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Review

Supply Chain Management for Improved Energy Efficiency: Review and Opportunities

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Abstract: Energy efficiency represents a key resource for economic and social development, providing substantial benefits to different stakeholders, ranging from the entities which develop energy efficient measures to everyone in society. In addition to cost savings, multiple benefits can be achieved by supporting a better alignment between energy issues and strategic business priorities: e.g., improved competitiveness, profitability, quality, etc. Thus, energy efficiency can be a strategic advantage, not just a marginal issue, for companies. However, most firms, especially small and medium enterprises (SMEs), face many problems and, in some cases, hostility when trying to effectively implement energy efficiency actions. The most dominant barriers are the access to capital and the lack of awareness (especially in terms of life cycle cost effects). The supply chain viewpoint represents one of the main opportunities for overcoming those barriers and improving energy performance even for weaker companies. Since the current literature on energy efficiency and practical approaches to ensure energy efficiency mainly focus on energy performance on a single-firm basis, this paper aims to provide a systematic review of papers on the integration of energy efficiency in supply chain design and management published in academic journal, thereby defining potential research streams to close the gaps in the literature. A number of literature reviews have been published focusing on specific aspects of sustainable or on green supply chain management; however, to the best of our knowledge, no review has focused on the energy efficiency issue. Firstly, the present paper shows how considering energy consumption in supply chain management can contribute to more energy-efficient processes from a systemic point of view. Then, the review methodology used is defined and the sampled papers are analyzed and categorized based on the different approaches they propose. From these analyses, potential future research streams are outlined.

Keywords: supply chain; energy efficiency; energy management; coordination mechanisms; green supply chain; literature review

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1. Introduction

1.1. Background

World energy consumption has experienced a significant increase in recent years, shifting from 3700 million tonnes of oil equivalent (Mtoe) in 1965 to 13,147 Mtoe in 2015 [1], despite the high level of energy productivity that many countries have already achieved. The industrial sector is one of the end-users that globally consumes the most energy; consequently, the focus on the industrial energy concerns has also become more relevant to regulators (e.g., the 2012 European Energy Efficiency Directive) in order to ensure a more sustainable environment [2]. During the previous decade, many companies started to undergo energy audits to provide essential information about the status of energy consumption throughout their entire production processes, in individual production processes or a single piece of equipment. The results of these audits depended on how the system boundaries

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were defined, and they highlight that there are many opportunities to improve industrial energy efficiency. Improving energy efficiency allows a company to deliver of the same service (e.g., product making, conversion of energy from one form to another etc.) using less energy. Additionally, energy efficiency has the potential to improve the overall performance of a single firm, and to generate relevant cost savings as well as additional revenues, thanks to the increasing environmental awareness of customers [3]. Currently, the results of these expected improvements are achievable thanks to existing and future policy framework conditions (Figure 1).

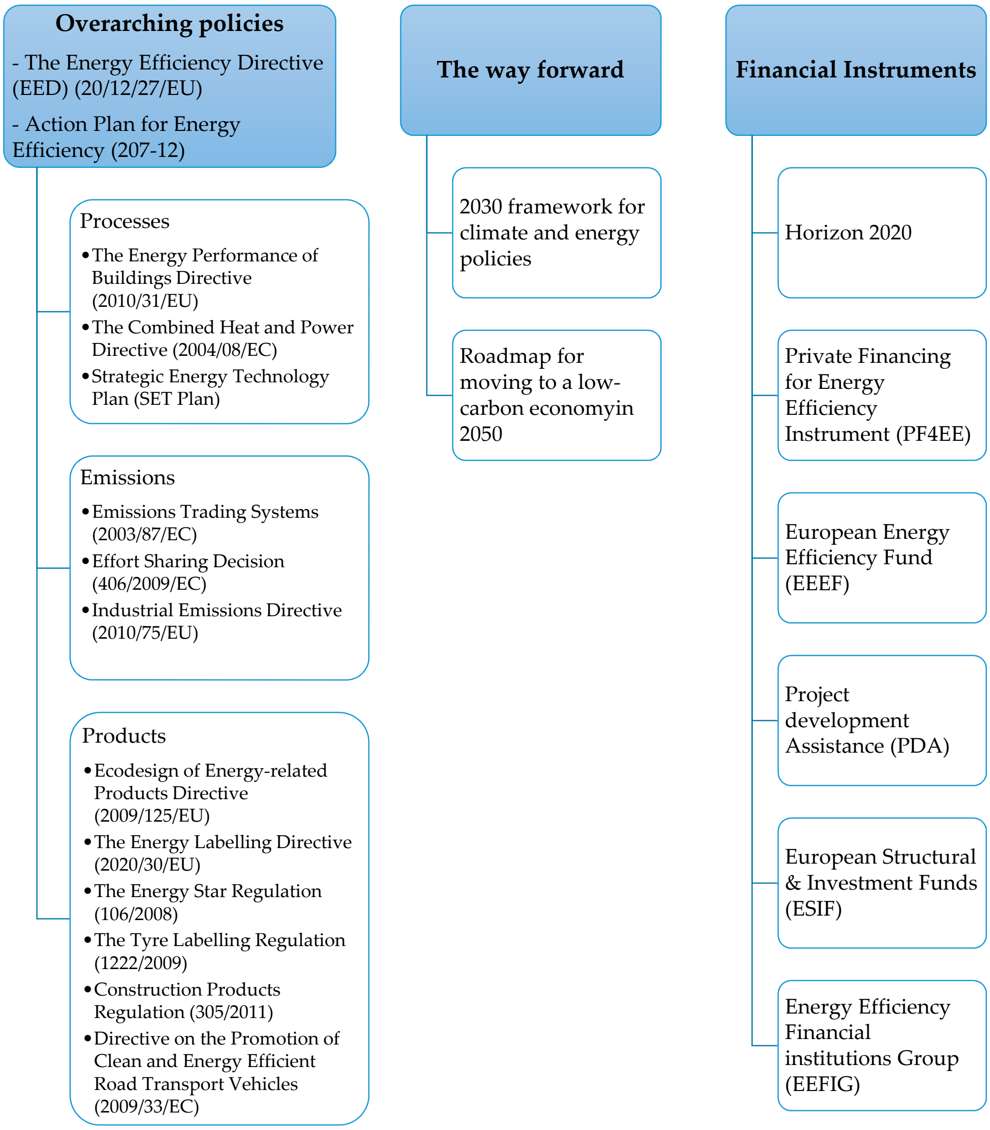

Figure 1. Legal Energy Efficiency framework in the EU [4].

The development and integration of new technologies with improved energy performance requires a certain period of learning and therefore the opportunities they offer may not be utilized immediately. For this reason, in 2011, a worldwide recognized energy management system (EMS) has been proposed under the ISO 50001:2011 which supports organizations in all sectors to use energy more efficiently through a Plan-Do-Check-Act (PDCA) continual improvement framework [5].

Expensive technologies are not the only way to increase energy performances: a cost-effective way to improve them is to combine investments in energy-efficient technologies with continuous energy management practices [6]. A wide variety of actions can be undertaken [7], such as: maintaining,

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furbishing and rearranging equipment to contrast degradation's effects and to reflect alterations in process parameters; retrofitting or substituting obsolete equipment with new technologies; decreasing heat loss and wasted energy through heat management (e.g., through insulation, utilization of exhausted heat); improving process control, for better energy and materials efficiency and process productivity. Recently, Biel and Glock [8] proposed a systematic review on models integrating energy aspects in support of the decision making process regarding mid-term and short-term production planning of manufacturing companies. The adoption of energy efficient production planning (EEPP) is not tied to huge investments as usually occurs when companies face technological adjustments of manufacturing systems; they provide a comparably inexpensive opportunity, even for small to mid-size companies, to improve their manufacturing processes accordingly to the rising importance of energy awareness. EEPP models can be classified into energy-efficient master production scheduling and capacity planning, energy-efficient lot-sizing, and energy-efficient machine scheduling (for instance, job allocation, sequencing, and load management). The review shows that costs related to energy consumption and emissions should be considered to recognize the true cost of manufacturing activities. Models lacking those aspects are based on incomplete information, and thus they may induce managers to make production planning decisions resulting in a suboptimal performance both economic and environmental. Energy efficiency measures (EEMs) can be summarized accordingly to Thiede et al. [9] into:

(i) Production machines: measures concerning the design and control of machines as well as process parameters.
(ii) Production planning and control (PPC): actions for improved energy and resource efficiency ranging from the avoidance of consumption peaks (e.g., through orders balancing) to the optimal usage of equipment, especially for those machines with low shares of non-value adding idling wastes.
(iii) Technical building services (TBS): measures responsible for an efficient supply of required forms of energy and resources (e.g., compressed air) for ensuring production and optimal environment conditions. For instance, these measures may concern the technical configuration of the equipment, the control of processes as well as the avoidance of losses.

