energies

MDPI

Article

Extending Energy Management Towards Suppliers—An Analysis of Drivers, Barriers and Selection Criteria

Lea Fobbe [1,*], Robin von Haartman [1], Per Hilletofth [1], Patrik Thollander [2,3] and Olli-Pekka Hilmola [1,4]

[1] Department of Industrial Management, Industrial Design and Mechanical Engineering, University of Gävle, 801 76 Gävle, Sweden
[2] Department of Building Engineering, Energy Systems and Sustainability Science, University of Gävle, 801 76 Gävle, Sweden
[3] Department of Management and Engineering (IEI), Division of Energy System, Linköping University, 581 83 Linköping, Sweden
[4] Estonian Maritime Academy, Tallinn University of Technology, Kopli 101, 11712 Tallinn, Estonia
* Correspondence: lea.fobbe@hig.se; Tel.: +46-26648442

Abstract

Energy management (EnM) is crucial for reducing GHG emissions, but there is still a large potential to improve the energy efficiency of manufacturing companies. One approach that could be leveraged is to reduce Scope 3 emissions by extending EnM towards suppliers and integrating it into supply chain management (SCM); however, research linking these perspectives remains limited. This paper aims to investigate drivers and barriers associated with extending EnM towards suppliers and how EnM practices are considered in supplier selection. Based on a nationwide online survey sent to Swedish manufacturing companies, this paper provides new insights for practitioners and policymakers to develop strategies to integrate EnM into SCM, contributing to closing the energy efficiency gap. The results show that organizational and economic drivers and barriers related to prioritization and structure are individually perceived as most important for extending EnM towards suppliers, but supply chain-related factors play an important role when factor groups are considered. Further, the study highlights that economic criteria are still perceived as more important than energy-related criteria when it comes to supplier selection, which is initially conceptualized as a potential supply chain EnM gap.

Keywords: energy management; energy efficiency; drivers; barriers; decarbonization; supply chain energy management; energy-efficient supply chain

Check for updates

Academic Editor: Simone Zanoni

Received: 3 August 2026
Revised: 20 September 2026
Accepted: 23 September 2026
Published: 29 September 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Over the past few decades, concerns about climate change, resource scarcity and security of energy supply have grown substantially [1,2]. Current energy supply remains heavily dependent on fossil fuels, which are the primary source of carbon dioxide emissions. In this context, the manufacturing industry plays a pivotal role, accounting for approximately one quarter of global energy-related greenhouse gas (GHG) emissions and 25 percent of final energy use in Europe [3–5]. Moreover, the energy sector experienced a significant shock in the aftermath of the Russian invasion of Ukraine in 2022. All European countries were affected [6], regardless of whether their electricity and energy mixes would have been more oriented towards renewable and sustainable sources [7]. As a result, policymakers, academia and industry increasingly prioritize supply chain decarbonization

and energy efficiency as key approaches to achieve climate neutrality and reduce risks associated with energy supply [8–11].

Energy efficiency can reduce GHG emissions by promoting the efficient use of energy resources and has been recognized as a strategic lever for competitive advantage in manufacturing companies [12–14]. However, considering the rising energy prices together with stricter environmental regulations, scholars highlight the need for more systematic approaches, such as adopting systematic energy management (EnM) practices [1,10,14,15].

EnM goes beyond mere cost reduction through energy efficiency measures and also includes the management of the use of such technologies [14,16]. Previous research has identified key in-house EnM practices [1,17,18] and drivers and barriers that support or hinder their implementation [12,19,20]. However, studies show that GHG emissions occurring beyond a company's boundaries, also called Scope 3, can exceed direct emissions generated by its own operations (Scope 1), and indirect emissions associated with purchased energy (Scope 2) [21–24]. Recent European Union directives requiring companies to account for Scope 3 emissions across their supply chains have further increased attention to the role of larger manufacturing companies [25,26], typically focal companies in the supply chain, in supporting their upstream suppliers in implementing energy efficiency measures to decarbonize the supply chain [27–29]. This is particularly relevant because many suppliers in manufacturing supply chains are small and medium-sized enterprises (SMEs), which often lack the time and resources required to effectively address energy efficiency issues [19,30,31].

To ensure energy efficiency in the upstream supply chain, scholars increasingly suggest integrating in-house EnM into supply chain management (SCM). This can be achieved, for example, by including energy targets for suppliers in in-house energy policies and targets [32,33]. Extending EnM towards suppliers may provide several benefits, such as reduced vulnerability to climate-related risk, higher profitability, increased resilience and better preparedness for increases in energy prices [11,32]. Nevertheless, the topic often remains overlooked when establishing EnM practices [27,28,32]. Indeed, over the last decade, research has progressively called for a shift from firm-centered approaches to energy efficiency to a broader supply chain perspective [33,34]. Existing studies have, however, primarily examined related issues such as supply chain optimization to achieve energy efficiency [35,36]. At the same time, research on drivers and barriers to EnM has predominantly focused on practices within organizational boundaries [12,19,20]. Thus, only limited empirical knowledge exists about establishing EnM practices in a supply chain context.

One mechanism through which EnM can be extended towards suppliers is procurement, where organizational energy objectives can be incorporated into supplier evaluation and selection. This may involve considering suppliers' energy-efficiency measures and EnM practices as part of supplier selection criteria [37,38]. However, existing research has predominantly addressed environmental and sustainability criteria more broadly [39,40], with energy efficiency and energy use typically being considered as one criterion among many [38,40,41]. Consequently, there is limited understanding of the specific role of EnM practices in supplier selection and how this may be associated with drivers and barriers to extending EnM into SCM.

Against this background, the aim of this paper is to investigate the drivers and barriers associated with extending EnM towards suppliers, and the extent to which EnM practices are considered in supplier selection. The paper addresses two research questions: (1) What are the drivers and barriers to integrating EnM into SCM? (2) How are EnM practices considered as supplier selection criteria and associated with drivers and barriers? The exploratory nature of the study means that the analysis focuses on associations between

supplier selection criteria and drivers and barriers, rather than confirming structural relationships between the variables.

This paper extends previous research in two respects. First, whereas previous studies on EnM drivers and barriers have focused on in-house EnM, this study examines these factors in the context of extending EnM towards suppliers and includes supply chain specific drivers and barriers. Second, this paper connects drivers and barriers to supply chain EnM with supplier selection by examining the consideration of EnM practices as supplier selection criteria. By integrating these two perspectives, the study provides an empirical and conceptual basis for understanding the conditions surrounding the extension of EnM from an internally focused management practice towards integration into SCM.

The remainder of the paper is structured as follows: the next section provides a literature review on EnM and drivers and barriers to its implementation. Section 3 describes the methods, followed by a presentation of the empirical findings in Section 4. In Section 5, the findings are discussed, and Section 6 provides the conclusions and implications of this study.

2. Theoretical Framework

2.1. Energy Management

Implementing energy efficiency strategies has been recognized as a crucial step in reducing overall energy use and mitigating GHG emissions [3,13,33]. Traditionally, energy efficiency efforts have primarily focused on technological measures and cost-reduction approaches [13,16]. However, many industrial companies continue to face challenges in implementing such measures, often due to limited capital, lack of awareness, and the overall complexity of energy efficiency initiatives [33,42]. Consequently, there is still a large gap between the potential of available energy efficiency measures and their actual implementation, commonly referred to as the "energy efficiency gap" [13,16]. This gap was later re-defined into the extended energy efficiency gap, which denotes an additional 50 percent potential arising from using these technologies, denoted the "energy management gap" [16]. To overcome these gaps, scholars increasingly emphasize the importance of adopting systematic and proactive EnM practices [14,16,43].

EnM can be described as "[...] the systematic activities, procedures and routines within an industrial company including the elements strategy/planning, implementation/operation, controlling, organization and culture and involving both production and support processes" [14] (p. 3704). The goal of EnM practices is therefore to enhance energy efficiency through the continuous identification of inefficiencies, evaluation of technologies and optimization of the energy system [16]. This also encompasses energy audits and the implementation of standards such as ISO 50001 [44].

To further drive improvement and implementation of EnM, scholars emphasize the need to understand the drivers and barriers to implementing EnM practices in the manufacturing industry [3,17,20]. Drivers and barriers are frequently used as an analytical lens in change management and SCM research to identify and structure the conditions that may facilitate or constrain the implementation of specific practices [45,46]. Within EnM research, scholars have investigated drivers and barriers influencing the adoption of energy efficiency measures since the 1970s, although earlier research primarily focused on investment decisions [12].

Most studies categorize drivers and barriers to EnM implementation as economic, organizational, and knowledge-related or behavioral factors, with some extending the analysis to include additional dimensions such as competence, awareness, technology, policy- or information-related aspects [1,3,19,47]. Despite these different categorizations, scholars note that the highest-ranked drivers and barriers tend to be similar across contexts,

even though the implementation of energy efficiency measures may differ depending on industry characteristics, company size and geographical location [3,12,17].

