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Review

Drivers, Barriers, and Success Factors for Improving Energy Management in the Pulp and Paper Industry

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Abstract: Successful energy management is a way to achieve energy efficiency in the pulp and paper industry (PPI), which is important for assuring energy supply security, for increasing economic competitiveness, and for mitigating greenhouse gases. However, research shows that although energy use within PPI can be reduced by 5.5–19.4% per year, some of this by energy management practices, energy management is not always implemented. Why is this so? What are the barriers to, and drivers of implementation? How can the barriers be overcome? A systematic review of barriers and drivers in energy management in the PPI within peer-reviewed scientific articles suggests that the world-wide events that affect energy supply, volatility, and use seemingly also affect the number and frequency of research articles on energy management in the PPI. The perception of energy management in the PPI seems to be dominated by the understanding that it can mostly be achieved through technological improvements aiming to improve energy efficiency. The main driver of energy management was shown to be economic conditions: high and unstable energy prices, followed by drivers such as the need to remain internationally competitive, collaboration and energy management systems. Meanwhile, examples of the most important barriers are technical risks, lack of access to capital, lack of time and other priorities, and slim organization. The success factors for enhancing drivers and overcoming barriers were continuous energy accounting, energy-related collaboration, energy-efficiency programmes, and benchmarking. Altogether, success factors for energy management for improved energy efficiency could be summarized in the 4M framework—the "4M for energy efficiency": mind, measure, monitor, and manage—that could be used as the energy management memory-tool that could lead to improved energy efficiency in other sectors as well.

Keywords: energy management; energy efficiency; pulp and paper industry; barriers; drivers; ISO 50001; success factors

1. Introduction

Nowadays, the pulp and paper industry (PPI) is dependent on energy efficiency (EE) not only for profitability but also as a necessity for assuring energy supply security, for increasing economic competitiveness, and for mitigating greenhouse gases. Furthermore, the PPI must eventually find a sustainable energy source as an alternative to fossil-fuel-based energy sources. Successful energy management (EnM) is a way to increase EE. Even so, EnM is still not fully implemented. Indeed, research has demonstrated the existence of an energy-efficiency gap—the difference between the EE that could be achieved theoretically and the actual EE [1]—and that some of this gap can be reduced by EnM practices ([2,3]). Research also presents the means for minimizing this gap by summarizing and describing the methods and technology for making use of energy more efficiently. Thus, key questions are as follows: why do firms not always implement profitable investments in energy-saving technology and methodology, thus becoming more energy efficient? In particular, why is EnM not used to its full extent?

Various barriers, for example, split incentives and imperfect information, could be among the reasons for the EE gap [1]. A further explanation could be the difference between the perception of how EnM is best practised for improving EE and which EnM practices actually do improve EE. Otherwise stated, this inaccurate perception of EnM can by itself be the driver or barrier to EnM for improved EE.

The PPI is the fourth largest industrial consumer of energy globally, with 5% of total industrial energy use, and accounts for 2% of global CO_2 emissions from industry [4]. Additionally, energy reduction in the PPI is important, since energy costs in the sector account for more than 10% of production costs [5], for example, the major costs in the Austrian paper industry are raw materials (40%), labour (20%), and energy (15%) [6], whereas energy costs were >25% in Indian PPI [7]. In some countries, for example, in Sweden, PPI is the major user of total energy used by industry and uses ~52% of the total industrial energy use [8]. The amount of energy that is used for producing a product—specific energy use—is a measure that is often referred to in literature as specific energy consumption (SEC). SEC varies, not only with the type of the mill, but also depending on the purpose of the intended comparison, for example, energy used per product sold or per product produced [9]. Despite the differences, SEC is a useful measure for comparing the changes in specific energy use, providing it is calculated in the same way, and it is often used for evaluating the EE in industry, such as in the PPI [10]. For example, by comparing SEC, Bajpai [7] showed that SEC in 2009 in the Indian PPI has decreased by ~22% compared to SEC in 2002 and ~33% compared to SEC in 1987, but is still ~43% higher than SEC that could be achieved by using the best available technology. Likewise, comparison of SEC in the Swedish PPI showed that SEC in the majority of the Swedish pulp and paper mills was fluctuating at about the same numeric value during the period 2006–2015 [9]. Hence, these studies yet again indicate that the EnM for EE could be improved and thus the EE gap could be decreased.

Furthermore, there is an increasing trend in production in the industry. For example, global paper and paperboard production increased by 50% between 1990 and 2006 [11]. However, this varies with country. The greatest increase in paper and paperboard production is in China—from 7 to 16% of the global production of paper and paperboard—whereas the share of paper and paperboard production in some other countries has fallen, for example, the USA, Japan, and Canada [11]. Continent-wise, the biggest producers of pulp were North America, Europe, and Asia (Figure 1a) [12], whereas the biggest producers of paper were Asia, Europe and North America (Figure 1b) [12]. Thus, the economic situation of the PPI located in traditional manufacturing countries has been uncertain for some time because of competition with PPI in countries with abundant resources, low manufacturing costs, and large newly established production facilities [13]. Consequently, the PPI situated in the traditional manufacturing countries has been forced to seek alternatives so that it can convert to being sustainable and profitable. Hence, re-evaluation is ongoing not only of production processes, for example, renewable resources and EE, but also of product ranges, for example, diversification of product mix. Here, successful EnM is one of the means used to achieve a sustainable PPI.

Research shows that energy usage can theoretically be reduced by 5.5–19.4% per year (Table 1), meaning that there is a difference between the EE that could be achieved theoretically and cost-effectively by utilizing all available energy-effective technologies and the actual EE, referred to as an energy-efficiency gap ([1,14]). Another study showed that reducing energy use caused profits to increase between 10% and 50% [15]. Additionally, empirical research has shown that if, in addition to cost-effective technologies being utilized, proactive EnM is also performed, then energy usage can be reduced still further. The latter is referred to as an extending energy-efficiency gap [2], also known as the energy-management gap [16].

Table 1. Selection of percentages of energy predicted to potentially be saved within the pulp and paper industry (PPI) based on results found in peer-reviewed articles published later than 2010.

Total Amount of Energy That Could Potentially Be Saved (%/year)	Examples of Means with Highest Potential for Energy Saving	Method That Identified the Potential for Saving Energy Use	Geographical Coverage	Studied Objects	Reference
19.4 *	Mostly by using more energy-efficient technologies in heat recovery in paper mills and paper drying section.	Techno-economic modelling.	Germany	PPI	[5]
7.4 *	Improving equipment efficiency and energy distribution.	The energy flow analysis that was based on the energy footprint model.	Taiwan	PPI	[17]
14.4	Retrofit low-efficiency boilers, improve press performance by switching to shoe press, implement heat recovery from the dryer section in a paper machine.	Audit.	China	Paper mill	[18]
15	EE improvement in the wire and press and in the drying sections.	Benchmarking of SEC of similar processes on detailed process level in 23 different Dutch paper mills.	The Netherlands	Paper mills	[19]
5.5–7.2 *	Technology upgrading by substantially increasing the level of Research and Development activities, application of taxes proportional to the consumption of energy, reducing the number of production units and increasing profits.	Co-integration model using historical data over the period 1985–2010 to test three scenarios up to 2025.	China	Paper industry	[20]

"*"—marks numbers calculated using data in the respective references.

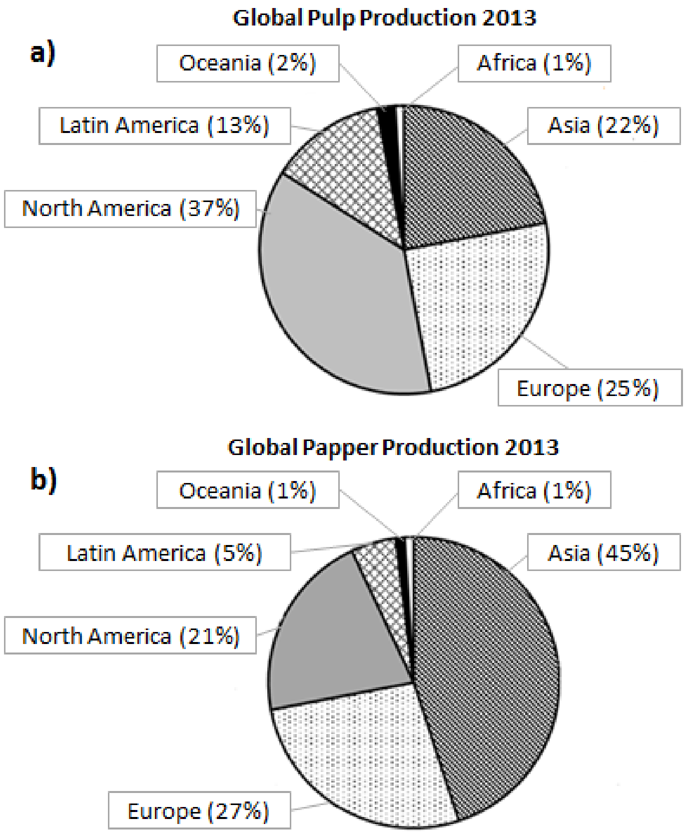

Figure 1. Global production 2013 of: (**a**) pulp [12] and (**b**) paper [12].

EnM can be defined as procedures for strategic work on energy [16]. This summarizes several definitions of EnM in the literature, some of which were presented by Schulze et al. [21]. Generally, EnM can be done via (i) management, (ii) technology, and (iii) policies/regulations ([18,22]). Note that the term "energy management" is often used instead of or interchangeably with "energy management system", which refers to the tools for implementing the procedures of EnM [16]. Nevertheless, the common perception that an "Energy management system" and "Energy management" are the same was disaggregated by several research studies (e.g., [16,23,24]). EnM practices, that is, good energy housekeeping in industry, could save 10–15% of the total energy used [25]. Specifically, research has shown that the potential for reducing energy use in energy-intensive Swedish firms was evaluated to be 18%: a 5% reduction in current energy use by energy-efficient technologies and 13% by improved EnM practices [26]. Nevertheless, most of the research on EnM for improving EE in PPI has focused on EE improvements via technology (e.g., [27–29]).

As summarised by Bajpai [7], examples of technological factors that affect EnM and influence the EE achieved are technology and processes used, plants size and location, technical age of the mill, utilization rate of the plant capacity, and integration level. Technological factors itself depend on factors such as the used product mix, feedstock quality, fuel prices, climate conditions and level of management attention to EE.

Examples of research addressing the possibilities for improving EE via improvements in technology in the PPI are several and of varying scope. Some studies have focused on specific niche solutions potentially leading to improved EE, for example, EE improvements in dryer-section heat recovery systems in paper machines have led to a 7–13% decrease in the specific heat use [27]. Other studies have focused on broader solutions involving several actors within a small geographical area. For example, raw materials and energy could be saved by integrating the processes of a Kraft pulp and paper mill with its supply chain into an integrated industrial site with a shared heat and power utility [28]. Yet another study suggested taking advantage of the possibility to benchmark with the best available technologies internationally and showed that such benchmarking could improve the EE of pulping in Taiwan by 33% if the best available technologies were applied [29].

Proactively EnM could be helped by the newest international EnM standard, ISO 50001:2011, intended to enable all types and sizes of organizations to establish the systems and processes aiming to improve energy performance [30]. ISO 50001:2011 is the latest standard for EnM that was constructed using as a base the earlier EnM standards: the Swedish standard SS 627750:2004, the European EN 16001:2009, quality management standard ISO9001, and environmental management standard ISO14001 [31]. For enabling easier adaptation, ISO 50001 is based on the common elements of ISO management systems standards compatible notably with quality standard ISO 9001:2008 and environmental standard ISO 14001:2004 [30]. There were 11985 certificates of ISO 50001 in the world, whereof 10152 were in Europe, until the end of 2015 [32]. ISO 50001 claims to have delivered current energy costs' savings of 5–30% during the first five years of its existence where even organizations with mature EE programs can still save 10% or more after using ISO 50001 [33]. Research has already addressed some aspects of ISO 50001 standard. For example, reasons to adopt ISO 50001 EnMS [34] include the possibility for using the certification including ISO 50001 as a tool to develop sustainability in project management [35], the methodology for successful integration of ISO 50001 into an operational environmental system ISO 14001 [36], and the contribution of ISO 14001 and Eco-Management and Audit Scheme (EMAS) to ISO 50001 [37]. A model for surpassing the ISO 50001 certification requirement and helping to achieve superior performance has also been proposed [38]. Nevertheless, no research study has yet identified what parts of ISO 50001 have been addressed by research on EnM, neither in PPI nor in industry generally.