From the industrial point of view, there is a range of multiple benefits of improving energy efficiency in addition to cost savings, namely non-energy benefits (NEBs), which influence the return on investment and may contribute to cost reductions, value generation and risk mitigation. Broader benefits may be extremely valuable since they extend to goals that stakeholders understand and may personally aspire to. Such added value creates a great potential to motivate energy efficiency action. The IEA report [10] highlighted the existence of numerous NEBs which can be grouped into the following categories: energy system security, economic development, social development, environmental sustainability and increasing prosperity. Moreover, additional benefits may derive from a range of other indirect impacts resulting from lower energy expenditures, economy-wide investment in energy efficiency and increased consumer spending. EEMs' benefits contributing to improve the productivity and value creation of the industrial firms include improved production process, quality and capacity utilization, reduced amount of resources, emissions and waste disposal, lowered operation and maintenance (O&M) costs, extended equipment lifetime, and better work conditions. Despite the large potential of improving energy efficiency in companies, the actual implementation rate of the EEMs is often no higher than 50% of the potential proposed by the energy audits [4]. Investments in energy efficiency generally appear to require very high rates of returns much higher than other investments even though they present comparable risks ("energy efficiency paradox"). This paradox can be due to different reasons, including perception of risk, unwillingness to replace equipment before end-of-life, energy efficiency not being a strategic issue, "hidden" costs. Since behavior plays a crucial role in promoting energy efficiency, understanding the causes and patterns behind it is the key to successful energy efficiency improvement. These aspects include

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energy culture and corporate policy as well as perceived risks, barriers and drivers at the different organizational and activity levels of a company as part of a certain industrial sector's supply chain. DECC [11] developed a conceptual framework to provide an outline theory of organizational behavior and behavioral change which seeks to integrate insights from organizational theory, sociology and economics. Different activity levels, which may shape the way a firm's investment and energy behavior is formed, can include: (i) the decision making and activity of individuals; (ii) the interactions between the various subcultures within a company; (iii) the independent course of the company indicated by its corporate policies and history; and (iv) the relationships that the company maintains with other companies in its supply chain. Understanding organizational behavior offers a more useful approach which can resolve the "paradox" since the strategic value of energy efficiency which confers competitive advantage may be the key influence on whether investment in energy efficiency will take place. Previous researches have extensively studied those barriers [12–17] and they observed that they can be resumed into several categories: i.e., technology-/information-related, economic, behavioral, organizational, competence-related barriers and lack of awareness. In particular, as stated in [17], the most perceived barriers that hinder efforts to select the most cost-effective measures, especially for especially small and medium enterprises (SMEs), are economic (such as high investment costs, hidden costs and low profitability), information-related (e.g., not sufficient information on costs, benefits and technologies) and lack of awareness and knowledge. A recent survey of the European Central Bank [18] shows that getting access to capital is the most pressing problem, especially for SMEs, even more than finding customers. Reduction in the availability of loans is often referred to as 'credit crunch' which has recently been interested by increased research focus [19,20]. Conversely, behavioral barriers are ranked at the lowest positions in the survey, showing that enterprises perceive themselves as proactive with respect to the topic. In particular, larger organizations present more strategy, time and capacity to act on energy issues and they are also more reactive to issues affecting their reputation. However, energy issues are far from the focus of senior managers mainly because of the distance from operations and facilities managers. Conversely, SMEs present lack of internal skills to interpret technical information and the time and capacity to plan energy management and they also perceive a "cultural" barrier to participation in the energy efficiency and carbon mitigation agendas. Regardless of the level of importance energy receives in different companies, creating awareness about its efficient use and what this could mean in terms of cost and benefits requires more attention. This is also evident from the mixed success in the implementation of EEMs.

1.2. Motivations

Manufacturing systems and processes are usually seen as independent entities; hence, the objective of improving energy efficiency is pursued at a single company level. However, these small and medium scale opportunities (i.e., focused on the individual company) do not allow to fully understand the consequences and benefits introduced. Conversely, at the largest scale, supply chains are systems of entities (i.e., different organizations and people), activities, and information responsible for the transformation of resources, raw materials, and components into finished products to fulfill the needs of final consumers. Figure 2 summarizes the main actors and activities that are included in supply chain management to better satisfy the final customer. Such information can be gathered along the supply chain of production processes leading to greater energy efficiency identifying opportunities that are hidden in a single company perspective [21]. For instance, there could be EEMs that generate few benefits for the actors that should implement the measures—and, in some cases, lower than the costs—which leads to very high return period from an individual point of view but great benefits for the overall supply chain. In addition, also the transportation between subsequent production process stages and disposal phases provide opportunities to better understand the importance of life cycle energy impacts. Thus, the logistic and waste management activities should be integrated in the analyses for the improvement of energy efficiency [22]. Supply chain energy efficiency is not the sum of

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the individuals whereas the wider point of view can include the overall effects of the implementation of EEMs, and, for that reason, it should be deeply analyzed.

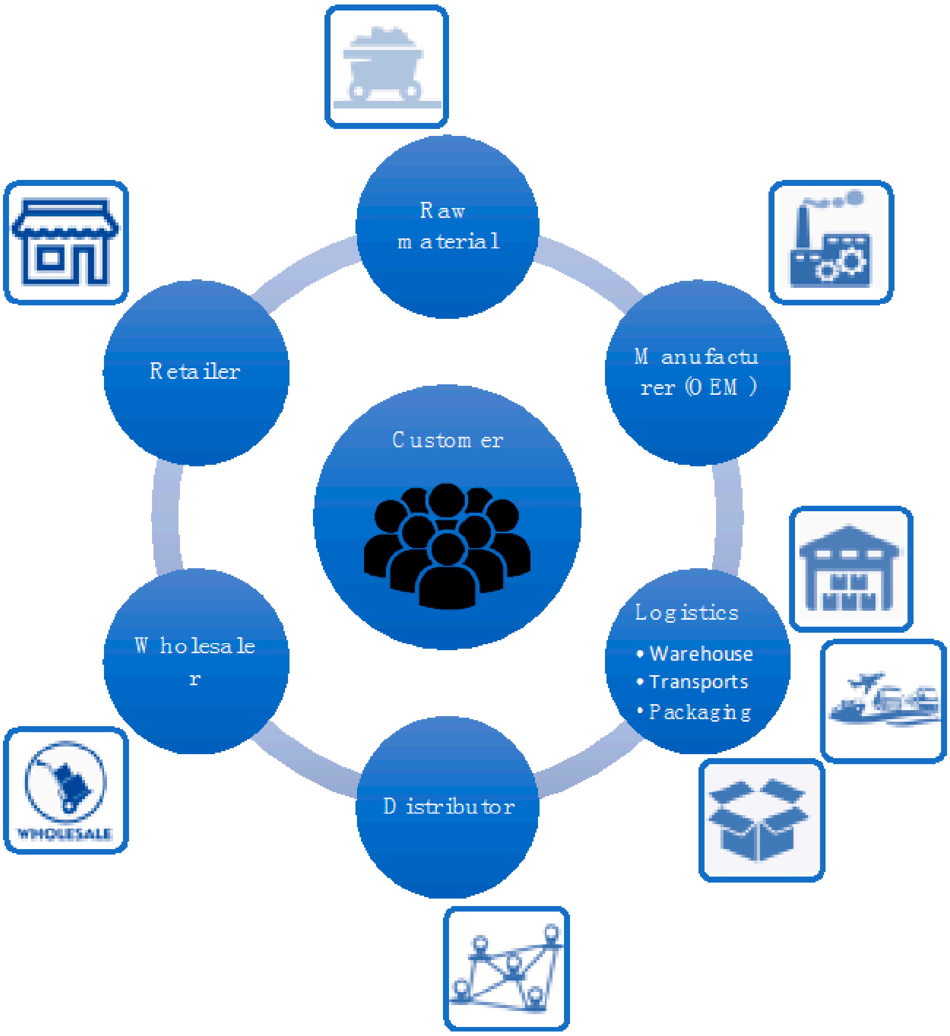

Figure 2. Key actors and activities included in supply chain management.

In an environment characterized by high globalization, rapidly advancing technology and increasingly demanding customers, companies within the same supply chain should cooperate to satisfy customer needs better than their competitors. Accordingly, the alignment of strategic and operational decisions among the different stages of the supply chain represents a prerequisite in nowadays' business environment for creating and maintaining competitive advantages. By working closely with customers and suppliers, companies can reduce environmental and social impacts and improve economic results. Therefore, it is important to acknowledge the potential influence that supply chain interactions may have on improving energy efficiency. However, most companies still pay secondary attention to whether their partners apply energy management systems in their business activities. Collaboration among partners in the supply chain will add value to each partner and to the supply chain as a system, since risks can be shared, costs can be saved and lead and response time can be reduced in an ever changing business environment [23]. As shown in [24], coordination schemes in supply chains are either centralized, in which the decision-making process assumes a unique decision-maker managing the whole supply chain or decentralized where multiple decision-makers with conflicting objectives are involved leading to an inefficient system. For that reasons, supply chain

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management (SCM) represents one of the main opportunities in overcoming the existing barriers [25]. The key aspects of SCM are depicted in Figure 3.

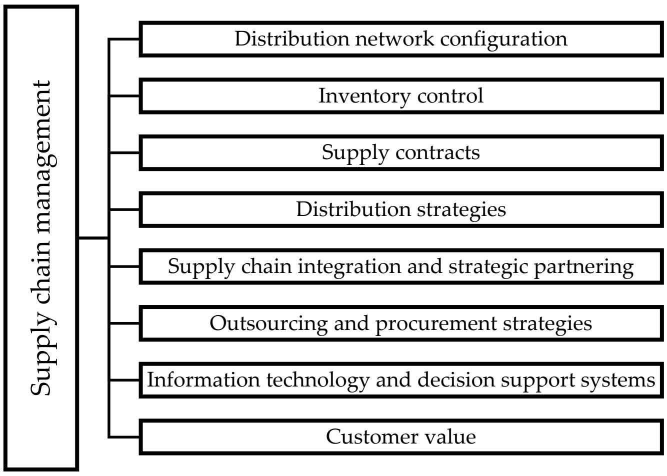

Figure 3. Key aspects of supply chain management.