Drivers in this context are typically described as stimuli that motivate companies to enhance their energy efficiency [1,19]. Among these, economic drivers, such as "cost reduction" and "threat for rising energy prices", along with knowledge or organizational drivers including "people with real ambition", "top management support" and "internal competence" are frequently identified as critical by several studies [3,17,20,48]. Furthermore, employee training and the implementation of EnM systems (e.g., ISO 50001) and frameworks (e.g., Science-based targets) linked to energy efficiency have been recognized as essential for raising awareness and transforming perceptions of energy issues. This can not only facilitate the implementation of EnM practices but also reinforce the broader integration of sustainability within supply chains [3,49–51]. In fact, studies have shown that broader sustainability efforts such as having an environmental profile, requirements for sustainability reporting or other environmental regulations can drive internal energy efficiency measures [3,12,20].

In contrast, barriers are often viewed as the main obstacles that prevent a company from implementing measures that are both environmentally and economically efficient [1,19]. Studies in different industrial contexts show that the most important barriers are a mix of behavioral, organizational and economic barriers, reflecting the multifaceted challenges companies face. For example, organizational and behavioral barriers such as "lack of time or other priorities", "technical risks" or "lack of energy manager's influence" hinder implementation efforts, whereas economic barriers such as "other priorities for capital investment" or "lack of access to capital" further hinder investments in energy efficiency projects [3,13,20]. Based on these findings, Johansson and Thollander [12] proposed ten in-house EnM practices designed to overcome barriers and facilitate the implementation of energy efficiency measures, including top-management support, establishing a long-term energy strategy, developing an energy plan, employing an energy manager, ensuring accurate allocation of energy costs, and providing employee training. Furthermore, scholars have underscored the importance of EnM practices such as establishing key performance indicators and focusing on measurement, monitoring, evaluation, and control as central [1,17].

However, even though EnM is widely recognized as an effective approach for improving in-house energy efficiency [12], growing evidence suggests that internal efforts alone may be insufficient. Several studies indicate that SMEs, which typically form the supplier base of large industrial companies, often face challenges in implementing EnM, mainly due to costs, lack of training and interest, and the absence of formal policies [19,30]. Scholars therefore increasingly emphasize the importance of extending EnM practices beyond the organizational boundaries of the focal firm to address energy efficiency issues associated with upstream supply chain activities. This involves coordinating and extending EnM practices towards upstream suppliers to enhance the overall energy efficiency of the supply chain [2,22,32].

2.2. Extending Energy Management Towards Suppliers

Scholars and practitioners have emphasized the pivotal role of focal companies in influencing suppliers on energy-related issues and in uncovering energy-saving potential throughout the supply chain [2,50,52]. Such an extension of EnM towards suppliers, however, differs from conventional in-house EnM. While EnM traditionally focused on internal operations or purchased energy, addressing energy efficiency within Scope 3 requires a shift beyond organizational boundaries, from direct managerial control towards influencing the energy use and emissions of independently managed suppliers. Supply

chain EnM may therefore be better understood as a governance challenge rather than an individual firm-level choice [31].

Some scholars have therefore started to develop frameworks that move beyond firm-centred approaches by focusing on governance feasibility and incentive alignment [34]. This requires new collaborative relationships with suppliers, facilitating the sharing of carbon emission data and implementing energy efficiency measures across the entire supply chain [29,32,37]. For example, a recent review by Xavier et al. [32] proposes that focal companies need to actively address the energy use of their suppliers and jointly identify opportunities to reduce emissions. Consequently, extending EnM towards suppliers cannot be understood merely as the replication of internal EnM practices at the supplier level. Rather, it requires focal companies to translate in-house EnM practices into interorganizational governance mechanisms capable of influencing suppliers.

However, although scholars increasingly explore the relationship between energy efficiency, decarbonisation and SCM [11,35,53], few companies employ a formalised approach to extend EnM towards suppliers. Recent studies show that while companies have started to reduce their emissions internally and beyond, few specifically focus on the supply chain level [37,54]. For example, few companies have specific goals or programs for measuring suppliers' GHG emissions [27], and most companies only engage to a limited extent with their suppliers to improve energy efficiency [55,56].

At the same time, extending EnM towards suppliers introduces additional challenges. Focal firms depend on suppliers for information about their energy use and emission data, while smaller suppliers often lack the capabilities required to generate such data. The resulting information entropy can hinder focal firms' ability to extend energy efficiency measures across the supply chain [31]. Thus, lack of awareness, lack of expertise and a resistant mindset have been highlighted as common barriers to supply chain decarbonisation [53,57]. This suggests that the drivers that motivate firms to engage in in-house EnM may not necessarily translate into supplier-facing practices, while additional barriers may emerge when EnM crosses organizational boundaries.

Drivers and barriers may therefore influence not only whether firms engage in EnM, but also whether existing EnM objectives are extended toward suppliers. However, compared with the extensive literature on drivers and barriers to in-house EnM, there is still little knowledge about the conditions that may facilitate or constrain the implementation of energy efficiency and EnM practices in the supply chain. The lack of knowledge about how companies can systematically extend their energy efficiency goals towards suppliers may limit further advances [27,37].

One mechanism through which focal firms can translate EnM objectives into supply chain practice is procurement. Selecting suppliers based on energy and environment-related criteria is increasingly recognized as essential to a company's competitiveness and sustainability performance [38,41,58]. Procurement links internal organizational objectives to decisions concerning external suppliers and can therefore serve as an enabler for extending EnM across organizational boundaries. Supplier selection refers to the decision-making process through which suppliers are evaluated and selected against predefined criteria to become a part of a company's supply chain; traditionally, this process has been approached from an economic perspective [39,59,60]. Incorporating energy-related requirements into supplier selection criteria can therefore be viewed as a concrete action for integrating EnM into SCM. Such selection criteria may concern, for example, suppliers' adoption of energy-efficiency technologies, use of clean energy, energy-management systems, or related certifications, thereby facilitating an effective integration of EnM into SCM [37,38,40].

However, existing supplier selection research has predominantly considered broader environmental and sustainability criteria, while considerably less attention has been given to the specific role of EnM and energy-efficiency practices [33,40,41,58].

3. Materials and Methods

3.1. Survey Design

An online survey was designed to analyze the integration of EnM into SCM in manufacturing companies. Sweden was selected as the empirical context because the manufacturing industry in Sweden accounts for almost 40% of final energy use [61] and has a long tradition of working with industrial EnM practices. This is also reflected in the large number of studies exploring the implementation of energy efficiency and in-house EnM in the Swedish manufacturing context [3,12,19,62]. However, these studies predominantly focus on in-house EnM practices linked to specific industries or company sizes and are often based on limited empirical samples. Given the underexplored nature of this research area, the survey was designed to be primarily exploratory.

The web application Qualtrics XM was used to administer the survey. The survey consisted of three sections. The first section focused on general company information, including markets served, main customers, company ownership and the number of products offered. The second section included questions on supplier management, including supplier selection criteria, including both standard economic criteria and criteria related to energy efficiency and EnM. The energy-related criteria were selected based on the literature on energy efficiency and EnM in supplier selection [37,38,40]. In addition, considering the dependency of local firms on energy-related data from their suppliers [31], transparency was added as a selection criterion. Transparency as a selection criterion has also received increasing attention because of expanding sustainability reporting and disclosure requirements [56,63]. The third section focused specifically on supply chain EnM, including questions on economic, organizational and knowledge drivers and barriers related to working with energy efficiency in the supply chain. The questions related to drivers and barriers were based on Rohdin et al. [62] and the extensions discussed by other scholars [3,12]. In addition, new drivers and barriers explicitly addressing energy efficiency and EnM in the supply chain and in relation to suppliers were developed for this study [53,57].

The questions were based on 7-point Likert scales, and each question had the option to be left unanswered. To ensure the clarity of the questions and avoid leading respondents, the survey was circulated among academic experts in industrial EnM for qualitative review during its development [64].

3.2. Data Collection

A list of 1199 companies that fall under the Swedish Act on Energy Audits [65] was obtained by compiling all companies that had filed a report during 2017–2021 and removing duplicates. For the period 2017–2020, the list included the email addresses of 278 companies within NACE codes 10–32. These companies were contacted directly by email, but 49 emails bounced back due to erroneous email addresses. Approximately 20 other respondents contacted the research team to be excluded for various reasons, primarily because they no longer held a relevant position that allowed them to answer the survey. The list of companies was complemented by companies that had reported in 2021 but not between 2017 and 2020. To find appropriate contacts, i.e., personnel who were familiar with EnM and SCM efforts, the manufacturing companies were contacted by phone before the survey was sent out. This was intended to improve the reliability of the study by ensuring that the respondents were familiar with the topics covered by the survey questions. Participation in the survey was voluntary, and the respondents were informed about the purpose of the

study and the handling of their responses before participating. Responses were treated confidentially and analyzed and reported in a manner that did not identify individual respondents or companies.

