balance of the different SCOR processes and components of performance, as well as a balance and integration of the different BSC's perspectives. As for the abovementioned features, the set of indicators proposed by Gunasekaran and Kobu (2007) is undoubtedly the most detailed one, nevertheless, it does not focus on sustainability. Contributions focusing on sustainability, on the other hand, do not make the same considerations. For example, Liebetruth (2017) and Baba et al. (2019) only focused on decision levels, Büyüksaatçi Kiriş et al. (2020) only on the SCOR processes, Verdecho et al. (2020) only on the BSC perspectives.

The empirical investigation allowed us to further corroborate the judgments about the completeness of the proposed set of KPIs. The details of this analysis are reported in Table 10. All the PIs listed by the firms were considered in the proposed set, or easily attributable to them, as *Sales Growth* PI, ascribable within the KPI *Market share* (see also Appendix IV). Although some indicators were not considered by the interviewees, the obtained overlap is significant. KPIs related to economic aspects appear to be the most considered, while environmental indicators are mainly related to emissions, and social ones to the relationship with the community, confirming Henri and Journeault (2008) and Pawłowska (2015). Notably, PIs like energy use or OHS are largely diffuse among firms (Trianni et al., 2019) but the same cannot be directly applied to SCs, as already noticed by Marshall et al. (2016). Some indicators related to Cost evaluation were not considered either, regardless of their proven importance in the literature (see Table 8) as the *Total SC costs* or *Investments*. The findings support the results of Vuorenmaa and Helo (2011) and Pettersson and Segerstedt (2013), also considering the highly confidential data that would need to be shared (Pagell and Shevchenko, 2014; Patrucco et al., 2019). Our set is contributing to this direction, helping SCs in identifying the sustainability KPIs to be collectively addressed, allowing for independent and autonomous management of the issues by each tier (Sisco and Chorn, 2009).

Perspective	KPI	KPIs considered by the investigated sample
	Return on investment	
Financial	Return on sales	
	Return on assets	

	Total SC cost	
	Inventory costs	
	Cash-to-cash cycle time	
	Capacity Utilization	
	Recycling	
Internal process	Certification	*Final aim of implemented interventions*
	Supply chain responsiveness	
	Supply chain cycle time	
	Process cycle time	
	Labour efficiency	
	New product development time	
Learning and growth	Investments	
	Integration with SC partners	
	Use of new technology	*Final aim of implemented interventions*
	Market share	
	Customer satisfaction	
	Product quality	
Customer	Product/service variety	
	Order fulfilment	
	Delivery reliability	
	Energy use	
	Water use	
Environment	Material use	
	Environmental impacts	
	Waste	
	Community relationships	
	Philanthropic investments	
Social	OHS performance	
	Labour turnover	
	Employee satisfaction	

Table 10. Analysis of the proposed KPIs compared to the KPIs considered by the investigated sample.

According to this preliminary empirical validation, the proposed set of KPIs seems to be applicable in different contexts, according to diverse firm size and sector, following the advice from Ahi and Searcy (2015). Moreover, as per the feedbacks from interviewees, the proposed set looked manageable and easy to be used: this result seems positive, although preliminary and with more empirical research needed, considering the share of SMEs in the investigated sample

(Arena and Azzone, 2012). The applicability along the entire SC was confirmed by investigating 3 SCs and by asking focal firms to consider their extended SC. This approach can provide better results than investigating only the perspectives focal firms, as largely recommended (Ahi and Searcy, 2015; Winter et al., 2013) and recently remarked (Tuni et al., 2018). As for the previous literature, not many applications exist along the entire SC in different sectors. Authors started moving in this direction, still the contributions show limitations as for the scope of the present study: Lauras et al. (2011) did not specifically address sustainability and focused only on the make SCOR process; Izadikhah and Saen (2018) entailed a limited number of indicator for a specific sector and country; Sellitto et al. (2015) and Tajbakhsh and Hassini (2015) both addressed a specific sector and suggested the use of specific indicators for each tier, thus not considering a general set applicable in all the tiers, as suggested by Ahi and Searcy (2015) and Aramyan et al. (2007).

5 Conclusions

The growing pressures experienced by SCs to address sustainability and the need for a balanced, holistic and integrated set of KPIs for measuring sustainability represent a crucial aspect that we wanted to tackle. We deem the proposed set of KPIs to successfully contribute to the discourse over the measurement of sustainability in firms and SCs.

From an academic perspective, the proposed set offers a balanced set of specific KPIs prioritized looking at the overall SC and not only from the perspective of the focal firm, and consolidated through an application in different real-world contexts involving industrial decision-makers. To our knowledge, as can be inferred by the conducted literature review, the present work provides a relevant advancement in the literature. As for the industry side, industrial decision-makers are provided with a set of KPIs for a comprehensive assessment of sustainability performance in SCs. This allows for a more focused and general approach along all the SC tiers, allowing a better grasping what actions could be undertaken to enhance sustainability performance. From a policy-making perspective, the set could also support policy-makers in developing more effective regulation and policy frameworks for sustainability, further encouraging firms and SCs towards improved sustainability, also considering the Sustainable Development Goals.

In conclusion, we would like to acknowledge some caveats and limitations. When conducting case studies, interviewees of the different firms and SCs were not in the same managerial position. Further, we could not interview multiple industrial decision-makers within the same firm, thus being unable to simultaneously gather multiple views and opinions within the same firm. Albeit the empirical validation was conducted in a relevant European economy, it is not representative of all manufacturing economies, and therefore slight differences could be experienced.

Nevertheless, the aforementioned limitations offer interesting opportunities for future studies, and we would like to conclude by sketching some research avenues. First, further empirical research could consider the perspectives of multiple industrial decision-makers differently acknowledgeable for sustainability, allowing a better understanding of possible mismatches and conflicting perspectives. Second, although the sample size of our empirical validation is

adequate for theoretical generalizability, statistical one would require further research. Third, future work could explore different contexts more in detail, considering SC sector, geographic location, length and characteristics, as well as leverage on longitudinal research, evaluating the evolution over time of firms and SCs. Our investigation revealed that some contextual variables seem to hinder or foster an integrated approach of the SC towards increased sustainability – as the degree of alignment - calling for further research on them to better understanding the decision-making process. As for additional stream of research, in our study, we could grasp a thorough relationship between sustainability-oriented and quality management-oriented SC literature, calling for additional research on the topic. Others interesting aspects seem to be then related to the quantitative evaluation of PIs and to the computation of the PIs along the whole SC. All these insights would provide strong support for the measurement of sustainability performance in SCs.

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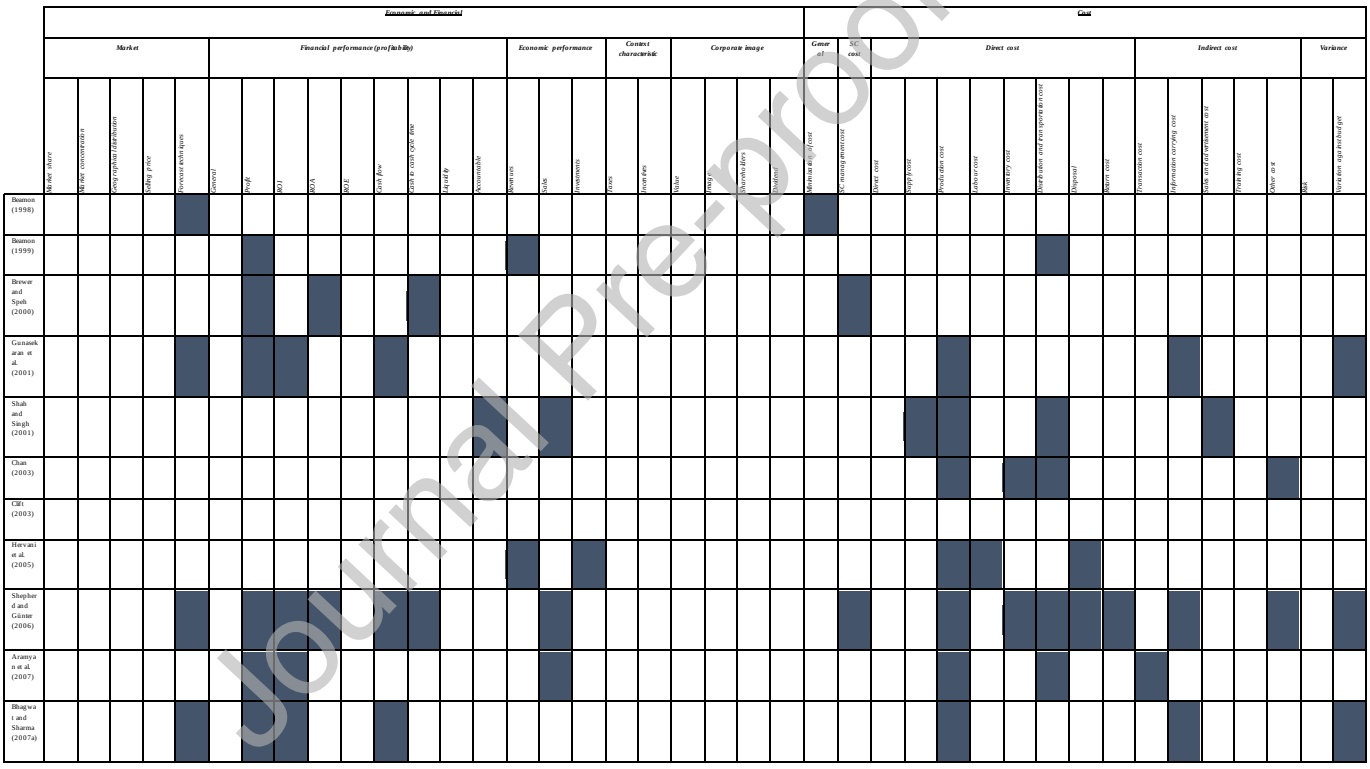
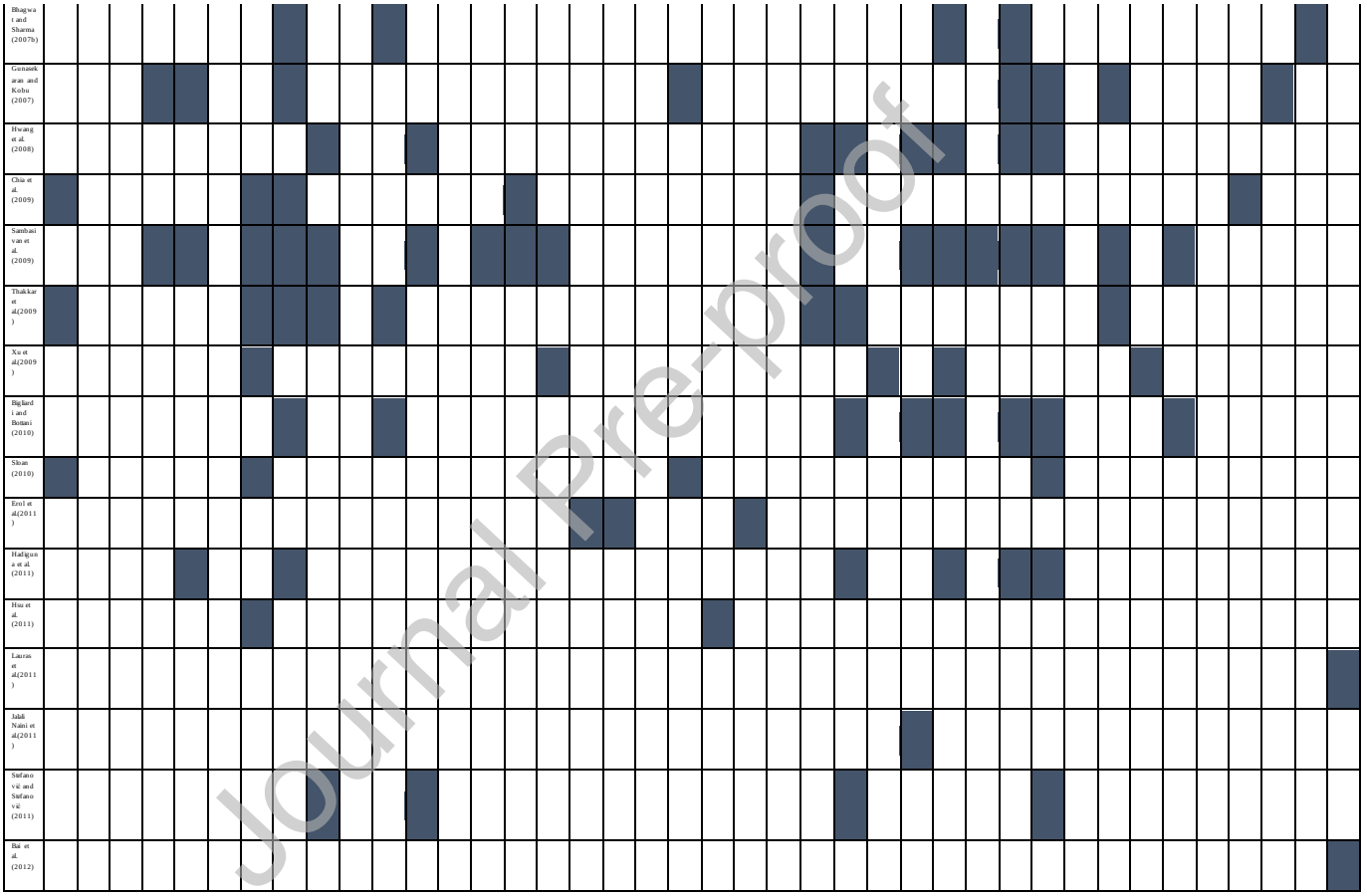
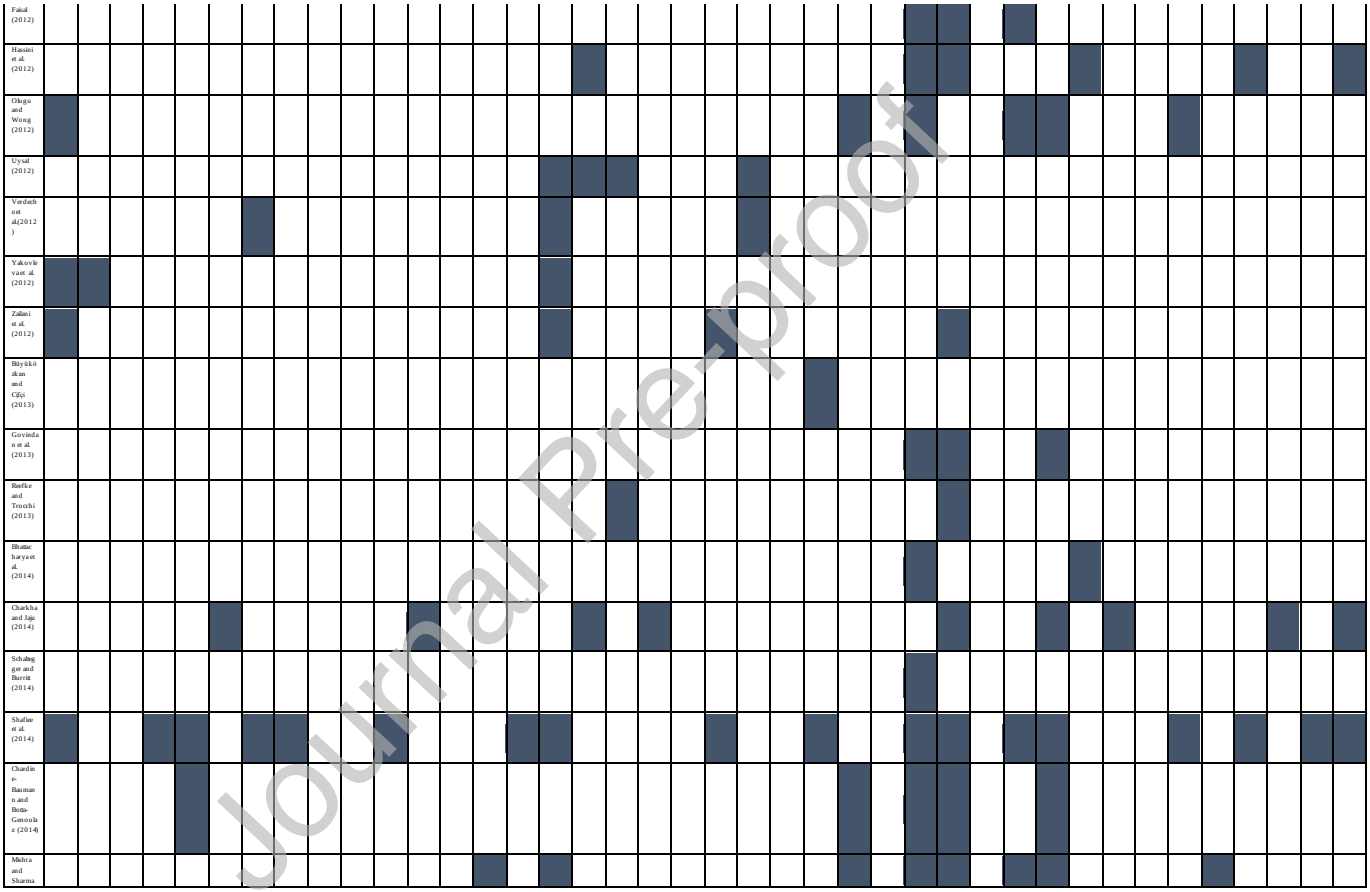
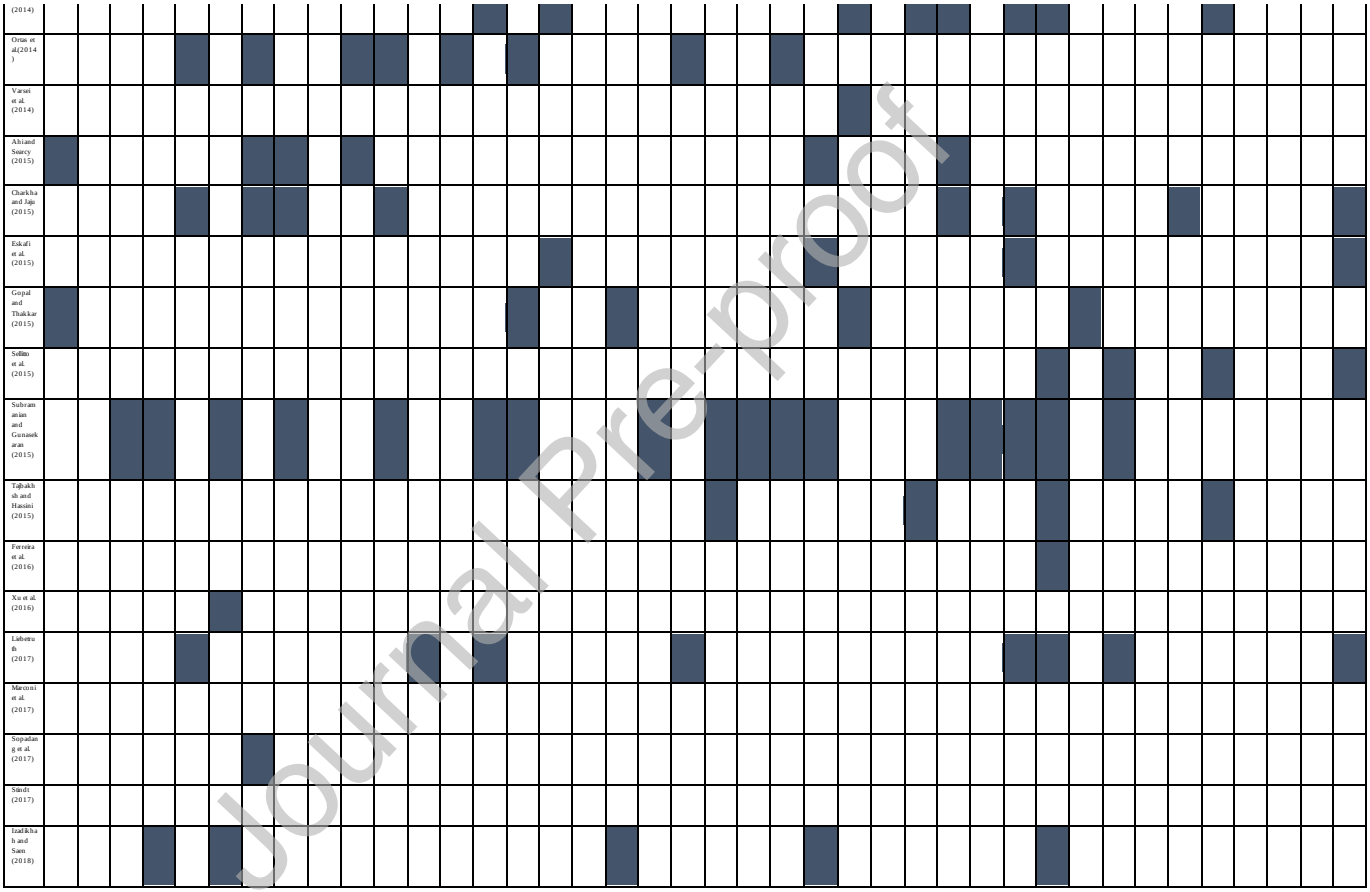
Appendix I