Comprehensive research on barriers to and drivers of the energy-efficiency gap, and various means to overcome these barriers in industry generally, was presented by Thollander and Palm [16]. Some types of barriers, as classified by Sorrell et al. [39], have been studied (e.g., [14,40]). These are structural and market barriers, for example, distortions and uncertainties concerning energy carriers and limited access to capital; and behavioural barriers, for example, attitudes towards EE, the perceived risk of energy-efficiency investments, misplaced incentives and information gaps (e.g., [14,40]). Regarding the PPI, barriers and drivers for cost-effective EE investments within the Swedish PPI generally have been thoroughly elucidated by Thollander and Ottosson [40]. In the study by Cagno et al. [41], perceptions of what constitute the major drivers and barriers for EE were shown to differ among different actors, that is, among enterprises and the major actors promoting EE. Outsourcing of EnM is seen as a promising means of deploying EE in industry and the European Energy Services and EE Directive from 2006 addressed energy services as a promising means for the EU to overcome barriers and improve EE [42]. In one study within the European foundry industry [43], energy services were seen to have reached some level of deployment, even though this was not large. About one fourth of the studied companies had used Energy Performance Contracting. In a qualitative study by Thollander and Ottosson [42], covering PPI, it is stated that energy services are likely to be more attractive to those parts of production in PPI where production processes have lower integration of energy. Furthermore, an "actor oriented approach" where the perspectives of different actors, for example, private companies and governmental organizations, on the drivers of and barriers to EE was presented by [44]. Additionally, Thollander and Palm [23] pointed out the difficulty of finding a single EnM solution suitable for all companies and, thus, the need to find a reflexive EnM model that can be adjusted. However, as far as we currently know, there are no studies addressing perceptions of EnM in the PPI, no studies addressing drivers of and barriers to EnM, and no studies addressing the success factors for encouraging the drivers and overcoming the barriers to EnM for EE in the PPI.

There is an extensive systematic review regarding EnM in industry generally, including the PPI, by Schulze et al. [21]. Regarding EnM in the PPI alone, there are three comprehensive reviews ([45–47]) that address technical solutions for increasing EE and the advantages that EE brings. An overview of EE practices in the PPI based on the US Environmental Protection Agency's energy star guidelines

(US EPA ENERGY STAR®) [45] described the energy-efficient technologies that can be implemented at various levels (i.e., component, process, facility, organizational). Additionally, US EPA ENERGY STAR® [45] presented the major processing technologies in use and described trends, structures, and energy use in the US PPI. Although this review was directed towards the US PPI, it is based on real case-study data from the PPI worldwide, thus making it beneficial in other countries too. Another study presented an energy overview of a conceptual possibility to integrate a green-forest biorefinery into a Kraft mill for a variety of products, for example, ethanol, lignin, heat and power, and so on [46]. Additionally, emerging but not yet fully commercialized energy-efficient technologies were compiled and presented [47]. However, according to our current knowledge, based on the results of this search, a comprehensive systematic review concerning EnM within the PPI alone is absent.

Thus, the primary research problem requiring a solution is to identify, describe, and synthesize the currently reported knowledge in scientific peer-reviewed articles on drivers of, barriers to, and success factors for EnM for improving EE in the PPI. This aim is to be achieved by answering the following questions:

1. What do studies addressing EnM in the PPI describe?
2. What is the perception of EnM in the PPI?
3. What is the current state of knowledge about barriers to and drivers of EnM in the PPI?
4. What are the known success factors for overcoming barriers and encouraging drivers for EnM in the PPI?

2. Method

This study is of an exploratory nature, because there is no knowledge yet synthesised and published on what has been published when primarily addressing the EnM in the PPI, meaning that the research-gap on EnM in the PPI is yet to be explored. According to Yin [48], exploratory research is to be preferred when such research is to be carried out, because of its objectiveness. Hence, the main research aim and research questions were formulated instead of hypotheses, because of the exploratory nature of this systematic review. This systematic review is exploratory, where answers were searched for in all the scientific articles that have fulfilled the chosen search criteria rather than formulating the null hypothesis and the alternative hypothesis and then conducting appropriate statistical tests in an attempt to reject the null-hypothesis in favour of the alternative hypothesis. Otherwise stated, there is no knowledge yet synthesised and published on what has been published when primarily addressing the EnM in the PPI that could be used as basis for formulating the null hypothesis and the alternative hypothesis.

Thus, the aim was achieved by conducting a systematic review, since systematic reviews allow the achievement of results that are generalizable to other contexts and reduce personal biases [49], which is advantageous compared to reviews using more sensitive to subjectivity techniques, for example, the "snowball" technique. The advantage of the systematic review is that answers to chosen research questions are extracted from all the articles that fulfilled the chosen search criteria, thus minimizing personal biases and subjectivity. Hence, generalizations were made and conclusions were drawn based on the content of all the articles that fulfilled the search criteria. The suitability of the systematic review to management and organizational studies was first described by Tranfield et al. [49] and the approach was used for EnM in industry by Schulze et al. [21].

The main goal of this systematic review was to identify drivers of, barriers to, and success factors for EnM for improvement of EE in PPI by conducting a systematic review of research articles focusing primarily on "Energy management" and/or "energy management systems" in PPI. This means that the goal was not to track articles considering industries overall, whereof PPI could be one of those industries. Hence, articles that did not fulfill the search criteria of this systematic review were not included. Namely, articles that have addressed EnM primarily in various manufacturing sectors, but included pulp and/or paper manufacturing industry among the studied industries were not considered in this systematic review as this systematic review is exploratory, where answers were searched for in all the scientific articles that have fulfilled the chosen search criteria. Hence, for example, the study by Jovanović et al. [50], where the manufacture of paper and paper products was among the studied manufacturing sectors for EnM improvement, and the study by Ates and Durakbasa [51], where the paper industry was among the studied industries for the evaluation of corporate EnM practices, were not included in this systematic review. Some of the articles that primarily focused on other aims than EnM and/or EnM in PPI, possibly did not come up in the list because of not fulfilling the search criteria. For example, a study by Prachar [52] that primarily aimed to develop an EnMS for small and medium-sized enterprises (SMEs), but that happened to select and use a small-sized paper mill as a case study for validation of the developed EnMS, did not come up in the list.

The General Workflow that was used for conducting the systematic review on EnM within the PPI is summarized in Figure 2. Four databases were used for the literature search: Web of Science, Science Direct, Scopus and UniSearch (Linköping University Library's discover system). To begin with, an attempt was made to identify drivers of and barriers to EnM in PPI by using more specific search strings adding to "Energy management" and "Energy management systems", strings like "driver" and/or "barrier" or synonyms such as "challenge" instead of "barrier" (21 search strings in total), for example, "Energy management systems" AND "pulp and paper industry" AND "barriers" AND "drivers". However, the inclusion of more specific search-strings gave no results or fewer results than "Energy management systems" and/or "Energy management" in "pulp and paper industry". An assumption has been made that most important for identifying drivers of, barriers to and success factors for EnM in PPI are the articles that primarily addressed "Energy management" and/or "Energy management systems" in PPI. Additionally, other aspects that could have affected EnM and/or EnM systems such as certification according to ISO 14001 have been excluded, since most of the studies on ISO 14001 primarily focused on other issues than the effects on issues related to EnM and use. In fact, to the authors knowledge, there was only one study so far that addressed the effects of environmental management systems and suggested that ISO 14001 has contributed to improving EnM and EE, showing that ISO 14001 use and certification has increased EE of fossil fuel use, but did not affect electricity use in industry [53]. Hence, two search strings were chosen to identify the list of articles of interest: string (a) "Energy management systems" AND "pulp and paper industry", string (b) "Energy management" AND "pulp and paper industry". These gave a total of 515 articles. These articles were further sorted by reading the titles, keywords, and abstracts. As a result, 39 articles were identified as dealing with EnM issues within the PPI. A table listing the scientific articles used for this review is given in the Appendix A (Table A1 in the Appendix A). The table summarizes findings by presenting authors and year of individual references, journal, type of study, geographical coverage, studied objects, and categories. Results were limited to only scientific articles in English which were available in full text; reports, publications within conference proceedings, and so on were excluded. We searched for scientific articles published from 1979 onwards, since that year is considered to be a turning point for global awareness of energy related issues and thus is when EnM activities in industry began [21].

Afterwards, our research questions were answered as follows:

- The first research question: "What do studies addressing EnM in the PPI describe?" This was answered by analysing the selected articles descriptively: (a) "Geographical coverage" and year of publication; (b) "Studied objects" by identifying whether the PPI was studied as a whole or in parts in the selected articles; (c) "Quantitative vs. qualitative" by assigning as "qualitative" those studies that focused more on answering the question "why?" rather than more descriptive questions, for example, "how?" "what?", "where?" "when?" and "who?", which we considered "quantitative". Furthermore, articles were evaluated as to whether or not the dominant orientation was towards EnM via technology.
- The second research question: "What is the perception of EnM in the PPI?" was answered by reading the selected articles and categorizing them according to

- ○ the type of study: whether they were more qualitative or quantitative,
- ○ whether they had a technical or non-technical orientation,
- ○ which areas within the ISO 50001 EnM systems were addressed,
- ○ which categories of research focus were described in comparison to categories of research areas in industry generally: (1) strategy/planning; (2) implementation/operation; (3) controlling; (4) organization and (5) culture [14].

- The third research question: "What is the current state of knowledge about barriers to and drivers of EnM in the PPI?" was answered by reading the articles and searching for the terms "barriers", "drivers", and "driving forces" in them. The results are presented in Section 3.3.
- The fourth research question: "What are the known success factors for overcoming the barriers and encouraging drivers for EnM in the PPI?" was answered by reading through the selected articles, and the results are presented in Section 3.4.

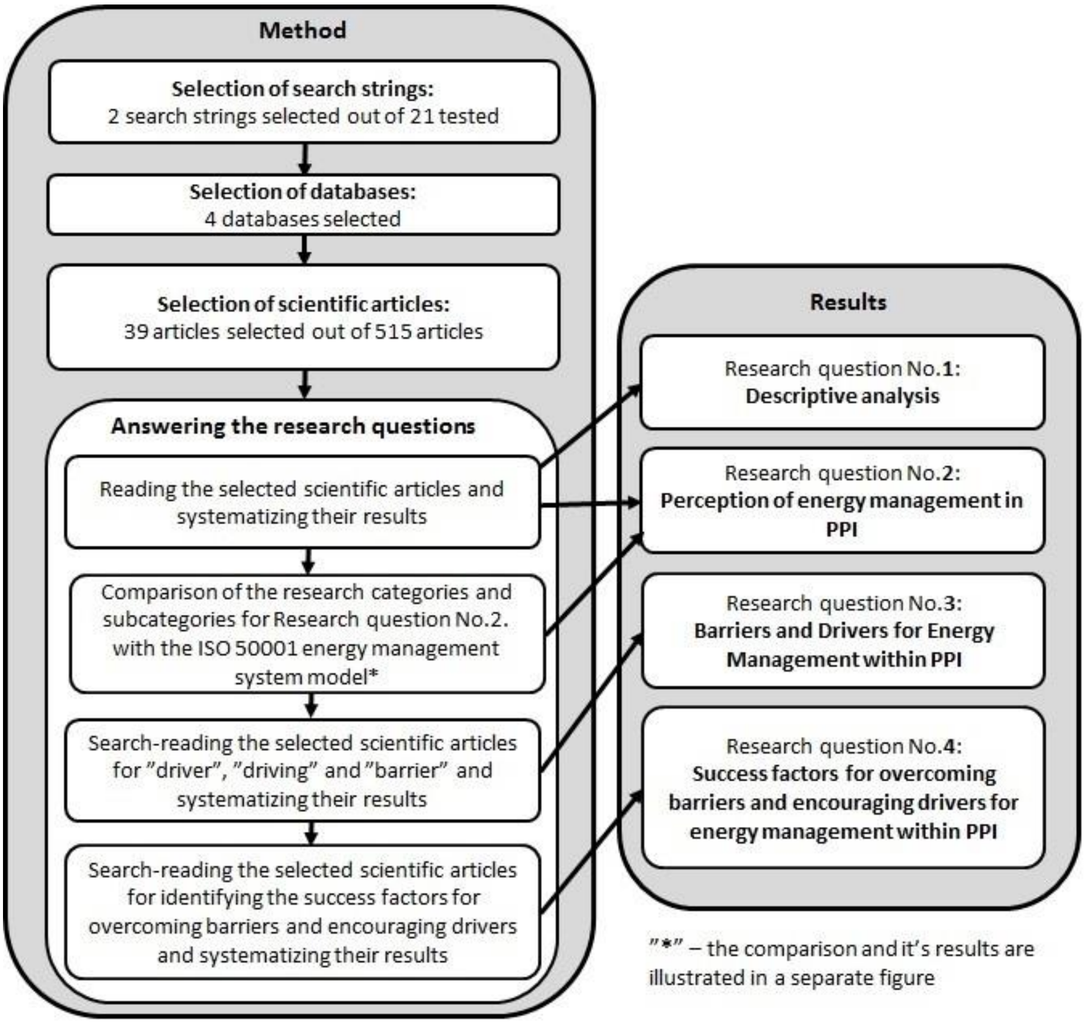

Figure 2. The General Workflow that was used for conducting the systematic review on energy management within the PPI.