Data were collected between October and December 2024, and a total of 391 surveys were sent out; the remaining companies either expressed no interest in participating or could not be reached. To increase the response rate, two reminders were sent out. This led to a total of 70 individual companies responding to the survey, resulting in a response rate of 17.9 percent. The response rate is consistent with other survey studies using similar approaches [30,66]. However, not all companies answered all questions as respondents were free to omit individual questions or discontinue the survey at any point. Therefore, the number of responses per question varies across questions. Responses containing only very limited information were excluded from the analysis. Consequently, 54 respondents were retained in the analytical dataset. Of the 70 respondents, 43 reached the supplier-selection section, 42 the supply-chain activities section, 39 the drivers section, and 36 the barriers section. The corresponding numbers of complete responses were 40, 42, 33, and 30, respectively. The number of observations therefore varies between analyses depending on the extent to which respondents had reached and completed the relevant section of the questionnaire. Item-level missingness among respondents who reached the respective sections was comparatively limited. Cases with missing values were excluded from the respective analyses using listwise deletion. Listwise deletion was applied separately to the variables included in each analysis, resulting in the varying sample sizes reported for the figures, category comparisons, and correlations.

To alleviate the risk of non-response bias, late respondents were compared with early respondents across all the variables used in this paper and no significant differences between the groups were found. Nevertheless, self-selection bias cannot be fully excluded, as companies with a greater interest in EnM may have been more inclined to participate. Common method bias was tested using Harman's single-factor test, in which all variables were inserted into a principal component analysis (PCA) to determine whether a single component would explain a large part of the variance [67]. No such effects were seen, as the analysis produced 15 components with eigenvalues above 1. While this test provides an indication of potential common method bias, it does not completely eliminate the risk of such bias.

3.3. Data Analysis

The analysis relied on four sets of questions: (1) general information about the company and its supply characteristics (9 items), (2) criteria for selecting suppliers (7 items), (3) drivers for energy efficiency in the supply chain (23 items) and (4) barriers to energy efficiency in the supply chain (25 items). For question sets 2–4, the data were checked for skewness and kurtosis, and all variables had values between −2 and +2, except for the selection criterion "economic viability of supplier" which had a kurtosis value of 4.27, reflecting that many respondents considered this criterion to be very important. As 54 out of 55 variables had skewness and kurtosis values within the indicated 'safe' levels, the distributions were considered sufficiently suitable for the parametric analyses used in this exploratory study. It should be highlighted that this research analyzes only one part of a longer survey investigating energy efficiency in supply chains. Other parts of the survey focused on supplier collaboration to increase energy efficiency were recently published in [55]. Overlap between the two publications is limited to the drivers of energy efficiency. In the earlier publication, however, these were analyzed at the item level using averages and median values, as well as in relation to energy-related supplier collaboration using correlations [55]. In the present study, the driver items are instead used in category-specific

PCAs as an exploratory data-reduction approach, together with the barrier items, and the resulting empirical dimensions are subsequently examined in relation to energy-related supplier selection criteria.

The statistical methods employed included frequencies for analyzing general information about the companies and their supply characteristics (Table 1), and mean values and paired-samples *t*-tests for the remaining variables. Paired-samples *t*-tests were used to examine whether there were statistically significant differences in mean values between different variables. For the pairwise comparisons between driver categories (Table 2) and between barrier categories (Table 3), *p*-values were adjusted using Holm's step-down procedure within each set of comparisons. The item-level comparisons of the drivers and barriers should be viewed as exploratory comparisons and interpreted primarily as indications of differences in perceived importance rather than as confirmatory hypothesis tests. For the Pearson correlations presented in Table 4, *p*-values were adjusted using Holm's step-down procedure within four families of comparisons: energy-related supplier selection criteria with the driver and barrier factors, driver–driver correlations, barrier–barrier correlations, and driver–barrier correlations.

In addition, PCAs were conducted for the driver and barrier categories, with each category (supply chain, economic, etc.) analyzed individually. Eigenvalues greater than 1 were used as retention criteria. For sensitivity assessment, parallel analysis based on 10,000 random permutations and the 95th percentile of the resulting random eigenvalues, together with Velicer's minimum average partial (MAP) test, was conducted to assess the sensitivity of component retention. Overall, the components (factors) showed acceptable internal consistency based on the reliability measures reported in Supplementary Material S1 and S2. All values were at acceptable levels, and only six variables in total were omitted due to low component loadings or showing almost no relationship to any other variable. These items were removed and excluded from the component-based analysis, while still recognizing that low loading does not imply that the omitted items are unimportant. Due to the relatively small effective sample size, the resulting factor structures should be interpreted as exploratory. One variable, "knowledge barrier", showed a KMO value of 0.55 (see Supplementary Material S2), slightly below the recommended level of 0.6, but was retained because all other values were satisfactory. The one-component solution for knowledge barriers was also supported by parallel analysis and MAP sensitivity assessments.

For most of the four driver categories and four barrier categories, all items loaded satisfactorily onto a single component. The exceptions were economic and organizational drivers, and economic barriers. For these three categories, the items were distributed across two components and, upon inspection, the resulting groupings were considered thematically coherent. Thus, the subcategories reflect both empirical patterns in the data and conceptual coherence among the items. However, sensitivity analyses using parallel analysis and minimum average partial (MAP) analysis suggested a one-component solution for these three categories. The two-component solutions are therefore considered provisional and should be interpreted as exploratory dimensions rather than established constructs. In further analysis, these components were treated as separate categories, resulting in six categories of drivers (Table 2) and five categories of barriers (Table 3). A Pearson correlation analysis between the factors was conducted (Table 4) to assess (a) the associations between different drivers and barriers and (b) whether the drivers and barriers were associated with the inclusion of energy-related issues as a supplier selection criterion. For complete PCA results, see Supplementary Material S3 and S4, and for item-level descriptive statistics for drivers and barriers, see Supplementary Material S6. Correlations between the factors are presented in Table 4.

4. Results

4.1. Sample Characteristics

The sample consists of medium- to large-sized companies in the manufacturing sector (NACE codes 10–32). The number of employees ranges from 60 to 22,000, with a mean value of 1844 and a median of 375 (this information is based on optional responses from 53 respondents).

The companies are predominantly active in the business-to-business sector and have a large number of different products (Table 1). More than half are more than 70 percent foreign-owned, and just under half sell their products on the international market.

Table 1. Company characteristics.

Company characteristics	
Companies selling products outside of Sweden (N = 52)	46%
Business-to-Business companies (N = 52)	71%
Companies producing more than 100 different products (N = 52)	85%
Foreign ownership (more than 70%) (N = 54)	56%
Supply characteristics	
Companies buying more than 100 parts/components (N = 49)	92%
Companies having more than 100 suppliers (N = 48)	71%
Companies practicing single sourcing (N = 44)	16%
Companies practicing dual sourcing (N = 44)	34%
Companies practicing international sourcing (N = 50)	68%

4.2. Drivers for Energy Efficiency in the Supply Chain

The most important drivers for energy efficiency in the supply chain are the organizational drivers "Full support from top management" and "Company's/corporate group's environmental profile" with mean values above 5.5 (Figure 1). The two least important drivers belong to the organizational and economic categories, that is "Energy management systems" and "Incentive agreements/3rd party financing/energy performance contracting" with mean values of 3.51 and 3.18, respectively. The overall mean value for all drivers is 4.55. Exploratory paired-samples *t*-tests were performed on all combinations of drivers, and in the present dataset, statistically significant differences were observed between many of the drivers (see Supplementary Material S5).

Although the two highest-ranked drivers are organizational, several of the lowest-ranking drivers are also organizational. The other categories of drivers are also scattered throughout the ranking. When the mean ratings of the drivers within each category (organizational, knowledge, etc.) are compared to the mean ratings of the other categories, the results show two clear groups (Table 2). One group comprises the drivers that are perceived as very important. These include the economic drivers related to profitability, namely "Lower production costs", "Threat of higher energy prices" and "Pressure from investors and/or shareholders", supply chain drivers, and organizational drivers related to general environmental sustainability issues, that is "Environmental management systems", "Company's/Corporate group's environmental profile" and "Influence of environmental or industry associations". The second group comprises the economic drivers related to external pressure, that is "International competition", "Requirements from environmental regulation" and "Requirements for sustainability reporting" and "Incentive agreements/3rd party financing/energy performance contracting", knowledge drivers, and organizational drivers related to energy issues "Energy management systems",

"Long-term company energy strategy" and "Ability to utilize and disseminate individuals' knowledge of support and production processes".