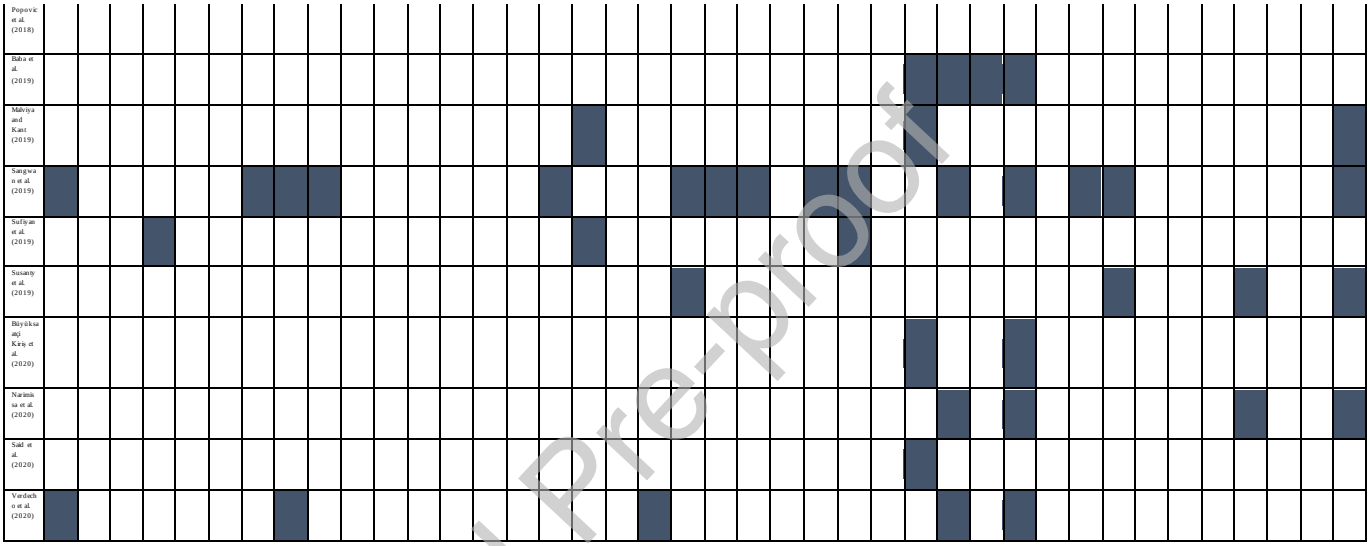
Details of the single performance indicators addressed by each contribution reviewed in the literature background.