Roehrich et al. [26] observed that by engaging in collaborative relationships with their supply chain partners, focal firms who wish to implement sustainability practices can spread costs and risks across other supply chain members, decreasing the issues due to conflicting priorities of financial targets. Since the supply chain considers the product from the initial processing of raw materials to the delivery to the customer, the holistic approach can generate a positive pressure on the sustainability topic, leading to a better satisfaction of environmental-friendly customers [27,28]. The main advantage of such holistic approach is that it provides an assessment at the system level, leading to the achievement of a global optimum instead of a local one [29]. In the meantime, it allows gaining insights about how the energy savings can be maximized across the entire supply chain which can otherwise not be reached by measuring how its individual components can be optimized. The leading companies of the supply chains are also in a strong position to influence their suppliers in energy-related decision-making [30]. In addition to mapping the individual components of the supply chain, this approach prioritizes the assessment of energy savings and their benefits by identifying the largest energy-using components of the supply chain.

Even though the growing importance of energy efficiency implementation into operations and supply chain management has recently caught the attention of many researchers [31], previous research has mainly considered energy efficient investment decisions within a single firm from an industrial point of view. Research focused on energy efficiency in the industrial sector has been widely spread during the last decades and several literature reviews exist: e.g., Biel and Glock [8] analyze the decision support models that integrate energy aspects into mid-term and short-term production planning of manufacturing companies; Schulze et al. [32] provide a systematic review of existing academic journal publications on energy management in industry; Tanaka [7] develops a contextual framework for policy analysis for enhancing energy efficiency and conservation in industry while [33] defines a map of the adopted technologies for the reduction of energy consumption in production and related them with the performances of manufacturing firms. However, it is also important to acknowledge the potential influence that supply chain interactions may have on such investment decisions [29,34].

From a supply chain perspective, as stated in [35], responsible supply chain management (RSCM) addressing socially and/or environmentally responsible supply chain issues can play a strategic role in protecting and enhance the reputation of the supply chain. For that reason, research on green supply chain management (GSCM) and sustainable supply chain management (SSCM) have been highly spread in recent years and several literature reviews have been developed. Srivastava [36] proposed one of the first state-of-the-art literature review on green supply-chain management, where various

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mathematical tools/techniques used in literature for GSCM contexts are mapped primarily taking a 'reverse logistics angle' but mainly concerning environmental friendly approaches. Sarkis et al. [37] categorized and reviewed GSCM literature using organizational theories with a special emphasis on investigation of adoption, diffusion and outcomes of GSCM practices but no reference to the energy efficiency issue is explicitly given. Brandenburg et al. [38] clustered the literature on sustainable supply chain management according to the approach adopted in the modelling phase with a focus on environmental factors and social aspects of supply chain. Grosvold et al. [39] proposed an empirical exploration of different industries to evaluate the relationships between management, measurement and performance of sustainability in supply chains. Fahimnia et al. [40] presented a thorough bibliometric and network analysis on GSCM; from the results, it can be evinced that the relevance of the energy issue is roughly recognized however it is not yet examined in a structured way. More recently Sarode and Kole [41] proposed a literature overview on green supply chain management and critical factors but they haven't explicitly considered the energy efficiency issue, while Rajeev et al. [42] proposed a conceptual framework to analyze trends across industries, economies concerning the evolution of sustainability issues. More than 50 literature reviews have been published focusing on specific aspects of sustainable or green supply chain management but to the best of our knowledge no one is focused on the energy efficiency issue. Nevertheless, a comprehensive analysis of published scientific articles on supply chain management to improve the overall energy efficiency is currently lacking. The aim of the present work is, thus, to provide a systematic review on the integration of energy performance in supply chain management and coordination in order to identify exiting gaps and then to make suggestions on potential future research streams that could improve the literature background. The explicit focus of our review on supply chain perspective of energy efficiency differentiates it from existing review papers in this area. This review aims at providing both researchers and practitioners with a structured overview on how considerably energy efficiency specific measures can be achieved through a holistic supply chain approach:

- Experts may use this review as an inspiring overview on how supply chain perspective may support the energy efficiency challenge and as a guideline to identify a specific practical intervention;
- Researchers may use this review to get an overview of supply chain contributions that have already accounted in different ways the energy efficiency issues and the gaps that still exist in the literature, moreover they may use our discussion to identify the most promising research opportunities.

The remainder of the paper is organized as follows. Section 2 presents the conceptual framework used for the literature analysis, Section 3 gives an overview on the review methodology and Section 4 proposes a descriptive analysis of the performed review. In Section 5, the content analysis of the selected works is proposed while in Section 6 a discussion of the state-of-the-art is presented and insights for future research streams are identified. Finally, Section 7 summarizes the main findings of the present review.

2. Conceptual Framework

In the present section, a conceptual framework is defined through some research questions in order to ensure a rigorous methodology for the evaluation, classification and discussion of the literature sample. Specifically, two dimensions are considered (Figure 4): the first dimension systematizes the role and relevance of energy in supply chain management, while the second dimension focuses on the proposed techniques and approaches for supporting the decision process.

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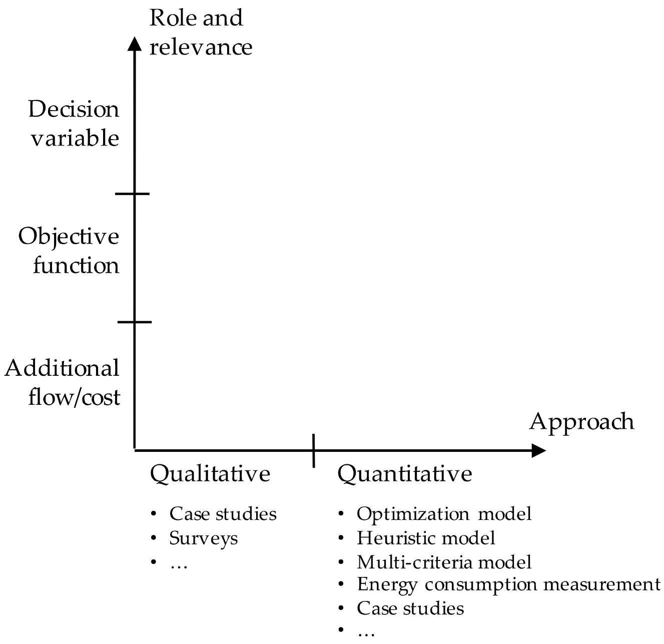

Figure 4. Classification scheme.

The presented literature review is focused on the following research questions trying to detect the existing theoretical gaps and then to propose managerial insights to fill them:

RQ1. Are any energy efficiency measures assessed or defined? Which kind of measures are mainly considered (i.e., production machines, production planning, auxiliary services and/or logistic activities)?

RQ2. Are the benefits introduced through energy efficiency measures in the supply chain quantitatively and/or qualitatively evaluated? If they are quantitatively evaluated, which model types (such as optimization models, heuristic models, multi-criteria decision-making) and solution approaches (such as linear, non-linear, integer, stochastic and dynamic programming, fuzzy logic, analytical hierarchy process and so on) are used? Are NEBs also considered?

RQ3. Which area of the supply chain are interested by the coordination and integration of the energy-related decision-making process (e.g., inventory, production process, etc.)?

RQ4. Are the effects of the uncertain and variable background investigated?

RQ5. Are case studies presented? Which is the context of application (i.e., industrial sector considered, location)?

3. Review Methodology

In this paper, a systematic review has been conducted to provide a rigorous methodology, as firstly outlined by [43] concerning the field of management and organization studies. The objective of a systematic review is to locate relevant existing studies based on a research question to evaluate the contributions and to draw managerial insights, conclusions and further research streams. The present work aims to outline and to analyze all the relevant studies concerning the integration of the energy efficiency in the supply chain design and management.

To identify the relevant papers for this review, combinations of the keywords defined in Table 1 have been searched either in article abstract, title and list of keywords. The main sources used for the research of the present review were the largest online databases of peer-reviewed literature [44], i.e., Scopus, ScienceDirect, Business Source Premier (Ebsco Host) and Wiley Online.

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Table 1. Overview of keywords used in the literature search.