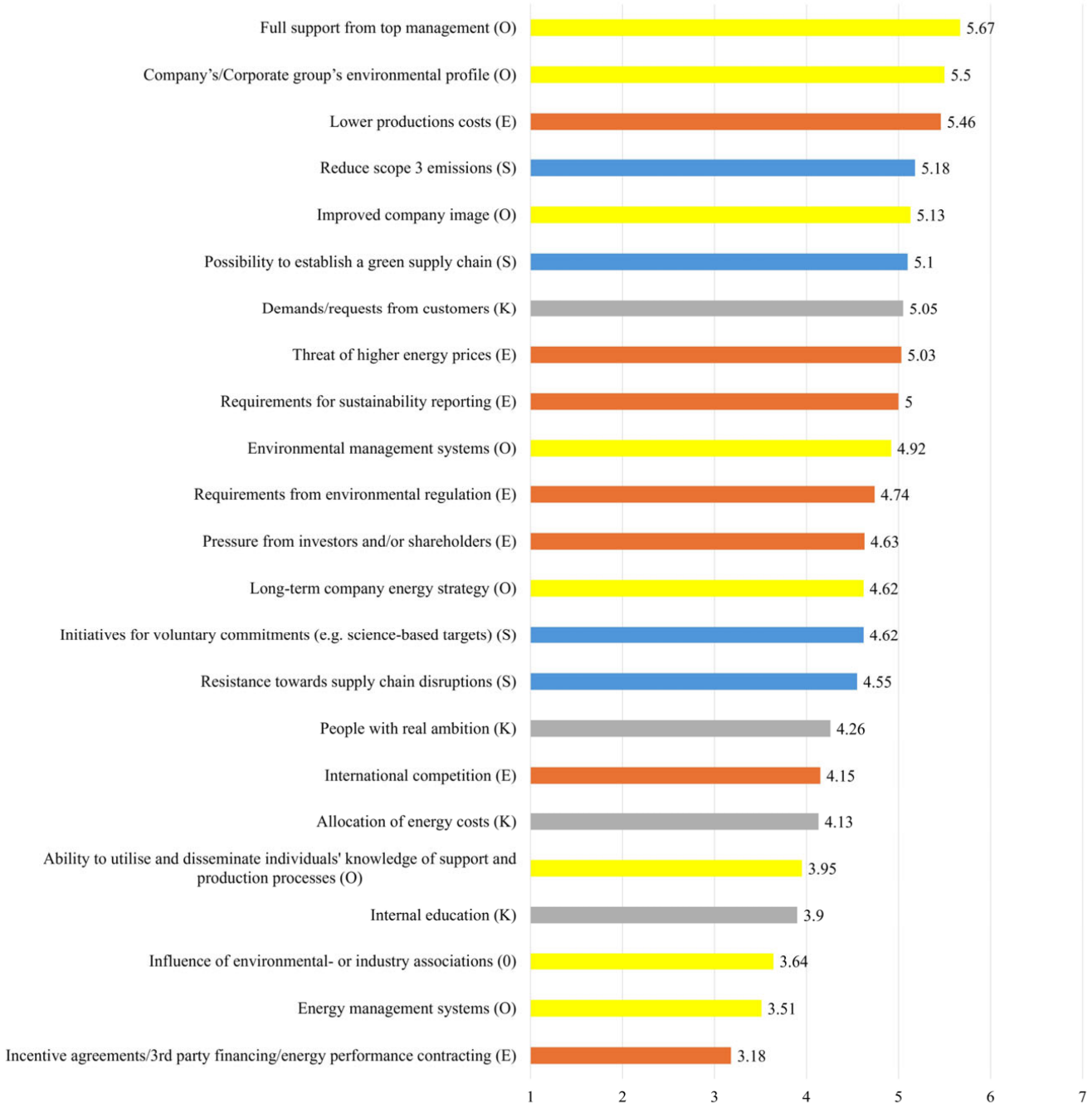

Figure 1. Drivers for energy efficiency in the supply chain (N = 38–39), where yellow = organizational (O), grey = knowledge (K), orange = economic (E), and blue = supply chain (S) factors.

The organizational drivers "Full support from top management" and "Improved company image", the knowledge driver "Demands/requests from customers", and the supply chain driver "Resistance towards supply chain disruptions" are omitted due to their low component loading and are thus not included in this analysis.

Table 2. Comparison of mean values for driver categories (N = 37–39, Paired-samples *t*-test (two-sided); *p*-values adjusted using Holm's step-down procedure, $p < 0.05$).

Driver Category	Mean	1.	2.	3.	4.	5.	6.
1. Economic—profitability	5.02						
2. Supply chain	4.97	[1] 1.00 [2] −0.03					
3. Organizational—environmental sustainability	4.72	[1] 0.73 [2] 0.26	[1] 1.00 [2] 0.21				
4. Economic—external pressure	4.22	**[1] 0.01** **[2] 0.60**	[1] 0.22 [2] 0.38	[1] 0.22 [2] 0.38			
5. Knowledge	4.10	**[1] <0.01** **[2] 0.71**	**[1] <0.01** **[2] 0.64**	**[1] 0.05** **[2] 0.49**	[1] 1.00 [2] 0.14		
6. Organizational—energy	4.03	**[1] <0.01** **[2] 0.65**	**[1] <0.01** **[2] 0.63**	[1] 0.06 [2] 0.47	[1] 1.00 [2] 0.15	[1] 1.00 [2] −0.05	

Yellow = organizational, grey = knowledge, organge = economic, blue = supply chain. **Bold** = $p < 0.05$, Light green = small effect size (>0.20), darker green = medium effect size (>0.50) [68]. In Relation to: [1] Paired-samples *t*-test (two-sided), with *p*-values adjusted using Holm's step-down procedure; [2] Effect size (Cohen D).

4.3. Barriers to Energy Efficiency in the Supply Chain

The most important barriers are all organizational, with "Lack of time/other priorities" being the most important with a mean value of 4.88, followed by "Non-energy-related tasks as priorities" and having a "Slim organization", each with a mean value of 4.66 and "Supply chain energy efficiency is not a core business" with a mean value of 4.46 (Figure 2). In comparison, the lowest-rated barriers are knowledge-related and economic factors, namely "Lack of external expertise" and "Difficult to get bank loans or other external financing" with mean values of 2.91 and 2.59, respectively. The overall mean value for all barriers is 3.78.

To further examine the ranking of the barriers, the mean value for all barriers within categories is compared to the mean value of the other categories. As shown in Table 3, there are also two groups of barriers. The first group comprises organizational, supply chain-related, and cost-related economic barriers, which are considered important. Economic barriers related to costs include "Funds are not allocated for supply chain energy efficiency", "Costs for developing supply chain energy efficiency tools and methods", "Indirect costs for recruitment and retraining of personnel", and "Costs for external expertise". In comparison, the second group comprises knowledge barriers and economic barriers related to financing, including "Lack of capital" and "Difficult to get bank loans or other external financing", which are not perceived as major barriers. The supply chain barriers "Indirect costs (e.g., time for supporting suppliers)" and "Lack of demand for environmentally friendly products" were omitted because of cross-loading and an almost complete lack of association with other items, respectively.

Table 3. Comparison of mean values for barrier categories (N = 31–34, Paired-samples *t*-test (two-sided); *p*-values adjusted using Holm's step-down procedure, $p < 0.05$).

Barrier Category	Mean	1.	2.	3.	4.	5.
1. Organizational	4.21					
2. Supply chain	3.86	[1] 0.24 [2] 0.34				
3. Economic—costs	3.85	[1] 0.24 [2] 0.35	[1] 0.95 [2] 0.01			

Table 3. *Cont.*

Barrier Category	Mean	1.	2.	3.	4.	5.
4. Knowledge	3.39	[1] **<0.01** [2] **0.79**	[1] **<0.01** [2] **0.63**	[1] **0.07** [2] **0.46**		
5. Economic—financing	2.84	[1] **<0.01** [2] **0.74**	[1] **0.01** [2] **0.63**	[1] **0.01** [2] **0.61**	[1] 0.24 [2] 0.35	

Yellow = organizational, grey = knowledge, organge = economic, blue = supply chain. **Bold** = $p < 0.05$, Light green = small effect size (>0.20), darker green = medium effect size (>0.50) [68]. In Relation to: [1] Paired-samples *t*-test (two-sided), with *p*-values adjusted using Holm's step-down procedure; [2] Effect size (Cohen D).