3. Results

A summary of the results of our systematic review on EnM within the PPI is presented in Figure 3 and described in detail in Section 3 as follows.

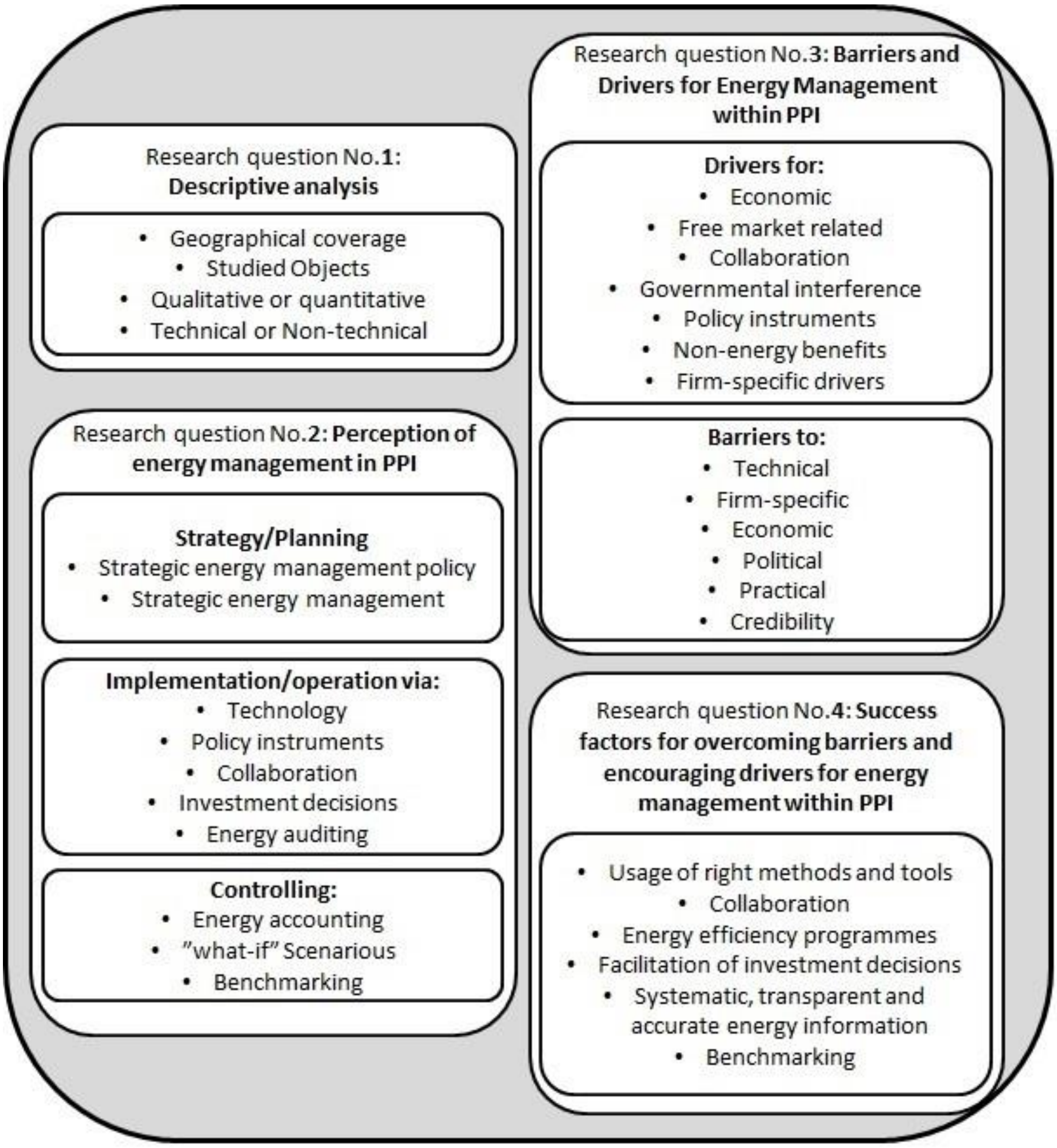

Figure 3. Summary of the results from the systematic review on energy management within the PPI.

3.1. What Do Studies Addressing Energy Management in the PPI Describe?

3.1.1. Geographical Coverage

The countries from which most articles on EnM in the PPI originated are: Sweden (nine articles) and China (six articles). Taiwan, the Netherlands, and the USA published three articles each, Canada and Austria published two each, while Brazil, Germany, India, Italy, and Turkey published one article each. There were also four articles with unspecified geographical coverage and four international articles in which several countries were compared.

The four international studies were as follows:

(i) A cross-time, from 1973 to 1991, and cross-country comparison on a physical basis were performed [54] using data for eight countries in the Organization of Economic Cooperation and Development (OECD): Austria, Japan, France, the former Federal Republic of Germany, the Netherlands, Sweden, the USA and the UK;

(ii) The comparison of energy uses by pulp mills in Canada, Finland, and Sweden [55];

(iii) Energy use was evaluated in the PPIs of Brazil, Canada, the USA, Finland and Sweden over a 30-year period from 1979 to 2009 [56];
(iv) For determining whether the energy costs can be reduced by improving energy conversion strategies, the use of primary energy and CO_2 emissions from paper mills in Poland, the Netherlands and Sweden was performed and compared [57].

The number of articles per year and country showed that at least one article was published each year from 2007, with a maximum of eight articles published 2012 during the analysed period of 1979–May 2016.

3.1.2. Studied Objects

The majority of articles, ~74% (29 of 39), addressed the PPI as a whole (Figure 4). However, there were three articles addressing only the paper industry and one addressing the paper and board industry. In addition, there were articles focusing on some more specific objects vs. the industry as a whole, that is, paper mills, pulp mills, and one study that focused on a paper machine; these took more of a case-study approach, attempting to draw more general conclusions by studying smaller objects.

Figure 4. Number of articles by studied object of the total of 39 articles.

3.1.3. Study Methodologies for Energy Management in the PPI

Quantitative methods were most prevalent in the studied articles (Figure 5); they were used in ~74% (29 of 39), followed by seven qualitative studies (~18%), and three reviews (~8%).

Although management is about effectively coordinating not only material resources but also human resources for achieving the goals of an organization, the majority of articles focused on EnM more from the technological point of view; ~80% of the studies (31 of 39 articles) had a technological orientation (Figure 6). Nevertheless, technology is just one of the means of improving EE, as explained in the introduction. EE can also be improved via policies/regulations and via management ([18,22]).

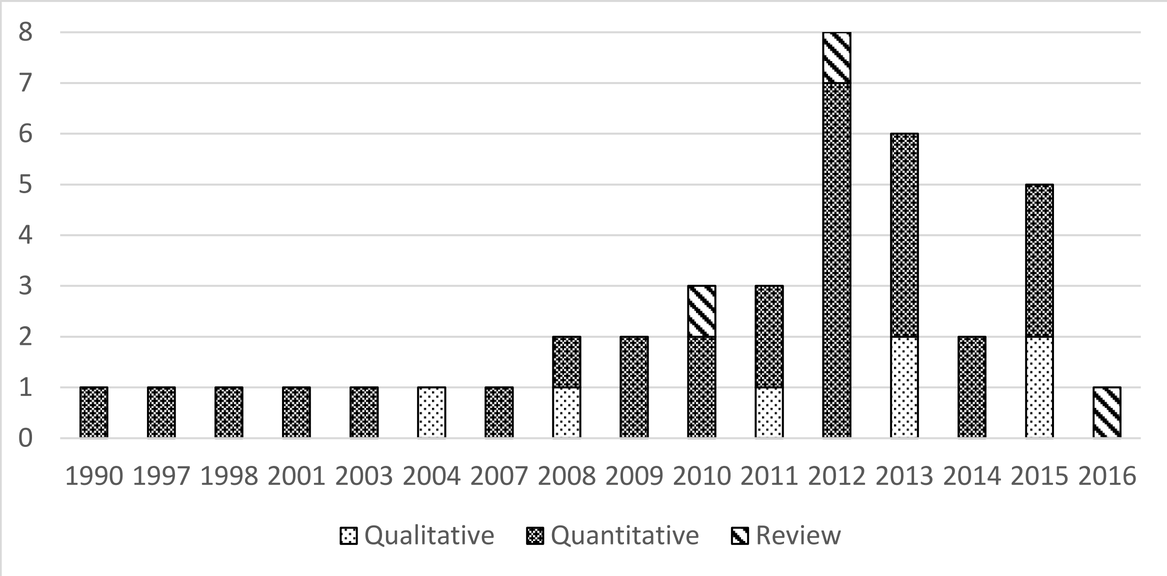

Figure 5. Number of study methodologies of the total of 39 articles.

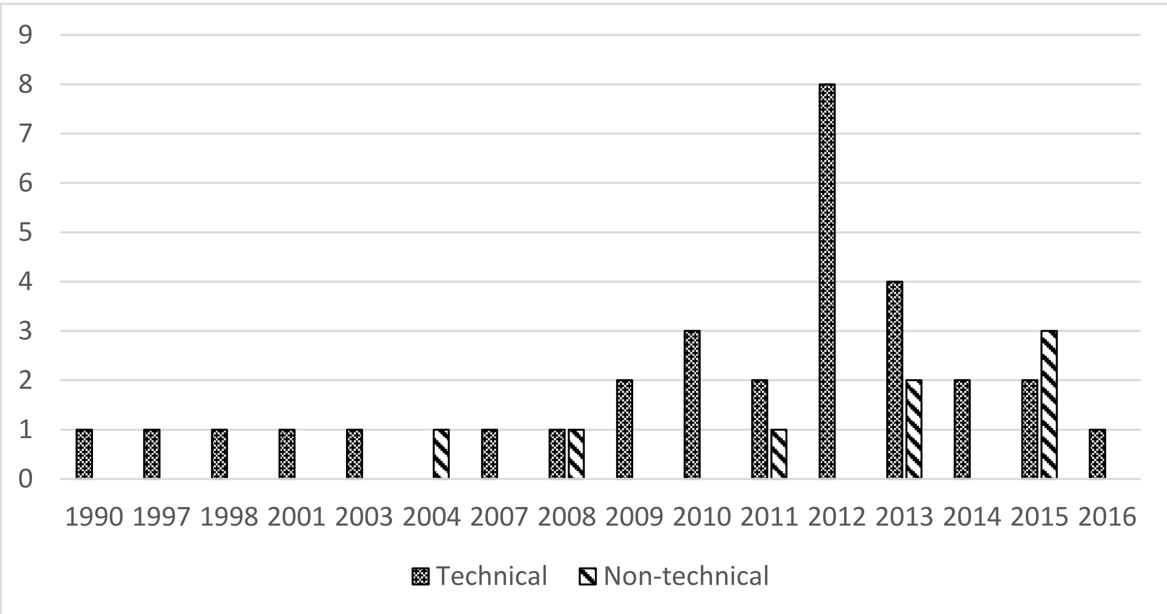

Figure 6. Number of articles per orientation of the total of 39 articles.

3.2. The Perception of Energy Management within the PPI—Categories by Research Focus (Research Question 2)

The articles addressing EnM within the PPI focused mainly on controlling (~51%—20 of 39) and implementation/operation (~49%—19 of 39), with an exception of ~10% (four of 39) that addressed strategy/planning (Figure 7). Controlling was the predominant category within the studied scientific articles, whereas there were no articles addressing organization and culture in EnM in the PPI. Note that three articles addressed both implementation/operation and controlling, while one addressed both strategy/planning and controlling. Figure 8 illustrates the number of articles by category and year, showing that articles on controlling and implementation/operation were published somewhat interchangeably, whereas articles addressing strategy/planning only appeared in 2011 and later. The dominant research themes were benchmarking (10 articles), implementation of EE via technology (nine articles), and evaluation of "what-if" scenarios, for example, forecasting (eight articles), whereas evaluation-energy accounting, implementation of EE via policy, and strategy/planning were addressed in four articles each, three addressed energy auditing and two addressed investment decision-making for EE measures (Figure 9). This, in combination with the dominance of technical studies rather than non-technical, and quantitative studies rather than qualitative, suggests that EnM in the PPI is perceived as a technical issue that can therefore be approached better by technology than by management practices, hence resulting in more studies addressing energy saving via technology.