	Research Area		Keywords
	Supply chain management	-	"Supply chain"
		OR	"Coordinated supply chain"
		OR	"Integrated inventory"
		OR	"Centralized decisions"
		OR	"Integrated supply chain"
AND	Energy issue	-	"Energy"
		OR	"Energy efficiency"
		OR	"Energy cost"
		OR	"Energy saving"
		OR	"Energy consumption"

The first step consisted in the exclusion of non-relevant papers from the analysis of the paper's title and abstract and then, only if the paper was considered significant for the review, the whole paper has been read. Afterwards, all the articles cited in the papers previously selected was examined through a manual screening of cross-referencing and a snowball-approach. Finally, an inverse search was performed in which the articles that cited one of the selected papers were analyzed. The research was conducted on several journals focused on the relevant topics for the presented literature such as operation management, energy and environment. As mentioned in [32], books, contributions to edited volumes, conference papers, periodicals, and working papers usually are subject to a less rigorous peer-review process and they are less readily available, for that reason we have not included them in our review. In this way, it is ensured that the publications included had been subject to assurance systems for academic quality and rigor [45]. Since energy efficiency is a generic term and unequivocal definitions and quantitative measures do not exists, we have adopt the more wider approach considering energy efficiency as the way to use lees energy to produce the same amount of useful output [46,47]. To keep the review focused on the integration of the energy performance into supply chain management, we excluded the papers focused only on the following topics:

- Energy sources mix
- Energy or RES supply chains and not production system
- Energy impacts on a single entity instead of the whole supply chain
- Effects only on environmental performances and reduction of emissions.

4. Descriptive Analysis

The results of the literature search are presented in the following review protocol (Table 2).

Table 2. Review protocol.

Step	Description	Total
Keywords Search	Articles needs to fulfil the search string in their title, abstract, or main text	4512
Journal Selection	Articles needs to belong to peer-reviewed journals	2417
	Exclusion of journal focused on subject areas not relevant for the literature review	1343
Content Analysis and Consolidation	Duplicates were eliminated and relevance ensured by reading the abstract focusing on relevant topics Ensure relevance by reading the title, the abstract and then the entire article	35
Snowball Search	Forward and backward searches based on articles selected in previous steps	9
Sample Size	-	44

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The application of the review protocol produced 44 papers suitable for the present systematic review. In Figure 5, the evolution over time of the integration of the energy issue into the supply chain management literature is shown. The huge growth in published articles in recent years reveals a great increase of the relevance of the topic studied in the present paper. In addition, the limited number of works underlines the need for a review which identifies and guides the major streams of research.

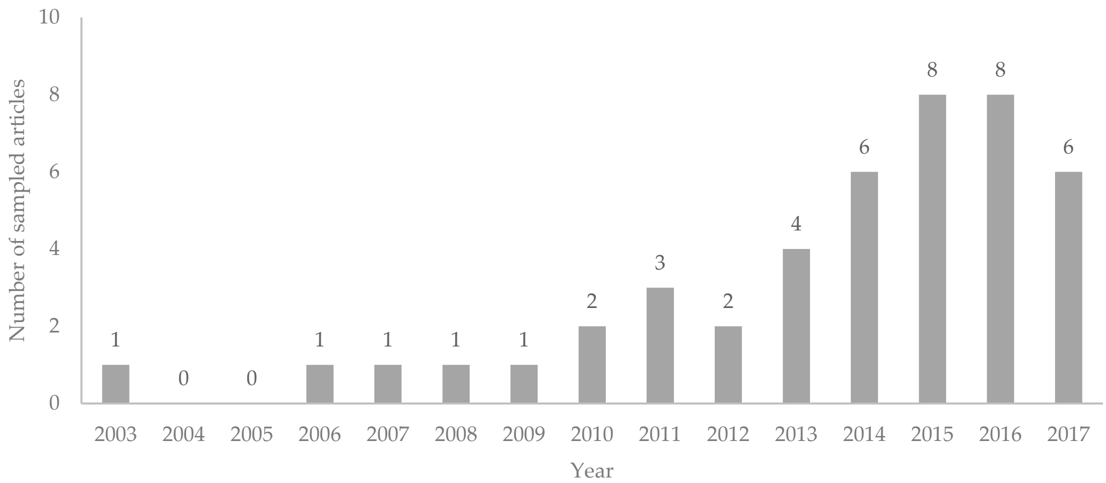

Figure 5. Number of scientific articles on energy integration in supply chain management per year.

Figure 6 shows in which journals the papers have been published. It is interesting to observe that the topic, even if it is recent, has interested many journals focused on different themes and that the first three journals cover almost the half of the publications selected for the review (43.2%).

Figure 6. Number of sampled articles per journal.

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5. Content Analysis

As shown in the classification scheme proposed in Figure 4, the articles are categorized according to the approached used (qualitative versus quantitative) and to the relevance and the role that energy covers in the models to evaluate if energy is considered as an additional flow with its related cost, an objective function or a decision variable. The classification result is illustrated in Figure 7, while the results of the analyses are reported in Appendix A Table A1 and discussed in the following sub-sections.

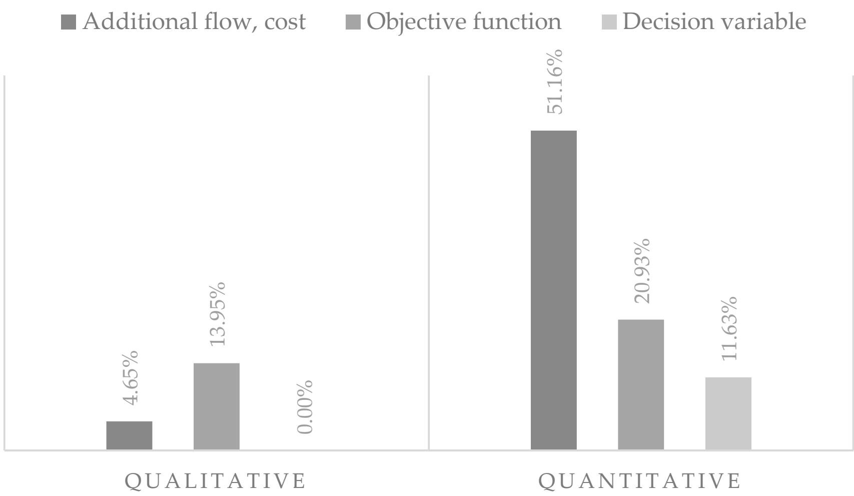

Figure 7. Classification output.

5.1. Qualitative Approach

A limited number of articles proposes a qualitative approach to show the relevance of the energy issue in both economic and environmental performances of the overall supply chain using different methodology. Mainly, these works consider the energy performance as one of the main aspects that should be considered in green and sustainable supply chain management (GSCM and SSCM respectively), which represents a process oriented to a sustainable and environmental-friendly approach to manage supply chains based on reduction of the ecological impact, cost savings, quality, reliability, increased performances and energy efficiency.

In particular, Cosimato and Troisi [48] showed how emerging green technologies with a focus on the logistic activities represent an important source of innovation for SCM, can contribute to gain a better energy efficiency, to reduce toxic emission, to increase the use of renewable source of energy, and to better manage or reuse waste. A case study of the DHL is also presented showing the green approach of the logistic company and investigating the EEM they adopted. Recently, Ahi et al. [49] performed a bibliometric analysis to identify the metrics that have been used in literature to address energy-related issues in GSCM and SSCM. The results highlight a lack of agreement on how energy-related issues should be measured in GSCM and SSCM and that the cooperation between members of the supply chain can aid the development of energy efficiency practices. Glover et al. [50] applied Institutional Theory and conducted 70 semi-structured interviews with different stakeholders across the dairy supply chain to explore the role of supermarkets in the development of legitimate sustainable practices. Findings from the case study revealed that the dominant player (i.e., supermarket) exerts pressure on other smaller organizations across the supply chain. They conclude that to approach sustainable practices to the dominant logic of cost reduction across the whole supply chain is a challenge and will require a broader and more systemic approach including investment and financing practices, so that all members of the supply chain can cooperate and contribute to energy reduction. While, Wu et al. [34] highlighted how collaboration among different actors of the supply chain can affect the relevance of energy performances examining the impact that pressure of adopting energy efficiency

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actions in production plants coming from two of the most strategic stakeholders (i.e., buyers and government) has on Chinese suppliers. Three categories of energy efficiency actions were identified, i.e., management-, equipment- and process-oriented initiatives, which implementation is contingent on ownership characteristics and value alignment with the two stakeholders. Winkler [51] showed that the implementation of SSCN leads to close relationships between the members of a supply chain and to reduced negative environmental impacts (i.e., waste, energy consumption, transport processes and packaging) of the process improving the economic and environmental performance. In this work, it is also introduced the relevance of lice cycle analyses as the most developed and most effective method for measuring and managing a business' effect on ecological sustainability. In addition, some sustainable practices are outlined for product planning and design, purchasing initiatives, and production processes. Halldórsson and Kovács [52] investigated the need to introduce energy issues in logistic and operation management. Specifically, they proposed a conceptual framework that reflects on the immediate and tangible challenges that energy efficiency has on logistics and supply chain management, even though it has been largely neglected in the past. They show also that, including energy efficiency requires considerable rethinking on both operational and conceptual levels. In [53] a review on the most effective cleaner production strategies in the seafood supply chain for improved environmental performance were identified aiming at reducing unnecessary handling, energy usage, storage costs and waste production. From the results, it is also recommended that a supply chain management system incorporating life cycle assessment modelling ensures the greatest reduction in environmental impact. Finally, Mulhall and Bryson [54] introduced the concept of risk underlining how the management capacity for technical price risks by individual firm is limited because of the interdependency between trading partners in the supply chain and thus an integrated management approach within the supply chain is required.