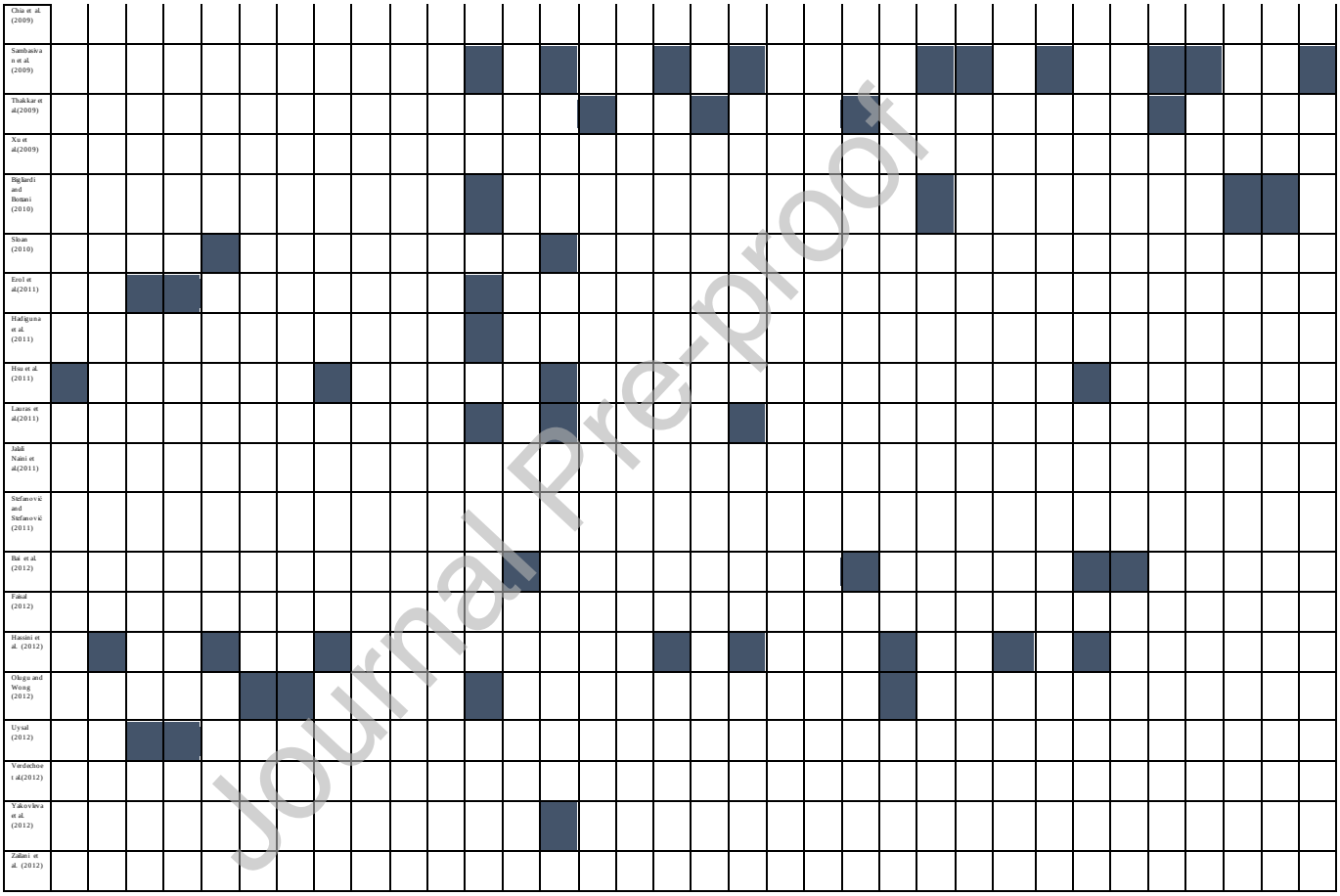


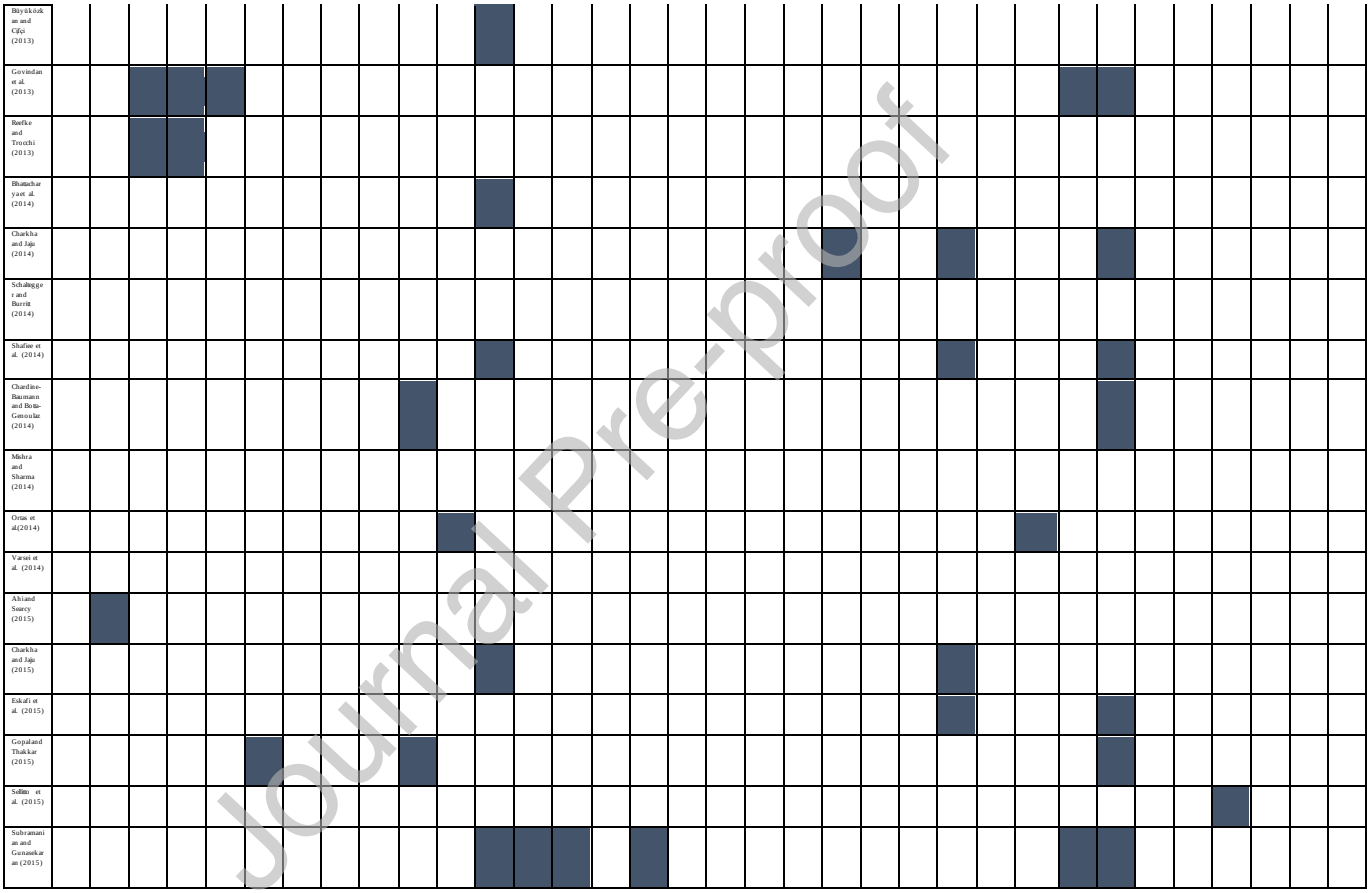


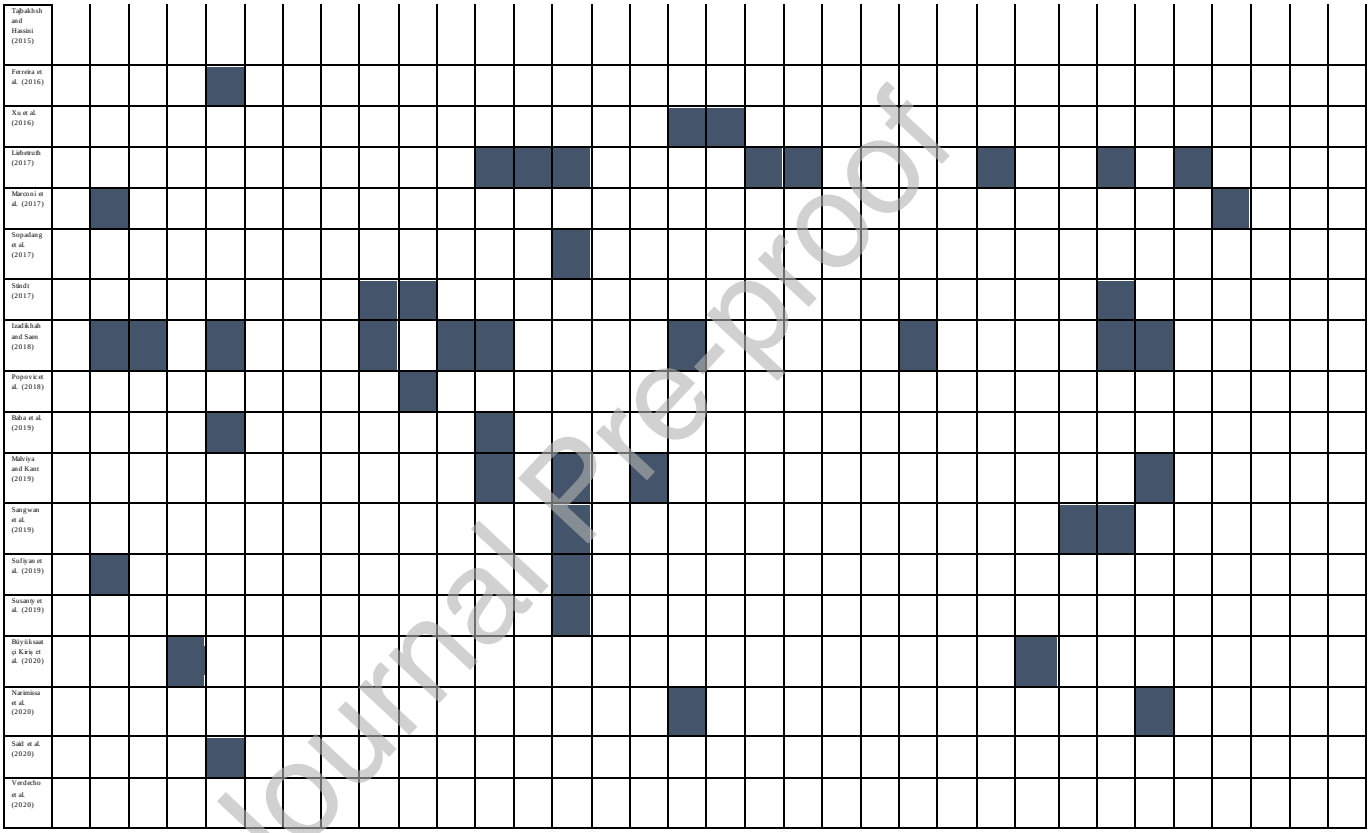


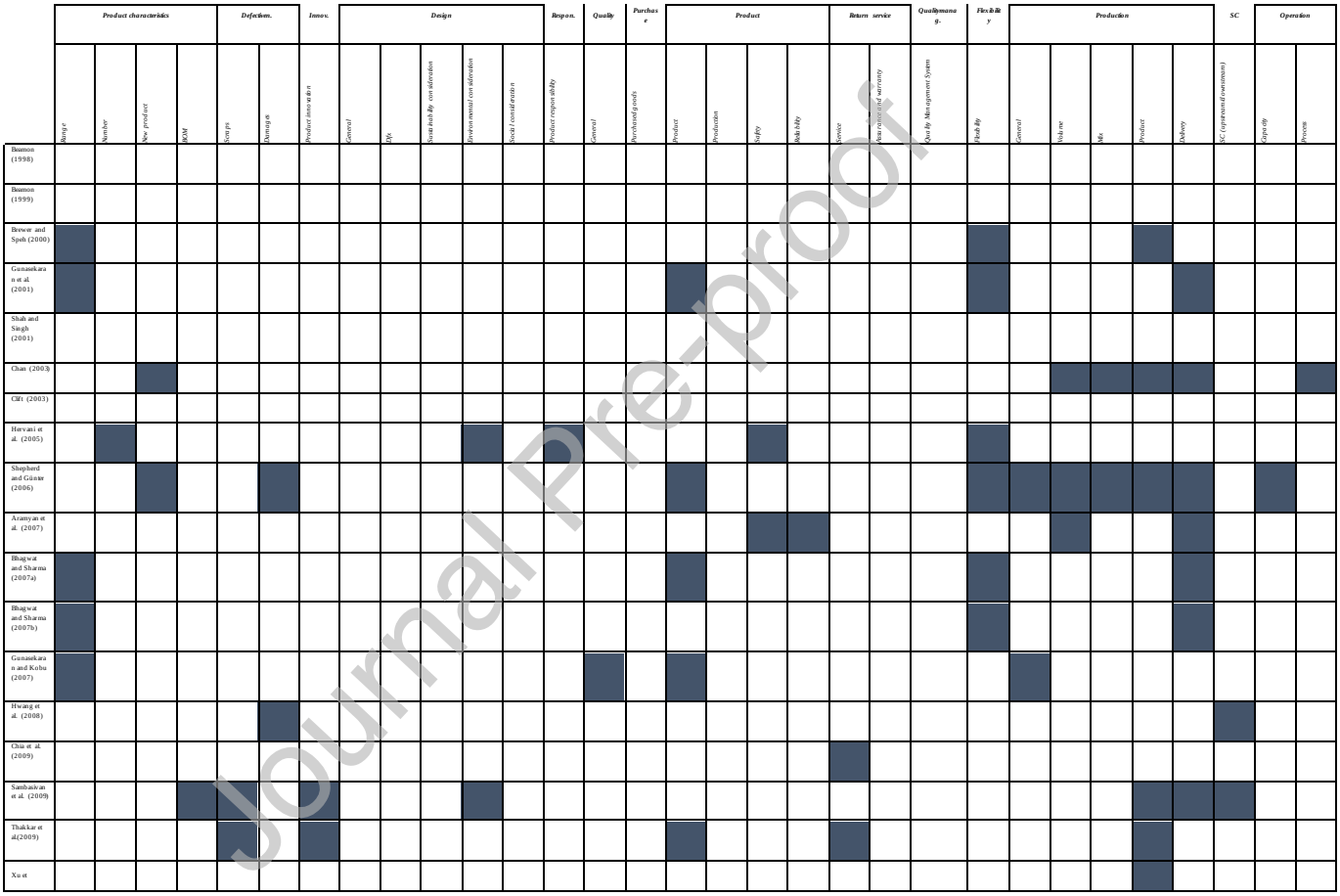


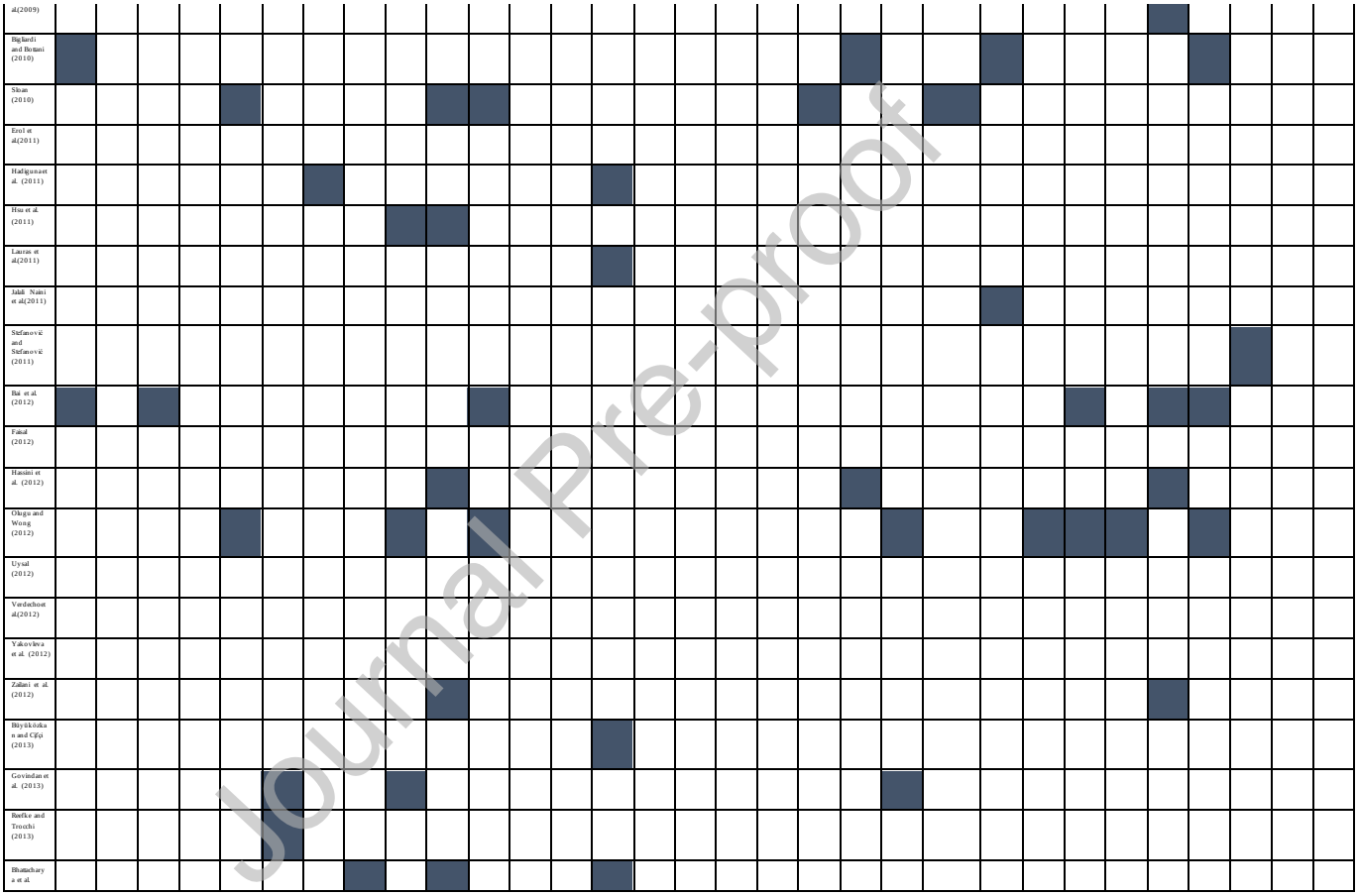
	Management										Production																										
	Awar.	Procedure				Motivational		Ethical Conduct			Performance										Process				Schedule		R&D		IT		Production characteristics							
	Continuously awareness	Process management	Standards	Effectiveness of procedures	Regulatory compliance	Motivation of effort employees	Motivation of effort suppliers	Code of conduct	Trustworthy	Corruption	General	Utilization	Efficiency	Productivity	Reliability	Readiness	Profitability	Responsiveness	Workability	Process accuracy	Process capability	Process innovation	Production planning and control	Effectiveness of scheduling	Inventory of scheduling	R&D investments	R&D capability	Use of IT	IT capability	Throughput	Variable	Set up	Economies of scope	Error				
Beamon (1998)												■																									
Beamon (1999)																																					
Brewer and Speh (2000)																												■									
Gunasekaran et al. (2001)												■						■							■												
Shah and Singh (2001)																																					
Chan (2003)												■																■									
Clift (2003)													■																								
Hervani et al. (2005)																																					
Shepherd and Günter (2006)												■		■											■				■		■	■					
Aramyan et al. (2007)																																					
Bhagwat and Sharma (2007a)												■						■							■												
Bhagwat and Sharma (2007b)												■													■												
Gunasekaran and Kobu (2007)					■							■	■													■											
Hwang et al. (2008)			■																																		