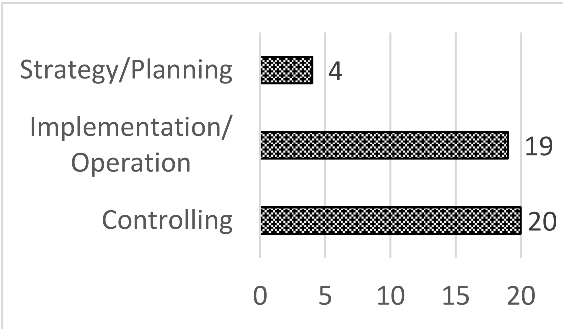

Figure 7. Number of articles by categories.

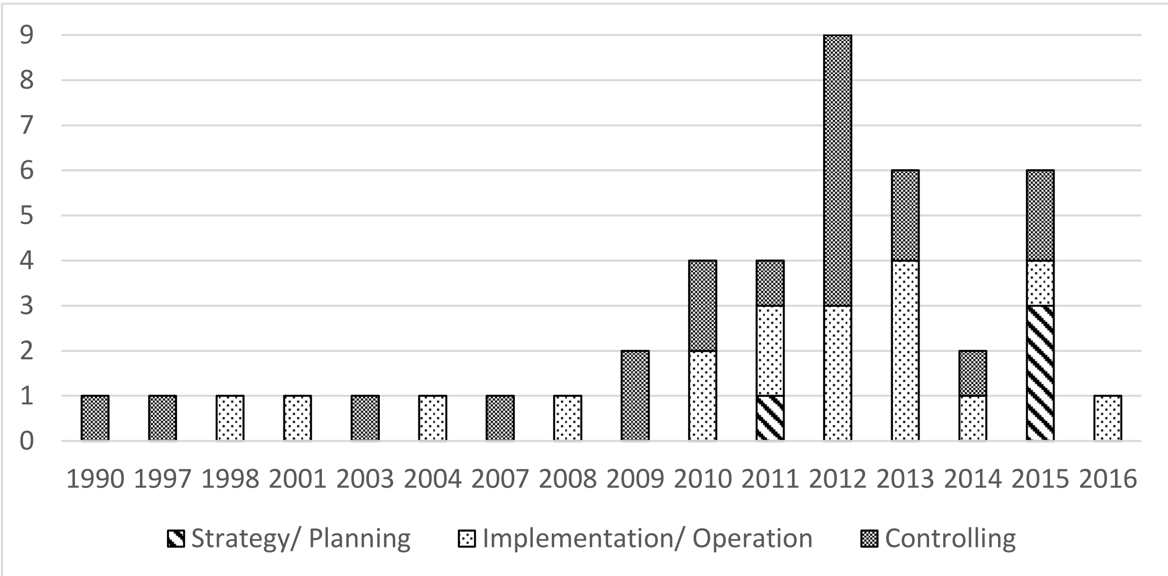

Figure 8. Number of articles by categories and years. In total 39 articles were evaluated, where four articles addressed two categories and the remaining articles addressed one of the categories, hence, four studies addressed Strategy/Planning, 19 studies addressed Implementation/Operation and 20 studies addressed Controlling.

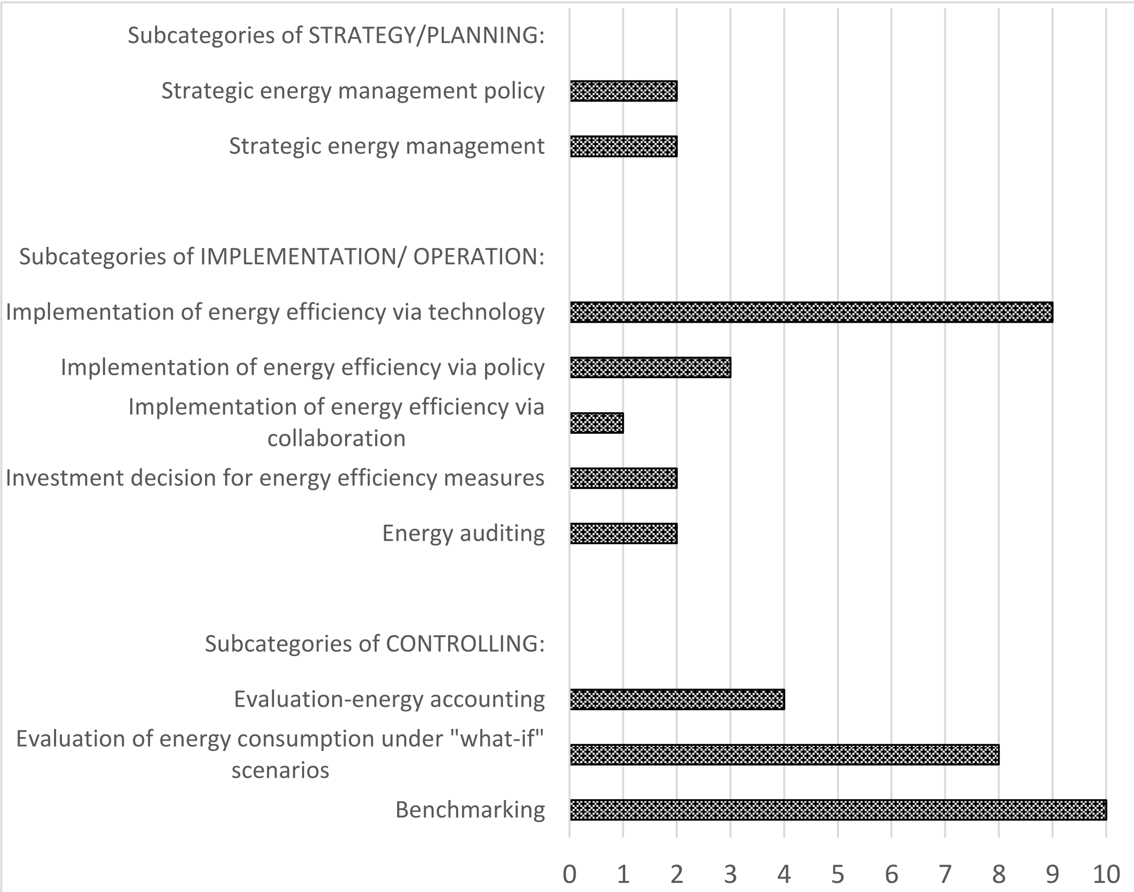

Figure 9. Number of articles per subcategory. Note that three articles addressed both Implementation/operation and Controlling and one articles addressed both Strategy/planning and Controlling. Altogether, Strategy/planning was addressed in four articles, Implementation/operation was addressed in 19 articles, whereas Controlling was addressed in 20 articles.

3.2.1. Strategy/Planning

The prevalent themes in the studies addressing EnM from a strategy/planning perspective in the PPI were (i) strategic EnM policy and (ii) strategic EnM. This was different from the analysis of studies on EnM in industry generally. Specifically, Schulze et al. [21] showed that the three prevalent themes for a strategic/planning perspective were the needs for (i) a documented long-term energy strategy/energy policy; (ii) energy planning, including target-setting processes at a company level; and (iii) a clear and systematic risk-management for minimizing the risks, for example, energy supply shortages and volatility of energy prices.

Regarding the PPI, ~10% (four of 39) of the studied articles addressed EnM from a strategy/planning perspective, possibly indicating that it is less prioritized than issues such as controlling or implementation/operation. This result is somewhat similar to the general tendency in industry, since Schulze et al. [21], in their systematic review on EnM in industry, also found that fewer studies focused on planning/operation relative to studies focusing on implementation/operation or controlling.

The need for a strategic energy policy in the short and the long term was addressed by Peng et al. [58], who formulated policies for accelerating the energy-efficiency process by using EE calculated over the period 1985–2010. Peng et al. [58] concluded that changes in the mills could provide opportunities for improvement of EE in the short term, whereas the introduction of new technologies and adjustment of the energy structure are long-term strategies for energy conservation.

Thus, according to Peng et al. [58], the EE of the PPI could be improved by using measures and policies for establishing an information system for EnM, adjustment of the energy structure and introduction of the new energy-efficient technologies. Additionally, strategies and policy support that are to be developed for energy saving and emission reduction for an efficient ecological industrial park, for example, Shandong Haiyun in China, were analysed and discussed [59].

Meanwhile, strategic EnM was addressed by Posch et al. [6], who analysed internal and external conditions in the Austrian PPI via a combination of strengths, weaknesses, opportunities and threats (SWOT) and an analytical hierarchy based on a survey of expert opinions. Posch et al. [6] showed that cost-related factors predominated; the four most important factors were related to the energy market, energy costs, and efficiency, whereas experts' attention was low for energy-market volatilities and environmental issues. This is partly in agreement with findings that the central driving force for energy transition in the Swedish PPI was high and unstable oil prices, as shown by a historic case study of energy transition in the Swedish PPI [60].

3.2.2. Implementation/Operation

Articles addressing implementation/operation in the PPI covered the following themes: (i) implementation of EE via technology; (ii) implementation of EE via policy instruments; (iii) implementation of EE via collaboration; (iv) investment decisions for EE measures, and (v) energy auditing.

Implementation of Energy Efficiency via Technology

Implementation/operation was dominated by the addressing of energy issues from a technical perspective on how EE in the PPI can be improved by a technical solution, similar to the findings of Schulze et al. [21] on EnM in industry generally. One example of a specific technical solution is a study by Bujak [61], who presented and evaluated a technical solution for improved EnM in a steam system for the production of corrugated board. Another example of a technical solution was when a pinch technology, used as a practical tool for effective EnM in the PPI, was described as being used for steam saving and for the reduction of fresh water intake [62]. Yet another example is a method based on the results of an exergy analysis of a paper mill that was carried out to identify and characterize technologies for the paper and board industry that in the long term could improve EE [63]. According to De Beer et al. [63], in the future paper mill, the specific electricity use is likely to remain about equal or to increase slightly. However, new pressing and drying techniques combined with latent heat recovery systems and various minor improvements could help to reduce the specific heat demand by 75–90% compared to the end of 1990s average.

Meanwhile, examples of more general technical solutions are as follows. Kong et al. [64] identified and analysed 23 energy-saving technologies, 18 fuel-saving, and five electricity-saving technologies, applicable to the PPI in China. Furthermore, 25 emerging technologies for reduced energy use were reviewed after compiling available information such as energy use, costs, environmental benefits [47]. Moreover, Marshman et al. [15] introduced a technical solution for improving EnM systems for cogeneration systems, for example, usage of steam to generate electricity and also to provide heat for the pulping process. The energy optimization algorithm presented by Marshman et al. [15] was shown as being applicable to popular mill configurations, fuel purchasing scenarios, and power sale contracts and able to handle weather-dependent cooling limitations. Furthermore, Kramer et al. [45] provided a brief overview of how to cost effectively reduce energy use while maintaining the quality of products in the PPI—the US EPA ENERGY STAR® for Industry energy-efficiency guidebook for pulp and paper manufacturers. Kramer et al. [45] presented many energy-efficiency practices and technologies applicable at various levels (e.g., process and facility levels), together with a discussion of the trends and energy use characteristic for the PPI in the USA. Despite the information in this Energy Guide being primarily intended to help the PPI in the USA, it was based on case-study data from actual applications in PPI and PPI-related industries internationally, which made the reported information applicable internationally.

Additionally, Fleiter et al. [5] assessed 17 process technologies for improvement of EE in the German PPI up to 2035 using a techno-economic modelling approach and showed a savings potential of 21% in fuel demand and 16% in electricity demand, which corresponds to a mitigation of 3 Mt of CO_2 emissions annually. From a firm's perspective, most of the technologies tested were found to be cost-effective, whereas the technologies for heat recovery and paper drying were the most influential technologies in paper mills. Also, Hong et al. [17] identified and evaluated areas with energy-saving potential in the PPI in Taiwan by analysing energy flows, and examined the potential technology options for capturing some of the energy currently lost in these processes and presented a list of energy-saving opportunities. The study results showed that 7.4% of annual energy use could potentially be saved, in which the greatest energy saving could be achieved by improving energy distribution and equipment efficiency. Together, these potentially constituted 86.8% of total energy conservation in the PPI in Taiwan [17].

Finally, alternatives for more sustainable energy use via the production of new products or alternative products that could be manufactured in combination with changed energy usage were also investigated. Specifically, the energy overview by Moshkelani et al. [46] presented the conceptual integration of a green-forest biorefinery into a Kraft mill for improving energy use and the possibility to produce lignin, ethanol, and heat. The application to actual case studies has shown that such integration is feasible. For example, this methodology has been applied to biorefining technologies for lignin and hemicellulose extraction and vaporization, where the gasification of wood residue was coupled to both technologies. Nevertheless, in all cases, such conversion was shown to present serious challenges: the operation of a biorefinery increases steam demand and the recovery boiler's heat production capacity was diminished since the components of the wood (e.g., lignin or hemicellulose) were withdrawn from the Kraft pulp line instead of being burnt in the recovery boiler as is done currently.