From the analysis (Appendix A Table A1), it can be observed that these papers are mainly focused on highlighting the cost reduction and the benefits that can be introduced including the energy flow in the assessment of the supply chain performance. Some of them present also case studies and generic analyses of EEM but there is only one work underling the relevance of considering a probabilistic approach while no works are focused on inventory theory.

5.2. Quantitative Approach

5.2.1. Additional Flow and Cost

In the publications that propose a quantitative approach, the ones that consider the energy flow as an additional cost that should be considered in the evaluation of the supply chain performance represent the greatest share. These works show how energy is relevant in affecting the overall economic outcomes of the supply chain and for that reason they underline that it should be considered in the analyses. One of the main works is represented by [55], since it shows the importance of the environmental consciousness in the design and operation of globally integrated supply chain networks. This research includes the energy consumption of every node in the supply chain and examines the carbon footprint across supply chains, contributing to the knowledge and practice of green supply chain management. Also in [56] the aim was the design of strategic network design of industrial supply chains, and it developed a holistic sustainability optimization framework considering both economic, social and ecologic objectives. The sustainability optimization addresses the overall consumption of resources (among which also energy) aiming at the reduction of carbon emissions and waste. Three sustainability optimization strategies are also presented: optimize financial performance only, optimize the trade-off between sustainability indicators, and target at an overall balance of defined sustainability indicators by minimizing the time-to-sustainability. In [57], the role of third parties (raw materials and utilities suppliers, clients, waste and recovery systems, etc.) which might face different objectives, was integrated in the supply chain management. In the study a generic model was developed aiming at the optimization of the planning decisions of the multi-product multi-site

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SC (production/distribution echelons), considering the coordination of several resources, among which energy flow. The mathematical model described was applied to a case study in which a main production-distribution supply chain based on a typical polystyrene production system and an energy generation supply chain cooperate.

The following publications were based on the study of specific real case and thus their findings where strictly related to the supply chain considered. Thollander and Palm [15] present different types of indicators for the measurement of the energy efficiency of supply chains considering different system boundaries. A case study on the paper and metal industries is also proposed and results show that the decisions-making process can highly affect energy consumption, although the production phase dominates the overall energy consumption. Rizet et al. [58] compared the energy consumption and CO_2 emissions of supply chains in different states (such as Belgium, France and UK) looking specifically at jeans, yogurts, apples, tomatoes and furniture, and observed also the influences of distance, retail type, area density and consumer behavior. Ferretti et al. [59] analyzed the energy and environmental impact that alternative supply methods for raw materials (solid vs. liquid phase material supply) have on the aluminium supply chain. The aim of the model proposed was the determination of the supply aluminium mix, i.e., molten and solid alloy, capable of balancing the economic benefits as well as environmental requirements. Meneghetti and Monti [60] proposed a model for the optimization of refrigerated automated storage and retrieval systems sustainability, considering specific features of the food supply chain (such as temperature control). The model allows a deep analysis of the impacts that supply chain decision variables (among which facility location, storage temperature and incoming product temperature) have on costs, energy consumption and emissions. Waldemarsson et al. [61] considered an integrated planning of the supply chain at a multi-site pulp company through a MILP model taking into account also energy aspects in addition to traditional ones. The aim of the study was to investigate the effects on profitability while taking energy issues into consideration. Marimin et al. [62] mapped and analyzed the green productivity of a natural rubber supply chain and formulated scenarios for increasing its green productivity level and the best strategy for green productivity improvement was determined by using the Analytic Hierarchy Process. Krikke et al. [63] developed a quantitative model to support decision-making in a closed-loop supply chain (CLSC) for refrigerators concerning both the design structure of the product (i.e., modularity, reparability and recyclability) and the design structure of the logistic network, measuring the environmental impacts through linear-energy and waste functions. In [64], a web-based tool is proposed to evaluate the energy and carbon emissions associated with each transportation link and storage echelon in wine distribution. The results from the case study application highlight how supply chain configurations can result in vastly different energy and emissions' profile. Waldemarsson et al. [65] proposed an optimization model for the supply chain planning of a pulp company. The scenarios considered involve market changes for energy demand and price, and alternative production opportunities. The main finding shows that including energy into the planning process allow the achievement of higher profitability.

Moreover, some contributions proposed the integration of the energy flow as an extension of the economic order/production quantity (EOQ/EPQ) and the joint economic lot size (JELS) models from the inventory theory research stream, in which the energy costs are included in the analyses and the total cost is minimized. Zanoni et al. [66] studied a single-vendor single-buyer integrated production-inventory system and explicitly considered energy use. The energy consumption was weighted with a cost factor and evaluated in addition to classical production-inventory costs. The main funding of the performed study is that, if energy costs are considered, then the inventory costs slightly increase in the optimal solution, but the total costs of the overall system decrease thanks to the great energy savings observed. Zanoni and Zavanella [67] aim to propose an analytical model jointly looking at economic and energy aspects of the food supply chain, explicitly considering the specific requirements, in terms of temperature and storage time, to preserve the product quality over time, so as to support decisions makers and improving the sustainability of the supply chain. Hasanov et al. [22] introduced a closed-loop supply chain model that considers the economic value and energy content of products

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and proposed a novel framework for studying lot-sizing policies of production processes through a life cycle analysis. The numerical results highlighted that energy, transportation and disposal costs in supply chain are strongly interdependent and highly affects the environmental performance of a production-inventory system. Bazan et al. [68] developed two models (classical coordination policy versus vendor-managed inventory with consignment stock agreement policy) which consider the energy usage and greenhouse gas (GHG) emissions of production and transportation operations in a single-vendor single-buyer system subject to a multi-level emission-taxing scheme. The numerical examples showed that the energy usage has been found to be the main cost component for both models, thus reducing energy usage is a priority.

The following works considered environmental implications in the specific case of reverse logistic supply chain: Bazan et al. [69] developed a model which considers energy consumption and GHG emissions from manufacturing, remanufacturing and transportation activities with emissions penalty tax. The objective of the model was to minimize the total cost determining the manufacturing batch size per cycle, the number of manufacturing and remanufacturing batches per cycle, and the number of times an item may be remanufactured. The results of the numerical examples show that optimizing all the environmental costs collectively promotes less remanufacturing with respect to 'traditional' reverse logistics models which focus is just on solid waste disposal. In addition, the results show the need to increase the recollection of available used products that can be remanufactured. In a following work [70], the authors proposed a classical and a vendor managed inventory with consignment stock (VMI-CS) coordination models for a two-level closed-loop supply chain considering three critical environmental issues: i.e., the energy used in production processes, GHG emissions from production and transportation activities, and the number of times to remanufacture a used item. Bazan et al. [71] reviewed the literature on the modelling of reverse logistics inventory systems that are based on the EOQ and JELS settings, given special attention to environmental issues. In addition, they show how modelling waste disposal, greenhouse-gas emissions and energy consumption during production is considered as the most pressing priority for the future of reverse logistics models. Chung and Wee [72] investigated green product designs and remanufacturing efforts into an integrated production inventory model with short life-cycles for energy using product (EuP). In [73] a two-stage production system has been model introducing the generation and transformation of waste heat into lot sizing decisions and the study investigates how lot sizing policies change if waste heat is used to operate the system. Results indicate that using haste heat reduces the overall requirements of a production system. Finally, also [74] considered the opportunity to recover excess heat from energy-intensive industries. In this study, the authors introduced the integration among a single-vendor single-buyer supply chain and analyzed the savings occurring thanks to the integrated network of heat exchange across the supply chain.

5.2.2. Objective Function

The need to include energy and environmental evaluation criteria in the analysis of supply chains performances is increasingly recognized both from limitations posed by Governments, through legislation and regulations, as well as for the various benefits that it can generate for companies. For that reason, another group of papers considers the improvement of energy performance as a relevant goal, modelling it as an objective function. In these works, the reduction of the energy consumption represents one of the main goal that should be addressed. General insights from Appendix A Table A1 show how this group of papers is mainly focused on specific supply chain case studies in deterministic conditions in which some energy efficiency measures are also analyzed.

Hanes and Carpenter [75] presented a Materials Flow through Industry (MFI) supply chain to fully understand the benefits and consequences of technology deployment since they have the potential to reduce material and energy consumption also in upstream or downstream processing stages. The MFI tool is then utilized to explore a case study in which three light-weight vehicle supply chains are compared to the supply chain of a conventional, standard weight vehicle. Michelsen et al. [76]

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presented a methodology about how eco-efficiency in extended supply chains (ESCs) can be measured, including all processes in the life cycle of a product, and nine different environmental performance indicators were identified. The paper is based on a case study of furniture production in Norway in which different product design are compared. Tsoulfas and Pappis [77] proposed a decision model based on environmental performance indicators classified in six different groups in correspondence with the activities in supply chains (i.e., product/process design and production, packaging, transportation and collection, recycling and disposal, greening internal and external business environment, and other management issues), which may support decision making assessing both potential and actual performance of supply chains. In [78], a tactical supply chain planning model was proposed to investigate trade-offs between cost and environmental issues including carbon emissions, energy consumption and waste generation. In this work, also other aspects of real world supply chains such as multiple transport lot sizing and flexible holding capacity of warehouses were considered. The proposed case study of a company involved in the production and distribution of metal containers, compares different scenario to improve the energy performance. In [79] a hierarchical simulation based approach for estimating the energy consumption to keep the products flowing through the supply chain was presented. The paper analyzed how supply chain design and operational decisions impact on the energy consumption. A case study for a closed loop supply chain of forklift brakes was used as an example of application of the approach and identifies specific energy efficiency measures for every single node of the supply chain considered. Concerning closed loop supply chain other two works can be found that consider energy performances as an objective function. Das and Posinasetti [80] integrated environmental concerns in CLSC to improve the overall SC performance in terms of sustainability and business operational metrics and one of the objective functions consists in the minimization of the total energy spent by the supply chain. In addition, a numerical example illustrated the applicability of the approach and the model. Then, Kadambala et al. [81] used a multi-objective particle swarm optimization approach to solve the proposed multi-objective mixed integer linear programming model in order to quantitatively measure the effective responsiveness of the CLSC in terms of time and energy efficiency. Wang et al. [82] explored China's retail system from a life-cycle perspective evaluating the energy-saving potential from improving supply chain efficiencies and reducing excess inventory. Finally, McBrien et al. [83] considered the steel supply chain and analyzed the savings that can be achieved through an integrated heat recovery across various processes along the supply chain. Moreover, they showed that limited additional savings may be obtained from a wider integrated network of heat exchange given by the integration of the steel supply chain with other industries.