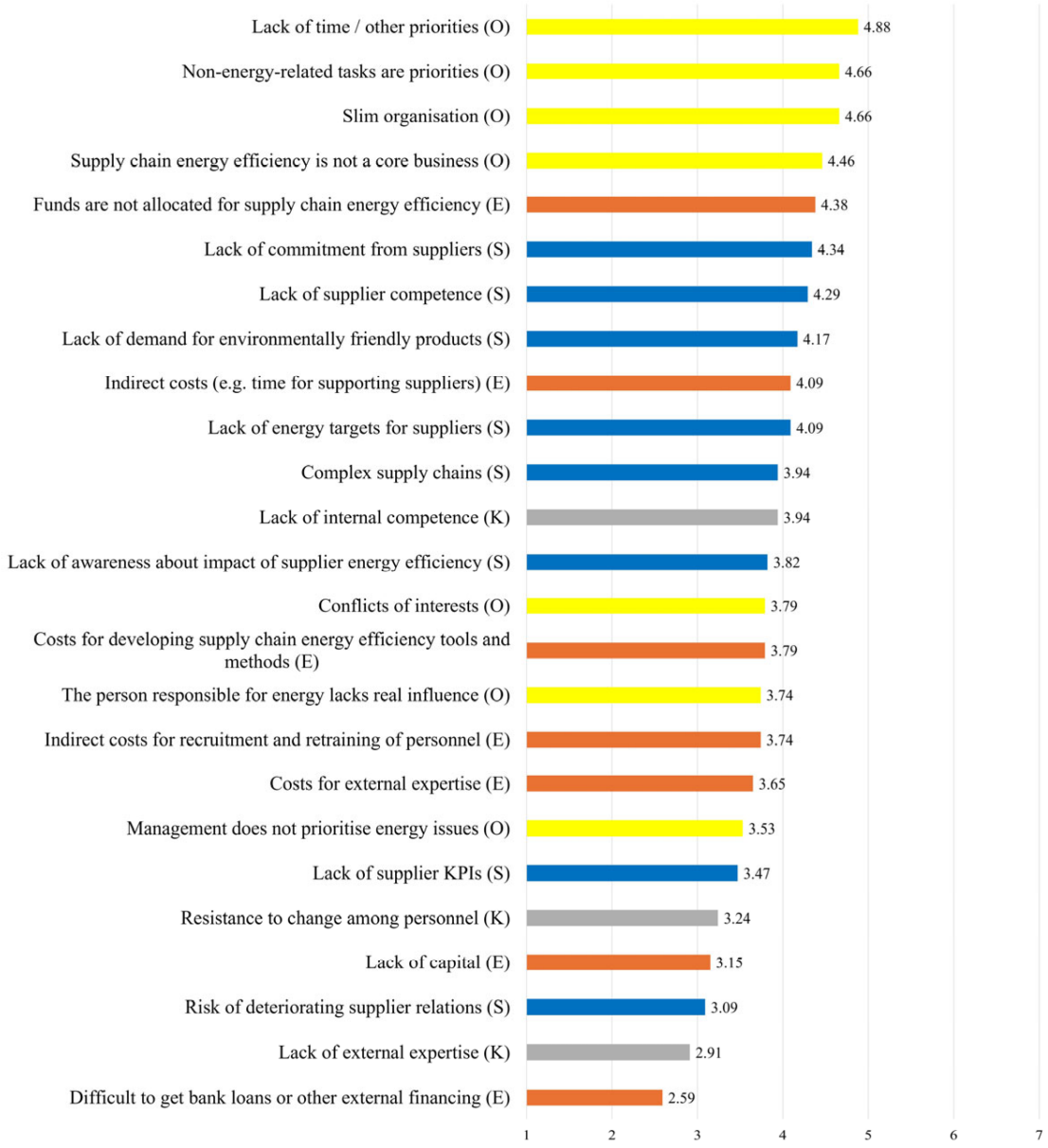

Figure 2. Barriers to energy efficiency in the supply chain (N = 32–35), where yellow = organizational (O), grey = knowledge (K), orange = economic (E), and blue = supply chain (S) factors.

4.4. Supplier Selection Criteria for Energy Efficiency in the Supply Chain

Among the supplier selection criteria included in this survey, the two economic criteria were perceived as most important, at mean values of close to 6 (Figure 3). Price received the highest mean rating, followed by the economic viability of suppliers, while transparency

ranked third among the criteria included in the survey. In comparison, the energy-related criteria included in this survey received significantly lower mean importance ratings than the economic criteria ($p < 0.01$, paired-samples t-test), although they were not rated as unimportant. In fact, all energy-related criteria are ranked in the middle of the scale, between 3.5 (energy certifications) and 4.5 (use of renewable sources).

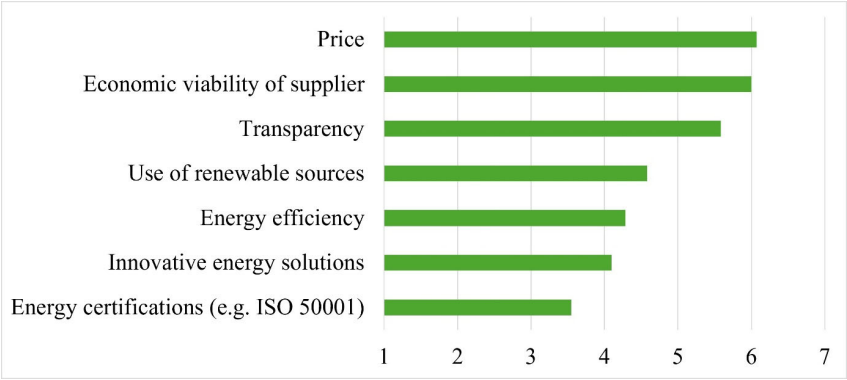

Figure 3. Importance of supplier selection criteria (N = 42).

4.5. Correlations Between Supplier Selection Criteria and Categories of Drivers and Barriers to Energy Efficiency in the Supply Chain

A PCA of the selection criteria showed that the energy-related criteria formed one group, except for "Energy certifications (e.g., ISO 50001)", which was omitted due to low component loading. An exploratory bivariate correlation analysis showed that the energy-related selection criteria are significantly associated with three driver factor groups, namely economic external pressure drivers, knowledge drivers and organizational drivers related to environmental sustainability (Table 4). The energy-related selection criteria are also significantly related to one group of barriers, that is knowledge barriers.

In addition, a correlation analysis of the categories (from the PCA) of drivers and barriers was conducted. Table 4 shows that the barriers, and to a somewhat lesser extent drivers, are highly interrelated. In particular, supply chain and organizational barriers are very closely related to all other barriers, except those in the economic–financing group. Knowledge barriers are closely related to all other barriers. In comparison, supply chain drivers are not significantly related to any other drivers or barriers.

Table 4. Correlations between components (N = 30–39, ** Holm Adjusted $p < 0.01$; where yellow = organizational, grey = knowledge, orange = economic, blue = supply chain, Dark green = very strong correlation (coefficient > 0.6, $p < 0.01$); light green = significant correlation ($p < 0.01$, coefficient ≤ 0.60)).

		1	2	3	4	5	6	7	8	9	10	11	12
	1. Energy-related supplier selection criteria	-											
Drivers	2. Supply chain	0.21	-										
Drivers	3. Economic—external pressure	0.56 **	0.23	-									
Drivers	4. Economic—profitability	0.03	0.20	0.38	-								
Drivers	5. Knowledge	0.51 **	0.34	0.56 **	0.39	-							
Drivers	6. Organizational—energy	0.25	0.39	0.29	0.36	0.72 **	-						
Drivers	7. Organizational—environmental sustainability	0.49 **	0.27	0.66 **	0.62 **	0.57 **	0.47 **	-					
Barriers	8. Supply chain	0.44	−0.05	0.51	0.15	0.33	−0.12	0.15	-				
Barriers	9. Economic—costs	0.32	−0.12	0.44	0.39	0.42	−0.03	0.25	0.66 **	-			
Barriers	10. Economic—financing	0.29	0.07	0.34	0.30	0.24	−0.03	0.21	0.35	0.42	-		
Barriers	11. Knowledge	0.49 **	0.00	0.50 **	0.25	0.53	0.05	0.22	0.84 **	0.77 **	0.52 **	-	
Barriers	12. Organizational	0.10	−0.11	0.21	0.14	0.17	−0.10	−0.03	0.79 **	0.79 **	0.21	0.70 **	-

5. Discussion

Scholars increasingly argue that advancing energy efficiency in the supply chain requires the integration of EnM into SCM. Although there is a growing discussion of related benefits and challenges of supply chain EnM, knowledge of how EnM can be integrated at the supply chain level remains limited and scattered [32,33].

In this sample, the exploratory category-specific analysis indicated that the three most important drivers were related to organizational and economic categories. However, no single category of drivers emerged as predominantly important; rather, the results suggest that a combination of supply chain, organizational, economic, and knowledge drivers may be considered when aiming to foster energy efficiency across the supply chain, consistent with previous research on in-house EnM [3,13,19,20]. Interestingly, the within-category analysis further indicated that the respondents perceived broader environmental sustainability drivers as more important than those specifically linked to energy. One possible explanation could be that research and public discourse have tended to focus on overarching sustainability issues rather than on energy-specific topics [14,32,33].