Implementation of Energy Efficiency via Policy Instruments

The implementation of EE via policy instruments was also addressed. For illustration, impacts that could be attributed to the European Emissions Trading Scheme (EU ETS) on energy use in the Swedish PPI were studied [65]. Ericsson et al. [65] suggested that the strategic reorientation of energy usage in the Swedish PPI has been driven by changes in underlying economic conditions, especially the increase of the price of electricity as a result of the Swedish energy market reform of 1996, and the start of the EU ETS. According to [65], the possibility to trade with renewable electricity certificates has introduced a new source of income for some PPI companies. Additionally, electricity demand in the Swedish PPI industry changed in response to the voluntary Swedish programme for EE (PFE), which grants tax exemptions if the participating firms implement energy-efficiency measures suggested by an energy audit [66]. Empirical results showed that electricity use in the PPI in Sweden was somewhat price insensitive, and the electricity savings that were self-reported as a result of the voluntary PFE programme indicated the presence of information asymmetries at the company level. Nevertheless, the results show a tendency that, in a baseline setting, the PPI already invested in private R&D with an impact on electricity saving. This was supported by model simulations suggesting that baseline effects could have caused up to about one-third of the electricity savings during PFE. In addition, whether the involvement of a firm in the EU ETS with the adoption of an Environmental Management System (EMS) favours the generation of organizational management and environmental planning was investigated, by analysing Italian PPI participating in the EU ETS [67]. The results showed the tendency that the organizations integrating ETS management with an EMS established satisfactory standards and procedures for environmental monitoring, although not all ETS-related activities were integrated into an EMS. The drivers for getting involved in the EU ETS and adopting an EMS were contradictory among the investigated companies. For example, according to one company profit maximization, rather than improvement of environmental performance, was the main strategic driver, when the dominating strategy was to trade without diverting attention from core activities. Meanwhile, another company considered the cost reduction as a result of the ETS to be important [33]. Furthermore, for other companies, the main driver was the need to improve internal performance by reducing the compliance risks [67].

Implementation of Energy Efficiency via Collaboration

The implementation of EE via collaboration was addressed by Möllersten and Sandberg [68], who studied how some of the barriers to EE, for example, lack of time, could be overcome by an energy-related collaboration between the PPI and energy service companies (ESCOs). However, the authors also identified barriers to the implementation of such collaboration, the main ones being: (i) credibility, that is, clear evidence that ESCOs can bring added value rather than capital to the PPI mills, and (ii) the lack of competition between ESCOs.

Investment Decision to Implement Energy-Efficiency Measures

The investment decision to implement energy-efficiency measures was addressed by studying the barriers to drivers of cost-effective energy-efficiency investments in the Swedish PPI [40]. The study results showed that the greatest barriers to investment in improving EE are technical risks, for example, lack of access to capital, the cost of production disruption/hassle/inconvenience, lack of time and other priorities, slim organization, and technology inappropriate to the mill. However, the study also showed the presence of driving forces for improving EE. The perceived drivers that were ranked highest were cost reductions resulting from lower energy use, a long-term energy strategy, people with real ambition, the threat of rising energy prices, the PFE and the electricity certificate system. Furthermore, this study revealed the presence of not solely marked related barriers and drivers; e.g., other priorities for capital investment, lack of time or other priorities, lack of staff awareness, slim organization, and long decision chains. Hence, the barriers to and drivers of investment decisions on energy-efficiency measures that are not solely market based are better dealt with internally within firms, whereas market-related barriers and drivers are better dealt with by policy instruments [40]. Ottosson and Magnusson [69] suggested that individual companies in the PPI respond to energy policies regarding investment decisions differently due to the different capabilities of individual companies. Hence, according to Ottosson and Magnusson [69], energy policies aiming to drive improvements in EE in the PPI are recommended to consider the heterogeneous capabilities of individual companies.

Energy Auditing

Audits can be preliminary, general, and detailed [22]. Preliminary audits are conducted by minimally interviewing site-operating personnel, a walk-through of the facility and a brief overview of a site's utility and operating data. General audits are expansions of preliminary audits, that are based on more detailed information about the facility's operation than the preliminary audits, whereas detailed audits are a further expansion that includes dynamic data.

Usage of the data from energy audits to identify the potential for EE and consequently CO_2 mitigation has been suggested. For example, Kong et al. [18] described results obtained from a plant-wide audit at a paper mill in Guangdong province in China. Methods for energy audit for calculating energy and carbon indicators—appropriate for Chinese standards—baseline energy use, and CO_2 emissions of the audited paper mill were presented along with a presentation of nine opportunities to improve energy-efficiency including their energy conservation and CO_2 mitigation potential. It was shown that these could lead to a 14.4% decrease in energy use and a 14.7% decrease in CO_2 emissions for the audited paper mill. Thus, it was suggested that an energy audit is a primary step towards improving EE at the facility level [18]. Additionally, Lin et al. [70] used data from on-site energy audits from 118 Taiwanese firms over the period 2009–2013 to summarize the energy-saving potential and energy savings implemented in 2011 by 72 PPI firms in Taiwan, with the intention that the results would be used as a reference by the PPI for stimulating changes in EE.

3.2.3. Controlling

Controlling was the dominant theme addressed in ~51% of the studies (20 of 39) and was addressed via the following aspects: ~10% (four of 39) addressed energy accounting, ~21% (eight of 39) addressed the evaluation of energy use under various "what-if" scenarios, for example, forecasting, and ~23% (nine of 39) addressed benchmarking.

Evaluation and Energy Accounting

The importance of systematic and accurate information about energy use on-line for a production process is claimed to be the fundamental condition for EnM and energy conservation [71]. Research shows that the real-time systematic, transparent, and accurate monitoring of energy use at a typical newsprint paper mill can be achieved by building an EnM system (EMS) for data acquisition, integration, and calculations from the integrated data, including energy calculations for water and steam and presentation of the energy information on-line [71]. Additionally, an evaluation was made of energy and exergy balances for the pulp and paper mill (PPM) in the SEKA Papermaking Plant in Izmit in Turkey [72]. The results were then used to analyse energy use and showed that the energy efficiencies were 34–97.4% for each of the mechanical and physical steps in the PPM, whereas the exergy efficiencies were 30.2–94.2% [72]. Furthermore, an assessment of energy savings and carbon reduction as a result of implementing energy-efficiency technologies in the US PPI were evaluated in 1994 and 2006 [73]. Potential savings were estimated to be ~32% of the PPI's final energy use in 1994 and ~62% in 2006. The associated carbon-emission reduction was 26% in 1994 and 45% in 2006 of the PPI's total carbon emissions from energy use. Hence, the final energy savings were estimated to be in the range of 15–25% of the annual energy use, with carbon-emission reductions ranging from 14% to 20% of annual carbon emissions by the sector [73]. Moreover, an evaluation was conducted of the extent to which seasonal variations affect the potential for making energy savings in a pulp mill. This was investigated using pinch analysis and showed that 88–94% of the theoretical energy savings could be attributed to seasonal variation [74].

Evaluation of Energy Use under Various "What-If" Scenarios

Energy accounting by modelling seemed to be prevalent in EnM in the PPI and was used for practical, real-time accountancy and the forecasting of various "what-if" scenarios. To begin with, the first article that fulfilled the search criteria for this study was indeed on modelling energy usage. Jaccard and Roop [75] employed an energy-demand forecasting model identifying the energy end-uses and associated technologies for the PPI in British Columbia in Canada. The study demonstrated the model's applicability to theoretical and practical analyses, for example, forecasting energy demand under different scenarios resulting from changes in public policies, cost, and so on.

In addition, modelling was utilized for minimizing energy costs, as described by Sarimveis et al. [76] and Marshman et al. [15]. Briefly, Sarimveis et al. [76] studied the utilization of mathematical programming tools to find the optimal EnM of the power plant in PPI mills, aiming to cost-effectively fulfil the total need of a plant for energy and steam. The study results showed that a detailed model of the power plant based on mass and energy balances, combined with the information from the electrical purchase contract, can be successfully used to enable optimal EnM. The model allowed the testing of "what-if" scenarios, for example, a change in the electricity price, an unexpected shutdown and/or the possible installation of a new energy supplying unit, or a shortage of a type of fuel used. Similarly, an energy optimization algorithm was shown to be applicable for use in a pulp and paper mill cogeneration system that uses steam for heat for the pulping process and for generating electricity to sell. Marshman et al. [15] demonstrated that the energy optimization algorithm is applicable to various mill types, fuel-purchasing, and weather dependent cooling scenarios.

Szabo et al. [77] presented a bottom-up global model of the PPI (PULPSIM), focusing on energy use and CO_2 emissions under different scenarios. The model can be used for assessing the effects of different energy, environment, and climate policies, since it incorporates not only the main economic drivers (e.g., demand of products), but also technological aspects for the industry in 47 global regions until 2030. Specifically, Szabo et al. [77] demonstrated that carbon emissions from pulp and paper making can be decreased by increasing the amount of energy generated from black liquor and waste wood while reducing fossil-based energy use. Additionally, a techno-economic analysis was used to assess 17 technologies for improving EE in processes in the PPI in Germany up to 2035 and showed that 21% of fuel and 16% of electricity could potentially be saved. This potential is achievable mostly by using more energy-efficient technologies in heat recovery and in the drying section in paper mills [5].

A model, called the "energy footprint" for analysing flows such as energy demand, supply and losses based on data gathered via questionnaires from Taiwan's PPI was used to identify, evaluate, and list areas with energy-saving potential [17]. The study results showed that the greatest energy saving could be achieved by improving not only equipment efficiency but also energy distribution, which together could be attributed for 86.8% of total energy savings in Taiwan's PPI. Although the study was performed using data from Taiwan's PPI, the authors suggested that these results can be used for benchmarking of the energy use in various parts of PPI and for encouraging improvements in energy use in the PPI more generally.

Lin and Moubarak [20] determined the effects of energy intensity per unit of value added on the studied variables—industry structure, technology, profit margin, and price of energy—under three different energy-saving scenarios based on historical trends over the period 1985–2010, and estimated the amount of energy that the paper industry in China could potentially save. The scenarios tested were business as usual (BAU), meaning that the studied variables follow their average growth rate; active, the most active energy-saving scenario, in which the values of the studied variables are assumed to grow according to the highest historical values observed; and an intermediate scenario between BAU and active. The results showed that active energy saving can lead to 91% energy saving by 2025 compared to the amount of energy intensity per unit of value added in 2010, whereas BAU would lead to an 82.5% saving by 2025.

The results of energy use, carbon emissions, and prices of electricity and biomass as a result of utilizing forest products with varying policy scenarios in the USA using the National Energy Modelling System were also estimated [78]. The tested scenarios were (i) a national standard for renewable electricity; (ii) a national policy of carbon constraints; and (iii) incentives that encourage improvement of industrial EE. Additionally, the covariation of these scenarios with the standards for renewable fuels in the USA was discussed. The results showed that in comparison to BAU forecast, each policy scenario reduces CO_2 emissions over time, but the national policy of carbon constraints leading to more reduction in CO_2 emissions than the other tested scenarios. However, the best result was achieved by implementation of all three policies together, whereby CO_2 emissions from the electricity sector could be reduced by 41% by 2030.

Benchmarking

Benchmarking can be determined by (i) industry benchmarks; (ii) historical benchmarks; (iii) company-wide benchmarks [79]. Benchmarking was a predominant theme in studies addressing EnM in the PPI, in ~26% (10 of 39), similar to findings regarding EnM in industry generally [21].

Farla et al. [54] presented a method applicable for comparison of the manufacturing industry's EE, time-wise and with other countries, which enables the tracking of changes in EE in electricity and fuel use separately. Activity growth in this method was measured by using physical production data, thus enabling comparisons of energy-efficiency comparisons with other countries without actual process data [54]. This methodology was applied to the PPI of eight countries of the OECD: Austria, Japan, France, the former Federal Republic of Germany, Sweden, the Netherlands, the UK, and the USA. The comparison showed that the production growth in the PPI in those countries would have caused the use of primary energy to increase by ~42% between 1973 and 1991. However, due to improved energy-efficiency by ~1.6%, the use of primary energy increased ~16%. This study also showed that changes in the product mix had no obvious effect on the use of primary energy.