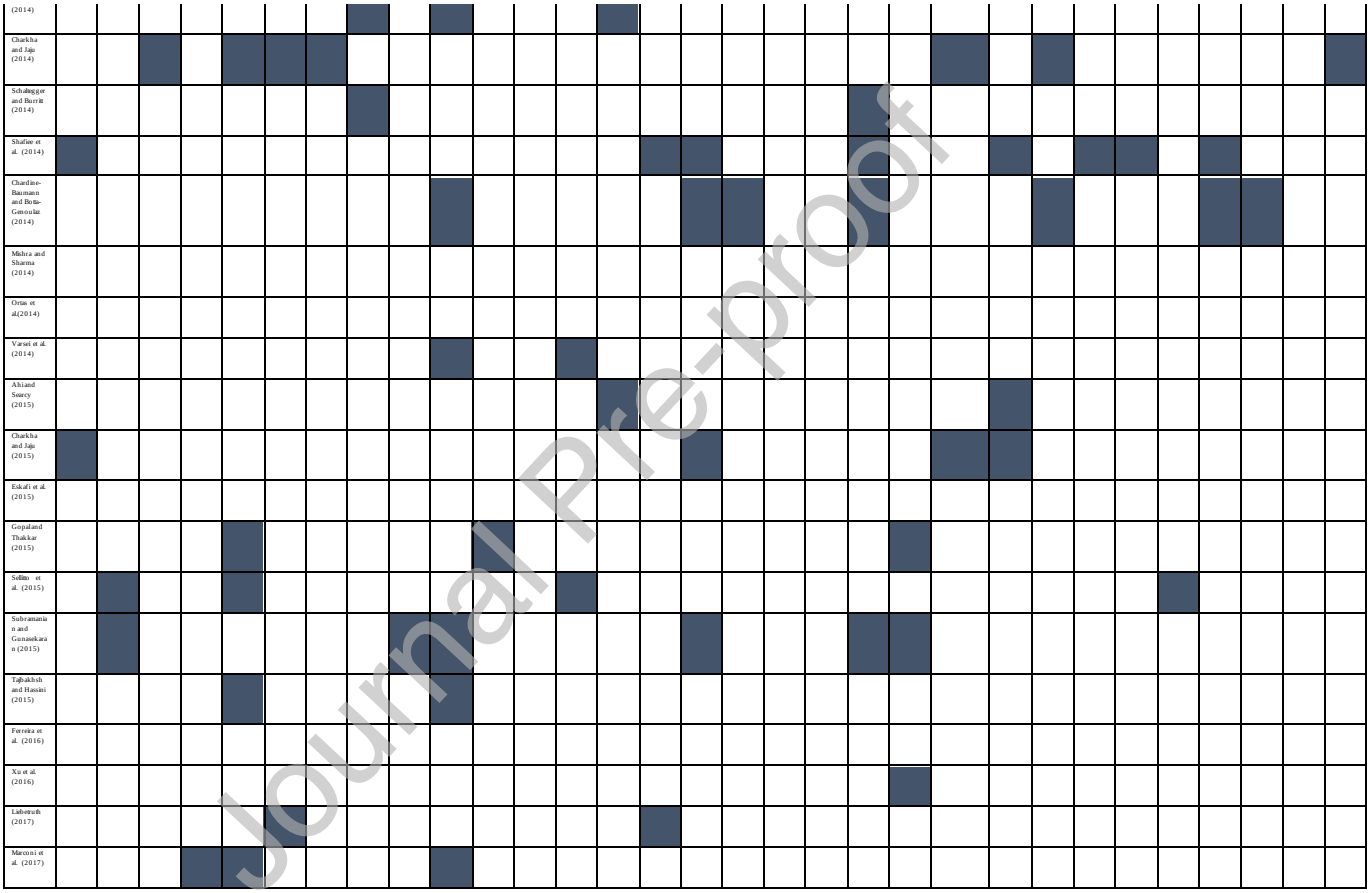


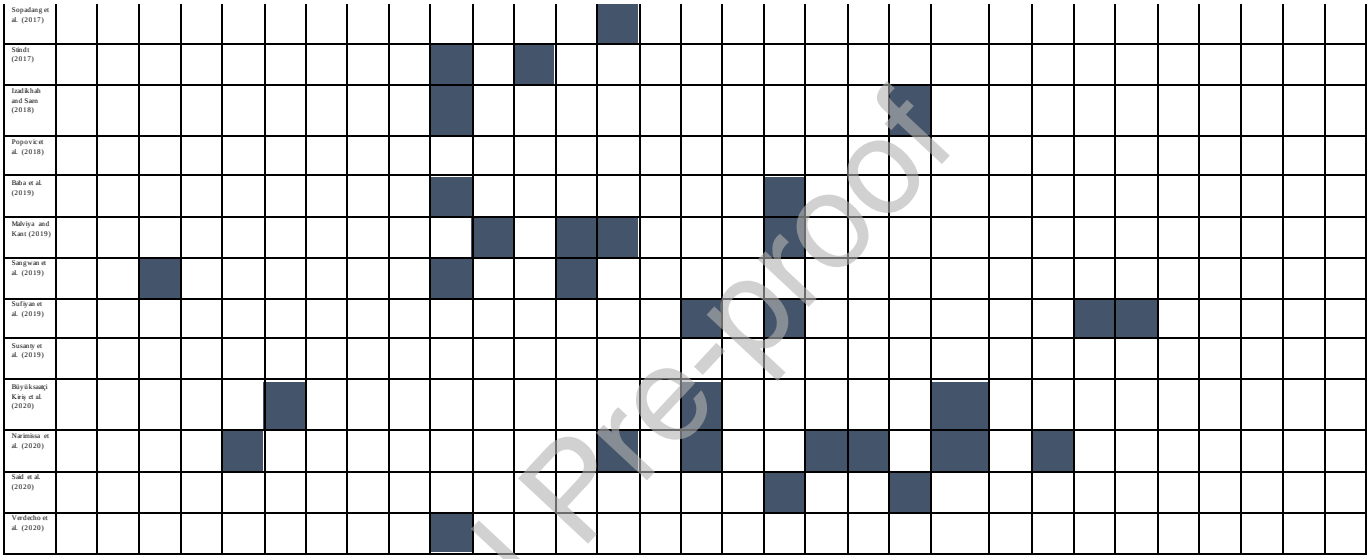




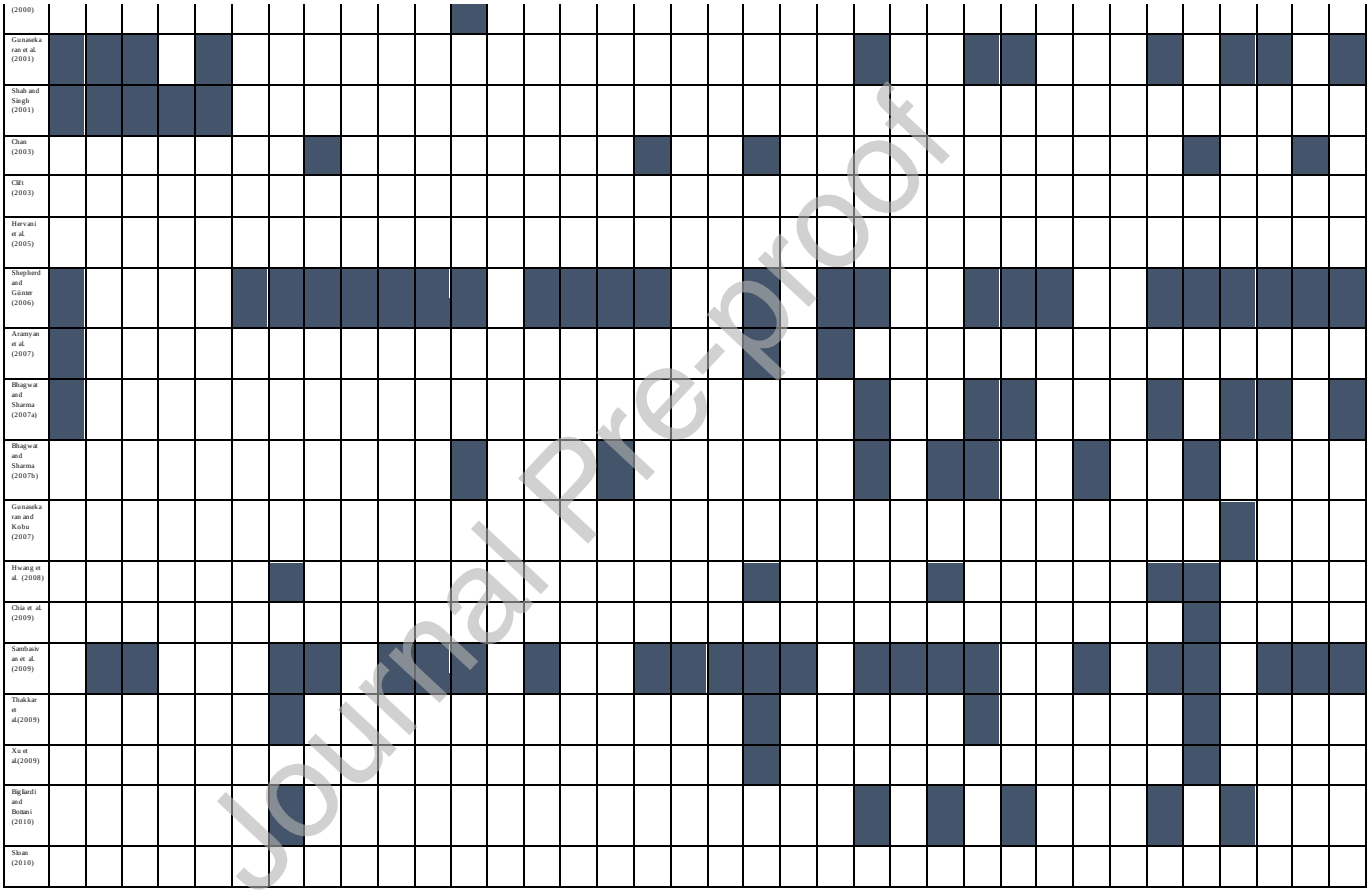


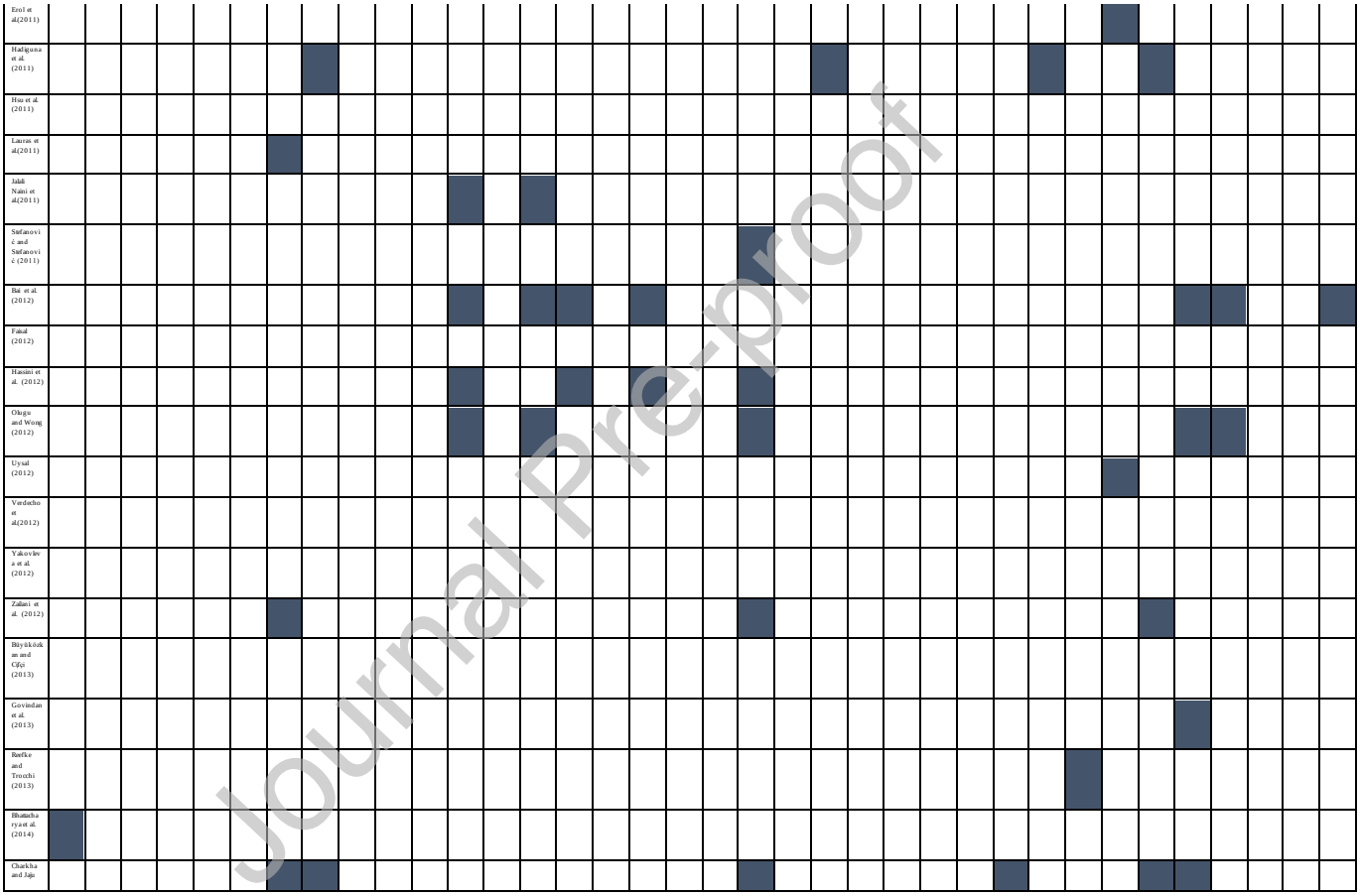


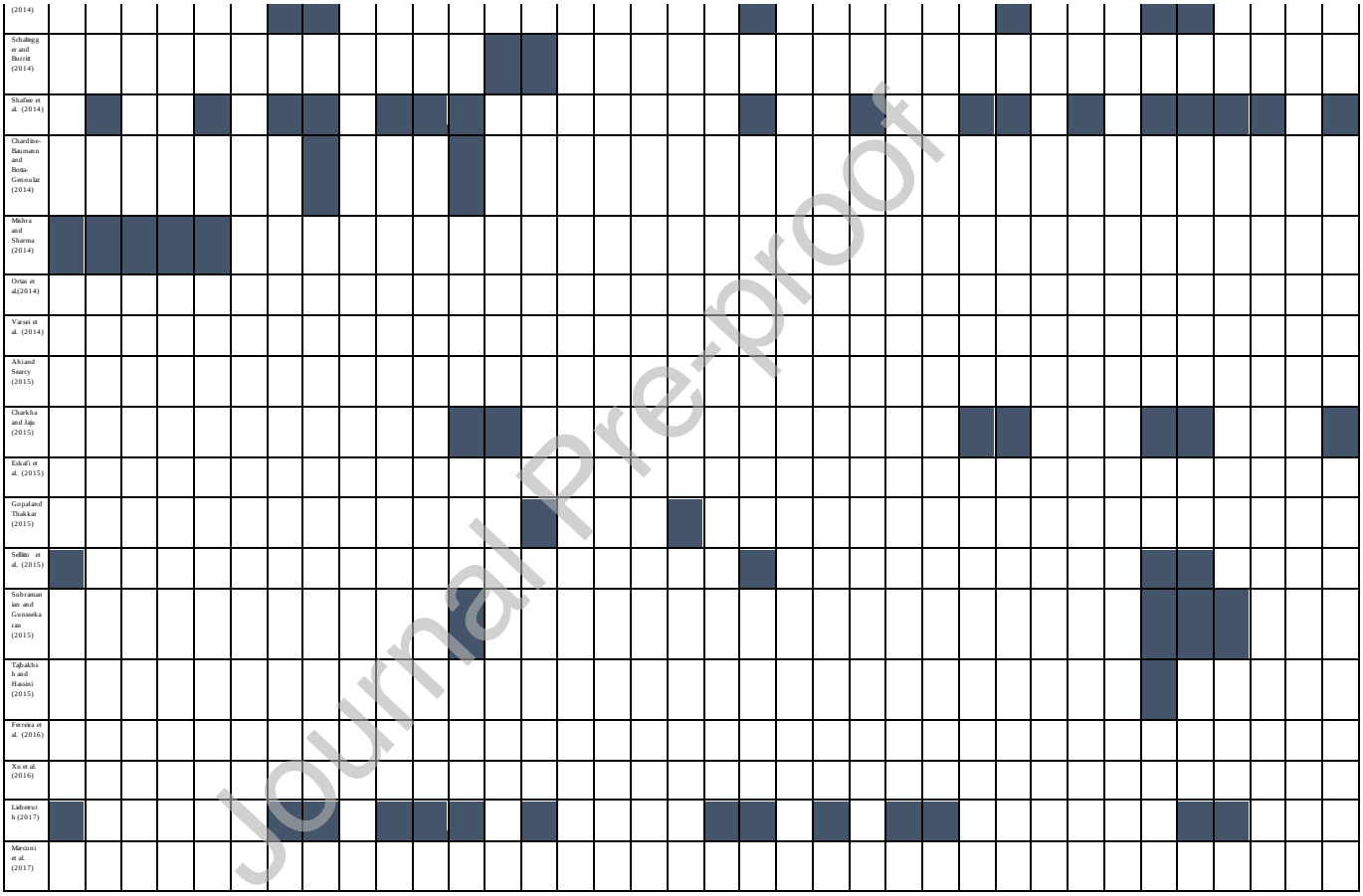


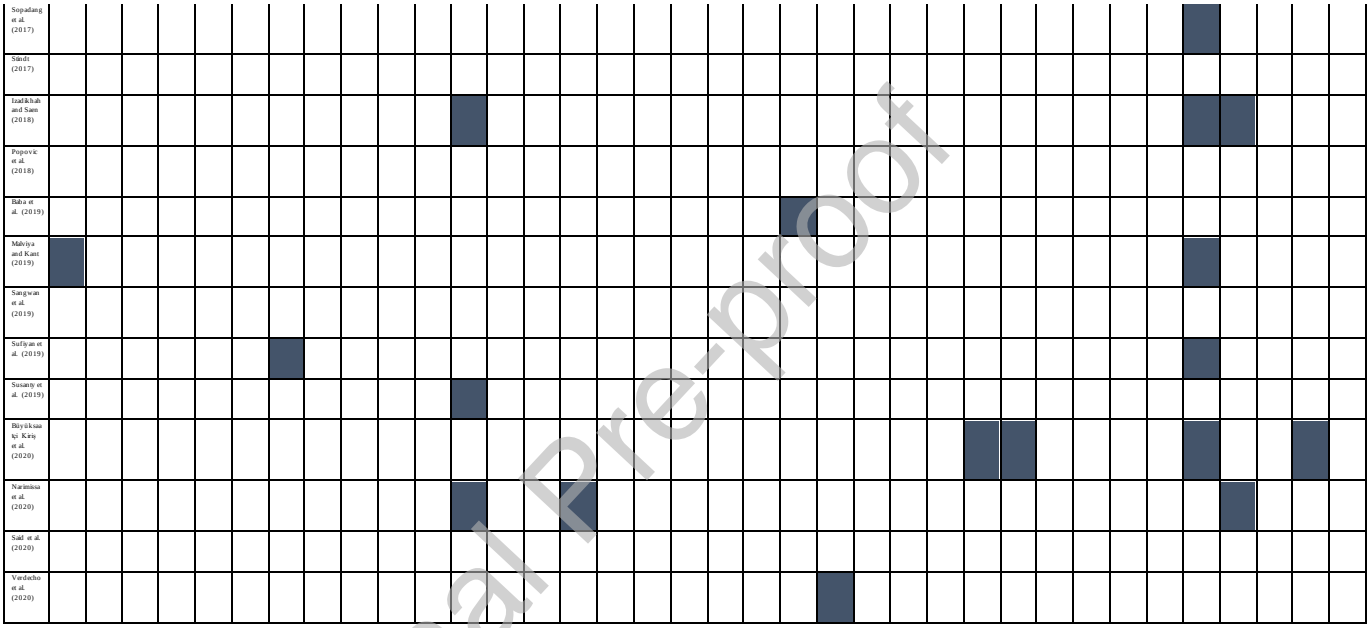


	Inventory										Information				Orders procedures and delivery																	
	Inventory level					Coverage			Performance			Extent of sharing			Characteristics				Order Performance				Invoice			Delivery performance				Timeliness of the delivery				Quality of the delivery	
	Total	Raw materials	WIP	Semifinished	Finished products	Margin	Turnover or days of supply	Service rate	Utilization	Accuracy	Obsolescence	Level of sharing	Information Manag ement System	Analysis By	Accuracy	Quality	Timeliness	Security	Number	Fill rate	Flexibility	Backorder	Easy methods	Correct	Accuracy	Method Effectiveness	Correct	Efficiency	Customer satisfaction	Effectiveness 3PL	Lead time	On time	Reliability	Frequency	Accuracy	Damage free
Beamon (1998)	■							■			■									■															
Beamon (1999)								■												■		■										■			
Brewer and Speh												■																							