Similarly, the exploratory category-specific analysis of barriers to energy efficiency in the supply chain indicated that organizational barriers were the only category ranking among the top three, whereas the lower-ranked barriers comprised a heterogeneous mix of factors. This pattern has also been reported in previous studies focused on in-house EnM [3,12,17]. The supply chain drivers and barriers did not consistently rank among the factors perceived as most important by respondents. This is in line with other studies highlighting the challenge of overcoming organizational and economic cost-related barriers that are not necessarily directly related to supply chain factors [53,57]. Nevertheless, the highest-ranked barriers were related to internal prioritization and structure. Barriers related to a lack of supplier competence and commitment also received higher ratings than those related to a lack of internal competence and commitment. The relatively high correlations among groups of barriers suggest that organizational and supply chain conditions may be interconnected. These results suggest that manufacturing companies may benefit from considering a dual approach: internally by building a governance structure for supply chain EnM, and externally by strengthening supplier knowledge to facilitate the extension of EnM towards suppliers [31]. The comparison across factor groups similarly showed that respondents rated supply chain drivers and barriers, on average, higher than several of the other factor groups, including knowledge, organizational–energy, and economic–external pressure-related drivers, as well as knowledge and economic–financing-related barriers.

This is further supported when considering the supplier selection criteria included in this survey. The energy-related criteria were perceived as moderately important, suggesting interest in this approach and aligning with recent studies emphasizing not only environmental, but also specific energy-related considerations in supplier selection [37,40]. Nevertheless, although supplier selection has been recognized as a key mechanism for enhancing a company's sustainability performance [41,58], the findings may suggest that economic criteria such as price and economic viability continue to be perceived as more important than energy-related criteria in supplier selection in the context of energy efficiency in the supply chain. The prioritization of economic over energy-related criteria, despite the recent fluctuations in and challenges related to energy prices and availability in Europe [6], may indicate that interest in supply chain EnM has not yet translated into a decisive role for energy efficiency-related criteria in supplier selection. Incorporating energy efficiency-related criteria may help industrial companies better coordinate EnM practices and reduce Scope 3 emissions [2,22,32], whereas their absence may constrain progress in enhancing energy efficiency across the upstream supply chain.

Together, these findings suggest that more formalized approaches to integrating EnM into SCM may warrant further consideration [27,33,58], bridging the gap between sustainability intentions and operational practice. The findings may also point to a challenge extending beyond the traditional "energy management gap" [16]. While the EnM gap primarily concerns the implementation of systematic EnM practices within organizational boundaries, the comparatively lower perceived importance assigned to energy-related selection criteria included in this study suggests what we propose as a potential "supply chain energy management gap", referring to challenges associated with integrating EnM into SCM [27,55,56].

Thus, the proposed supply chain EnM gap concerns the extension of EnM towards suppliers. While recent research has proposed operational frameworks for supply chain energy efficiency programmes [34], their implementation requires ongoing management that integrates in-house EnM practices with SCM considerations. Previous evidence from an Austrian energy-efficiency policy programme has demonstrated substantial improvements associated with systematic EnM compared with business-as-usual, illustrating the potential value of formalized EnM approaches [51]. Still, in this study, EnM systems were one of the lowest-ranked drivers for implementing supply chain EnM. Although this finding does not establish limitations of ISO 50001 itself, it raises the question of whether existing EnM standards and management approaches provide sufficient incentives and guidance for extending EnM practices across organizational boundaries and towards suppliers.

6. Conclusions

Concerns about climate change, resource scarcity and energy security have intensified, alongside growing interest in closing the "energy management gap". As a result, researchers and practitioners increasingly focus on exploring factors that drive or hinder the integration of EnM practices and the reduction in GHG emissions. While the focus of EnM historically has been on Scope 1 and 2, there is growing interest in Scope 3 emissions. However, despite the growing body of literature on EnM and SCM, there is still very limited research that combines these two perspectives. This paper investigates the drivers and barriers to integrating EnM into SCM and how EnM practices are considered in supplier selection. Extending EnM towards suppliers represents a potentially important approach for addressing the energy efficiency gap across supply chains. This paper provides an in-depth analysis and structured overview of the drivers and barriers that support or hinder the implementation of supply chain EnM and contributes to the debate on energy efficiency and EnM in supply chains in three ways.

First, by extending the investigation of drivers and barriers to EnM in manufacturing companies with specific supply chain drivers and barriers and supplier selection criteria, this paper contributes to empirically linking EnM and SCM literature. Second, by identifying exploratory, sample-specific categories of drivers and barriers and examining exploratory bivariate associations with supplier selection criteria in the context of energy efficiency, the findings provide an overarching perspective on the conditions surrounding the extension of EnM beyond organizational boundaries. This highlights the potential relevance of considering in-house EnM and SCM practices jointly rather than as separate areas of management. Third, this paper contributes to reducing the knowledge gap regarding how companies can extend their EnM towards suppliers, while also providing empirical evidence on the relatively low perceived importance of the measured EnM-related criteria in supplier selection. The findings provide an empirical basis for an initial conceptualization of a potential "supply chain energy management gap", referring to challenges associated with integrating EnM into SCM. This paper thereby provides a first step towards

conceptualizing and addressing this challenge and identifies factors that may be relevant to addressing it.

From a managerial perspective, the results provide exploratory insights into the drivers and barriers that companies may consider when developing approaches for extending EnM towards suppliers. This may support industrial companies in developing strategies that strengthen relevant drivers and overcome the barriers to extending EnM towards suppliers, thereby addressing the potential supply chain EnM gap. The perceived lower importance ratings of the measured energy-related selection criteria included in the survey may suggest that a starting point could be to review whether and how energy-related considerations are represented in supplier selection. Tools such as the EnM maturity matrix [69] may provide one possible means of supporting companies in operationalizing EnM in the supply chain. The results may also have implications for public policy. The recent European Union directives on supply chain due diligence and sustainability reporting [25,26] have further increased attention to environmental impacts beyond companies' organizational boundaries, including Scope 3 emissions. Within this context, policymakers could consider the drivers and barriers to integrating EnM into SCM to facilitate the transition towards decarbonized supply chains. In particular, the comparatively high perceived importance of barriers related to supplier competence and commitment may warrant further consideration of policies or support mechanisms that facilitate better access to relevant knowledge and capabilities, especially for suppliers with limited resources for EnM.

The study has several limitations. First, the study focused on Swedish manufacturing companies covered by the Swedish Act on Energy Audits [65], which may limit the generalizability of the findings to other national or industrial contexts. However, many of the participating companies operate internationally, and similar regulatory and sustainability pressures apply to manufacturing companies across the EU. The results may therefore provide relevant insights for companies that face comparable institutional and regulatory conditions. Further research may investigate the drivers, barriers and use of selection criteria across European countries as well as in contexts where regulatory requirements concerning energy audits and sustainability differ. Second, the relatively small and varying sample size limits statistical power; the results should therefore be interpreted as exploratory. Third, the dimensionality of the three categories for which two-component solutions were retained should be considered provisional. Future studies with larger samples should reassess the dimensionality of these categories. Moreover, the study does not examine heterogeneity in terms of firm size, ownership, or other firm characteristics and their potential influence on the results. Fourth, the study measures respondents' perceived importance of drivers, barriers and supplier selection criteria rather than observing actual behavior. Future research could therefore consider procurement records or supplier evaluation data to investigate actual supplier selection in the context of supply chain energy efficiency. Fifth, the study relies on self-reported data from a single respondent in each participating company. Although respondents were selected based on their familiarity with EnM and SCM activities, individual responses may not fully capture practices and perspectives across different organizational functions. Future research could therefore employ multiple respondents from functions such as EnM, procurement, sustainability, and operations. Further, dyadic or multi-tier perspectives could be considered, investigating both the perspectives of focal companies and suppliers, particularly those of SMEs, and how they perceive the integration and coordination of EnM across the upstream supply chain. Such research could further develop the proposed supply chain EnM gap and investigate how existing standards, including ISO 50001, as well as practical approaches such as supply chain EnM maturity models, could support the integration of EnM across supply chains.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en19194618/s1. S1. Principal component analysis for drivers (N = 36–39); S2. Principal component analysis for barriers (N = 30–34); S3. Principal component analysis for supplier selection criteria (N = 42); S4. Summary of components; S5. Significance test for drivers for supply chain energy management; S6. Item-level descriptive statistics for drivers and barriers.

Author Contributions: Conceptualization, L.F., R.v.H., P.H., P.T. and O.-P.H.; methodology, L.F. and R.v.H.; writing—original draft, L.F. and R.v.H.; writing—review and editing, L.F., R.v.H., P.H., P.T. and O.-P.H.; project administration, P.H. and P.T.; funding acquisition, P.H. and P.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Swedish Energy Agency, grant number 52744-1.