Historical benchmarking was used for the identification and evaluation of energy-efficiency potential and improving EE. Indeed, benchmarking appears to be a useful tool of EnM since it has been shown to improve EE in the PPI. Specifically, benchmarking was shown to be used successfully during the energy transition in the Swedish PPI between 1973 and 1990. Information on the best available energy-saving measures was made available to all mills through collaboration within the PPI and between state and PPI, thus enabling companies to benchmark their own energy use and to take measures to improve their EE [60]. Additionally, a study analysing changes in energy-efficiency improvements in the Swedish PPI over the period 1984–2011 showed that the total production increased by 49%, but the use of primary energy increased by 26% because the PPI became less fuel-intensive but more electricity-intensive [80].

Industry benchmarking has been used to identify energy saving potentials. For illustration, Klugman et al. [55] used the most efficient technology that is available for comparing the use of energy at a chemical wood-pulp model mill in Sweden with a Canadian model mill. A comparison was performed among 11 non-integrated sulphate Swedish and Finnish pulp mills. Klugman et al. [55] showed that the model pulp mills were slightly more energy efficient in Scandinavia than in Canada. However, the use of energy was large among the mills in Scandinavia, indicating energy-saving potential. Moreover, the results showed that large amounts of heat, especially in the evaporation plant, could be saved. Another example is the benchmarking of similar processes at a detailed process level by comparing SEC in 23 different Dutch paper mills [19]. The benchmarking identified that 15% of the total primary energy use could be saved by improving EE in the drying, wire, and press sections [19]. The benchmarking of SEC also identified possibilities and challenges of using SEC. For example, the benchmarking of SEC allowed the calculation of average SECs for different paper grades per different processes and, hence, enabled comparisons of SECs required to produce the same grades at different mills. However, SEC in some processes of paper production was too dependent on the characteristics of products for the quantification of improvement potential to be possible.

Industry benchmarking was used to evaluate the conversion of energy-source options, and for analyses of which of those options could reduce primary energy use and CO_2 emissions in paper mills and counteract energy price differences in the Netherlands, Poland, and Sweden [57]. The three-country comparison showed that mainly the differences in the availability and prices for energy carriers historically was the reason for the different conversion of energy-source options in the three countries. For example, in the Netherlands, natural gas was available domestically for the long-term, hence, a natural gas combined cycle is used. However, in Sweden, biomass is used, due to availability, and electricity, because of the low electricity prices historically, and in Poland coal and biomass are used. Laurijssen et al. [57] suggested country-specific improvements for EE. Specifically, Sweden could use biomass-gasification-based combined heat and power (CHP) solutions if electricity prices increase, whereas Polish mills could switch from coal to biomass if the carbon price is to be 20–25 €/tonne [57]. Meanwhile, according to Laurijssen et al. [57], mills in the Netherlands could increase EE from the start, since a carbon price of more than 60 €/tonne could make the use of biomass instead of natural gas worthwhile. Additionally, Peng et al. [58] performed a cross-province study in China, as well as cross-country and cross-time studies, based on calculations of EE over time, and investigated the energy-efficiency gap between China and some other countries: Germany, the EU, the USA, and Japan. According to Peng et al. [58], EE can be improved by energy-related changes in mills within a short period, whereas new technology and energy-structure adjustment were found to be long-term strategies.

Energy use in Brazil's PPI was compared against energy use in the PPI in Canada, the USA, Finland and Sweden, and the energy use in the Brazilian PPI was evaluated over a period of 30 years by using an energy-efficiency index and an energy decomposition analysis [56]. The study showed that, due to improvements of energy-efficiency, 5.6 PJ of electricity use and 38.6 PJ of fuel use between 1979 and

2009 was saved [56]. Meanwhile, the international comparison showed that the most energy-efficient PPI were those in Sweden and Finland, followed in a descending order by the Brazilian, American, and Canadian PPI [56].

There have also been two studies aiming to be used as a benchmark and for encouraging improvements in EE in PPI ([17,81]). Both studies identified areas with energy-saving potential, consequently presenting the technology options for capturing some of the wasted energy after analysing the energy flows of Taiwan's PPI ([17,81]). The results showed that improvements in energy-efficiency of equipment and energy distribution together could cover 86.8% of total potential energy savings [17].

3.3. Barriers and Drivers in Energy Management (Research Question 3)

In total, barriers to and/or drivers of EnM in the PPI were selected from ~23% (9 of 39) of studies: barriers were selected from seven studies and drivers from three. Specifically, there was only one out of 39 (~3%) studies that focused primarily on both barriers and drivers, although in energy-related investments in the PPI not on EnM in PPI. Therefore, barriers to and drivers of EnM in the PPI were selected additionally from ~21% (8 of 39) of the studies where barriers and drivers were mentioned or understood from context although the primary research focus of those studies was on other subjects. Figure 10 illustrates the number and dates of the studies from which barriers and/or drivers were selected. As already stated, the most suitable was a study that thoroughly investigated barriers and drivers for cost-effective EE investments within the Swedish PPI, by Thollander and Ottosson [40]. Their study results showed that the greatest barriers were: (i) technical risks, e.g., disruption of production; (ii) inappropriateness at the mill; (iii) lack of time and other priorities; (iv) lack of access to capital; and (v) slim organization. The driving forces were: (i) cost reduction; (ii) people with real ambition; (iii) long-term energy strategy; (iv) threat of rising energy prices; (v) the electricity certificate; (vi) participation in a tax exemption programme (known in Sweden as PFE). The authors showed that neither the barriers nor the drivers were solely market related, meaning that firm-specific barriers and drivers were also found to be important. For example, lack of time and other priorities, slim organization, lack of staff awareness and long decision chains were the most common firm-specific barriers, whereas people with real ambition and a long-term energy strategy were the strongest drivers in the Swedish PPI. However, the study addressed barriers to and drivers of cost-effective energy-efficiency investment within the Swedish PPI. Energy-efficiency investment is one of many aspects of EnM, thus, the mentioned barriers and drivers represent EnM via technology, which are only one aspect of EnM.

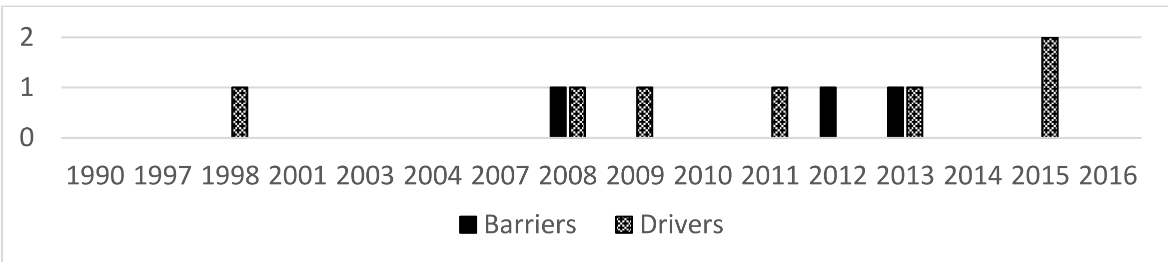

Figure 10. Number of articles where barriers and/or drivers for energy management in PPI were selected from: barriers were selected from seven studies and drivers were selected from three studies from the total of 40 articles.

Altogether, this systematic review showed that the following drivers have been mentioned in the studied research articles:

(i) Economic (cost-related) factors were shown to be the major driving force ([6,65,82]). Economic factors were shown as being dominant compared to environmental factors. The perceived need to minimize energy costs by reducing energy use was the main driver in the Austrian PPI [4]. The finding that the central driving force and trigger for energy transition was underlying economic conditions (i.e., high energy prices) is in agreement with the findings of studies addressing the reasons behind the energy transition in the Swedish PPI ([60,65]). Additionally, energy prices were shown to be the most correlated variable influencing energy intensity [20]. Furthermore, cost reduction and the perceived risk that the energy prices might increase were some of the drivers for cost-effective EE investments within the Swedish PPI [40].

(ii) Free-market-related factors (i.e., product demand and international competitiveness) were the drivers considered in energy accounting by Szabo et al. [77].

(iii) Effective industry-wide collaboration, as well as collaboration between the PPI and government, facilitated and speeded up the change, for example, many of the projects addressing energy transition were performed in collaboration with universities, research institutes, equipment suppliers outside the PPI and consultancy companies [60].

(iv) Proactive governmental interference: for example, governmental R&D that focused on collecting and spreading knowledge on current and new energy-related R&D projects, regularly performing energy studies and distributing handbooks [60].

(v) Policy instruments: taxes and fees ([60,65]). For example, it was shown that the introduction of the EU ETS for renewable electricity certificates not only increased on-site electricity production, but that the EU ETS even provided a new source of income in some cases [65]. Another example is that electricity certificates and participation in a tax-exemption programme (known in Sweden as PFE) were found to be drivers for cost-effective energy-efficiency investments within the Swedish PPI [40].

(vi) Non-energy benefits (benefits other than the improved energy-efficiency), for example, improvements of the quality of products, were the drivers for the development of energy-efficient technologies according to de Beer et al. [63]. Another example is the case of energy transition in the Swedish PPI between 1973 and 1990, which showed that, by phasing out oil, the PPI not only became more energy efficient, but also reduced its emissions of CO_2 by 80% over the 17 years [60]. This also turned the previous manufacturing waste problem into a raw material to be used as energy and saved virgin wood for pulp and paper manufacturing by increasing the ratio of recycled paper [60]. Additionally, the reduction of compliance risks was considered the main driver by some companies [67].

(vii) Firm-specific drivers: long-term energy strategy and people with real ambition were found to be drivers for investments in energy-efficiency in the Swedish PPI [40].

Note that drivers for the same instrument for the improvement of energy performance can be perceived as contradictory by different companies within the same industry and country, as demonstrated by a study focusing on analysing the effects of the EU ETS and the adoption of EMS for companies in Italy's PPI [67]. The study showed that driving forces were contradictory, for example, one company claimed that profit maximization rather than improvement of environmental performance was the main strategy driver, when the dominating strategy was to trade in the short run, and another company considered the main driver to be the possibility to reduce costs in relation to the ETS [67]. In contrast, for other companies the driver was to reduce the compliance risks [67].

This systematic review also showed that the following barriers have been mentioned in the studied research articles:

(i) Technical barriers: technical risks, for example, disruption of production or inappropriateness at the mill [40].

(ii) Firm-specific barriers, for example, lack of access to capital, lack of time and other priorities and slim organization [40].

(iii) Economic barriers, for example, large investment decisions have to be justified over the long term [69].
(iv) Political barriers, for example, the established companies have significant political power thus making the implementation of a new policy harder [69].
(v) Practical barriers, for example, barriers to acquiring comprehensive energy information (i.e., accurate, clear and systematic information regarding energy use on-line for various production processes) were found to be important [71].
(vi) Barriers to energy-related collaboration between the PPI and energy-service companies (ESCOs) were: credibility, that is, clear evidence that ESCOs can add value other than capital to PPI mills, and the lack of competition between ESCOs [68].

3.4. Success Factors for Overcoming the Barriers and Encouraging Drivers of Energy Management within the PPI (Research Question 4)

One way to overcome barriers and enhance drivers is to use the right instruments. Market-related public policy instruments are one of the best means to overcome market-related barriers. For example, the threat of rising energy prices could be overcome by enhancing and encouraging market-related drivers, for example, the PFE [40]. Meanwhile, more firm-specific drivers, for example, a long-term energy strategy and people with real ambition, are more likely to be encouraged by improving EnM within firms [40]. Similarly, the improvement of EnM within firms is also more likely to overcome firm-specific barriers, for example, other priorities for capital investment, slim organization, lack of time or other priorities, long decision chains, and lack of staff awareness [40].

Collaboration was shown to be an important factor for successful EnM by a historical case study conducted by Bergquist and Söderholm [60]. This study showed that the highly collaborative strategy of the PPI—both between PPI and the Swedish state administration, as well as internally among the PPI mills—was of central importance for the transition towards increased use of renewable energy and improved EE in the PPI in Sweden during the 1970s and 1980s. Specifically, CO_2 emissions decreased by 80% between 1973 and 1990. This reduction was achieved by (i) focusing on unutilized potential, for example, substituting oil with biofuels, the latter mainly being internal by-products from the pulp manufacturing process, thus solving a manufacturing waste problem at the same time; (ii) increasing production of electricity on-site through back-pressure turbine power generation; (iii) energy-efficiency improvements in general due to, for example, technological development; (iv) policy instruments, for example, energy taxes and fees introduced by government; (v) knowledge management and collaboration between industry and government; and (vi) benchmarking. Some barriers, for example, lack of time and other priorities, could be overcome by energy-related collaboration between the PPI and ESCOs, providing ESCOs have pulp and paper-specific competence. The authors also identified barriers to the utilization of such collaboration, with the main barriers being (i) credibility, that is, clear evidence that ESCOs can add value rather than capital to PPI mills; and (ii) the lack of competition between ESCOs [68].