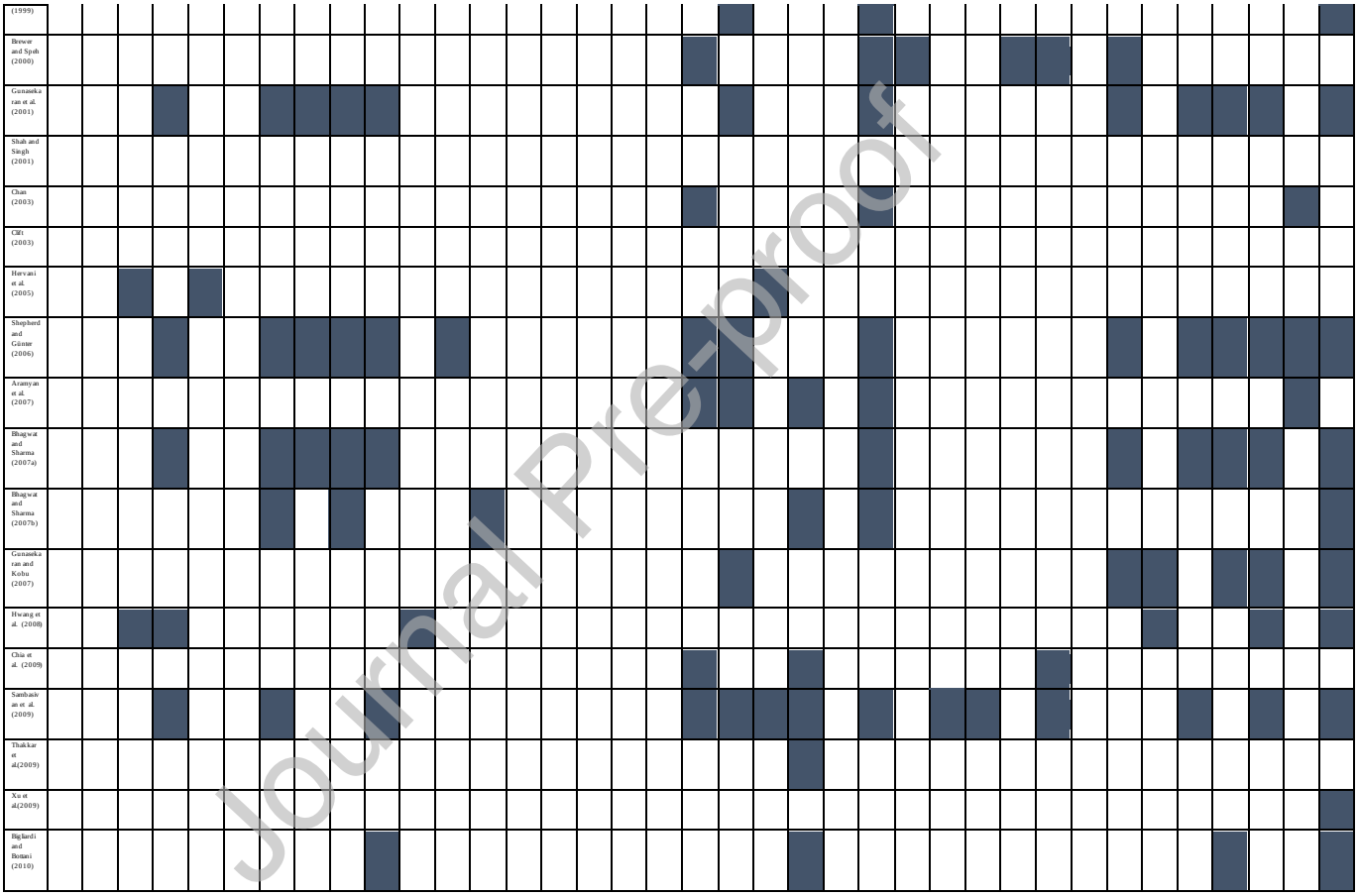


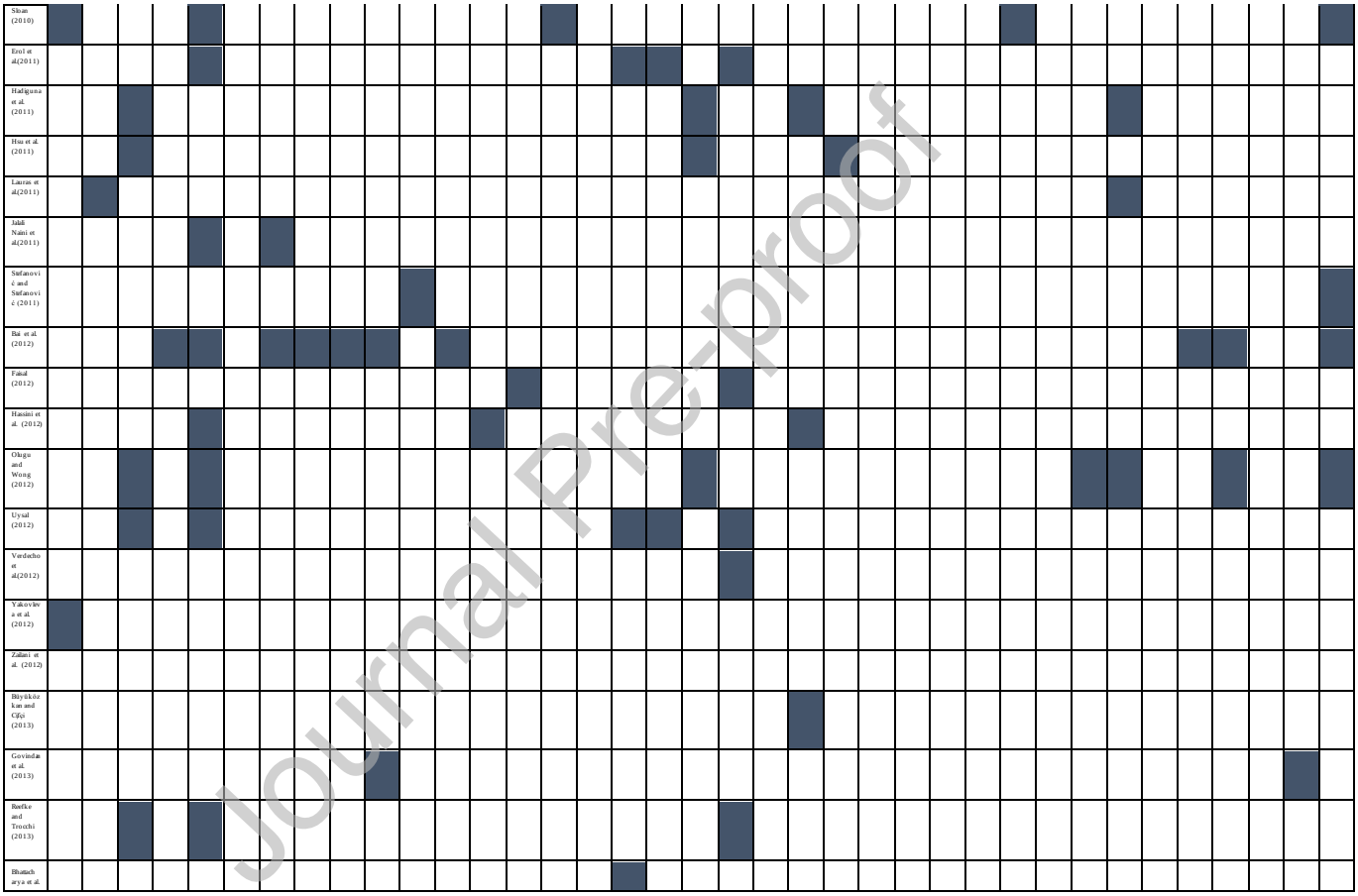


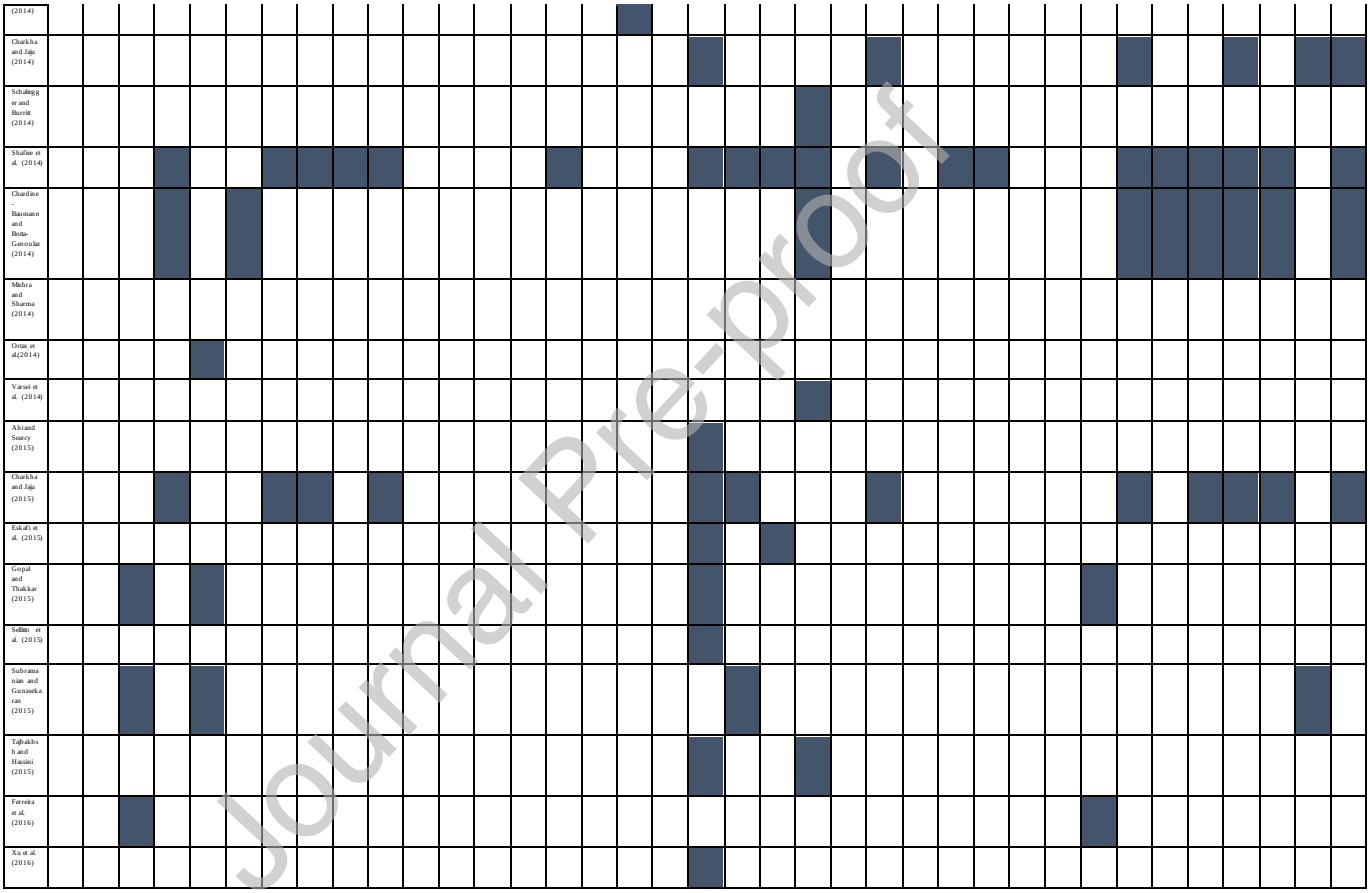


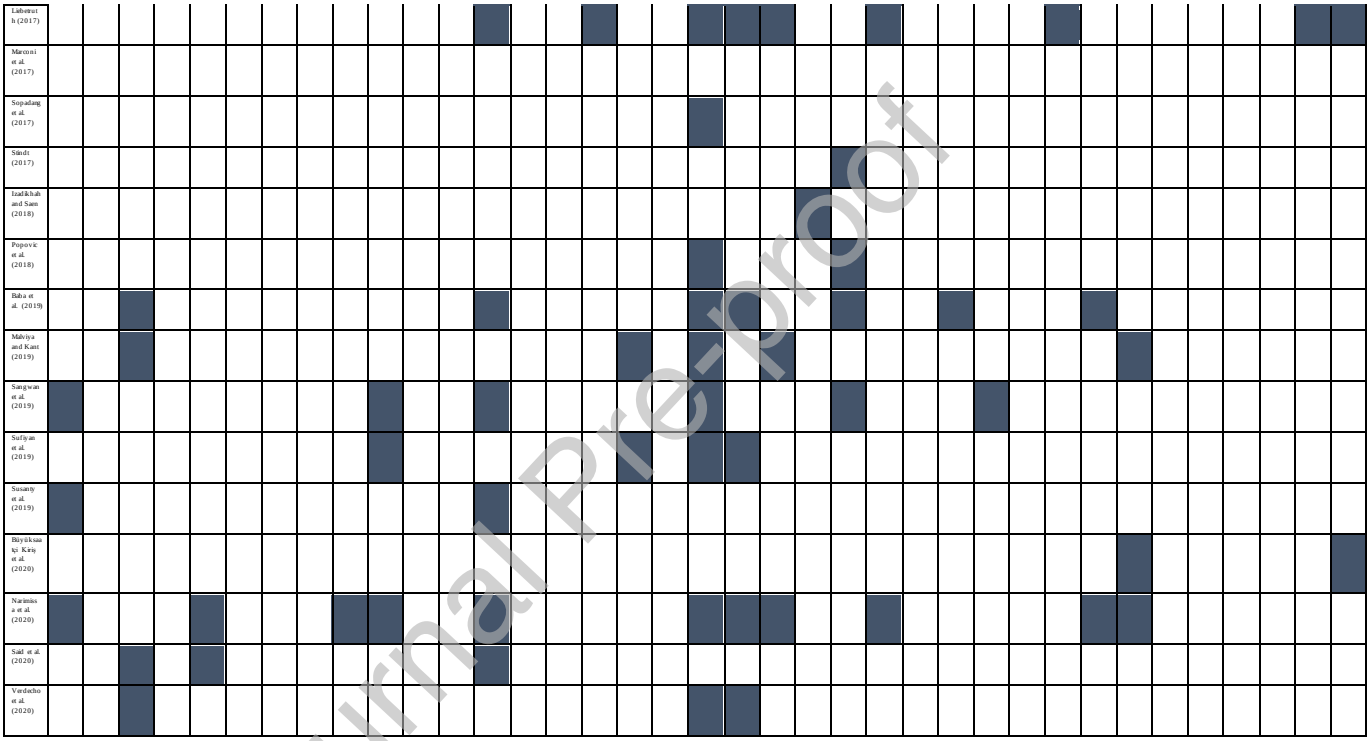


	Supplier																		Customer										SC response time							
	Dependency		Performance							Collaboration			Characteristics				Reverse SC		Satisfaction			Service			Characteristics					Cycle time					Lead time	
	Vertical integration	Subcontracting cost	Certification	Risk fly	Sustainability	Green	Quality warranty	Quality prevention	Resistance	Partnership	Reliability	Satisfaction	Geographical distribution	Diversity	Length	Complexity	Effectiveness	Completeness	Customer satisfaction	Complaints	Returns	Service	Safety	Delivery time	Contact points	Number	New	Type	Relevance	Inventor in sustainability	Supply chain cycle time	Raw material procurement cycle time	Purchase cycle time	Product development cycle time	Production cycle time	Lead time	Manufacturing lead time
Beamon (1998)										■												■														
Beamon																				■				■												■