Institutional Review Board Statement: Ethical review was not required for this study under the Swedish Ethical Review Act (2003:460). Under the Act, ethical review is required for research involving, among other conditions, sensitive personal data, physical or psychological intervention, or identifiable biological material. The present survey did not involve such conditions requiring ethical review under the Act. The study was conducted in accordance with applicable national legislation and institutional requirements. The information is available on the Swedish Government website: https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/lag-2003460-om-etikprovning-av-forskning-som_sfs-2003-460/ (accessed on 20 September 2026).

Informed Consent Statement: Prior to participation, respondents were informed about the purpose of the study, the voluntary nature of participation, and the confidential handling of their responses. Participation in the online survey was voluntary, and informed consent was indicated by respondents choosing to proceed with and submit the questionnaire.

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EnM	Energy Management
SCM	Supply chain management

References

1. May, G.; Stahl, B.; Taisch, M.; Kiritsis, D. Energy Management in Manufacturing: From Literature Review to a Conceptual Framework. *J. Clean. Prod.* **2017**, *167*, 1464–1489. [CrossRef]
2. Marchi, B.; Zanoni, S.; Ferretti, I.; Zavanella, L. Stimulating Investments in Energy Efficiency Through Supply Chain Integration. *Energies* **2018**, *11*, 858. [CrossRef]
3. Lawrence, A.; Nehler, T.; Andersson, E.; Karlsson, M.; Thollander, P. Drivers, Barriers and Success Factors for Energy Management in the Swedish Pulp and Paper Industry. *J. Clean. Prod.* **2019**, *223*, 67–82. [CrossRef]
4. Eurostat Final Energy Consumption in Industry—Detailed Statistics. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics (accessed on 15 April 2025).
5. International Energy Agency (IEA) Industry Tracking. Available online: https://www.iea.org/energy-system/industry#tracking (accessed on 15 April 2025).
6. Martin-Valmayor, M.A.; Gil-Alana, L.A.; Infante, J. Energy Prices in Europe. Evid. Persistence Across Markets. *Resour. Policy* **2023**, *82*, 103546. [CrossRef]
7. Fan, Y.; Chang, T.; Ranjbar, O. Analyzing the Degree Persistence of Shocks to Energy Security of the G7 Countries: Evidence Using Panel SPSM-Quantile Unit Root Test. *Econ. Anal. Policy* **2024**, *82*, 389–399. [CrossRef]
8. European Commission (EC) Energy Efficiency Directive. Available online: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en (accessed on 15 April 2025).

9. International Energy Agency (IEA) What Does Doubling Global Progress on Energy Efficiency Entail? Available online: https://www.iea.org/reports/energy-efficiency-2023/what-does-doubling-global-progress-on-energy-efficiency-entail (accessed on 15 April 2025).
10. Renna, P.; Materi, S. A Literature Review of Energy Efficiency and Sustainability in Manufacturing Systems. *Appl. Sci.* **2021**, *11*, 7366. [CrossRef]
11. Lintukangas, K.; Arminen, H.; Kähkönen, A.K.; Karttunen, E. Determinants of Supply Chain Engagement in Carbon Management. *J. Bus. Ethics* **2023**, *186*, 87–104. [CrossRef]
12. Johansson, M.T.; Thollander, P. A Review of Barriers to and Driving Forces for Improved Energy Efficiency in Swedish Industry—Recommendations for Successful in-House Energy Management. *Renew. Sustain. Energy Rev.* **2018**, *82*, 618–628. [CrossRef]
13. Lee, K.H. Drivers and Barriers to Energy Efficiency Management for Sustainable Development. *Sustain. Dev.* **2015**, *23*, 16–25. [CrossRef]
14. Schulze, M.; Nehler, H.; Ottosson, M.; Thollander, P. Energy Management in Industry—A Systematic Review of Previous Findings and an Integrative Conceptual Framework. *J. Clean. Prod.* **2016**, *112*, 3692–3708. [CrossRef]
15. Mahi, M.; Ismail, I.; Phoong, S.W.; Isa, C.R. Mapping Trends and Knowledge Structure of Energy Efficiency Research: What We Know and Where We Are Going. *Environ. Sci. Pollut. Res.* **2021**, *28*, 35327–35345. [CrossRef] [PubMed]
16. Backlund, S.; Thollander, P.; Palm, J.; Ottosson, M. Extending the Energy Efficiency Gap. *Energy Policy* **2012**, *51*, 392–396. [CrossRef]
17. Hasan, A.S.M.M.; Tuhin, R.A.; Ullah, M.; Sakib, T.H.; Thollander, P.; Trianni, A. A Comprehensive Investigation of Energy Management Practices within Energy Intensive Industries in Bangladesh. *Energy* **2021**, *232*, 120932. [CrossRef]
18. Schulze, M.; Heidenreich, S.; Spieth, P. The Impact of Energy Management Control Systems on Energy Efficiency in the German Manufacturing Industry. *J. Ind. Ecol.* **2018**, *22*, 813–826. [CrossRef]
19. Jalo, N.; Johansson, I.; Andrei, M.; Nehler, T.; Thollander, P. Barriers to and Drivers of Energy Management in Swedish SMEs. *Energies* **2021**, *14*, 6925. [CrossRef]
20. Ahmad, I.; Arif, M.S.; Cheema, I.I.; Thollander, P.; Khan, M.A. Drivers and Barriers for Efficient Energy Management Practices in Energy-Intensive Industries: A Case-Study of Iron and Steel Sector. *Sustainability* **2020**, *12*, 7703. [CrossRef]
21. Wang, Y.; Hao, Y.; Hou, Y.; Quan, Q.; Li, Y. Optimizing Scope 3 Emissions in the Automotive Manufacturing Industry: A Multidisciplinary Approach. *Carbon Res.* **2024**, *3*, 49. [CrossRef]
22. Meinrenken, C.J.; Chen, D.; Esparza, R.A.; Iyer, V.; Paridis, S.P.; Prasad, A.; Whillas, E. Carbon Emissions Embodied in Product Value Chains and the Role of Life Cycle Assessment in Curbing Them. *Sci. Rep.* **2020**, *10*, 6184. [CrossRef] [PubMed]
23. CDP Transparency to Transformation: A Chain Reaction. 2020. Available online: https://www.env.go.jp/earth/ondanka/supply_chain/gvc/files/dms_trends/20210311_1_CDP_Dexter_Galvin.pdf (accessed on 15 April 2025).
24. Stenzel, A.; Waichman, I. Supply-Chain Data Sharing for Scope 3 Emissions. *npj Clim. Action* **2023**, *2*, 7. [CrossRef]
25. European Commission (EC) Corporate Sustainability Due Diligence. Available online: https://commission.europa.eu/topics/business-and-industry/company-law-and-corporate-governance/corporate-sustainability-due-diligence_en (accessed on 5 September 2026).
26. European Commission (EC) Corporate Sustainability Reporting. Available online: https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en (accessed on 4 March 2026).
27. Ellram, L.M.; Tate, W.L. Impact Pathways: A Call for Impactful Research in Supply Chain GHG Emissions Reduction. *Int. J. Oper. Prod. Manag.* **2024**, *45*, 236–245. [CrossRef]
28. World Economic Forum (WEF). Supply Chain Sustainability Is Key to Achieving Climate Goals: Here's How Organizations Can Get Started. Available online: https://www.weforum.org/stories/2023/04/why-supply-chain-sustainability-key-to-achieving-climate-goals/ (accessed on 15 April 2025).
29. Steiner, B.; Münch, C.; Beckmann, M.; von der Gracht, H. Developing Net-Zero Carbon Supply Chains in the European Manufacturing Industry—A Multilevel Perspective. *Supply Chain. Manag. Int. J.* **2024**, *29*, 164–181. [CrossRef]
30. Cagno, E.; Trianni, A.; Spallina, G.; Marchesani, F. Drivers for Energy Efficiency and Their Effect on Barriers: Empirical Evidence from Italian Manufacturing Enterprises. *Energy Effic.* **2017**, *10*, 855–869. [CrossRef]
31. Uchendu, C.; Okorie, O.; Khosravi, F.; Connop, S.; Haddad, H.; Medas, M. What Do We Know About Scope 3 Emissions in Small- and Medium-Sized Enterprises? Mapping Current Knowledge and Advancing a Theory–Practice-Oriented Framework. *Bus. Strategy Environ.* **2026**, 1–28, *ahead of print*. [CrossRef]
32. Xavier, B.M.; Thollander, P.; Hilletofth, P.; Johansson, M. Exploring Energy Management Integration into Upstream Supply Chains: A Systematic Literature Review. *Front. Energy Res.* **2024**, *12*, 1425795. [CrossRef]
33. Marchi, B.; Zanoni, S. Supply Chain Management for Improved Energy Efficiency: Review and Opportunities. *Energies* **2017**, *10*, 1618. [CrossRef]