Some of the market failures and barriers could be overcome by energy-efficiency programmes explicitly promoting technological progress and addressing the most important failures related to behaviour and information, according to the analysis by Blomberg et al. [83], who investigated how EE changed as a response to the Swedish energy-efficiency programme (PFE). Blomberg et al. [83] suggested that some market barriers can be overcome by (i) supporting public research efforts, thus reducing asymmetric information problems; (ii) implementing innovation policies, because improved methods imply positive spill-over effects; (iii) increasing the time that programmes for improvement of EE are in effect; and (iv) encouraging policies aimed at reducing technical risks—the most important barriers for decreasing of the energy-efficiency gap.

It was also suggested that, to facilitate investment decisions in the PPI, policy-makers need to provide a stable framework and direction for the future to restrict the possibilities for continuous adaptation, and thus overcoming the barrier of unwillingness to invest in the PPI if such investments seem not to be justifiable on a long-term basis [69].

Barriers to acquiring comprehensive energy information can be overcome by gathering, following, and analysing energy use data for various production processes on-line, systematically, and accurately [71].

3.5. Comparison of Energy Management Aspects—Proposal of a Framework

ISO 50001 is internationally recognized EnM systems and has been used as a base for research on EnM in industry in several studies (e.g., [38,84]). The intention in this study was to summarize the most important aspects of ISO 50001 into a simple, short, and easily memorable framework that could complement existing EnM systems. This would help to remember the most important aspects of EnM that are best practiced together for continuous improvement of EE. This framework would be associated primarily with EnM systems. Besides ISO50001, the identified categories when addressing EnM in PPI, shown in this study, and in industry generally [21] are summarized in the same way as for ISO50001 in the framework. By this approach, any EnM aspects in the PPI that are absent or scarce may be identified.

Consequently, success factors, the most important inter-related aspects for EnM for improved EE could be summarized by the 4M conceptual framework—the "4M for improving energy efficiency" (hereafter shortened as "4M"): mind, measure, monitor and manage (Table 2 and Figure 11). The terms in "4M" are based on [85]. "Mind" refers to "the will or determination to improve EE". "Measure" is "to assess the importance, effect, or value of (something)", for example, the amount of energy used to produce one ton of product. "Monitor" means "to observe and check the progress or quality of the energy usage and improvements of EE over a period of time". "Manage" refers to "running and supervising all the plans, decisions, work, and so on leading towards improved EE. The 4M is a generic EnM memory-tool, since it summarizes the parts of internationally recognized EnM standard ISO 50001 that is "applicable for all types and sizes of organizations, irrespective of geographical, cultural and social conditions" [86]. The terms are inter-related and influence each other. However, all four of them have to be proactively practiced together in order to continuously improve EE. Results of examples of the ISO50001 parts that could be summarized by the individual Ms are presented in Table 2.

Table 2. Examples of aspects summarized by the individual Ms in the 4M energy management (EnM) memory-tool.

The Ms:	Explanation According to [85]	ISO 50001	Categories	In Industry Generally [21]	In PPI
Mind	"the will or determination to improve EE"	Energy policy, energy planning	Strategy/planning	Energy strategy, energy policy	Energy strategy, energy policy
Measure	"to assess the importance, effect, or value of (something)"	Energy auditing	Implementation/operation	Energy auditing	Energy auditing
Monitor	"to observe and check the progress or quality of the energy usage and improvements of EE over a period of time"	Monitoring and analysis	Controlling	Energy accounting, benchmarking	Energy accounting, benchmarking
Manage	"running and supervising all the plans, decisions, work, etc. leading towards improved EE	Management review	Organisation and Culture	Energy manager, training, staff motivation	Not found as being addressed

The justification for introducing the 4M EnM memory-tool is that it is simple, short, and easy to memorize and helps to consider all the inter-related aspects of EnM. The 4M EnM memory-tool is a complement to the EnM systems, emphasizing the importance of practicing all the parts of EnM systems together for the best result in improving EE.

The primary intention with this EnM memory-tool is to complement the existing tools by helping to remember and practice the EnM tools such as, for example, ISO 50001 to its full extent, not to compete with them. The 4M EnM memory-tool is simple, short, and easily memorable. It is an attempt to introduce some simple easily memorable terms summarizing most important aspects of EnM that have to be proactively practiced together for achieving continuous improvement in EE.

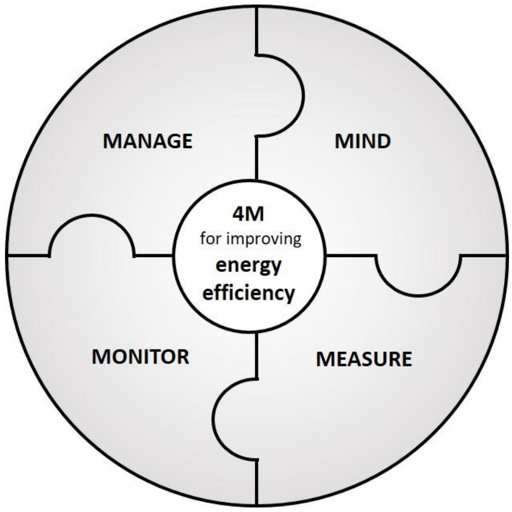

Figure 11. The 4M framework—the"4M" for energy management for improving energy efficiency.

The 4M EnM memory-tool originates from summarizing information that is found in the universally recognized EnM systems, such as ISO 50001, that is based on a plan-do-check-act (PDCA) cycle, hence it resembles the PDCA cycle, that is associated with any improvement work [87]. However, the purpose of 4M EnM memory-tool is to complement the existing EnM systems by emphasizing the importance of practicing every one of the individual 4M inter-related terms together and that it would be associated primarily with EnM systems.

Comparison of research categories that were addressed when primarily studying EnM in PPI with the ISO 50001 EnM systems model confirmed that research addressed "Energy policy", "Energy planning", "Implementation and operation", and "Validation (Checking)" of the ISO 50001 EnM systems model, but did not address "Internal audits of the EnM systems (EnMS)" or "Management" (Figure 12). This meant that the reviewed articles on EnM and EnM systems in PPI addressed "mind", "measure", and "monitor", but not "manage". Further, findings from this systematic review were compared with the framework developed by Schulze et al. [21] regarding EnM in industry generally. This comparison showed that research studies addressing categories: "organisations" and "culture" that could be summarized as addressing "manage" were present in EnM in industry generally but absent in the PPI (Table 2). Results of the comparison among aspects addressed in EnM and/or EnM systems in PPI and in industry generally, together with the examples of EnM systems aspects that were summarized by the individual Ms in the 4M EnM memory-tool are presented in Table 2.

This review showed that most of the studies addressing EnM and/or EnMS in PPI, addressed EnM via technology, which is only one aspect of EnM, which in turn could partly explain why the energy-efficiency gap remains untapped.

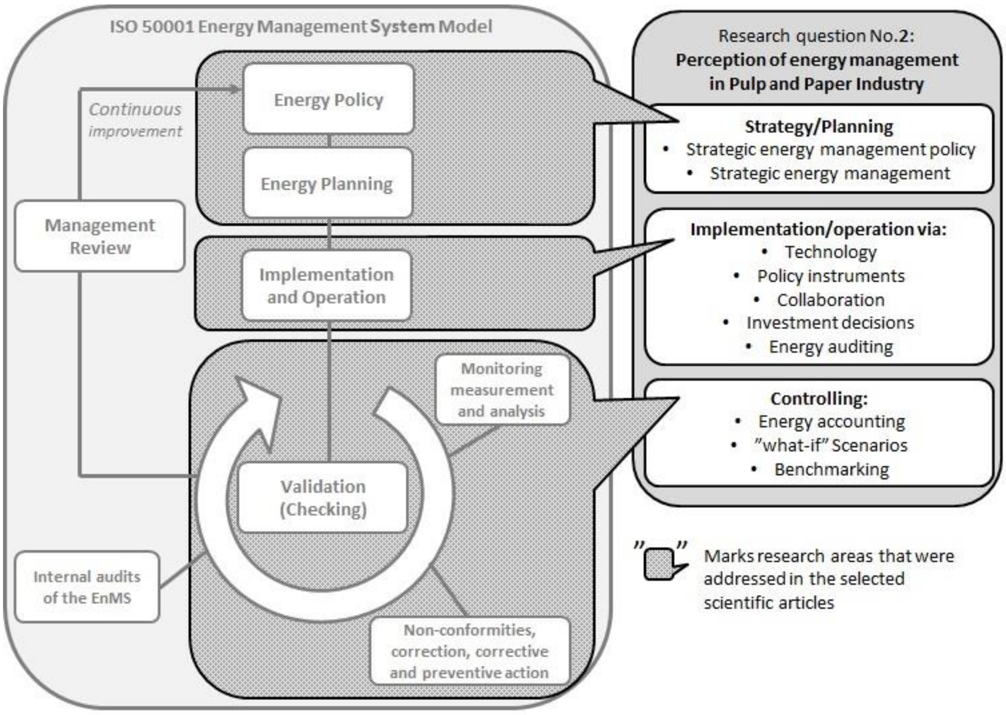

Figure 12. The relation between research categories for energy management within the PPI and the ISO 50001 Energy Management System Model.

4. Discussion

4.1. What Is Described in Studies Addressing Energy Management in the PPI

The world-wide events that affected energy supply and volatility seemingly had an effect on the number and frequency of research articles on EnM in the PPI. For instance, the critical article about clearcutting published in 'Der Spiegel' in November 1993 caused an international public debate and showed that consumer attitudes can be a vital condition for papermaking [88]. Luukkanen [88] suggested that the origin of wood is not the only factor of production that has to meet the requirements of environmental sustainability and that it is likely that the same criteria can be applied to energy, since energy is an important production factor in the PPI. This could be one of the reasons why all but one of the articles about EnM within the PPI investigated by us were published in 1997 or later. Furthermore, there were two peaks in the number of articles published: 2007 and 2012. It is possible that these depended on the events that led to problems in accessing fossil fuels; countries were dependent on the International Energy Association (IEA) reserves due to hurricanes Katrina and Rita in the USA during August and September 2005 and the civil disruption in Libya in 2011 [89]. If we assume that it takes about one to two years for a study to be presented as a published scientific article, both of those dates suggest the connection. Furthermore, if those two reasons were the triggers, this would suggest that energy is still fossil-fuel dependent to a significant extent. Furthermore, the greatest annual number of articles was published in 2012. Possibly, there could be a connection with the appearance of the international management systems ISO 50001:2011 [90].

Note that the channel for publishing and the language in which the studies were presented could have affected our search results, and thus the results of this review. Specifically, in terms of country, most articles were published about Sweden (nine articles) and China (seven articles). This could be because, according to the statistics for 2014, Sweden was the fifth largest producer of pulp (after the USA, Canada, China and Brazil) and the ninth largest producer of paper. Meanwhile, China is the third largest producer of pulp and paper in the world [12]. There were fewer articles from larger producers relative to Sweden, that is, from the USA, Canada, Brazil, and Germany. There were three articles about the USA and two about Canada, which could be because the results of studies were presented elsewhere than in scientific articles found in the databases searched by us, for example, TAPPI journal, conference proceedings, and so on. Given that there was only one article for Germany and one for Brazil, this small number relative to Sweden and China could be due not only to the different sources for publishing, but also to the language, since we limited our search results to English only. Nevertheless, our results portray the current state of scientific research reported in peer-reviewed international journals in English.

4.2. The Perception of What Energy Management in the PPI Is

EnM in the PPI is perceived more as EnM by technical means, for example, by upgrading to a newer, energy-efficient technology, conducting online monitoring, and so on. This is further supported by the finding that studies addressing the research categories "culture" and "organization" were absent and most of the reviewed articles addressing EnM in the PPI were quantitative. In addition, the categories "Internal audit of the EnMS" and "Management review" within the ISO 50001 EnM systems model were also absent. This is in agreement with the findings of Bergquist and Söderholm [60], who conducted a qualitative historical case study on the energy transition between 1973 and 1990 in the Swedish PPI and also observed that qualitative research on EnM is lacking. One explanation for this could perhaps be that energy use in production is perceived to be more effectively reduced by technology than by pure management as perceived by, for example, the ECEEE energy audit policy programme report [91], and therefore more studies have focused on energy saving via technology. Another explanation could be that the saving of energy in the PPI has historically mostly been done by engineers and/or technicians since an in-depth holistic understanding of the causes and effects of various processes and technologies is needed to do so, and therefore the technical personnel do what they are meant to do—save energy via technology and engineering. This explanation is supported by the results of research conducted for paper mills, which emphasized the importance of a decent understanding of the processes, since without such understanding even a detailed benchmarking of processes may not lead to accurate estimations of energy improvement potentials [19].