5.2.3. Decision Variables

The last group consist of a few publications that model the energy efficiency as a decision variable influencing the overall supply chain performance. In [84], a channel coordination problem in a green supply chain is addressed. The manufacturer determines the energy efficiency level and wholesale price, while the retailer controls sales price. In a sequent work [85], the same authors proposed a Nash bargaining model to distribute the extra-profit between channel members. The main finding resulting from their work was that in centralized scenario green innovation investment, energy efficiency level and channel profit are greater than the one in the decentralized one. In [86], the author compared a vertical integration and a decentralized setting and examined the impact on the energy saving level and on the price of environmentally friendly products. Xie [87] proposed a mathematical model to support decision-making in improving sustainability in a decentralized supply chain with two competing suppliers under different cooperative strategy combinations. The main finding is that the energy efficiency and the consumer surplus can be efficiently enhanced by cooperative strategies. More recently, Xie et al. [88] analyzed the decisions for the energy efficiency of main engines for the improvement of sustainability and proposed a model for the selection of portfolio of main engines that would maximize the return of the supply chain, subject to a specific risk level, implied by the uncertain

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demand. Results show also that when supply chain coordination is realized, the best environmental performance and the highest consumer surplus can be achieved.

6. Discussion and Insights for Future Research Streams

In Figure 8, a map of the key themes of the present literature review (i.e., supply chain management and energy efficiency) and their corresponding subthemes across different levels of analysis are presented.

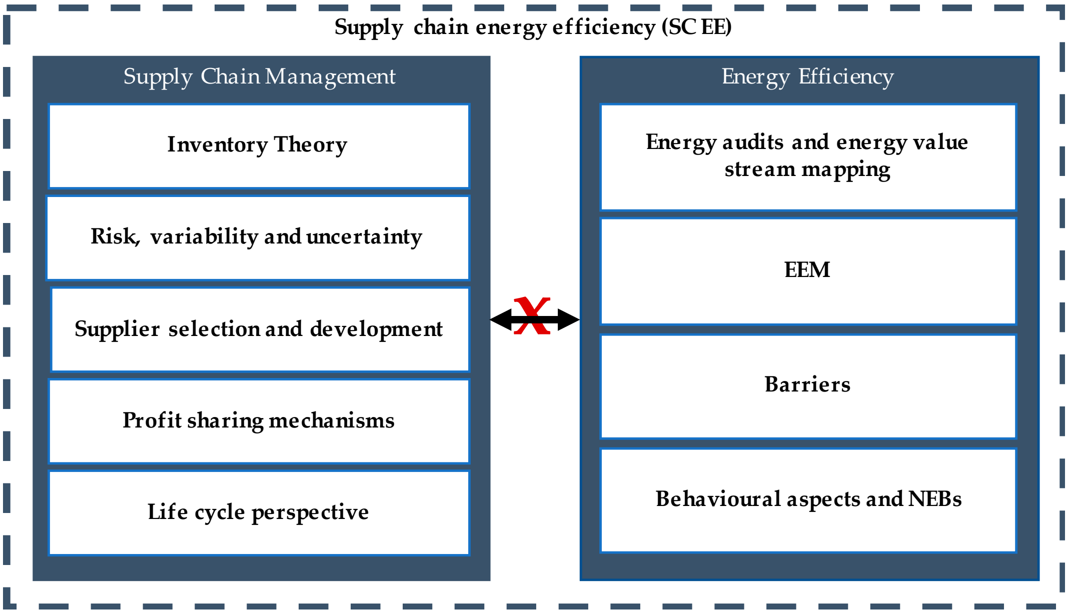

Figure 8. Key themes and subthemes of the literature review.

From Figure 8 and from the content analysis of the selected peer-reviewed papers presented in Section 5, several research streams can be identified for closing the gaps existing in the current literature as summarized in the following Table 3.

A first stream of research that can be identified consists in the evaluation of supply chains features for energy performance improvements. Information collected from energy audits at a company-level can be aggregated showing the energy use of an entire supply chain, and providing valuable insight about the potential for energy savings compared to a sector benchmark, for instance a best practice plant or the efficiency of the plant next door [58,89]. Industrial sectors vary a lot from one another. A process industry like a cement plant uses limestone as a raw material that is extracted from the earth and produces cement as its final product. The process of a food producer could be much different where production relies on multiple inputs of raw materials that are processed in several steps over the supply chain, and logistics are much more complex requiring producers to follow strict hygiene requirements. In addition, the impact on the total energy consumption of the different stages of the production process is strictly dependent on the sector and/or product considered. These differences and peculiarities should be dealt with. Hence, supply chain impact analyses should be tailored to address different system boundaries of the sectors to encompass the varying production processes, steps in the supply chain and inputs/outputs. A supply chain impact analysis enables to map the energy consumption of each company in the supply chain with different levels of analysis to perform an energy impact assessments. Subsequently, the outcomes obtained allow the recognition of the key processes and/or auxiliary services, such as transportation and stocking activities, which account for the highest share of total energy use and the identification of the relevant parameters influencing supply chain's energy performances. Once the energy flows are mapped and the minimum energy

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required and best practices identified and evaluated, it can be interesting also to assess the impact of alternative measures on the energy efficiency for different supply chains allowing a prioritization of these measures and to compare the effects that different background specifics present.

Table 3. Resume of gaps identified in current literature and potential future research streams.

Research Stream	Gaps
• EE peculiarities for different supply chain (Benchmarking and best practices)	• Industrial energy audits outcomes are not exploited for supply chain energy efficiency analyses • Several case studies exist but not generalized prioritization of EEM • Comparison between different supply chains and background specifics
• Life cycle perspective for EEM assessment in supply chains, including non-energy benefits and behavioural aspects	• EEM can generate benefits in different periods and different stages of the supply chain but life cycle perspective is not yet considered in the evaluation of EEM • The focus of EEM assessment is only on energy savings at a company level
• Supply chain coordination for energy performance improvement	• Cooperation among the supply chain represents a potential way to overcome the main barriers against EEM implementation but it is not investigated yet • Evaluation of alternative profit sharing mechanisms to support the overcoming of financial barriers of EEM • Inventory theory extensions for energy performance improvement • Energy performance as a strategic criterion for supplier selection and development • Effects on energy performance of coordinated logistic activities (e.g., transportation, packaging)
• SC EE probabilistic assessment	• Risks, variability and uncertainty effects on SC EE improvement are not systematically investigated • Supply chain cooperation effects against risk-averse companies is not addressed

While energy audits provide a snapshot of the current situation of energy use in a specific company, they do not necessarily involve a dimension describing the magnitude of the investments needed or the benefits that may be generated from improving energy efficiency. Such cost-benefit assessment is essential as the main aim of companies is to generate profits, and the energy bill could represent a significant share of a sector's total production costs. It is necessary to combine this techno-economic information about improving energy efficiency in a company and its supply chain (since improving energy efficiency will also create savings to other members) to provide a full picture to the company decision-makers and project financiers. It is a general perception that energy efficiency measures typically come with a higher cost. It could indeed be true that investment in new and more efficient equipment is higher compared to a paid-off obsolete equivalent or a new, but less efficient, one. However, upfront initial cost is only one of the components in the product's life cycle. Energy costs, which could cover up to 30% or more of the total production costs of a sector, are equally important. The savings in the energy bill from investing in new highly performant equipment can typically cover the additional investments. In past years, the more attention has been focused on reductions in energy consumption and GHG emissions, which are the only benefits that have been measured systematically. Currently, the magnitude and role of NEBs and the relevance in the supply chain management are not sufficiently well understood and very few studies have been conducted. Gaining more insight about these benefits could play an important role to inform decision makers to evaluate the actual feasibility of investing in energy efficiency measures. Another aspect that is relevant and that should be considered is represented by the role of behavior. However, at present, it is hard to determine the actual effectiveness of behavioral interventions implemented under energy efficiency programs since there are relatively little information available. The life cycle perspective in the assessment of costs and

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benefits allows to evaluate all the relevant impacts that EEMs have on the economic and environmental performance encompassing a broader view of the supply chains. According to ISO 14001 [90], life cycle is defined as 'consecutive and interlinked stages of a product (or service) system, from raw material acquisition or generation from natural resources to final disposal. Life cycle stages include acquisition of raw materials, design, production, transportation/delivery, use, end-of-life treatment and final disposal'. Such a systematic approach can provide relevant information to the top management supporting the creation of success over the long term. Moreover, it provides important inputs in the decision-making process: for instance, product suppliers can optimize their designs by comparing competing alternatives on the same basis and by performing trade-off studies and they can also evaluate various operating, maintenance and disposal strategies [91]. Two main valuable tools are the life cycle assessment (LCA) methodology, according to the ISO Standard 14044:2006 [92], which determines the environmental impacts (and benefits) of products allowing the identification of the most impactful unit process toward the supply chains; and the life cycle cost (LCC) which evaluate the economic impact of a product over its lifetime and consists of six cost-causing phases [93]: (a) concept and definition; (b) design and development; (c) manufacturing; (d) installation; (e) operation and maintenance and (f) disposal. Life cycle approaches avoid shifting energy, economic and environmental issues from one production stage to another, from one geographic area to another and from one period to the following ones. In this way, it is possible to increase and harvest the benefits introduced through EEMs, to improve risk and quality management, as well as developing and applying cleaner process and product options and improving the product's added value for environmental-friendly consumers.