34. Zanoni, S.; Marchi, B.; Ferretti, I.; Zavanella, L.E. CHAIN-EE: A Collaborative Holistic Framework for Supply Chain Energy Efficiency Diagnosis, Investments Prioritisation, and Governance. *Energies* **2026**, *19*, 3455. [CrossRef]
35. Beheshtinia, M.A.; Fathi, M. Energy-efficient and Sustainable Supply Chain in the Manufacturing Industry. *Energy Sci. Eng.* **2023**, *11*, 357–382. [CrossRef]
36. Liu, J.; Li, Y.; Ma, Y.; Qin, R.; Meng, X.; Wu, J. Coordinated Energy Management for Integrated Energy System Incorporating Multiple Flexibility Measures of Supply and Demand Sides: A Deep Reinforcement Learning Approach. *Energy Convers. Manag.* **2023**, *297*, 117728. [CrossRef]
37. Tian, Y.; Ou, L.; Guo, J.; Chen, Z.S.; Chen, Z. A Configuration of Green and Low-Carbon Strategy in Clean Energy Economy: A Perspective of Supply Chain Management. *Energy* **2025**, *322*, 135642. [CrossRef]
38. Wu, C.; Xu, X.; Barnes, D.; Qi, Z. Sustainable Energy Supplier Selection in Turbulent Environments: A Multi-Stage DEA-Malmquist Based Dynamic 3D-Kraljic Model. *Energy* **2026**, *344*, 140036. [CrossRef]
39. Masoomi, B.; Sahebi, I.G.; Fathi, M.; Yıldırım, F.; Ghorbani, S. Strategic Supplier Selection for Renewable Energy Supply Chain under Green Capabilities (Fuzzy BWM-WASPAS-COPRAS Approach). *Energy Strategy Rev.* **2022**, *40*, 100815. [CrossRef]
40. Sahoo, S.K.; Goswami, S.S. Green Supplier Selection Using MCDM: A Comprehensive Review of Recent Studies. *Spectr. Eng. Manag. Sci.* **2024**, *2*, 1–16. [CrossRef]
41. Chen, Y.; Chung, W. Sustainable Supplier Selection with Multidimensional Overlapping Criteria under Carbon Neutrality. *Ind. Manag. Data Syst.* **2023**, *123*, 2607–2630. [CrossRef]
42. Andrei, M.; Thollander, P.; Sannö, A. Knowledge Demands for Energy Management in Manufacturing Industry—A Systematic Literature Review. *Renew. Sustain. Energy Rev.* **2022**, *159*, 112168. [CrossRef]
43. May, G.; Barletta, I.; Stahl, B.; Taisch, M. Energy Management in Production: A Novel Method to Develop Key Performance Indicators for Improving Energy Efficiency. *Appl. Energy* **2015**, *149*, 46–61. [CrossRef]
44. *ISO 50001*; Energy Management Systems. International Organization for Standardization (ISO): Geneva, Switzerland, 2011. Available online: https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100400.pdf (accessed on 28 April 2025).
45. Hueske, A.K.; Guenther, E. Multilevel Barrier and Driver Analysis to Improve Sustainability Implementation Strategies: Towards Sustainable Operations in Institutions of Higher Education. *J. Clean. Prod.* **2021**, *291*, 125899. [CrossRef]
46. Walker, H.; Di Sisto, L.; McBain, D. Drivers and Barriers to Environmental Supply Chain Management Practices: Lessons from the Public and Private Sectors. *J. Purch. Supply Manag.* **2008**, *14*, 69–85. [CrossRef]
47. Cagno, E.; Worrell, E.; Trianni, A.; Pugliese, G. A Novel Approach for Barriers to Industrial Energy Efficiency. *Renew. Sustain. Energy Rev.* **2013**, *19*, 290–308. [CrossRef]
48. Blass, V.; Corbett, C.J.; Delmas, M.A.; Muthulingam, S. Top Management and the Adoption of Energy Efficiency Practices: Evidence from Small and Medium-Sized Manufacturing Firms in the US. *Energy* **2014**, *65*, 560–571. [CrossRef]
49. Zimon, D.; Jurgilewicz, M.; Ruszel, M. Influence of Implementation of the ISO 50001 Requirements on Performance of SSCM. *Int. J. Qual. Res.* **2021**, *15*, 713–726. [CrossRef]
50. Farsan, A.; Chang, A.; Kerkhof, A.; Cserna, B.; Yan, C.; Rangel Villasana, F.; Labutong, N.; Ketelaar, B.; Van Petersen, D.; De Haan, F.; et al. *Value Change in the Value Chain: Best Practices in Scope 3 Greenhouse Gas Management*; Science Based Targets Initiative: London, UK, 2018.
51. Schützenhofer, C. Overcoming the Efficiency Gap: Energy Management as a Means for Overcoming Barriers to Energy Efficiency, Empirical Support in the Case of Austrian Large Firms. *Energy Effic.* **2021**, *14*, 45. [CrossRef]
52. Fagundes Alves, M.Y.; Marques Vieira, L.; Beal Partyka, R. Suppliers' GHG Mitigation Strategies (Scope 3): The Case of a Steelmaking Company. *J. Manuf. Technol. Manag.* **2024**, *35*, 383–402. [CrossRef]
53. Centobelli, P.; Cerchione, R.; Esposito, E. Environmental Sustainability and Energy-Efficient Supply Chain Management: A Review of Research Trends and Proposed Guidelines. *Energies* **2018**, *11*, 275. [CrossRef]
54. Ghosh, S.; Singh, J. Eliciting Supplier Cooperation for Value Chain Decarbonization: A Field Experiment with Smallholder Farmers in India. *Manag. Sci.* **2026**, *ahead of print*. [CrossRef]
55. Hilmola, O.P.; Fobbe, L.; von Haartman, R.; Hilletofth, P. Energy Efficiency of Manufacturing Supply Chains: Swedish Survey Findings. *Front. Energy Res.* **2025**, *13*, 1619417. [CrossRef]
56. Xavier, B.M.; Andrei, M.; Thollander, P.; Johansson, M. Integrating Energy Management into Supplier Performance Assessment: Challenges and Opportunities in Buyer–Supplier Relationships. *Clean. Logist. Supply Chain.* **2026**, *19*, 100331. [CrossRef]
57. Zhang, A.; Alvi, M.F.; Gong, Y.; Wang, J.X. Overcoming Barriers to Supply Chain Decarbonization: Case Studies of First Movers. *Resour. Conserv. Recycl.* **2022**, *186*, 106536. [CrossRef]
58. Genovese, A.; Lenny Koh, S.C.; Bruno, G.; Esposito, E. Greener Supplier Selection: State of the Art and Some Empirical Evidence. *Int. J. Prod. Res.* **2013**, *51*, 2868–2886. [CrossRef]
59. De Boer, L.; Labro, E.; Morlacchi, P. A Review of Methods Supporting Supplier Selection. *Eur. J. Purch. Supply Manag.* **2001**, *7*, 75–89. [CrossRef]

60. Wetzstein, A.; Hartmann, E.; Benton, W.C.; Hohenstein, N.O. A Systematic Assessment of Supplier Selection Literature—State-of-the-Art and Future Scope. *Int. J. Prod. Econ.* **2016**, *182*, 304–323. [CrossRef]
61. Swedish Energy Agency (SEA) Statistics—Sweden´s Energy Supply and Consumption during a Year. Available online: https://www.energimyndigheten.se/en/facts-and-figures/statistics/ (accessed on 28 April 2025).
62. Rohdin, P.; Thollander, P.; Solding, P. Barriers to and Drivers for Energy Efficiency in the Swedish Foundry Industry. *Energy Policy* **2007**, *35*, 672–677. [CrossRef]
63. Khan, S.A.; Kusi-Sarpong, S.; Arhin, F.K.; Kusi-Sarpong, H. Supplier Sustainability Performance Evaluation and Selection: A Framework and Methodology. *J. Clean. Prod.* **2018**, *205*, 964–979. [CrossRef]
64. Forza, C. Survey Research in Operations Management: A Process-Based Perspective. *Int. J. Oper. Prod. Manag.* **2002**, *22*, 152–194. [CrossRef]
65. Sveriges Riksdag Lag (2014:266). Om Energikartläggning i Stora Företag. Available online: https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/lag-2014266-om-energikartlaggning-i-stora_sfs-2014-266/ (accessed on 3 April 2025).
66. Jazairy, A.; von Haartman, R. Measuring the Gaps between Shippers and Logistics Service Providers on Green Logistics throughout the Logistics Purchasing Process. *Int. J. Phys. Distrib. Logist. Manag.* **2020**, *51*, 25–47. [CrossRef]
67. Tehseen, S.; Ramayah, T.; Sajilan, S. Testing and Controlling for Common Method Variance: A Review of Available Methods. *J. Manag. Sci.* **2017**, *4*, 142–168. [CrossRef]
68. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Lawrence Erlbaum Associates: Hillsdale, NJ, USA, 1988.
69. Carbon Trust Energy Management Self-Assessment Tool. Available online: https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/energy-management-self-assessment-tool (accessed on 9 June 2025).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.