Some of the research themes that dominate within the research on EnM in the PPI are in agreement with the findings of analyses of EnM in industry more generally [21]. However, in contrast to the themes dominating within EnM in industry generally, articles addressing "organization" and "culture" were absent. Amongst other things, the absence of such studies could indicate that EnM in the PPI is perceived as mostly achieved via technology.

4.3. The Current State of Knowledge about Barriers and Drivers in Energy Management in the PPI

There is little research regarding barriers to and drivers of EnM in the PPI relative to research addressing implementation/operation and controlling. Here again, the reason for the lack of focus on barriers and drivers seems to be that energy issues are categorized as technical rather than management issues and thus have been studied mostly from a technological perspective, as shown by the dominance of "technical" articles. However, it seems that not only studies on the barriers and drivers in the industry themselves could be of benefit but also when such barriers and drivers are valid and under what circumstances. For example, it was shown that an ambiguous barrier is the underlying difficulty of predicting technological progress, which may cause a perception that there is value in waiting and saving more with new technology, thus causing an adoption time lag [92]. Although the issue of waiting for a better technology is double-sided—it can be worth waiting for a better-suited and more energy-efficient technology—government policies aimed at enhancing the adoption of new technologies may lead to the installing of less than optimal energy-efficient technology and may therefore also be counterproductive [92]. The articles addressing barriers to and drivers of EnM within the PPI similar to the other articles addressing barriers to and drivers of EnM within other industrial sectors (e.g., [16]) had more of a nontechnical orientation. Hence, it seems to be beneficial to conduct studies addressing barriers to and drivers of EnM from different perspectives, for example, engineering, environmental, and so on, rather than from a national economic perspective which sets the hypothesis that price is the major driver as a starting point. In conclusion, more knowledge regarding barriers and drivers in EnM in PPI would seem to be beneficial and this issue remains to be tackled.

4.4. The Known Success Factors for Overcoming Barriers and Encouraging Drivers in Energy Management in the PPI

The main success factors seem to be the continuous management of energy issues, collaboration, and a holistic approach, as shown by [60]. Indeed, this study showed that a change in EnM can trigger several events, leading not only to EE but also to non-energy benefits that together lead towards sustainability. For illustration, the need to find an alternative energy source for oil increased interest in domestic energy sources, for example, wood incineration. This generated a fear that the actual accessible quantities of wood for fuel could be over-used, which in turn could outcompete the cheap access to wood for use in pulp and paper manufacturing. However, the consequence of such a fear turned out to be the generation of positive results. Specifically, the use of recycled paper in PPI has increased. And this in turn not only reduced the need for wood as a raw material but also decreased energy use, since the energy required for producing pulp from recycled paper is only ~20% of that needed to make mechanical pulp from virgin wood [60]. Furthermore, the usage of previous by-products from the pulp manufacturing process became a solution to the previous waste disposal problem, which together led to the improvements of EE and reduction of energy use, further decreasing CO_2 emissions [60]. Concerning the importance of a holistic approach and understanding, the results showed that by affecting one factor, such as the need to find an alternative energy source, one can trigger a complex process that was not intended from the start. For example, it was not only the known relationships that were affected, such as the relationship between the need to find an alternative energy source and the disposal of waste (e.g., newspaper and bark), but also emissions (e.g., CO_2, elemental chlorine and organic substances). Indeed, the Swedish example shows that, by phasing out oil, the PPI had reduced its CO_2 emissions considerably, prior to concerns about climate change being discussed internationally. Furthermore, the Swedish example shows the importance of government intervention. Indeed, much of the basic knowledge that was used for improving EE and using more sustainable energy carriers was known before the oil crises because of the stable and low prices for oil. For example, the possibility of burning internal organic residual products through back-pressure turbine for power generation was known. This shows that the driving forces towards sustainability can be need and price.

The literature review acknowledged a scarcity of papers in the area of ESCOs and energy services, while for other sectors energy services has been shown to be deployed. If this is due to a real lack or just a scarcity of studies is difficult to state. As stated by Thollander and Ottosson [42], energy services in the PPI are more likely to be more attractive in activities that are outside of the core production process, and where the lower the energy integration is in relation to the production processes, as it may take 5–10 years to gain sufficient knowledge of the production to deploying EE. A general conclusion, based on this, may be that different explanatory models exist between different sectors, even regarding the organizational issues. For example, a Swedish pulp mill, normally using 1–3% of Sweden's total industrial energy use, demands a very thorough understanding of the energy using processes and waste heat flows, before even considering making a change. Meanwhile, a large automobile manufacturer, using less than 0.1% of the Swedish industrial energy use, can rely more heavily on procurement practices, procuring the most efficient new technologies, and also being able to utilize energy service companies to a higher extent. In comparison, a study among European foundries showed deployment levels of energy services in about one fourth of the studies foundries [43].

The comparison revealed that the "manage" aspect of EnM systems was not being addressed, when addressing EnM in PPI. Nevertheless, according to [21], "EnM comprises 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, which aim to continuously reduce the company's energy consumption and its related energy costs". Meaning that according to Schulze et al. [21], the human dimension is an important part of the EnM. This is in agreement with other studies; for example, Caffal [25] claimed that EnM is all about managing and encouraging people to use energy more efficiently. Jovanovic et al. [84] also emphasized the importance of the human dimension in EnM: "An EnM system cannot be implemented if there is no leadership. Without the support of top management, employees will not take part". This, from research studies addressing EnM practices, suggests that "manage" could be a success factor leading to the decrease in the EE gap in the PPI.

5. Conclusions

This systematic review showed that like many manufacturing industries, the PPI has the potential to become more sustainable, more robust in the face of sudden and unexpected energy-market variations and shortages, more diversified, more profitable, and more resilient to international competition, and that EnM is an important means to achieve these goals.

The descriptive analysis conducted within the systematic review indicated that world-wide events affecting energy supply, volatility, and usage seemingly also affected the number and frequency of research articles on EnM within the PPI.

This systematic review has revealed the dominance of the perception that EnM consists of the improvement of EE via technological innovations. Research is dominated by studies addressing implementation/operation and controlling, mainly from a technical perspective, whereas research addressing organization and culture was absent. Similarly, research articles addressing "internal audits of the EnMS", and "Management"—areas within ISO 50001—were also absent. This indicates research areas still to be addressed.

Research primarily addressing barriers to and drivers of EnM within the PPI, that is, research focusing on reasons for implementing and conducting EnM, was absent. Barriers and drivers were addressed in some studies without being the main focus and this revealed that economic factors, such as high and unstable energy prices, dominated compared to environmental concerns, hence, the main driver was the perceived need to reduce energy costs by increasing EE. Additionally, important drivers were shown to be governmental intervention via policies and regulations, for example, the EU ETS, which increased general awareness of other energy-related issues and non-energy benefits, for example, enhanced production rates. The barriers that were addressed within the reviewed scientific articles were technical risks, lack of access to capital, inappropriateness at the mill, lack of time and other priorities, slim organization, large investments that need to be justified over the long-term, and established companies possessing political power. Again, this suggests another research area remaining to be tackled.

Similarly, research primarily addressing success factors for overcoming the barriers and encouraging the drivers for EnM within the PPI was absent. Nevertheless, success factors could be selected from research studies focusing primarily on other issues. Successful implementation and maintenance of continuous EnM, continuous energy accounting, energy-related collaboration, a holistic approach, energy-efficiency programmes, benchmarking, market-related public policy instruments for overcoming market-related barriers, and firm-internal EnM for overcoming firm-related barriers were the success factors that were addressed. Once again, this is another research area that needs to be explored.

The results demonstrated the importance of continuous EnM and a holistic understanding not only of the direct and indirect effects that a change in energy use might have, but also of the interactions between different policies and the impacts of those policies, the urgency of the problem to be solved, and cooperation between industry and government. Hence, this systematic review suggested that to overcome the challenge of achieving a sustainable and profitable PPI, there is a need for research that focuses on identifying and defining both the barriers to and drivers of EnM in the PPI and the means for overcoming the barriers and encouraging the drivers, based on a holistic understanding of EnM in this industry.

This study showed that the most important inter-related aspects of EnM for improving EE could be summarized by the 4M EnM memory-tool, that is, "4M for improving energy efficiency": mind, measure, monitor, and manage (Figure 11). The 4M EnM memory-tool is intended to be a complement to the EnM systems and would be associated primarily with EnM for improving EE and emphasise the importance of practicing all the four Ms together. This study also demonstrated that the 4M EnM memory-tool could be used for identifying whether all the parts of EnMS are addressed, which in turn could lead to eventually decreasing the EE gap.

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

Appendix A

Table A1. Articles included in the systematic review on EnM in the PPI.

Authors and Year	Journal	Type of Study	Geographical Coverage	Studied Objects	Categories
Bergquist and Söderholm (2015)	EE	Qualitative	Sweden	PPI	Strategy/planning and Controlling
Brown and Baek (2010)	Energy Policy	Quantitative	USA	PPI	Controlling
Bujak (2008)	Energy	Quantitative	Poland	PM	Implementation/operation
Chen et al. (2012)	Energy Policy	Quantitative	Taiwan	PPI	Controlling
De Beer et al. (1997)	Energy	Quantitative	The Netherlands	Paper and board industry	Implementation/operation
Ericsson et al. (2011)	Energy Policy	Qualitative	Sweden	PPI	Implementation/operation
Farla et al. (1997)	Energy Policy	Quantitative	International (USA, Japan, Germany (former FRG), France, the UK, the Netherlands, Sweden and Australia)	PPI	Controlling
Fleiter et al. (2012)	Energy	Quantitative	Germany	PPI	Implementation/operation and Controlling
Fracaro et al. (2012)	Energies	Quantitative	Brazil	PPI	Controlling
Gasbarro et al. (2013)	European Management Journal	Qualitative	Italy	PPI	Implementation/operation
Henriksson et al. (2012)	Energy Policy	Quantitative	Sweden	PPI	Implementation/operation
Hong et al. (2011)	Energy	Quantitative	Taiwan	PPI	Implementation/operation and Controlling
Jaccard and Roop (1990)	Energy Economics	Quantitative	Canada	PPI	Controlling
Klugman et al. (2007)	Applied Energy	Quantitative	International (Scandinavia and Canada)	Pulp mills	Controlling
Kong et al. (2013)	Applied Energy	Quantitative	China	Paper mill	Implementation/operation
Kong et al. (2015)	Resources, Conservation and Recycling	Quantitative	China	PPI	Implementation/operation
Kong et al. (2016)	Journal of Cleaner Production	Review	Unspecified	PPI	Implementation/operation
Koufos and Retsina (2001)	Water Science and Technology	Quantitative	Unspecified	PPI	Implementation/operation
Kramer et al. (2010)	Engineering	Review	USA	PPI	Implementation/operation
Laurijssen et al. (2012)	Applied Energy	Quantitative	International (The Netherlands, Poland and Sweden)	Paper industry	Controlling
Laurijssen et al. (2013)	Energy Efficiency	Quantitative	The Netherlands	Paper industry	Implementation/operation

Table A1. *Cont.*

Authors and Year	Journal	Type of Study	Geographical Coverage	Studied Objects	Categories
Lin and Moubarak (2014)	Energy	Quantitative	China	PPI	Controlling
Lin et al. (2014)	Energy	Quantitative	Taiwan	PPI	Implementation/operation
Marchman et al. (2010)	Applied Energy	Quantitative	Canada	PPI	Implementation/operation and Controlling
Moshkelani et al. (2012)	Applied Thermal Engineering	Review	Unspecified	PPI	Implementation/operation
Möllersten and Sandberg (2004)	Business Strategy and the Environment	Qualitative	Sweden	PPI	Implementation/operation
Ottosson and Magnusson (2013)	Technology Analysis and Strategic Management	Qualitative	Sweden	PPI	Implementation/operation
Peng et al. (2015)	Energy Policy		China	PPI	Strategy/planning
Persson and Berntsson (2009)	Energy	Quantitative	Sweden	Pulp mill	Controlling
Posch et al. (2015)	Journal of Cleaner Production	Qualitative	Austria	PPI	Strategy/planning
Sarimveis et al. (2003)	Energy Conversion and Management	Quantitative	Unspecified	PPI	Controlling
Stenqvist (2015)	Energy Efficiency	Quantitative	Sweden	PPI	Controlling
Szabo et al. (2009)	Environmental Science and Policy	Quantitative	International	PPI	Controlling
Thollander and Ottosson (2008)	Energy Efficiency	Qualitative	Sweden	PPI	Implementation/operation
Ting (2011)	Energy Procedia	Qualitative	China	Paper industry	Strategy/planning
Utlu and Kincay (2013)	Energy	Quantitative	Turkey	Pulp and Paper mill	Controlling
Wu et al. (2012)	Applied Energy	Quantitative	China	Paper mill	Controlling
Xu et al. (2013)	Sustainable Cities and Society	Quantitative	USA	PPI	Controlling

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