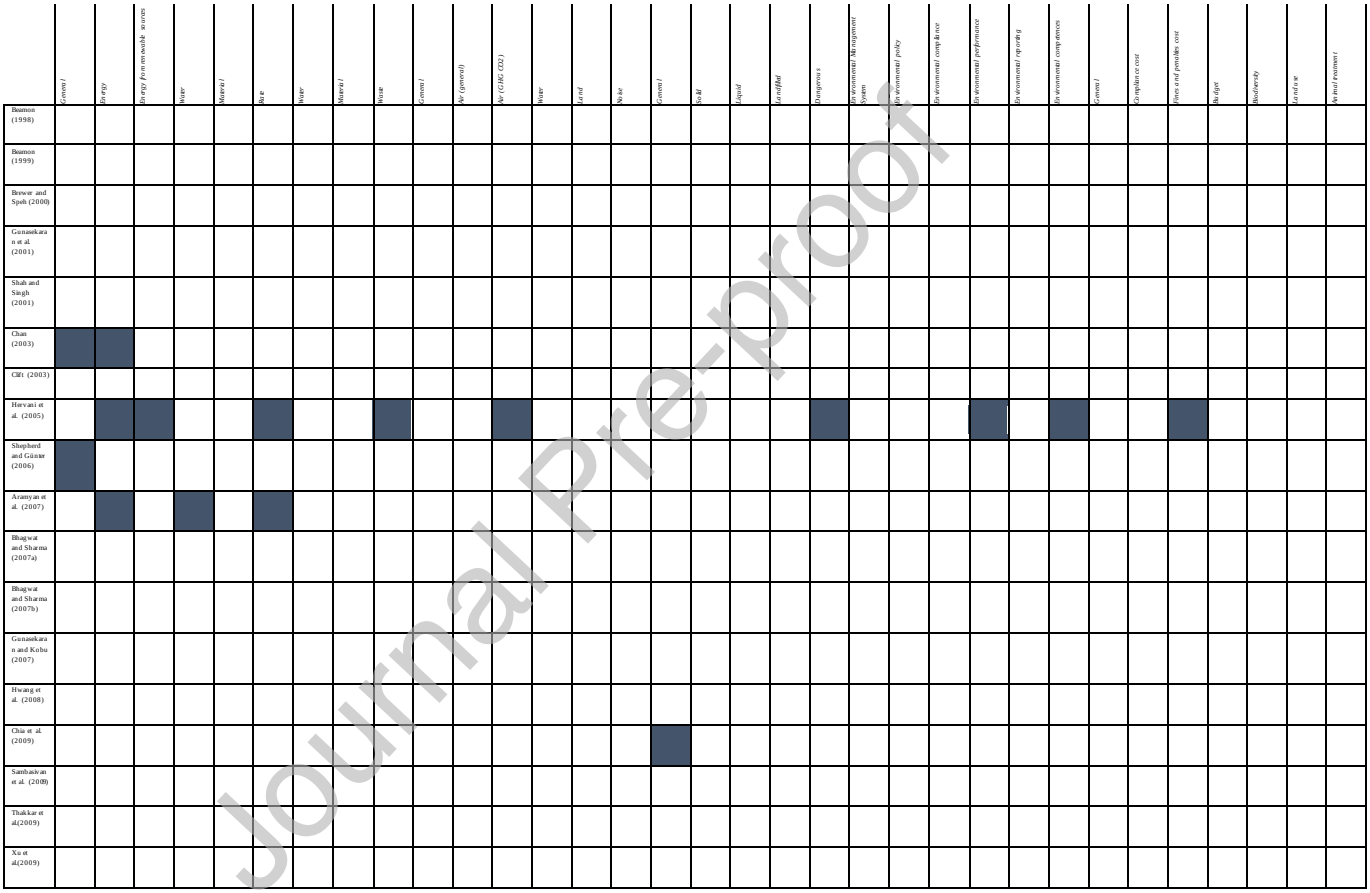


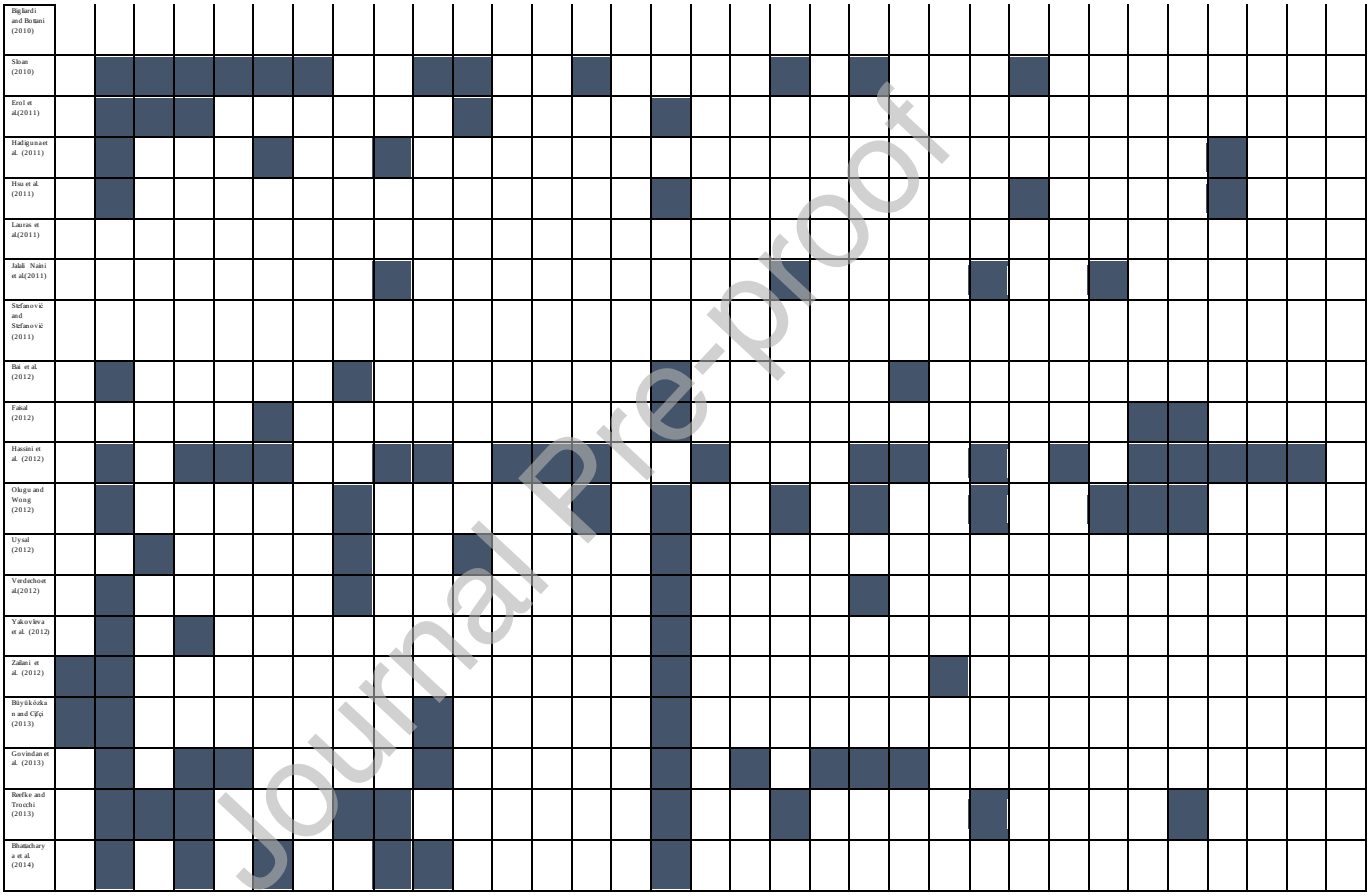


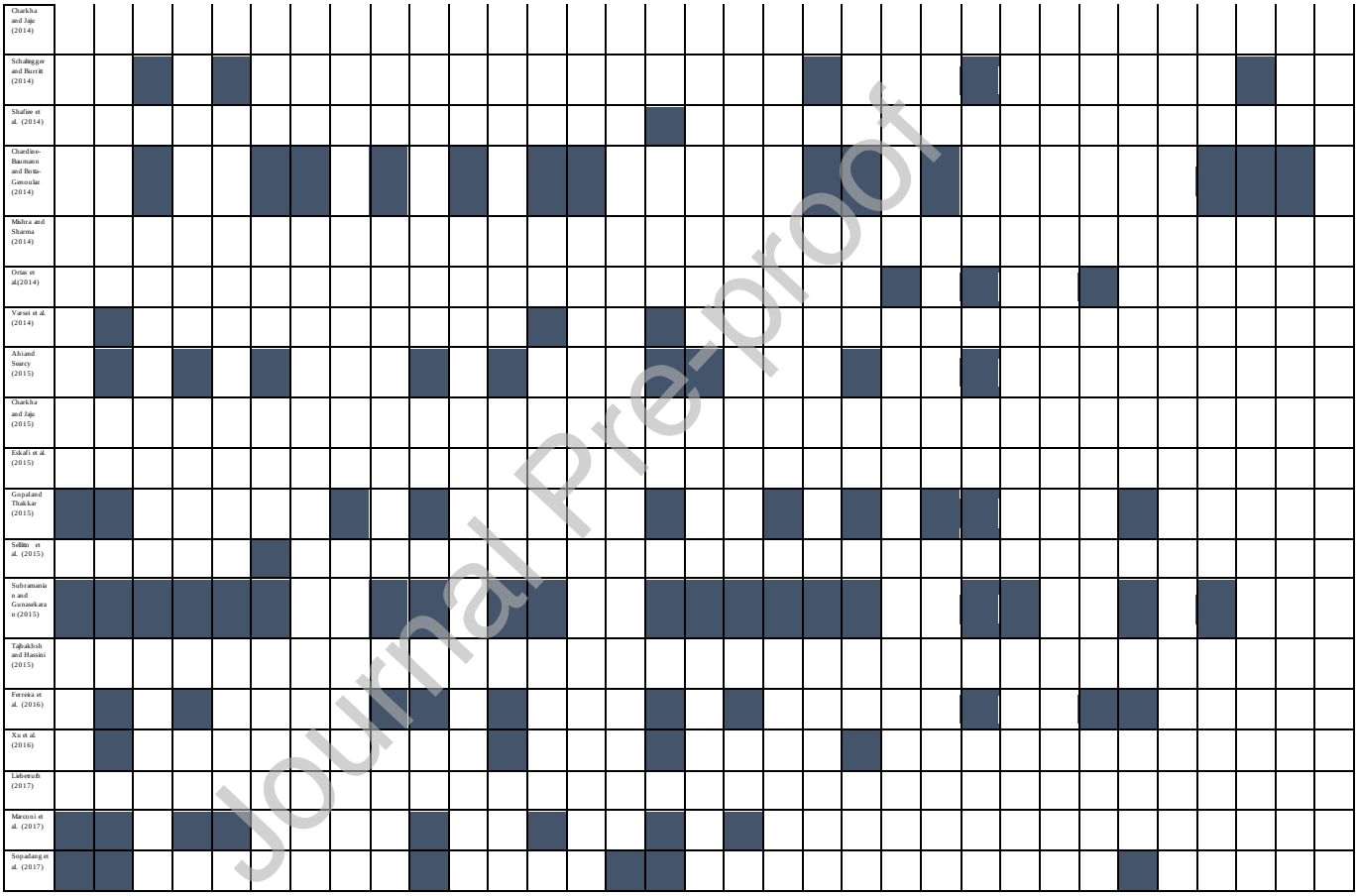


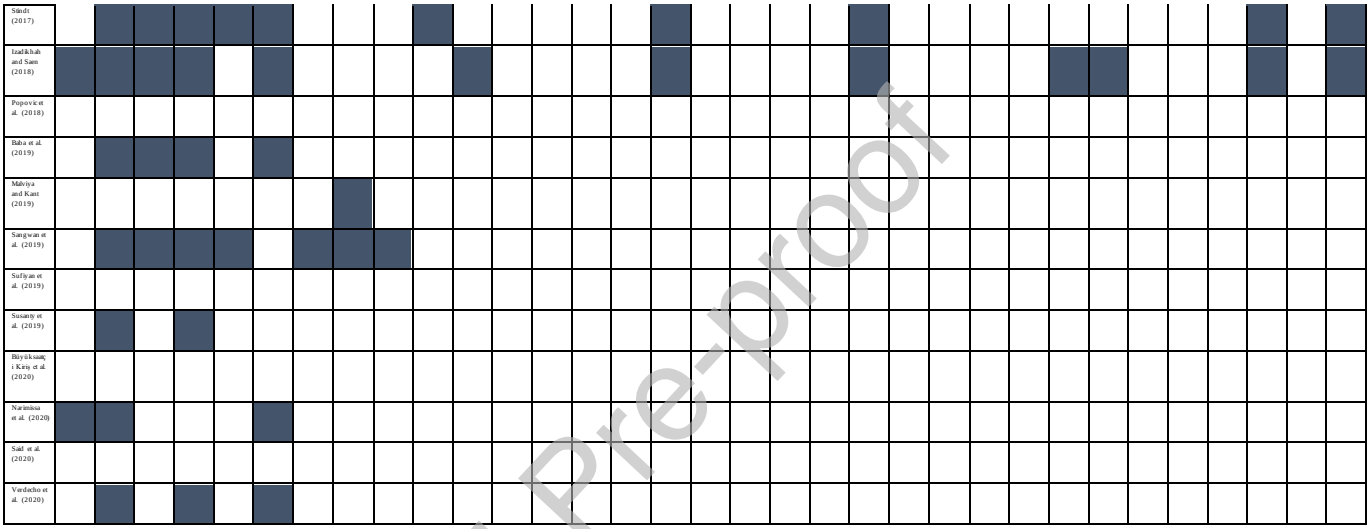


Environment						
Resources consumption	*Reuse and Recycling*	*Emissions*	*Waste*	*Environmental management*	*Environmental Cost*	*Environ. ethical conduct*