Supply chain cooperation represents a great opportunity in overcoming the barriers against the implementation of energy efficiency measures. Hence, a possible future research interests the evaluation of the effects that the coordination among the actors of the supply chain has on the energy performance improvement extending the existing research on inventory theory. In literature, some works integrating energy performances in lot sizing decisions and inventory theory already exist. However, no one of these contributions considers the opportunity of improving the energy performances as an objective function or a decision variable. Before the coordination of the decisions across the supply chain are implemented, the supplier selection and development process covers a key role in the determination of the overall economic and environmental performance. For that reason, energy efficiency represents a strategic criterion in the selection of the suppliers and supplier development, instead of switching to other suppliers, can increase the supply chain performance even in terms of sustainability; however, there are no evidence of that aspect in the current literature. Since not always the cooperation satisfies all the supply chain members, another interesting extension is to consider efficient profit sharing mechanisms (e.g., trade contract, transfer payment scheme) that induce cooperation even under decentralized decision making. By using these mechanisms, none of the participants is encouraged to deviate from the optimal supply chain decisions and actions. Apart from incentive mechanisms, it would be interesting to analyze alternative methods of investment financing also through third-parties (e.g., EPC, loan, leasing, mortgage, etc.), and to evaluate how the introduction of energy performance improvements affects the outcomes of profit sharing mechanism. It is important to observe the effects of the coordination not only of production processes but also of logistic activities (for instance in terms of transportation, packaging, product design) since they are responsible for a great share of the overall cost and energy consumption.

The environment is characterized by huge uncertainty and variability of the conditions. For that reason, decisions makers should consider a probabilistic approach to properly investigate the energy efficiency measures implementation and to analyze the effects that supply chain coordination has on the overcoming of barriers due to risk-averse companies.

Once the previous gaps will be filled and the analysis of the supply chain energy efficiency structured in a rigorous way, several extensions can be undertaken (see Figure 9). Among them, the main are represented by the analyses of the effects and impacts on the economic and environmental performances obtained through the linkage of supply chain energy efficiency and: advanced

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manufacturing, additive manufacturing, smart concepts (i.e., smart grid, smart factory, and so on), e-commerce, renewable energy sources, industrial symbiosis and circular economy.

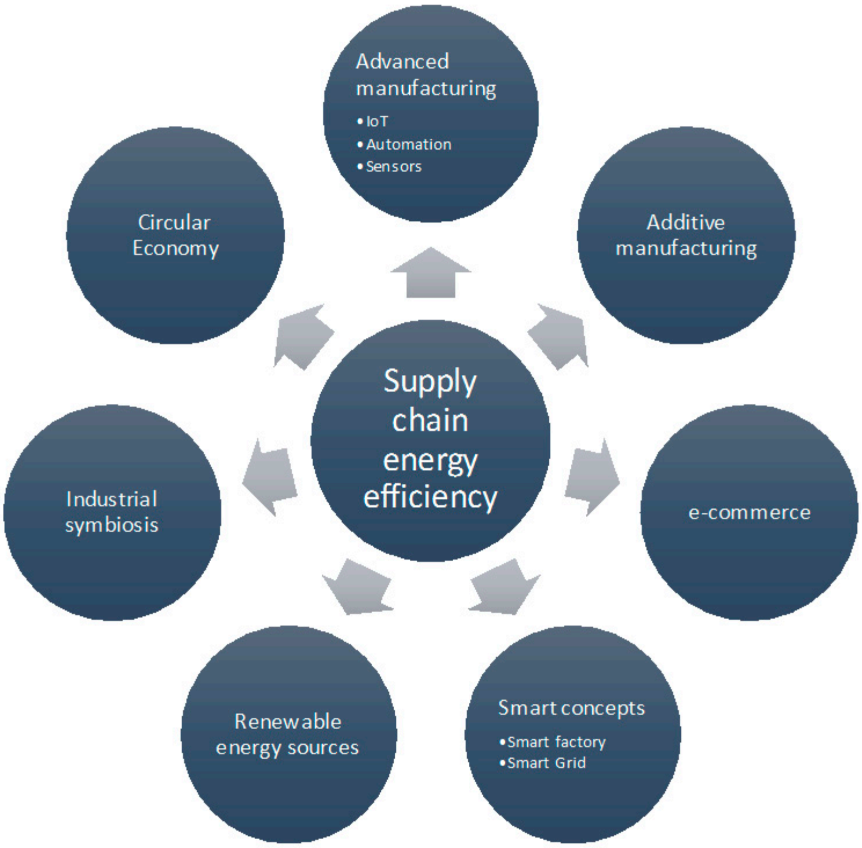

Figure 9. Future research opportunities.

Advanced and additive manufacturing techniques have the potential to save great amount of energy in manufacturing systems [94] by eliminating production steps, using less material, enabling reuse of by-products, and producing lighter products. Another innovative practice that affects the energy consumption is the opportunity to substitute conventional trade (through stores) with e-commerce (through home-delivery channels). In the majority of the case, the e-commerce channel is more energy efficient in terms of product waste and product returns, buildings, packaging, passenger transport and freight transport [95]. However, these implications are not obvious when the focus is shifted to a broader supply chain perspective since also other decision variables can be affected (such as lot size, number of shipments) and currently, no studies have investigated such effects. Further investigations can concern energy efficiency improvements in the supply chain that can be enabled by the smart concept (such as smart factory and smart grid). For instance, Information and Communication Technologies (ICT), energy management systems, energy storage systems and demand side management through demand response schemes represent the main challenges in improving power operational forecasts (both load and generation) and in monitoring the energy performance. In this way, it is possible to find potential sources of losses reducing the energy consumptions and improving the energy efficiency. In the meantime, these systems allow also to enable an effective and efficient penetration of renewable energy sources (RES) leading to a cleaner energy production: activating supply chain integration in terms of energy efficiency it is expected to convert to at least 5% of the supply chain primary energy consumption (related to electricity and gas consumption) with means of different renewable energy sources (that might also be activated using synergies with other actor within the area where the different companies of the supply chain are located and with the

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possible support of local utilities). Energy efficiency measures do not directly increase the share of renewable energy production, however several synergies between the two can be found [96]:

- the increased use of RES in substitution to both traditional uses of biomass and conventional fuels leads to relevant energy savings, since renewables introduce more energy efficient technologies compared to their traditional alternatives;
- the combination of accelerated deployment of renewable energy technologies and energy efficiency measures has the potential to further contribute to raising renewable energy shares and accelerating energy intensity improvements.

Therefore, it is possible to state that energy efficiency measures allow to increase the share of renewables and that renewable technologies can be considered as one of the possible measures for improving energy efficiency.

In addition, potential synergies for boosting energy efficiency can be obtained through industrial symbiosis with other entities (e.g., companies, public facilities, etc.). Specifically, three types of symbiotic transactions can occur among different companies [97]: (i) by-product exchanges in which waste are used as raw material inputs from others; (ii) shared utilities or access to services (such as energy management or waste treatment); and (iii) cooperation on general issues of common interest (e.g., emergency or sustainability planning). A broader vision of industrial symbiosis considers an increasing collaboration between private companies and regional or national authorities through public-private partnerships which allows to incur in greater benefits also for public organizations [98]: (1) improved performance of the public service facilities; (2) reduced and stabilized cost for providing services such as heat, cooling and electricity to public facilities (e.g., hospitals, offices and schools) leading to greater cost-efficiency and (3) reduced environmental impact. Even the application of a wider range of circular economy approaches (such as eco-design and production, consumption encouraging repair, increased recycling especially for packaging) can influence the energy use [99]. A deeper understanding of the connection between supply chain energy efficiency and circular economy can represents another relevant extension of the current research streams.

7. Conclusions

Over the past several years, energy efficiency has acquired greater relevance representing a strategic key resource for economic and social development because it provides multiple benefits to different stakeholders. From the industrial user's perspective, energy efficiency can result in great cost savings, improved competitiveness, profitability and quality, a better working environmental, etc. Despite these multiple benefits, most firms still face many difficulties and, in some cases, hostility when trying to implement energy efficiency plans. The most dominant of these barriers, especially for SMEs, are access to capital and lack of awareness. Supply chain management is one of the main ways to overcome those barriers; it can also support the implementation of energy efficiency measures for companies with a lower competitive positioning in the marketplace. Since the current literature has mainly focused on the single firm point of view, the present work aims to provide a systematic review of existing papers on energy efficiency integrated into supply chain management that were published in academic journals, and to define a stream of research to further develop this topic. From the analyses presented in this paper, it is possible to observe that very few works have integrated energy efficiency concerns into the study of supply chain management using both qualitative and quantitative approaches.

The publications that propose a qualitative approach have mainly focused on showing the relevance that energy issues have in affecting supply chain performance, the optimal decision-making process, and the opportunity to improve the energy performances that results from collaborative efforts of members of a company's supply chain.

The quantitative models provided in most of the reviewed studies mainly aim to introduce the additional costs associated with the energy flow in the total supply chain cost, and only a few

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studies have considered energy performance as an objective function or as a decision-making variable. The analyses show how energy efficiency achieved through appropriate supply chain design and management is still poorly investigated. Thus, there are many opportunities to develop this topic from the practice and research point of view.

For instance, interesting further developments would be to evaluate the following aspects:

(i) The effects that the introduction of the energy topic have on the supply chain economic and environmental results and on the form of cooperation;
(ii) How supply chain management can support the development of energy efficient measures to overcome existing barriers;
(iii) How different learning curves and knowledge of participants along the supply chain can influence the outcomes;
(iv) The effects introduced by considering risks and uncertainties that characterise the current environment.

Moreover, previously published papers do not analyze specific supply chain energy efficiency measures, so it would be interesting to compare and prioritize the existing alternatives in different industrial sectors, since they may have different relevance and impacts.

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Appendix A

Table A1. Content analysis.

ID	Reference	Solution Technique	EEMs	Case Studies	Coordinated Decisions	Uncertainty	NEBs	Life Cycle Perspective	Approach	Relevance
[21]	Kalenoja et al., 2011	Case study	Logistic activities	Paper and metal industries	Raw material procurement, inbound logistics, production and outbound logistics	-	-	✔	QN	AF
[22]	Hasanov et al., 2013	Optimization model	-	-	Production, inventory, transportation and waste disposal	-	-	✔	QN	AF
[34]	Wu et al., 2014	Case study	Auxiliary services	Apparel and kitchenware production industries	Energy consumption	-	-	-	QL	OF
[48]	Cosimato and Troisi, 2015	Case study	Logistic activities Auxiliary services	Logistic company	Sustainable practices	-	-	-	QL	AF
[49]	Ahi et al., 2016	Literature review	-	-	Sustainable practices	-	-	✔	QL	OF
[50]	Glover et al., 2014	Institutional theory	-	Dairy supply chain	Sustainable practices	-	-	-	QL	OF
[51]	Winkler, 2011	Qualitative analysis	Logistic activities	-	Waste, energy consumption, transport processes and packaging	-	-	✔	QL	AF
[52]	Halldórsson and Kovács, 2010	Conceptual framework	Logistic activities	-	Sustainable practices	-	-	-	QL	OF
[53]	Denham et al., 2015	Literature review	Logistic activities Auxiliary services	Seafood industry	Sustainable practices	-	-	✔	QL	OF
[54]	Mulhall and Bryson, 2014	Case study	-	Intermediate metal processing industry	Purchasing	✔	-	-	QL	OF
[55]	Sundarakani et al., 2010	Optimization model	Logistic activities	-	Logistic	-	-	-	QN	AF
[56]	Kannegiesser and Günther, 2013	Optimization model	Logistic activities	-	Production and logistic	-	-	-	QN	AF
[57]	Zamarripa et al., 2014	Optimization model	-	Polystyrene production-distribution and energy generation supply chain	Resources procurement, production, inventory, transportation	✔	-	-	QN	AF

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Table A1. *Cont.*

ID	Reference	Solution Technique	EEMs	Case Studies	Coordinated Decisions	Uncertainty	NEBs	Life Cycle Perspective	Approach	Relevance
[58]	Rizet et al., 2012	Case study	-	Yogurt, jeans, fruits and furniture supply chains	Transportation and storage	-	-	-	QN	AF
[59]	Ferretti et al., 2007	Optimization model	Logistic activities	Aluminium supply chain	Production, inventory, transportation and green practices	-	-	-	QN	AF
[60]	Meneghetti and Monti, 2014	Optimization model	Logistic activities	Food supply chain	Production, inventory and transportation	-	-	-	QN	AF
[61]	Waldemarsson et al., 2013	Optimization model	Production planning	Pulp industry	Raw materials purchasing, production, inventory, transportation and energy consumption	-	-	-	QN	AF
[62]	Marimin et al., 2014	Multi-criteria decision making	Production planning	Natural rubber supply chain	Sustainable practices	-	-	-	QN	AF
[63]	Krikke et al., 2003	Case study	Logistic activities	Refrigerators closed-loop supply chain	Transportation, waste and energy consumption	-	-	✔	QN	AF
[64]	Cholette and Venkat, 2009	Case study	Logistic activities	Wine industry	Transportation and storage	-	-	-	QN	AF
[65]	Waldemarsson et al., 2017	Optimization model	Production planning	Pulp industry	Raw materials, production, storage, distribution and transportation	-	-	-	QN	AF
[66]	Zanoni et al., 2013	Optimization model	Production planning	-	Production, inventory and energy consumption	-	-	-	QN	AF
[67]	Zanoni and Zavanella, 2012	Optimization model	Production planning	Food supply chain	Production, inventory, transportation and energy consumption	-	-	-	QN	AF
[68]	Bazan et al., 2015a	Optimization model	Production planning	-	Production, inventory, transportation and emissions	-	-	-	QN	AF
[69]	Bazan et al., 2015b	Optimization model	Production planning	-	Production, inventory, transportation, waste disposal and emissions	-	-	-	QN	AF
[70]	Bazan et al., 2017	Optimization model	Production planning	-	Production, inventory, transportation, waste disposal, energy consumption and emissions	-	-	-	QN	AF

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Table A1. *Cont.*

ID	Reference	Solution Technique	EEMs	Case Studies	Coordinated Decisions	Uncertainty	NEBs	Life Cycle Perspective	Approach	Relevance
[71]	Bazan et al., 2016	Literature review	-	-	Production, inventory, transportation, waste disposal, energy consumption and emissions	-	-	-	QN	AF
[72]	Chung and Wee, 2011	Optimization model	Production planning Logistic activities	-	Production, inventory and remanufacturing	-	-	✔	QN	AF
[73]	Biel and Glock, 2016	Optimization model	Production planning	-	Production, inventory and energy consumption	-	-	-	QN	AF
[74]	Marchi et al., 2017	Optimization model	Production planning	-	Production, inventory and energy consumption	-	-	-	QN	AF
[75]	Hanes and Carpenter, 2017	Case study	Production machines	Light-weight vehicle supply chain	energy consumption	-	-	✔	QN	OF
[76]	Michelsen et al., 2006	Case study	Production planning	Furniture industry	Eco-efficiency decisions	-	-	✔	QN	OF
[77]	Tsoulfas and Pappis, 2008	Multi-criteria decision making	Logistic activities	-	Sustainable practices	-	-	✔	QN	OF
[78]	Fahimnia et al., 2015	Optimization model	Logistic activities	-	Production, inventory, transportation and environmental performance	✔	-	-	QN	OF
[79]	Jain et al., 2013	Case study	Production planning	Forklift brake supply chain	Raw materials purchasing, production, inventory, transportation and energy consumption	-	-	✔	QN	OF
[80]	Das and Posinasetti, 2015	Optimization model	Logistic activities	-	Production, inventory, transportation and energy consumption	-	-	✔	QN	OF
[81]	Kadambala et al., 2017	Multi-criteria decision making	Logistic activities	-	Purchasing, production, inventory, transportation, remanufacturing and energy consumption	-	-	✔	QN	OF
[82]	Wang et al., 2016	Case study	Production planning	China’s consumer goods retail system	Energy consumption	-	-	✔	QN	OF

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Table A1. *Cont.*

ID	Reference	Solution Technique	EEMs	Case Studies	Coordinated Decisions	Uncertainty	NEBs	Life Cycle Perspective	Approach	Relevance
[83]	McBrien et al., 2016	Case study	Auxiliary services	Steel supply chain	Energy consumption and heat recovery	-	-	✔	QN	OF
[84]	Zhang et al., 2016a	Optimization model	-	-	Prices and energy efficiency levels	-	-	-	QN	DV
[85]	Zhang et al., 2016b	Optimization model	-	-	Prices and energy efficiency levels	-	-	-	QN	DV
[86]	Xie, 2015	Optimization model	-	-	Prices and energy saving level	-	-	-	QN	DV
[87]	Xie, 2016	Optimization model	-	-	Prices and energy saving level	-	-	-	QN	DV
[88]	Xie et al., 2017	Optimization model	Production machines	Shipbuilding supply chain	Prices and energy saving level	✔	-	-	QN	DV

Notes: "QN" = Quantitative approach; "QL" = Qualitative approach; "AF" = Additional flow, cost; "OF" = Objective function; "DV" = Decision variable.

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