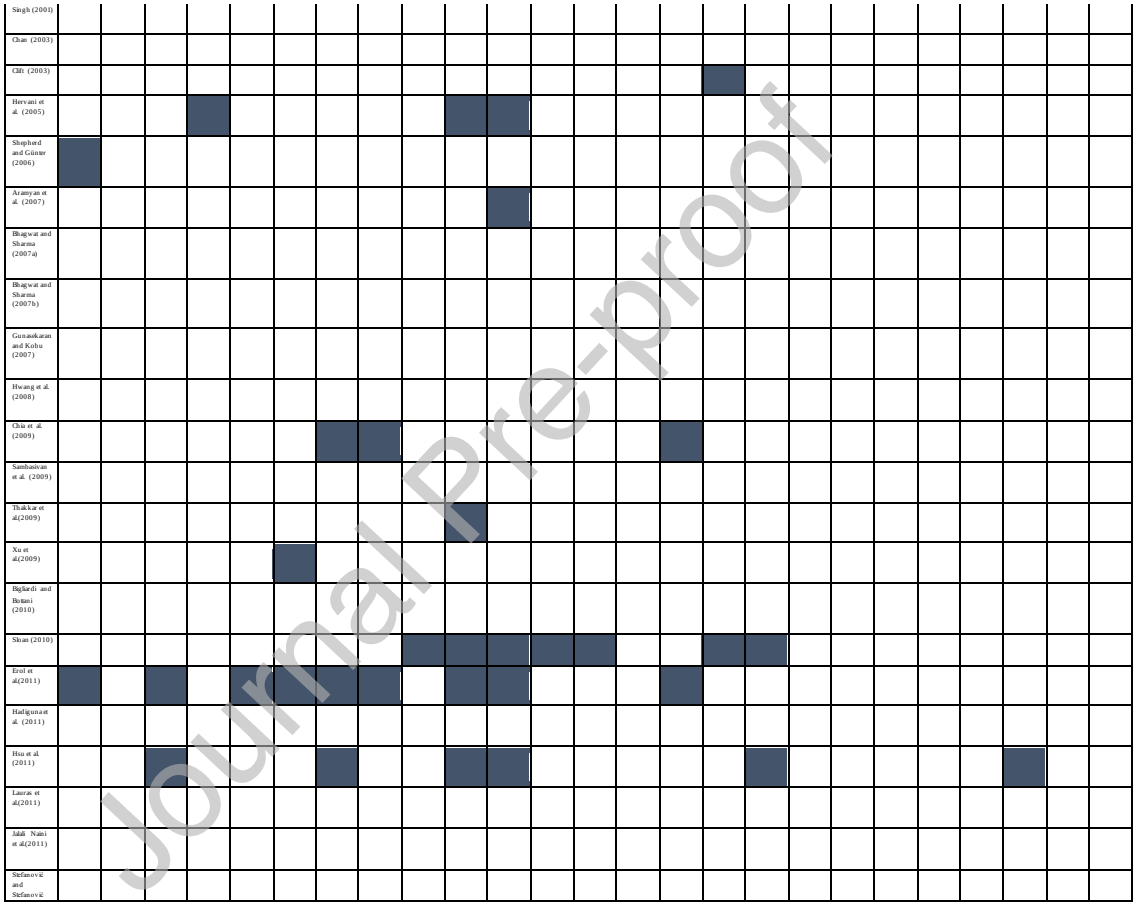


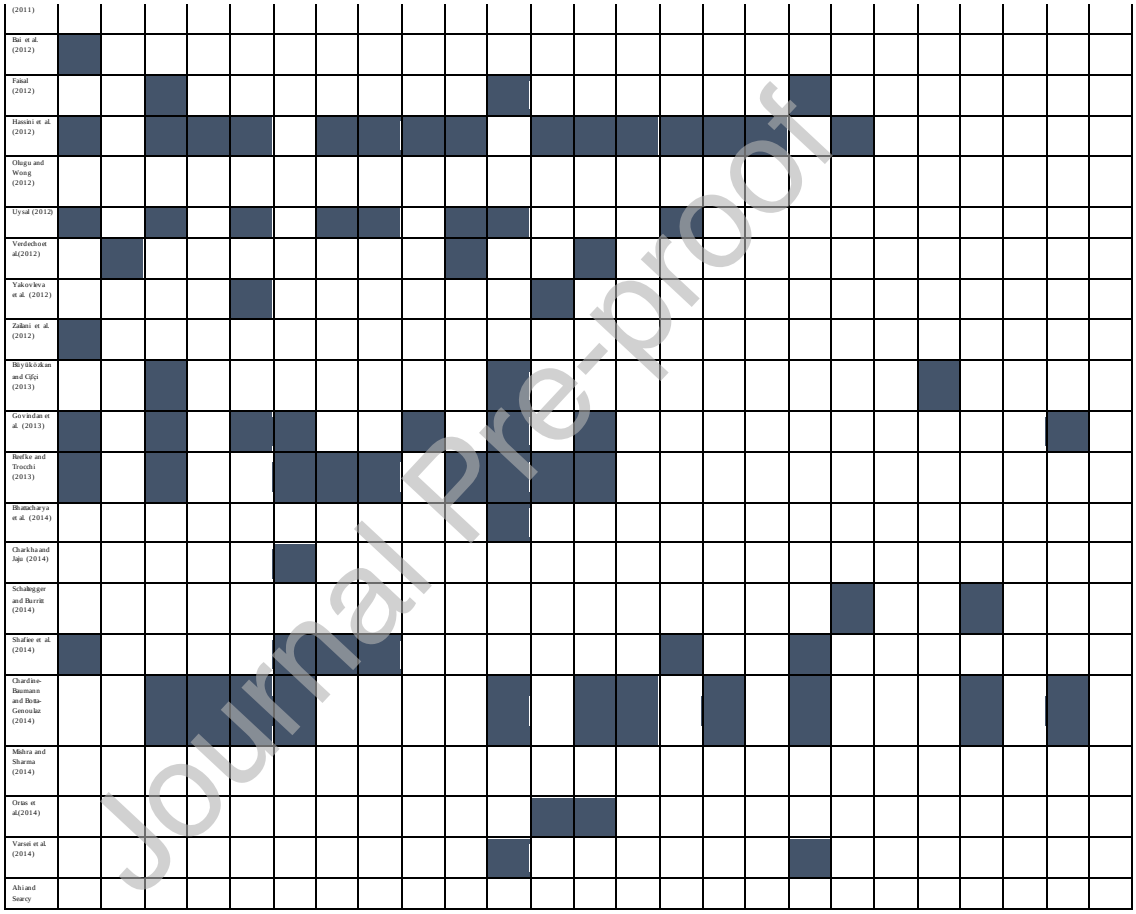


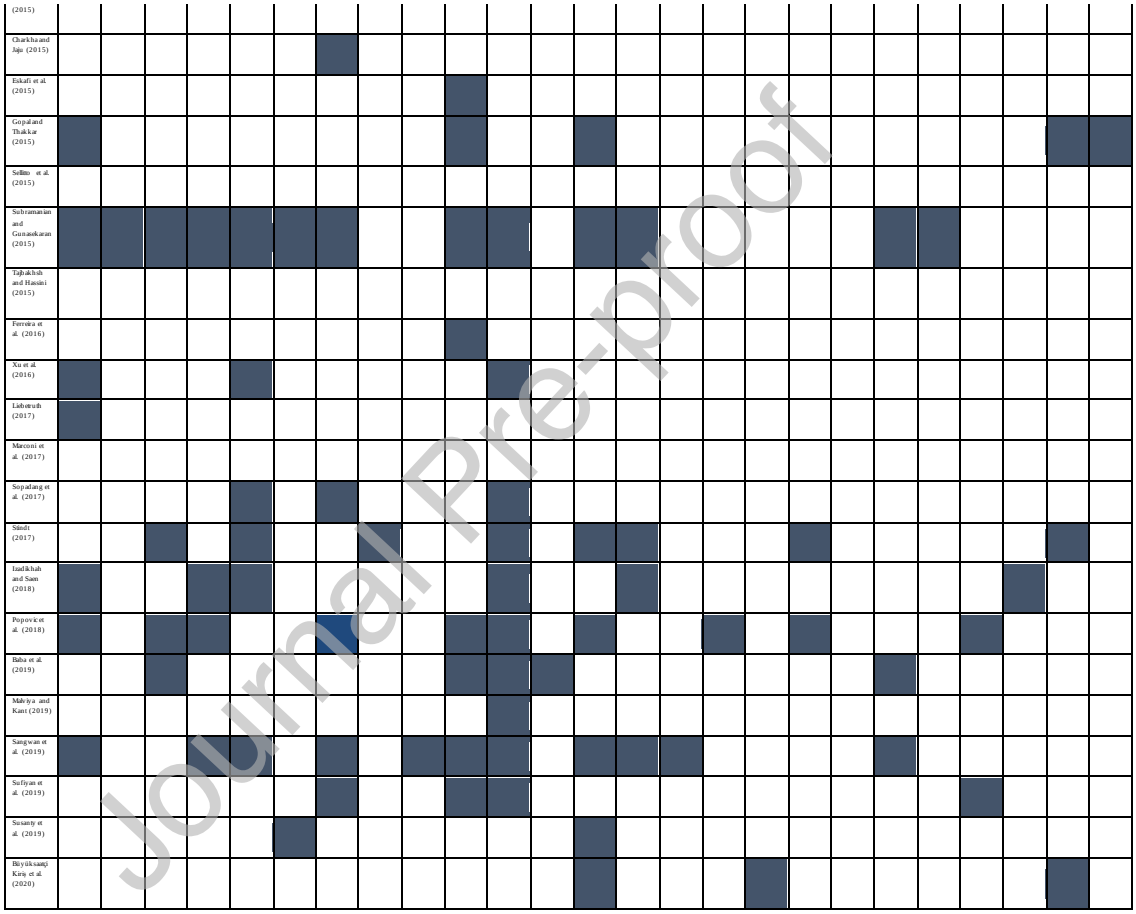


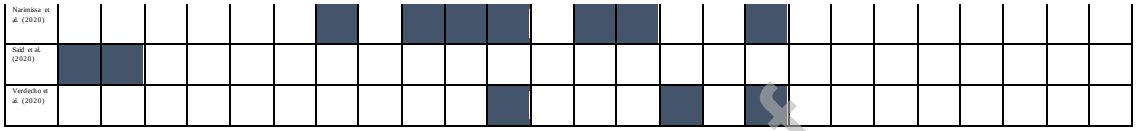


	Social																														
	External stakeholders		Community			Employees											Social management			Social related cost		Ethical conduct									
	Relationship	Communication	Investments and initiatives	Involvement	Development	General	Satisfaction	Turnover	Characteristics	Training	Occupational Health and Safety	Wages	Working	Rights	Involvement	Benefits	Social Management System	Social policy	Social performance	General	Compliance cost	Fair trade	Marketing	Child labour	Charity
Beamon (1998)																															
Beamon (1999)																															
Brewer and Speh (2000)																															
Gunasekaran et al. (2001)																															
Shah and																															




(2011)
Bai et al. (2012)
Faisal (2012)
Hassini et al. (2012)
Olugu and Wong (2012)
Uysal (2012)
Verdecho et al(2012)
Yakovleva et al. (2012)
Zailani et al. (2012)
Büyüközkan and Çifçi (2013)
Govindan et al. (2013)
Beske and Trocchi (2013)
Bhattacharya et al. (2014)
Charkha and Jaju (2014)
Schaltegger and Burritt (2014)
Shafiee et al. (2014)
Chardine-Baumann and Botta-Genoulaz (2014)
Mishra and Sharma (2014)
Orsis et al(2014)
Varsei et al. (2014)
Ahi and Searcy





Appendix II

Details of the protocol used for the conduction of the case studies and of the different multiple sources of evidence.

Primary data	**Source of Evidence 1. Semi-structured interview**	
	General questions	• Interviewee/s introduction (role within the firm, interests, background, experience) • Firm's description (turnover, employees, 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 within the context of the SC? • How would you describe your SC? What are the main features?
	Sustainability	• How would you define a sustainable SC?
	Sustainability performance measurement within the SC	• How do you measure sustainability-related performance in the context of the SC? *To stimulate the discussion:* • What actions/intervention did you adopt towards increased sustainability in the firm and/or in the SC? • How were the SC's sustainability performance measured?
	Source of Evidence 2. Questionnaire based on 3 points Likert-like scale	
	Evaluation of the proposed set of KPIs	Provide an answer between 1 and 3, whit 1= Yes and 3=No. *Capacity to represent* • Do the KPIs properly represent and cover all the relevant performance for industrial sustainability in a SC? • Are the KPIs clearly distinct among them? *Usefulness* • Did the set help you in identifying new KPIs? • Did the set lead you to better reorganised your KPIs? • Could the proposed KPIs provide a valid and quick help? *Ease of use* • Would it be easy for you to apply the proposed set? • Would the proposed set worth the effort of being adopted?
	Source of Evidence 3. Direct observations	
	Plant tour	Direct observation of the production plant during working hours, with the possibility to contextually ask additional questions to interviewees.
	Source of Evidence 4. Field notes	
	Field notes – semi-structured interview and questionnaire	Field notes collected during the conduction of the semi-structured interview and questionnaire within the firms (descriptive and reflective).
	Field notes – plant tour	Field notes collected during the production plant tour (descriptive and reflective)
Secondary data	**Source of Evidence 5. Secondary materials**	
	Firm's website	General firm's information; certifications; sustainability reports and initiatives.
	News and press	News related to the firm, also in terms of initiatives toward enhanced sustainability
	AIDA	Economic reports

Appendix III

The analysis conducted for SC A and SC B.

Category	Subcategory	A1	A2	A3	B1	B2	B3
Firm's profile	Size	Micro	Medium	Small	Medium	Medium	Large
	Sector	Metalwork	Metalwork	Metalwork	Rubber	Rubber	Automotive
	Organisation of production and processes	*"We produce very complex precision mechanics components."* *"Our firm manages almost all the part of the process inside […] we outsource the heat and burnish treating."*	Assembler of highly complex and customized products.	Producer of valves.	Producer of elastomer compounds. *"The 60% of our products is tailor-made."*	Producer of vulcanised and thermoplastic elastomer components.	Producer of automotive components.
	Certifications held	*"We are not certified ISO 9001. We started the path towards the certification, but then we abandoned: we are certified by our customers."*	ISO 9001	*"We are certified ISO 9001 […] we then integrated the points of the OHSAS 18001 within the structure of the ISO 9001."* *"In the past, they asked us for ISO 14001, but we don't have emissions or wastewater."*	ISO 9001 ISO 14001	ISO 16949 ISO 9001 ISO 14001	ISO 9001 ISO 14001 ISO 26000 ISO 50001
Description of the SC	Suppliers	*"We have four suppliers for the steel, all Italians, and we ask for Italian or European steel, always certified with the standard certification."*	*"We have about 100 suppliers, but the main ones are about 20.* *We have 5-6 suppliers from Lombardy and South Italy that work almost exclusively for us"*	*"Our suppliers of cast iron are few and located in the Czech Republic, Poland, Bergamo, Vicenza and Milan."* *"A2 supplies us the machine's tools we use to produce our final products."*	*"We have 115 suppliers but we keep a thigh control on the first 30, representing the 90% of both volumes and turnover."*	*"We have about 100 suppliers, mostly in Italy and mostly around this area […] We have 2-3 foreign raw material suppliers, but they are imposed by the customers."* *"The major supplier is B1."*	*"The structure of our supply chain is very complex."* *"B2 has appropriate competences regarding its products: we show them our requirements and they develop the product for us."*
	Customers	*"The larger share of our customers is mainly located in the metropolitan area of Milan, other customers are situated in Lombardy, Lazio and Switzerland."*	*"We sell through resellers. They are about 20 in Italy. We then have an importer in each of the 40 countries in which we sell."*	*"Our customers are mainly located in northern Europe, specifically in the UK, Germany, Netherlands and then Italian resellers that sell to the Middle East."*	*"We mainly cover the Italian, Chinese, Turkish and polish markets […] being mainly related to the automotive, a big part is in Germany."* *"We are direct suppliers of B2. After B2 there are probably other 2-3 tiers until the final customer."* *"We mainly work in a pull way […] 60% of our production is tailor-made."*	*"Our customers are mainly European regarding the headquarters, but they operate worldwide, like B3."* *"Our customers are almost all large enterprises."*	OEM
Sustainability	Sustainability and SSC Definition	*"A supply chain is sustainable if it can minimize the economic risks for all the tiers […] Moreover, a supply chain is sustainable if it is built on relationships like the one we have with A2, where we can discuss."* *"I am very sensitive towards people […] there is huge attention on emissions and products used for the production […] I particularly value the PPE and I pay attention to consumptions, in terms of both energy and impacts on the environment."* *"However, I'm interested in these issues from an ethical and personal perspective […] I don't think sustainability can bring a competitive advantage to the firm."*	*"Sustainability is focused on materials. The first point is to find suppliers that are as close as possible. After that, you can pass to the evaluation of the modus operandi, but this becomes rather costly."* *"Speaking about distribution, a rationalization of shipping would be very helpful, since it would lead to an economic saving."* *"I can't tell you about the social aspects: there are more stringent issues, like the normative ones."*	*"A sustainable supply chain must be trustworthy for what it is about timings."* *"The fundamental parameters for me are certainty of supply, price stability, quality."*	*"It should be something that minimizes the emissions in the atmosphere. With this, I mean not only the ones deriving from the transport, but also all the emissions related to what you are transporting."*	*"Environmental sustainability does not depend on us since we work based on customers' specifications e we don't owe the raw material. Within our firm we don't account for environmental unsustainability, rather the one related to the daily management of the firm."* *"The economic sustainability is very important for us: we have recently started some activities inspired by Toyota's Kata method."* *"Regarding social sustainability, we have an ethical code and an anti-bribery code."* *"Sustainability is something for rich: first of all, you need the economic availability, after that, you need foresight"* *"The tactical level is easy to manage: it would be good to extend the horizon because it would allow taking completely different decisions."*	*"It is a supply chain in which all the tiers share the idea of a sustainable activity, which includes environmental, safety, CSR and financial issues. A joint approach to the problems that may arise along a supply chain can guarantee an improvement in our performance through the solving of our suppliers' problems."*
	Sustainable practices	*"A sustainable intervention can both satisfy the customer and optimise the internal production process of the firm."*	*"Renewable energy, recyclable materials, employment of disabled people, helping less fortunate people in the territory in which the firm operates."*	*"There is little range for improve the sustainability of the valves."*	*"We have too many constraints to be able to act on the transportation […] what we do is trying to develop a product with its own sustainability in terms of energy consumption, recyclability and possibility of disposal of the packaging and raw material."*	*"All those actions aimed at controlling the production of wastes (and so scraps) and those actions related to emissions, and in general to the environmental impact of the firms."*	*"We teach our supplier in terms of competences and compliance with the regulation."*
SC	SC	New machineries within A1	Improvement of SC scheduling	Optimization of internal logistic A3	Supplies auditing by B1	Quality control machineries by B2	DOTG removal in the SC

performance	performance indicators	- Expected increase in orders in the overall SC *"Customers know we can produce more"* Renewable energy sources by A1 - Possible increase in orders in the overall SC Improvement of SC scheduling - Delivery optimization in the SC - Accuracy of forecasting - Increased SC integration	- Delivery and shipping optimization in the SC	- Reduction of production lead time for the direct customers *"The intervention cannot eliminate or compensate other bottlenecks in the overall SC"* Adoption of ISO 9001 by A3 - Increase the quality in the overall SC - Increase the transparency in the overall SC New test bench in A3 - Increase the quality in the overall SC Fully automated work centre in A3 - Increase the quality in the overall SC - Reduce lead time in the overall SC CNC in A3 - Increase the quality in the overall SC - Reduce lead time in the overall SC Improvement of SC scheduling *"We have not been involved because we are occasional customers"*	- Expected fluxes optimization - Improvement in delivery lead time - Less delivery errors - Waste reduction - Increased SC integration Code of conduct in B1 - Competitive advantage International Material Data System (pushed by B2) - Better integration with B2 DOTG removal in the SC - Increased SC integration	- Expected increase in quality if every ties of the SC implement the same intervention Implementation of Kata system in B2 - Customer satisfaction Ethical code in B2 (pushed by customers) - Customer satisfaction - Unkept commercial relationship CNC in B2 - Increase SC integration - Increase quality in the overall SC - Increase customer satisfaction DOTG removal in the SC - Increased SC integration - Increase in product quality International Material Data System (pushed by B2) - Better information exchange - Increase in the traceability of the substances contained in the product - LCA adoption - Increased SC integration	- No margin erosion/ competitive product price General SC performance indicators - Commercial insolvency - New product development lead time - Product quality - Delivery reliability (time, quantity, documentation) - Complaints towards suppliers - Suppliers response time

Appendix IV

Detail of the selection of each KPI included in the set. For each KPI, the table details the related performance areas, performance, performance indicators and performance measure identified in the literature.

		Related aspects identified in the literature			
	KPI	**Performance areas**	***Performance***	*Performance indicators*	Performance measure
Financial	Return on investment	**Economic and financial, cost**	***Financial performance (profitability)***	*ROI, Profit, Investments*	ROI, Profit, Operating income, Profitability, EBIT, Profit margin by supply chain partner, Investments, New investments
	Return on sales	**Economic and financial, cost**	***Financial performance (profitability)***	*ROS, Profit, Revenues, Sales,*	ROS, Profit, Operating income, Profitability, EBIT, Profit margin by supply chain partner, Total/gross revenues, Revenues from green products, Sales, Sales growth, Set sales, sales from new products, Lost sales
	Return on assets	**Economic and financial; Cost**	***Financial performance (profitability)***	*ROA, ROE, Profit, Value, Shareholders*	ROA, ROE, Profit, Net profit, Operating income, Profitability, EBIT, Profit margin by supply chain partner, Company value, Value added, Market value, Capital invested by shareholders, Investors
	Total SC cost	**Cost**	***Supply chain cost; Direct cost; Indirect cost***	*SC management cost, Direct cost, supply cost, Production cost, Labour cost, Inventory cost, Distribution costs, Disposal cost, Return cost, Transaction, Information, Sales and advertisement cost, Training costs, Other cost*	SC Cost, Total supply chain management cost, Cost of raw material, Supplier selection (procedure and cost), Ordering cost, Procurement cost, Cost of production, Manufacturing cost, Operational (operating) cost, Scraps/ rework cost, Product cost, Design cost, Set up/change-over cost, Labour cost, Inventory cost, Cost of distribution, Shipping errors (number and cost) Logistics costs, Delivery costs, Transport costs, Pick error cost, Cost of goods sold, Cost of waste treatment , Cost processing of recyclables, Warranty/returns costs, Warranty cost, Transaction cost, Cost of sales, Advertisement costs, Training cost, Overhead costs
	Inventory costs	**Cost; Inventory**	***Direct cost; Inventory level; Inventory performance***	*Inventory cost, Total (inventory level), Raw material (inventory level), WIP (inventory level), Semi-finished (inventory level), Finished products (inventory level), Obsolescence (inventory performance), Utilization (inventory performance), Accuracy (inventory performance)*	Inventory cost, Warehouse cost, Opportunity cost, Obsolescence cost, Stockout cost, Inventory cost, Incoming stock level, Inventory cost WIP, Inventory cost scrap, Inventory cost finished good, Cost Minimization in transit, Cost of storage (3rd part), Total (inventory level), Raw material (inventory level), WIP (inventory level), Semi-finished (inventory level), Finished products (inventory level), Inventory obsolescence, Inventory utilisation, Inventory accuracy
	Cash-to-cash cycle time	**SC cycle times; Economic and financial; Cost,**	***Cycle time; Financial performance (profitability)***	*Cash to cash cycle time, Cash flow, Accountable*	Cash to cash cycle time, SC working capital, Cash flow time, Cash flow, NPV, Accountable (payable/receivable)
	Capacity Utilization	**Production; Flexibility**	***Performance; Operation flexibility***	*Utilisation, Productivity, Capacity flexibility*	Capacity utilization Space utilisation, Labour utilisation, Overtime, Productivity, Manufacturing productivity, Capacity flexibility
	Recycling	**Environment; Cost; Product**	***Reuse and recycling; Direct cost; Responsibility***	*Recycling rate, Water (recycling), Material (recycling), Waste (recycling), Disposal costs, Product responsibility*	Recycling, Recyclability of product, Secondary input, Water recycled, Recycled material use, Waste recycling, Cost processing of recyclables, Product remanufactured
	Certification	**Management; Quality; Environment; Social**	***Awareness; Procedure; Ethical conduct; Quality management; Environmental management; Environmental ethical conduct; Environmental cost; Social management; Social related cost; Social ethical conduct***	*Standards, Process management, Effectiveness of procedures, Regulatory compliance, Code of conduct, Dishonesty, Corruption, Quality management system, Environmental Management System, Environmental policy, Environmental compliance, Environmental performance, Environmental reporting, Environmental competences, Biodiversity, Land use, Animal treatment, Compliance cost, Social Management System, Social policy, Social performance, Social compliance cost, Anti-bribery Child and forced labour*	ISO standard developed, ISO 9001 certification, ISO 14001 certification, Social certification Regulatory compliance, Process management, Sustainable consciousness of top management, Effectiveness of management, Effectiveness of performance management systems, Code of conducts, False claims/dishonesty, Corruption, Quality management techniques and system, Environmental management system, Environmental reward system, Environmental policy, Planning for environmental improvements, Environmental compliance, Environmental impact analysis, Environmental risk analysis, Number of environmental accidents, LCA (performed), Carbon verification and neutrality calculation, Carbon footprint, Environmental performance reporting, Carbon disclosure and report, Corporate sustainability reporting, Environmental consciousness, Environmental competences, Employees environmental incentives, Environmental competences, Biodiversity, Land use, Animal treatment, Environmental compliance cost, Social management system, Health and safety management system, Social standards and human rights, Social -LCA, Social audits, Health and safety compliance cost, Anti-bribery, Child and forced labour
	Supply chain responsiveness	**SC cycle times; Flexibility; Management; Information; Suppliers; Customers**	***Cycle time; Production flexibility; Motivational effort; Extent of sharing information; Characteristics of information; Collaboration; Characteristics (suppliers); Service (customers)***	*Supply response time, Motivational effort, Training cost, Volume flexibility, mix flexibility, Product flexibility, Delivery flexibility, SC flexibility, Level of sharing information, IMS, Availability (information), Accuracy (information), Availability (information) Timeliness (information), Security (information), Assistance (suppliers), Partnership, Adaptability (Suppliers), Satisfaction (suppliers), Geographical distribution (suppliers), Diversity (suppliers), Length (suppliers) Complexity (suppliers), Query time (customers)*	Total supply chain response time, Production flexibility, Volume flexibility, Mix flexibility, Product flexibility, Modification flexibility, New product flexibility, Expansion flexibility, Delivery flexibility, Order flexibility, Transport flexibility, Upstream Supply Chain Flexibility, Downstream Supply Chain Flexibility, Management effort to motivate suppliers, Order information sharing, Information system, Information availability, Information accuracy, Quality of information, Information timeliness (transfer time), Security of information, Suppliers assistance and mutual assistance in solving problems, Suppliers assistance and mutual assistance in solving environmental problems, Buyer-supplier partnership level (also collaboration and benefits), Extent of mutual co-operation and exchange of information leading to improve quality, Suppliers - customer partnership (and innovation created), Entity and stage at which supplier is involved, Supplier development initiatives, Supply chain integration, Green supply chain management (teaming up), Upside Supply Chain Adaptability, Downside Supply Chain Adaptability, Satisfaction with supplier relationship, Local suppliers, Geographical distribution (suppliers), Diversity in supply base, Supply chain length, Supply chain complexity, Reaction time to inquiries, Response time, Customer response time

	Supply chain cycle time	**SC cycle times; Performance; Information; Suppliers**	***Cycle time; Schedule, Lead time; Time, Flexibility; Extent of sharing information; Characteristics of information; Collaboration; Characteristics (suppliers)***	*Supply chain cycle time, Bid management cycle time, Purchase cycle time, Product development cycle time, Production cycle time, Manufacturing lead time, PPC, effectiveness of scheduling, Accuracy of the scheduling, SC Flexibility, Level of sharing information, IMS, Availability (information), Accuracy (information), availability (information) Timeliness (information), Security (information), Assistance (suppliers), Partnership, Adaptability (Suppliers), Satisfaction (suppliers), Geographical distribution (suppliers), Diversity (suppliers), Length (suppliers) Complexity (suppliers),*	Total supply chain cycle time, Bid management cycle time, Purchase order cycle time, Product development cycle time, Process/Production cycle time, Planning process cycle time, Manufacturing lead time, Order lead time, Supplier lead time, Distribution lead time, PPC, Effectiveness of distribution planning schedule, Accuracy of scheduling, Planning systems accuracy, Average time for decision making, Administration time, Upstream Supply Chain Flexibility, Downstream Supply Chain Flexibility, Information sharing, Order information sharing, Information system, Information availability, Information accuracy, Quality of information, Information timeliness (transfer time), Security of information, Suppliers assistance and mutual assistance in solving problems, Suppliers assistance and mutual assistance in solving environmental problems, Buyer-supplier partnership level (also collaboration and benefits), Extent of mutual co-operation and exchange of information leading to improve quality, Suppliers - customer partnership (and innovation created), Entity and stage at which supplier is involved, Supplier development initiatives, Supply chain integration, Green supply chain management (teaming up), Upside Supply Chain Adaptability, Downside Supply Chain Adaptability, Satisfaction with supplier relationship, Local suppliers, Geographical distribution (suppliers), Diversity in supply base, Supply chain length, Supply chain complexity,
	Process cycle time	**SC cycle times; Performance; Flexibility**	***Cycle time; Lead time; Production; Process; Schedule; Efficiency; Throughput; Operation flexibility***	*Production cycle time, Product development cycle time, Manufacturing lead time, Process accuracy, Process capability, Process innovation, PPC, Effectiveness of scheduling, Accuracy of the scheduling, Efficiency (operational), Throughput, Lot size, Set up, Capacity flexibility, Process flexibility*	Process/Production cycle time, Product development cycle time, Planning process cycle time, Manufacturing lead time, Time to market, Process accuracy, Process capability, Process innovation, New processes, PPC, Effectiveness of scheduling techniques, Effectiveness of master production schedule, Accuracy of scheduling, Planning systems accuracy, Throughput, EOQ, Lot size, Set up/change-over time, Capacity flexibility, Process flexibility, Labour flexibility, Machine flexibility, Material handing flexibility, Routeing flexibility, Operation flexibility
Learning and growth	Labour efficiency	**Production; Flexibility**	***Performance; Operation flexibility***	*Efficiency, Productivity, Flexibility (performance), Process flexibility*	Labour efficiency, Efficiency, Labour productivity, Manufacturing productivity, Flexible workforce, Labour flexibility
	New product development time	**Performance; Product; Flexibility; SC cycle time**	***R&D; Innovation; Design; Responsibility; Production flexibility; Cycle time; lead time***	*Product development cycle time, R&D capability, Product innovation, Dfx, Sustainability consideration, Environmental consideration, Social consideration, Product responsibility, Product flexibility, Manufacturing lead time*	Product development cycle time, Product development lead time, Capability (R&D and Design), Product innovation, Product changes, DfA, DfE, Eco and sustainable design, Use of hazardous and toxic substances, Product eco-efficiency, Product with environmental consideration, Products with social consideration, Modification flexibility, New product flexibility, Time to market
	Investments	**Financial and economic; Performance**	***Economic performance; R&D; Process***	*Investments, R&D investments, Process innovation*	Investments, New investments, Investment in R&D, Developing new ideas to improve (continuous improvement)
	Integration with SC partners	**Suppliers; Information**	***Dependency; Performance (suppliers); Collaboration; Characteristics (suppliers); Extent of sharing information; Characteristics of information; Reverse SC***	*Partnership, Vertical integration, Sub-contracting rate, Assistance (suppliers), Adaptability (Suppliers), Satisfaction (suppliers), Certification (suppliers), Quality (Suppliers), Sustainability (Suppliers), Service (Suppliers), Cost saving (Suppliers), Booking procedure (Suppliers), Geographical distribution (suppliers), Diversity (suppliers), Length (suppliers) Complexity (suppliers), , Effectiveness reverse SC, Competitiveness reverse SC, Level of sharing information, IMS, Availability (information), Accuracy (information), Availability (information) Timeliness (information), Security (information)*	Supply chain integration, Vertical integration (Dependency), Subcontracting rate, Suppliers assistance and mutual assistance in solving problems, Suppliers assistance and mutual assistance in solving environmental problems, Buyer-supplier partnership level (also collaboration and benefits), Extent of mutual co-operation and exchange of information leading to improve quality, Suppliers - customer partnership (and innovation created), Entity and stage at which supplier is involved, Supplier development initiatives, , Green supply chain management (teaming up), Upside Supply Chain Adaptability, Downside Supply Chain Adaptability, Satisfaction with supplier relationship, Certified suppliers, Certified suppliers in ISO 14001/environmental certification, Quality performance of suppliers, Suppliers' ability to respond to quality problems, Supplier's rejection rate, Suppliers sustainability performance, Suppliers evaluation-social factors, Evaluating the environmental performance of suppliers, Supplier training in environmental issues, Suppliers commitment to environmental issues, Supplier processing raw material, Suppliers' service, Supplier cost-saving initiatives, Supplier's booking procedures, Local suppliers, Geographical distribution (suppliers), Diversity in supply base, Supply chain length, Supply chain complexity, Effectiveness of reverse logistic system, Competitiveness of the forward reverse supply chain, Information sharing, Order information sharing, Information system, Information availability, Information accuracy, Quality of information, Information timeliness (transfer time), Security of information
	Use of new technology	**Performance**	***IT***	*Use of IT, IT capabilities*	Use of IT and new technology, Green R&D/innovation technology, Technology capability
Customer	Market share	**Financial and economic; Customers**	***Economic performance; Customers characteristics***	*Market share, Revenues, Sales, Image, Number of customers, New customers, Type of customers, Relevance of customers, Interest in sustainability of customers*	Market share, Market share green products, Total/gross revenues, Revenues from green products, Sales, Sales growth, Net sales, Sales from new products, Lost sales, Promotion, Image, Green image, Market concentration Geographic breakdown of markets, Price (performance and compliance), Forecast accuracy, Customer retention, Customer lost, New customer order , Repeat vs new customer, Breadth of customer base, Customer rating, Customer profitability, Management effort to enlighten customers on sustainability, Customers interest in green products
	Customer satisfaction	**Customer; Quality**	***Customer satisfaction; Customer service; Return service***	*Customer satisfaction, Complaints, Return, Service (quality), Assurance and warranty, Service (customers), Safety (customers), Query time (customers), Contact points (customers)*	Customer satisfaction, Customers satisfaction in green products, Customer complaints, Level of customer perceived value of product, Customers returns, Customers' product return rate, Service quality, Quality assurance warranty and claim policies, Green product warranty, Customer service, After sales service, New services, Customer health and safety, Reaction time to inquiries, Response time, Customer response time, Number of customers contact points
	Product quality	**Product; Quality**	***Defectiveness; Responsibility; Product quality***	*Product quality, Production quality, Product safety, Product reliability, Scraps, Damages, Product responsibility,*	Product quality, Quality of delivered goods, Conformity, Production quality, Product safety, Product reliability, Defects, scraps/rework, product damaged/rejected, Product responsibility
	Product/service variety	**Product; Flexibility; Customers**	***Product characteristics; Production Flexibility; Customer service***	*Range, Number, New products, Product flexibility, Service (customers)*	Range of product and services, Number of green products, Number of products in a mix, New products, Product flexibility, Modification flexibility, New product flexibility, Customer service, After sales service, New services
	Order fulfilment	**Orders procedures and Delivery**	***Order Performance; Invoice; Delivery performance***	*Fill rate, Number (orders), Tracking, Backorder, Entry methods, Accuracy (invoice), Methods Effectiveness (invoice) Efficiency (delivery), Container utilisation, Effectiveness 3PL*	Fill rate, Orders (number/ per unit time), Order cancellation, Order track and trace performance, Backorders, Order entry methods, Invoice accuracy, Delivery invoice methods' effectiveness, Quality of delivery documentation, Delivery channel, Delivery efficiency, Transport productivity, Container/truck utilization, Vehicle scheduling, Effectiveness of the 3PL
	Delivery reliability	**Orders procedures and Delivery, Cost, Product, Inventory, SC cycle times**	***SC cost; Direct cost; Indirect cost; Lead time***	*Reliability (delivery), Accuracy (delivery) Defects (delivery), Distribution cost, Product quality, Range (inventory coverage), Turnover days of supply, Stockout, Lead time (delivery), On time (delivery), Frequency (delivery), Lead*	Delivery reliability, Delivery lead time, Delivery on-time, Average lateness of orders, Average earliness of orders, Delivery frequency, Number of shipments, Delivery accuracy (product delivery), Shipment accuracy, Delivery damage/defect free, Damaged shipment, Pick error cost, Quality of delivered goods, Inventory range, Inventory days of supply/inventory turnover rate, Inventory days of supply/inventory turnover rate finished goods, Inventory days of supply/inventory turnover rate raw materials, Stockout probability (reliability of stocks), Stockouts,

				time	Stockouts material, Stockouts finished products, Lead time, Product lateness
Environment	Energy use	**Environment**	***Resources consumption***	*Energy, Resources*	Energy consumption (energy cost), Fuel consumption, Energy efficiency, Energy from renewable sources, Resources consumption, Resources efficiency
	Water use	**Environment**	***Resource consumption; Reuse and recycling***	*Water, Resources, Water (recycling)*	Water consumption, Resources consumption, Resource efficiency, Water recycled
	Material use	**Environment; Performance; Cost**	***Resources consumption; Direct costs; Production; Reuse and recycling***	*Material, Resources, Productivity, Supply cost, Reuse and recycling, Material (recycling)*	Material consumption, Wood consumption, Consumption of raw material, Resources consumption, Resource efficiency, Resources productivity, Cost of raw material, Secondary input, Recycled material use
	Environmental impacts	**Environment**	***Emission; Environmental management; Environmental ethical conduct***	*Air emissions, Water emissions, Land emissions, Noise emissions, Environmental performance, Environmental reporting, Biodiversity, Land use, Animal treatment*	Emissions, Air emissions, GHG emissions, CO2 emission, Water emissions, Land emissions, Noise emissions, Environmental impact analysis, Environmental risk analysis, Number of environmental accidents, LCA (performed), Carbon verification and neutrality calculation, Carbon footprint, Environmental performance reporting, Carbon disclosure and report, Corporate sustainability reporting, Biodiversity, Land use, Animal treatment
	Waste	**Environment; Cost**	***Waste; Reuse and recycling; Direct cost***	*Solid waste, Liquid waste, Landfilled waste, Dangerous waste, Waste recycling, Disposal costs*	Waste, Solid waste, Wastewater, Landfill waste disposal, Dangerous/ hazardous/ toxic waste, Waste recycling, Disposal costs, Cost of waste treatment, Cost processing of recyclables
Social	Community relationships	**Social**	***External stakeholders; Community***	*Relationship, Communication, Involvement, Development*	Trust (partners, stakeholders), Openness to stakeholder involvement and participation, Rights of stakeholders and empowerment, Commitment on stakeholder welfare, Societal commitment, Number of meetings with stakeholders, Social dialogue, Community complaints, Involvement in local community, Local community influence, Public consultation (number)
	Philanthropic investments	**Social**	***Ethical conduct; Community***	*Fair trade, Charity, Investments*	Fair trade product, Charitable activities, Community and Social investment, Community initiatives, Fraction of total sales invested for social project, Grants and donations, Employment opportunities, Education (supporting education), Housing, Development of urban and rural areas
	OHS performance	**Social**	***Employees; Social related cost***	*Occupational Health and Safety, Compliance costs*	Health and safety of employee, Working conditions, Number of lost workdays, Number of accidents, Health and safety incidents, Number of incidents, Excessive working hours, Health and safety investment, Health and safety compliance cost
	Labour turnover	**Social; Costs**	***Employees; Direct cost***	*Turnover, Characteristics (employees), Wellbeing, Training, Labour cost*	Employees turnover, Type of employees (full-time, part time, temporary), Employee development, Training (hours) (employees), Turnover per working hour, Labour cost
	Employee satisfaction	**Management**	***Employees; Motivational effort; Indirect cost***	*Employee satisfaction, Characteristics (employees), Training, Wages, Diversity, Well-being, Rights, Involvement (employees), Benefits, Motivational effort, Training cost*	*Employee satisfaction*, Employee complaints, Type of employees (full-time, part time, temporary) Training (hours) (employees), Wages, Workforce diversity (Gender, race, area), Discrimination, Employee well-being, Wealth (profit per employee), Employee development, Cost of benefits per employees, Freedom of association, Employees interests and rights, Employees sense of team, Suggestions from employees (applied), Social benefits, Healthcare benefits, motivational effort towards employees, Training cost/ investment

Declaration of interests

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

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: