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Thematic Section - Future of Energy-efficient Operations and Production Systems

Energy efficiency decision-making in non-energy intensive industries: content and social network analysis

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Abstract

Paper aims: The present study aims to identify the limitations of the artifacts used in the decision-making process in the adoption of energy efficiency measures in productive systems, using non-intensive energy companies as a delimitation.

Originality: Identifies authors and connections, the relationships between them and how these interactions contribute to the advancement of knowledge on the subject. Regarding energy efficiency, studies show that the real investment in initiatives in the industrial sector is below the full potential and that the artifacts used in the decision-making process have severe limitations when used in a complex and dynamic context.

Research method: In this paper a systematic literature review was conducted from the Literature-Grounded Theory. Additionally, social network analysis was used.

Main findings: It concludes that the approaches are limited to technical and financial factors and does not consider a systemic and dynamic understanding of different internal and external variables to the organization.

Implications for theory and practice: The contribution of this study is that it identifies the initiatives that help in the process of decision-making for the adoption of energy efficiency measures in productive systems. Specifically, the focus of this study is on non-intensive energy companies. Scientific articles published in the main databases of management were selected.

Keywords

Energy efficiency. Energy management. Decision support systems. Manufacturing industries.

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1. Introduction

Until the economic crisis of the 1970s, energy costs were reduced compared to other production expenses, which led to an uncontrolled increase in energy consumption (Aplak & Sogut, 2013). The oil crisis challenged the industrialized world, forcing decision makers and researchers to think about a future in which it would be necessary to turn to alternative energy sources and reduce consumption (Olanrewaju & Jimoh, 2014).

Energy development is a barometer of economic development. Countries seeking economic growth will necessarily consume more energy. However, increasing the levels of energy production and use through existing initiatives can be difficult, costly and environmentally unsustainable (Reddy, 2013). One of the methods found to solve this given problem is energy efficiency.

Energy efficiency (EE) refers to the decreasing use of energy in producing a "useful output". In industrial environments, this useful output is the number of services or products generated from a production process (Aplak & Sogut, 2013). In this sense, increased energy efficiency can be achieved with the use of more efficient initiatives, energy recovery in the same process or greater use of energy waste in different processes and greater energy conversion efficiency or optimized operating practices (Bunse et al., 2011; Perroni et al., 2016).

Considering the implementation of energy efficiency, there are different approaches to classifying companies in terms of energy consumption. In Brazil, the terms electro-intensive or energy-intensive are used to classify organizations operating in the cement, copper, aluminum, chemical and petrochemical, ferroalloys, steel, mining, paper and cellulose, air gases, among others commonly classified as heavy industry. For other companies, the most used term is non-energy intensive industries. Therefore, the term "non-energy intensive" is generally used to refer to companies classified as a non-energy intensive industry, or light industry.

In this scenario, energy management can play an important role in contributing to increase profitability and productivity of companies (Aplak & Sogut, 2013). At the same time, neglecting energy management and energy efficiency can constrain organizations' performance. In companies classified as non-intensive, energy consumption is not the largest share of production costs (Finnerty et al., 2017). This leads to a lack of studies and research agendas related to energy efficiency in these industrial environments (Fenerich et al., 2017; Hasan et al., 2019) that guides to non-intensive industries not entirely aware of the concepts of energy management and energy efficiency (Hasan et al., 2019).

However, when contextualizing energy efficiency in a segmented manner with emphasis on the industrial sector, Thollander And Palm (2015) present important information about the potential and actual use of initiatives to increase energy efficiency. In the electro-intensive industry, there is a smaller disparity between the potential and the real possibility of energy efficiency, considering the available initiatives. In non-intensive industry, however, this disparity is greater.

Small and medium-sized enterprises (SMEs), which can be classified as non-intensive energy use, consume more than 13% of the total global energy demand (International Energy Agency, 2016). The energy efficiency measures in these companies have the potential to save up to 6.1×10^{12} terawatt-hour (TWh), representing more energy than the sum of the annual consumption in Japan and South Korea (International Energy Agency, 2016). Studies have shown that there is a significant disparity between the potential and the actual implementation of energy efficiency initiatives between intensive and non-intensive industries (Bunse et al., 2011; Cassettari et al., 2017; Perroni et al., 2016; Pusnik et al., 2016; Schulze et al., 2016; Nehler & Rasmussen, 2016; Cooremans, 2012; Knobloch & Mercure, 2016; Lung et al., 2005; May et al., 2015, 2017; Never, 2016; Palm & Thollander, 2010; Paramonova & Thollander, 2016). Therefore, there is potential to use energy efficiency initiatives in non-intensive industries, and it is termed as a gap in power management (Thollander & Palm, 2015). Regarding that, the aim of this study is to identify the limitations of the artifacts used in the decision-making process in the adoption of energy efficiency measures in productive systems.

An artifact, models, techniques and tools, can be defined as the organization of elements of the internal environment to achieve goals in each external environment (Dresch et al., 2015; Lacerda et al., 2013). This study contributes with the identification of the artifacts that assist in the process of decision-making when adopting energy efficiency measures in productive systems, specifically focusing on non-intensive energy companies. Structure of this paper: first, the methodology is discussed, followed by a section focused on the results and discussion, and the final considerations are presented in the last section.

2. Methodology

It is essential to be sufficiently informed about what was researched, how it was researched, and the results found in the research (Morandi & Camargo, 2015), in order to discover what is not known or not understood (Ermel et al., 2021). Literature-Grouded Theory consists of a systematic set of steps that seek to review, analyze, and synthesize the literature (Ermel et al., 2021). In this sense, a systematic literature review was performed (SLR) to conduct the study (Ermel et al., 2021; Veit et al., 2017). Initially, the problem of revision and the conceptual framework was defined to understand how the impacts of decisions and initiatives to increase energy efficiency are evaluated in industrial environments. Decision support tools have been identified, including any structured and systematized models, methods, techniques and/or approaches, that are used by companies in the industrial segment, manufacturing companies, production systems, and manufacturing systems within the context of efficiency energy.

Terms were defined to search for studies related to the decision process on energy efficiency in production systems. The strings used are the combination of the terms and are shown in Table 1.

Table 1. Search Terms.

#	TERM 1	TERM 2	TERM 3
P01	"Energy efficiency"	"Decision support"	Manufacturing OR Industr*
P02	"Energy efficiency"	"Decision-making"	Manufacturing OR Industr*
P03	"Energy efficiency"	"Economic evaluation"	Manufacturing OR Industr*
P04	"Energy efficiency"	"Impact assessment"	Manufacturing OR Industr*
P05	"Energy efficiency"	"Strategic decision"	Manufacturing OR Industr*
P06	"Energy Management"	"Decision support"	Manufacturing OR Industr*
P07	"Energy Management"	"Decision-making"	Manufacturing OR Industr*
P08	"Energy Management"	"Economic evaluation"	Manufacturing OR Industr*
P09	"Energy Management"	"Impact assessment"	Manufacturing OR Industr*
P10	"Energy Management"	"Strategic decision"	Manufacturing OR Industr*
P11	"Industrial energy efficiency"	"Decision support"	
P12	"Industrial energy efficiency"	"Decision-making"	
P13	"Industrial energy efficiency"	Evaluation	
P14	"Industrial energy efficiency"	Assessment	
P15	"Industrial energy efficiency"	Strateg*	
P16	"Industrial energy management"	"Decision support"	
P17	"Industrial energy management"	"Decision-making"	
P18	"Industrial energy management"	Evaluation	
P19	"Industrial energy management"	Assessment	
P20	"Industrial energy management"	Strateg*	

The databases used were *ProQuest-Technology Collection*, *Scopus-Elsevier*, *Science Direct-Elsevier*, and *Web of Science* - Main Collection, as they are among the main databases for research in the field of management (Dresch et al., 2015), and the *IEEE Xplore Digital Library,* that is known for making available quality technical literature in the field of engineering and technology. The search of documents was made regarding the fields Title, Abstract and Keywords aiming to ensure a wide coverage. The time horizon was articles published since 1973, a milestone year due to the oil crisis. The research protocol used in the RSL can be found in Appendix A. The total numbers of records found from each string search in the cited databases are presented in Table 2.

The total number of records found was 4,573 in all the cited databases. To finish this step, the duplicate records were removed, resulting in 3,509 articles, which comprised the eligibility step. Figure 1 shows the overview of the search process, eligibility and coding used in the SLR.

Table 2. Total of records found.

#	PrQ	Sco	SDi	WoS	IeX	*Total*
P01	34	230	34	138	20	456
P02	92	1.021	116	533	47	1.809
P03	16	138	22	70	3	249
P04	16	233	26	90	1	366
P05	1	26	5	13	-	45
P06	7	106	15	36	26	190
P07	31	407	32	165	81	716
P08	5	43	2	8	1	59
P09	3	65	-	11	-	79
P10	-	12	2	4	-	18
P11	1	4	2	3	-	10
P12	5	43	9	37	1	95
P13	9	41	13	26	1	90
P14	12	60	22	39	1	134
P15	17	65	16	52	-	150
P16	-	1	-	-	1	2
P17	1	8	1	7	1	18
P18	-	5	4	3	-	12
P19	2	16	3	3	-	24
P20	3	28	7	11	2	51
					Total:	4.573

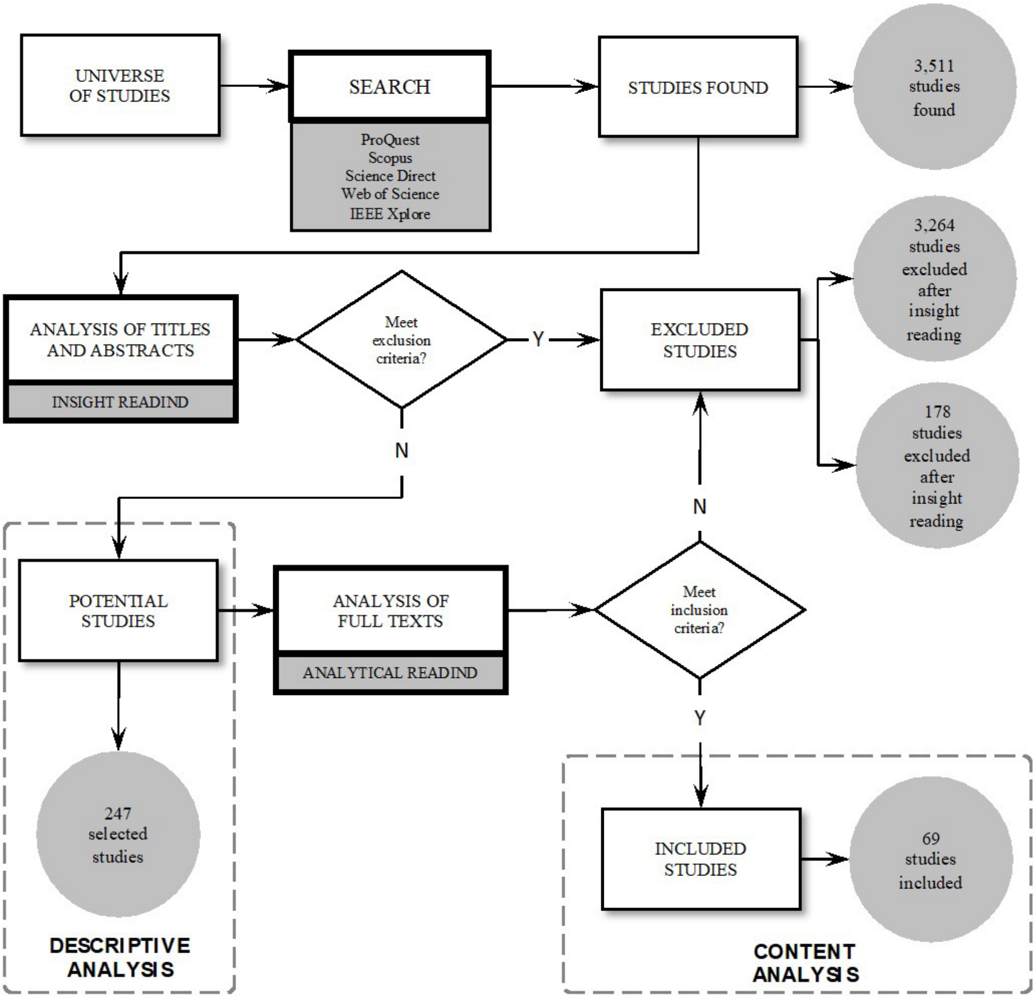

Figure 1. Search process, eligibility and coding.

The titles and abstracts of the studies were evaluated by insight reading (Adler & van Doren, 2010). The exclusion criteria considered at this stage were: (i) papers that do not present artifacts related to evaluation and/or decision making; (ii) research on energy efficiency of motors, turbines and the like and building energy efficiency; (iii) studies on energy efficiency related to the use of electric vehicles; (iv) papers on chip energy efficiency, memories and the like; (vi) research on mechanical and thermodynamic energy efficiency; (vii) studies specific to the electro-intensive industry only. The last exclusion criterion keeps electro-intensive industry papers, if they are in conjunction with non-intensive industry ones.

Overall, 3,511 studies were found, from the first analyses, 3,264 studies were eliminated based on the exclusion criteria, resulting in 247 studies with analytical reading (Adler & van Doren, 2010) and descriptive analysis potential. In this stage of eligibility, the inclusion criteria were considered to be studies that contemplated: (i) application in industrial settings; (ii) use of modeling; (iii) use, methods, techniques and/or structured and systematized approaches; (iv) strategies, indicators and/or practices related to energy efficiency. At the end of the analytical reading of the full texts, 69 articles were included in the study for content analysis. The descriptive and content analyses are detailed and explored.

3. Results and discussion

From the RSL, 247 studies were pre-selected for analytical reading that make up the set of works considered in the descriptive analysis. From this set, 69 studies were selected based on the inclusion criteria, which were used to carry out the content analysis. The result of both analyzes will be described below.

3.1. Descriptive analysis

To analyze the temporal evolution, we considered the period between 1995 and the first eight months of 2021, time of the oldest and of the most recent study. The behavior of the volume of publications can be observed in Figure 2. It is possible to highlight two distinct periods in relation to the quantity of publications. The first, between 1995 and 2007, presents a small and stable volume of publications. During this period, the amount of annual publications ranged from zero to four. Although it is not possible to say that there is any relationship, from 2007-2008, when it triggered one of the biggest economic crises of international scope, the number of annual publications began to grow significantly, ranging from 3 to 34 annual publications in 2017. In the first 8 months of 2021, the quantity of publications reached 8, allowing a total of 12 to be projected in the year if the frequency of publications on the subject is maintained.

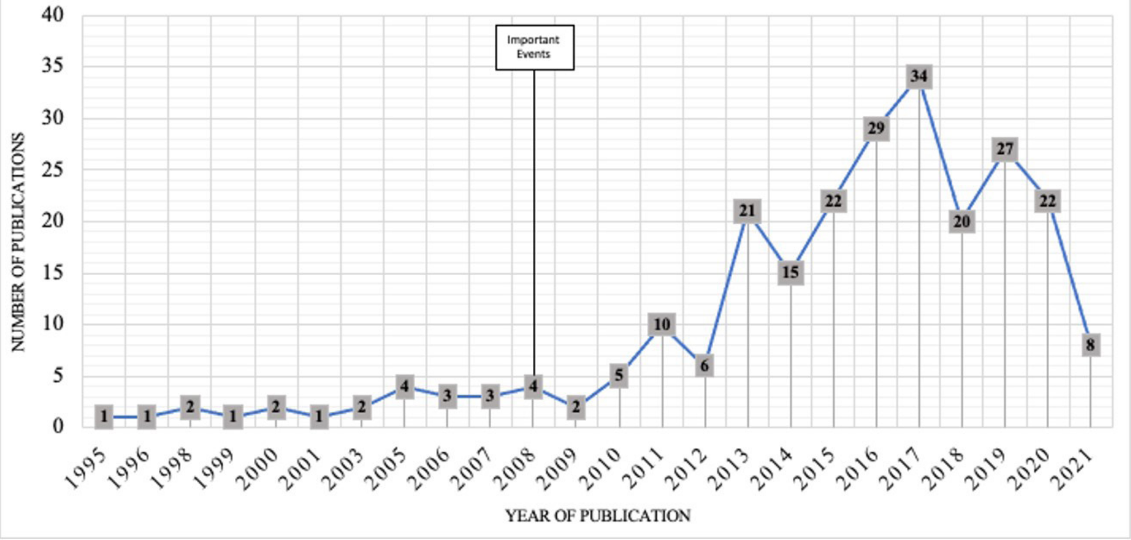

Figure 2. Publications per year.

Two important events in the energy scenario occurred during this period. On January 2nd, 2008, the price of a barrel of oil reached US$100 for the first time in history. On the 29 of March 2008, there was the "Earth Hour" in more than 400 cities on the planet, a global movement to mobilize society against global warming. On that date, governments, businesses and people around the world turned off the lights for an hour to express concern about global warming.

Of the 245 selected studies, seven journals concentrate 155 publications, which is equivalent to 63% of publications. The other 90 publications are distributed among other 73 journals. That is, a restricted quantity of journals concentrates most of the publications in the area. Figure 3 presents the quantity of publications per journal, highlighting the most relevant ones.

A detailed analysis of the data presented in Table 3 shows that, between 2013 and 2021, the journals "Journal of Cleaner Production (JCL) IF-JCR 9.297, Applied Energy (AEN) IF-JCR 9.746 and Energy (ENY) IF-JCR 7.147 published 82 studies. The volume of publications increased in three journals. The remaining publications have been distributed in the journals Energy Policy (EPL) IF-JCR 6.142, Energy Efficiency (EFF) IF-JCR 2.574, Renewable and Sustainable Energy Reviews (RNW) IF-JCR 14.98 and Energies (ENS) IF-JCR 3.004. This allows us to infer that the evolution of the publications was mainly concentrated in 3 journals.

3.2. Social Network Analysis (SNA)

Social Network Analysis (SNA) emphasizes network actors and their relationships by mapping the connections established in each community (Piovezan & Fujita, 2015). The parameters for SNA are as follows:

a) density: it is an indicator for the general level of connectivity of the graph, and it is defined as the ratio between the number of connections and the number of vertices in a complete graph with the same number of nodes (Otte & Rousseau, 2002);

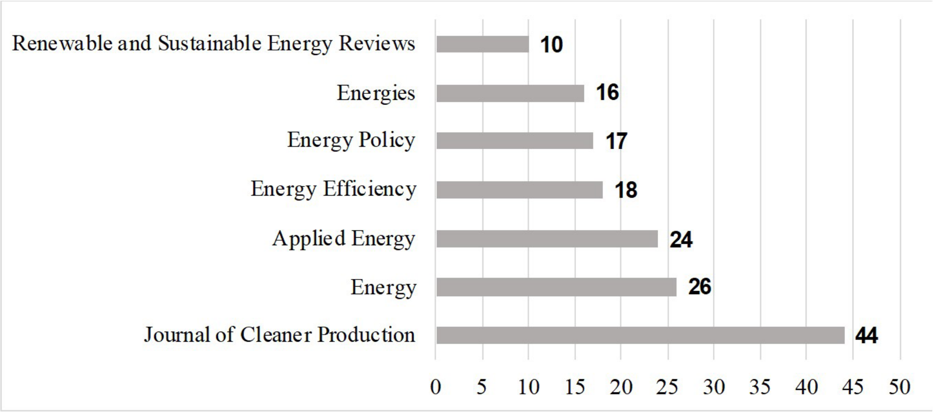

Figure 3. Publications per journal.

Table 3. Annual publications of the main journals.

	Journal of Cleaner Production	Applied Energy	Energy	Energy Policy	Energy Efficiency	Renewable and Sustainable Energy Reviews	Energies	Total
1996	-	-	-	1	-	-	-	1
1997	-	-	-	-	-	-	-	-
1998	-	-	-	1	-	-	-	1
1999	-	-	-	-	-	-	-	-
2000	-	-	-	1	-	-	-	1
2001	-	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-
2003	-	-	1	1	-	-	-	2
2004	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-
2006	-	-	-	1	-	-	-	1
2007	-	-	-	2	-	-	-	2
2008	1	1	-	1	1	-	-	4
2009	-	-	1	-	-	-	-	1
2010	-	1	-	2	1	-	-	4
2011	1	1	2	1	1	2	-	8
2012	-	-	3	-	2	-	-	5
2013	3	3	2	2	-	1	1	12
2014	2	3	-	1	2	1	-	9
2015	5	3	1	2	1	1	1	14
2016	6	5	4	-	1	1	-	17
2017	10	3	3	-	4	4	3	27
2018	6	1	1	1	4	-	3	16
2019	7	3	3	-	-	-	5	18
2020	2	-	3	-	-	-	2	7
2021	1	-	2	-	1		1	5
Total	44	24	26	17	18	10	16	155

b) centrality of degree: in a co-authoring graph, the degree of centrality of an actor is the number of authors in the graph with collaboration in at least one article (Otte & Rousseau, 2002);

c) distance: it is also an indicator of centrality, but with a more general characteristic than the previous one. The proximity of a node is equal to the total distance of this node to the other nodes in the graph (Otte & Rousseau, 2002).

A total of 664 authors were involved in the 245 studies. The coauthoring analysis allows establishing if there is a relation or proximity to the authors. From VOSviewerÒ software, was considered as a parameter for coauthoring analysis authors who published at least two documents, as well as each cluster with least three authors. In all, eight clusters were found, formed by 33 authors, according to Table 4.

Table 4. Co-authorship analysis.

Cluster	Authors	Documents	Region or Country	Research line
1	Andrei, Mariana	2	Sweden	Barriers, SMEs, Energy Management, Energy Efficiency, Decision Process, Practices, Models
	Karlsson, Magnus	3	Sweden	
	Nehler, Therese	2	Sweden	
	Ottosson, Mikael	2	Sweden	
	Palm, Jenny	4	Sweden	
	Paramonova, Svetlana	4	Sweden	
	Rasmussen, Josefine	2	Sweden	
	Rohdin, Patrik	3	Sweden	
	Sa, Aida	3	Italy, Sweden	
	Thollander, Patrik	23	Sweden	
2	Chiaroni, Davide	2	Italy	Internal barriers, Power Systems Audit, EE Measures, Financial Indicators
	Chiesa, Vittorio	2	Italy	
	Franzò, Simone	3	Italy	
	Frattini, Federico	3	Italy	
3	Andersson, Elias	2	Sweden	Barriers, Drivers, EE Measures, SME
	Cagno, Enrico	18	Italy	
	Neri, Alessandra	3	Italy	
	Trianni, Andrea	17	Australia, Italy	
4	Eichhammer, Wolfgang	2	Germany	SME, Impact assessment, Barriers, EE Measures, EE policies
	Fleiter, Tobias	2	Germany	
	Worrell, Ernst	6	The Netherlands	
5	May, Gökan	2	Switzerland, Italy	Energy Management Systems
	Stahl, Bojan	2	Italy	
	Taish, Marco	3	Italy	
6	Al-mansour, Fouad	2	Slovenia	Energy Management Systems, EE Measurements
	Pusnik, Matevz	2	Slovenia	
	Sucic, Boris	2	Slovenia	
7	Ren, Jingzheng	2	China	Barriers, Risks, Decision Making under Uncertainty
	Wang, Zhenfeng	2	China	
	Xu, Guangyin	2	China	
8	Hasan, A. S. M. Monjurul	3	Australia, Bangladesh	Energy Management, Industrial EE, Energy Policy, Energy Management Practices, Assessment Model
	Sakib, Taiyeb Hasan	2	Bangladesh	
	Tuhin, Rashedul Amin	2	Bangladesh	

The clusters 1 and 3 are representative of the three authors (Cagno, Trianni, and Thollander). Studies were carried out mainly in Italy and Sweden. Figure 4 allows for a complementary analysis of the co-authorship network, as it represents density (size of circles), centrality (position of circles) and proximity (distance between circles).

In addition to the coauthoring analysis, the term network is another element of SNA that allows the visualization of connections between the main terms used in the studies, complementing the characteristics of density, centrality and proximity used in the coauthoring analysis, with the addition of a temporal factor. Figure 5 shows the temporal evolution of each term using the blue color for the most used terms, going through the colors of the Kelvin scale, until reaching the terms most recently used, which are represented by red. For the joint elaboration of terms, a minimum incidence of 5 was considered.

Even though the term "energy efficiency" is in the Cluster B, all the clusters interconnect with this term, what was expected since it is the main term of the work. Cluster A, together with Cluster B, are the ones with the highest number of terms, eight and six, respectively. A is focused on the management and industrial terms, formed by "barriers", "decision-making", "drivers", "energy efficiency measures", "energy management practices", "industrial energy efficiency", "non-energy benefits", "small and medium-sized enterprises" (SME). B, in the other hand, have its terms linked to the energy and efficiency area, those are "data envelopment analysis", "efficiency",

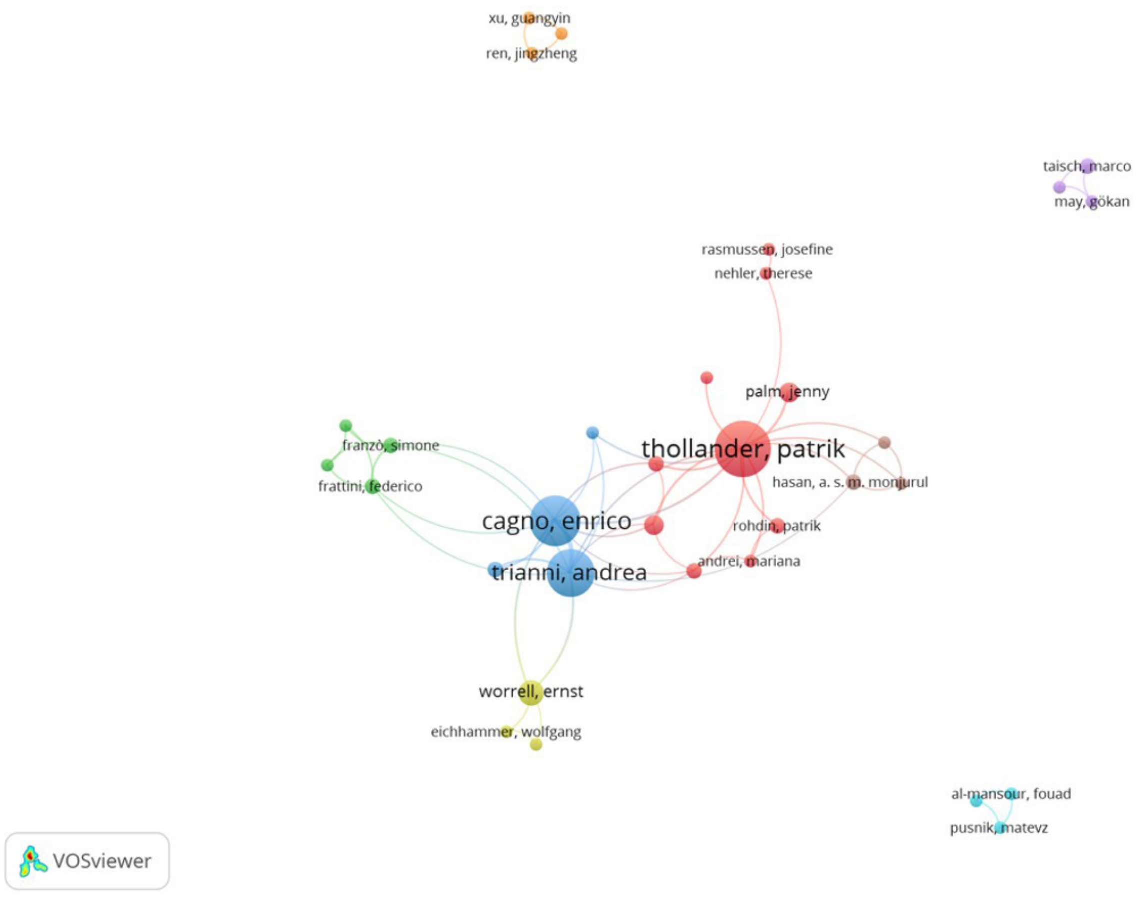

Figure 4. Co-authorship networks.

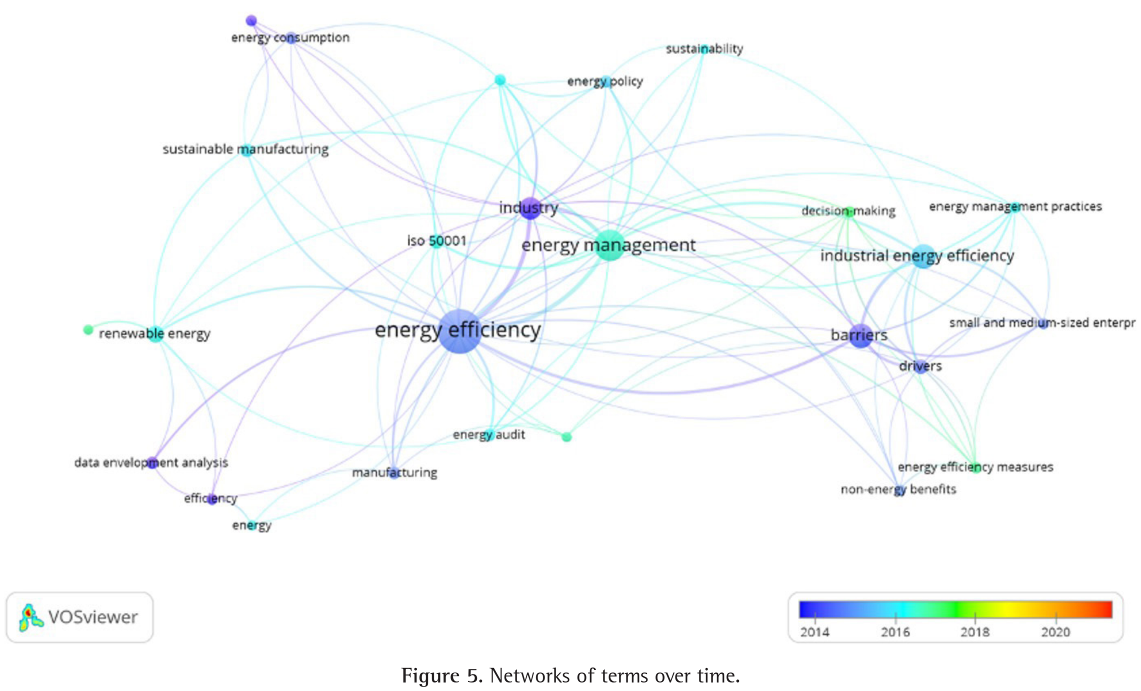

Figure 5. Networks of terms over time.

"energy", "energy efficiency", "renewable energy", "sustainable energy". Regarding time distribution, there is a recent network of studies formed by the terms "energy efficiency measures", "decision-making", "renewable energy" and "iso 50001", which may indicate a new field of research, still at an early stage. There is therefore room for further research and consolidation of concepts. Another important point is that after 2018 there are no new terms added.

Based on descriptive analysis, it is possible to observe research trends (Figure 5), central authors (Figure 4), and the main research lines (Table 4) regarding the decision-making process for adopting measures of energy efficiency in production systems. The next section deepens the analysis to achieve the research objective.

3.3. Content analysis

In order to carry out the content analysis (Bardin, 2015; Mozzato & Grzybovski, 2011) of the 69 studies included, the main concepts used in the studies related to energy efficiency in industrial environments were initially identified inductively. The analysis sequence was built from a set of codes elaborated and grouped into families, as shown in Table 5. During the content analysis, the studies were initially classified according to such categories to assist in the evaluation of the works and to identify gaps in the literature.

Table 5. Categories for content analysis.

Analysis Categories	Description
TYPE OF INDUSTRY	
Non-eletro itensive	Non-electro intensive industry
Non-eletro itensive and Electro intensive	Electro intensive industry in conjuntion with non-electro intensive industry
TYPE OF STUDY	
Empirical	Presents practical application or part of a practical context
Theoretical	Does not include application such as SLR
THEME	
Strategy	Presents a strategic approach around EE
Indicators	Displays indicators for EE
Practices	Presents practices and recommendations for EE
ARTIFACTS	
AHP	Using the AHP approach for decision support in EE.
DEA	Use of DEA approach for decision support in EE.
DES	Use of DES approach for decision support in EE.
Fuzzy	Use of Fuzzy approach for decision support in EE.
Game Theory	Use of Game Theory approach to support decision in EE.
IRR	Use of the IRR approach to support decision in EE.
MCDA	Use of the MCDA approach for decision support in EE.
Monte Carlo	Using the Monte Carlo approach for decision support in EE.
NPV	Use of NPV approach for decision support in EE.
Optimization	Use of the Optimization approach for decision support in EE.
Hybrids	Use of other methods for decision support in EE.
Payback	Use of Payback approach for decision support in EE.
SD	Use of the MDS approach for decision support in EE.

Most empirical studies are related exclusively to indicators (Table 6), totaling twelve publications, followed by strategy with eight and practices with seven. Two empirical studies contemplated more than one theme, strategy and practice.

Among the theoretical studies (Finnerty et al., 2017; Palm & Thollander, 2010; Thollander & Palm, 2015; Bhanot et al., 2017; Cooremans, 2011, 2012; Henriques & Catarino, 2016; Reddy, 2013; Trianni et al., 2017; Cagno et al., 2018; Neri et al., 2018; Rotzek et al., 2018; Mawson & Hughes, 2019; Çoban et al., 2020; Simeonovski et al., 2021), there are publications focusing on strategic character. The topic indicators are treated theoretically in twelve publications, practices are the object of theoretical study in eight publications. Two theoretical studies approach strategy, indicators and practices at the same time one mention strategies and indicators, two strategies and practices and four approach indicators and practices, all this information can be seen in Table 6.

Table 6. Classification of studies.

	Approach		Theme		
Studies	Empirical	Theoretical	Strategies	Indicators	Practices
Alcorta et al. (2014)	X	-	X	-	-
Alkaraan (2020)	X	-	-	-	X
Aplak & Sogut (2013)	X	-	X	-	-
Paramonova & Thollander (2016)	X	-	X	-	-
Andrei et al. (2021)	-	X	X	-	X
Bhanot et al. (2017)	-	X	X	-	X
Buccieri et al. (2020)	X	-	X	-	X
Cagno et al. (2018)	-	X	X	-	-
Adane et al (2014)	X	-	-	X	-
Boehner (2015)	X	-	-	X	-
Cassettari et al. (2017)	X	-	-	X	-
Dong & Huo (2017)	X	-	-	X	-
Karlsson (2011)	X	-	-	X	-
Kim et al. (2015)	X	-	-	X	-
Knobloch & Mercure (2016)	X	-	-	X	-
Landini & Sant'Ana (2017)	X	-	-	X	-
Lung et al. (2005)	X	-	-	X	-
Never (2016)	X	-	-	X	-
Çoban et al. (2020)	-	X	X	-	-
Finnerty et al. (2017)	-	X	X	X	-
Fresner et al. (2017)	X	-	-	-	X
Sáenz et al. (2012)	X	-	-	-	X
Zeng et al. (2015)	X	-	-	-	X
Hasan & Trianni (2020)	-	X	-	X	X
Hasan et al. (2019)	X	-	-	-	X
Ionescu & Darie (2020)	X	-	-	X	-
König et al. (2020)	X	-	X	-	X
Fenerich et al. (2017)	-	X	X	X	X
May et al. (2017)	-	X	X	X	X
König (2020)	X	-	X	-	-
Cooremans (2011)	-	X	X	-	-
Cooremans (2012)	-	X	X	-	-
Henriques & Catarino (2016)	-	X	X	-	-
Palm & Thollander (2010)	-	X	X	-	-
Reddy (2013)	-	X	X	-	-
Thollander & Palm (2015)	-	X	X	-	-
Trianni et al. (2017)	-	X	X	-	-
Lawrence et al. (2019)	-	X	-	X	-
Li et al. (2020)	-	X	-	X	-
Lopes et al. (2018)	-	X	-	-	X
Lyubchenko et al. (2020)	-	X	-	X	-
Martins et al., 2019)	X	-	-	-	X
Martins et al. (2020)	-	X	-	X	X
Mawson & Hughes (2019)	-	X	X	-	-
Neri et al. (2018)	-	X	X	-	-
Horschig & Thrän (2017)	-	X	-	X	-

Table 6. Continued...

	Approach		Theme		
Studies	Empirical	Theoretical	Strategies	Indicators	Practices
May et al. (2015)	-	X	-	X	-
Nehler & Rasmussen (2016)	-	X	-	X	-
Olanrewaju & Jimoh (2014)	-	X	-	X	-
Patterson (1996)	-	X	-	X	-
Perroni et al. (2016)	-	X	-	X	-
Pusnik et al. (2016)	-	X	-	X	-
Rasmussen (2017)	-	X	-	X	-
Trianni et al. (2014)	-	X	-	X	-
Palm & Thollander (2019)	-	X	-	-	X
Roemer & Strassburger (2019)	-	X	-	-	X
Rotzek et al. (2018)	-	X	X	-	-
Bunse et al. (2011)	-	X	-	X	X
Sa et al. (2018)	X	-	X	-	-
Sarkar et al. (2019)	X	-	-	X	-
Schützenhofer (2021)	X	-	-	-	X
Antunes et al. (2014)	-	X	-	-	X
Schulze et al. (2016)	-	X	-	-	X
Zhu et al. (2017)	-	X	-	-	X
Simeonovski et al. (2021)	-	X	X	-	-
Trianni et al. (2019)	-	X	-	-	X
Wang et al. (2019)	-	X	-	-	X
Wen et al. (2021)	X	-	X	-	-
Zanardo et al. (2018)	-	X	-	X	X

3.3.1. Strategy studies

Energy is generally not an issue when relevant decisions are made about it (Cooremans, 2011). Decision makers are generally unwilling to invest in energy efficiency, even if the investment is profitable, due to the lack of connection to the core business. This means that there is a tendency to concentrate efforts on what is strategic for the company, that is, on known domains, and consider investment in energy efficiency as something secondary (Cooremans, 2011).

However, the study by Cooremans (2011) questions the attitude of neglecting energy efficiency initiatives by stating that an investment can be considered strategic if it contributes to creating, maintaining or developing a sustainable competitive advantage. Thus, if initiatives to increase the company's energy efficiency contribute to expanding an organization's competitive advantage, they are strategic and, therefore, must be considered by decision makers.

From the study by Cooremans (2011), other theoretical studies have come to consider the strategic nature of investments in energy efficiency (Finnerty et al., 2017; Cooremans, 2012; May et al., 2017; Thollander & Palm, 2015; Bhanot et al., 2017; Henriques & Catarino, 2016; Reddy, 2013; König, 2020), but without delving into the subject. An advance was made by Cooremans (2012), which stated that in order to measure the strategic character of an investment, it is necessary to measure its contribution to competitive advantage in each dimension: value, costs, and risk (Cooremans, 2012). The more an investment decision contributes to competitive advantage, the more strategic it is (Cooremans, 2011). In this sense, the way an organization strategically works the energy issue, as well as the procedures chosen for it, is the core elements of the concept of energy management (Thollander & Palm, 2015).

Two recent studies (Bhanot et al., 2017; Trianni et al., 2017), presented aspects about the lack of metrics to evaluate energy efficiency projects, as well as the absence of models that allow a systemic understanding of internal and external factors to be considered in the strategic evaluation of investments in energy efficiency.

The scarcity of metrics was addressed by two empirical studies (Aplak & Sogut, 2013; Alcorta et al., 2014), but only considered financial indicators as part of the evaluation in decision-making. The study of Paramonova & Thollander (2016) advanced in the theme as it presented the learning of SMEs in the Swedish industry. The relevance of Sweden in the field of energy efficiency research for non-intensive energy companies was highlighted in the co-authoring analysis, as shown in Table 3.

3.3.2. Indicator studies

There is no consensus on the energy efficiency indicator that can be widely applied. Appropriate indicators should be defined according to the decision to be made or the decision tool to be applied (Bunse et al., 2011). The study by Bunse et al. (2011) provided an overview of different energy efficiency indicators. Although studies have been conducted on energy efficiency indicators at a national or sector level, there are a limited number of studies in companies, plants, or production processes (Bunse et al., 2011).

Most theoretical studies (Olanrewaju & Jimoh, 2014; Perroni et al., 2016; Pusnik et al., 2016; Nehler & Rasmussen, 2016; May et al., 2015; Horschig & Thrän, 2017; Rasmussen, 2017; Trianni et al., 2014) present conceptual proposals for integrating indicators with energy management systems. These integration proposals aim to evaluate energy efficiency by considering physical, thermodynamic, and economic characteristics. However, the indicator Energy Intensity stands out when it comes to energy efficiency mainly in broad assessments to measure the competitiveness of industry in different countries (Bunse et al., 2011).

The other studies address the theme of indicators and measurements of performance in energy efficiency as complementary elements for the development of models to assist in the evaluation and the decision-making using different approaches, such as linear programming (Karlsson, 2011), dynamics modeling systems (Adane et al., 2014), multicriteria decision (Boehner, 2015; Li et al., 2020), DEA (Kim et al., 2015; Simeonovski et al., 2021), computational simulation (Cassettari et al., 2017; Ionescu & Darie, 2020), mathematical model (Sarkar et al., 2019) and fuzzy logic (Dong & Huo, 2017; Çoban et al., 2020).

3.3.3. Practices studies

Five of the total studies only approach non-electro intensive industries (Zeng et al., 2015; Zhu et al., 2017; Lopes et al., 2018; Hasan et al., 2019; Martins et al., 2019, 2020). Two empirical studies stand out for evaluating the minimum requirements proposed by (Schulze et al., 2016) in real environments. The first (Zeng et al., 2015) used system dynamics modeling (SDM) to regularly measure and monitor the energy consumption of the main production processes, and the second (Fresner et al., 2017) evaluated the initial energy audit to identify potential energy savings in 280 SMEs in Europe. Although energy audits are one of the most widely used and widespread tools to overcome barriers to energy efficiency, comprehensive and effective tools are still needed to conduct an effective energy auditing (Fresner et al., 2017).

The practices most found in the studies analyzed are related to what is defined as the energy management system (EnMS) (Antunes et al., 2014). The EnMS is a set of interrelated elements used to establish an energy policy and energy goals, as well as processes and practices to achieve such goals (Schulze et al., 2016). Thus, the selected theoretical studies that address the elements and characteristics of EnMS in industrial environments constitute the majority among the energy efficiency practices (Finnerty et al., 2017; Bunse et al., 2011; Schulze et al., 2016; May et al., 2017; Bhanot et al., 2017; Antunes et al., 2014; Palm & Thollander, 2019; Schützenhofer, 2021).

3.3.4. Artifacts, limitations, and gaps

Among the artifacts identified in the RSL, PB (Payback), NPV (Net Present Value) and IRR (Internal Rate of Return) are those that represent most of the applications, totaling 31 incidences. This means that these 3 investment analysis tools are the most widely used to assess the feasibility of adopting energy efficiency initiatives in industrial settings. However, as highlighted in the literature, the approaches using PB, NPV and IRR have important limitations, causing initiatives not to be adopted even when these methods present attractive results. Among the limitations of financial techniques, there is the absence of non-economic factors or non-financial benefits. A summary of these limitations is presented in Table 7.

The limitations found by financial techniques include the absence of non-economic factors, also called non-financial benefits. Given the fact that financial characteristics alone are not sufficient to drive the choice of an energy efficient technology, the absence of non-financial factors implies an even greater misalignment

Table 7. Artifacts Overview.

Area	Technique	Occurrences	Gaps (in the application context)
Financial	Payback	14	It does not include non-financial benefits;
	NPV	8	It does not consider the possible interrelation between external and internal variables.
	IRR	9	
Non-financial	MCDM	8	Linear and static process.
Modeling	Monte Carlo	2	It does not consider the possible interrelation between external and internal variables;
	DES	5	Linear and static process (Optimization);
	Optimization	10	Local focus.
	System dynamics	6	

of these approaches. In this sense, other studies have begun to evaluate the use of non-financial tools to complement financial tools.

In artifacts that have non-financial characteristics present techniques related to multi-criteria decision methods (MCDM) consumption (Olanrewaju & Jimoh, 2014; Finnerty et al., 2017; Boehner, 2015; Dong & Huo, 2017; Aplak & Sogut, 2013; Bhanot et al., 2017; Horschig & Thrän, 2017; Li et al., 2020), such as the analytic hierarchy process (AHP) (Lyubchenko et al., 2020; Li et al., 2020) and fuzzy logic (Ho & Ma, 2018; Çoban et al., 2020; Li et al., 2020) were found in the SLR. The study of Aplak & Sogut (2013), proposed an approach combining elements of AHP, Fuzzy and Game Theory to deploy industrial strategies and prioritize the choices related to energy management. Despite being comprehensive, this approach presents a linear process, without considering the possible interrelationships between internal and external variables. Other studies have used techniques such as Monte Carlo (Cassettari et al., 2017; Knobloch & Mercure, 2016), simulation of discrete events (Cassettari et al., 2017; Sáenz et al., 2012; Horschig & Thrän, 2017), optimization (Karlsson, 2011; Sáenz et al., 2012; Hasan & Trianni, 2020; Sarkar et al., 2019; Ionescu & Darie, 2020; Simeonovski et al., 2021; Roemer & Strassburger, 2019) and system dynamic modeling (Adane et al., 2014; Zeng et al., 2015; Horschig & Thrän, 2017; Martins et al., 2020).

The theoretical model identified in the literature presents a set of gaps and limitations, focusing on the use of artifacts that, in summary, do not consider the possible inter-relationship between external and internal variables and adopting a static linear decision process, with a local focus. In the current model, evaluations of the decision to adopt an Energy Efficiency Action are made based on traditional approaches such as NPV, ROI and Payback, which has not contributed to the adoption of energy efficiency practices by small industrial consumers, increasing the energy efficiency gap.

3.3.5. Energy efficiency initiatives

There is a so-called energy efficiency gap related to the non-implementation of energy efficiency and energy management initiatives despite their cost-effectiveness (Finnerty et al., 2017; Fenerich et al., 2017; Bunse et al., 2011; Thollander & Palm, 2015; Alcorta et al., 2014; Henriques & Catarino, 2016; Reddy, 2013; Wen et al., 2021; Palm & Thollander, 2019). That is, practical evidence and theoretical studies suggest that while the industrial sector records a continuous improvement in energy efficiency, there is ample potential to be explored (Bunse et al., 2011).

The debate on the energy efficiency gap should focus on the reasons why companies do not make investments considered profitable to increase energy efficiency. Understanding the disparity between the potential and the implementation of energy efficiency initiatives, as well as the scarcity of specific artifacts, is the main limitation found in the literature.

Despite the existence of studies that call for an integrated and strategic approach to consider energy efficiency (Cooremans, 2011, 2012; Patterson, 1996), there are few studies in the researched literature that detail ways to make this integration feasible. In other words, the literature has advanced in relation to "what to do", but practically ignores the "how to".

The first gap is related to how the potential of energy efficiency measures are evaluated by companies, especially non-energy intensive companies. It means the industry's need to establish a set of metrics to assess the impacts of energy efficiency initiatives. However, the approaches found in the literature indicate that most companies use only financial indicators. Even if the results of these indicators are financially attractive, the level of adoption of energy efficiency initiatives are low.

Thus, the question of how to reduce the gap in the implementation of measures to increase energy efficiency has been a recurrent issue in recent studies. The main model used to explain this discrepancy is barriers, according to which different barriers to energy efficiency inhibit the adoption of economically attractive measures (Thollander & Palm, 2015). Barriers are mechanisms that inhibit a decision or a behavior that seems to be energy efficient and economical. Several studies have examined barriers to the implementation of measures to improve energy efficiency in enterprises in different contexts (Perroni et al., 2016; Knobloch & Mercure, 2016; Palm & Thollander, 2010; Paramonova & Thollander, 2016; Thollander & Palm, 2015; Henriques & Catarino, 2016; Reddy, 2013; Trianni et al., 2014, 2017; Rasmussen, 2017; König, 2020; Hasan & Trianni, 2020; Li et al., 2020; Schützenhofer, 2021).

The factors pointed out in the literature that can contribute to the adoption of practices to increase energy efficiency in production systems are called drivers. Drivers may influence part of the organization and the decision-making process to overcome barriers (Perroni et al., 2016; Reddy, 2013; Trianni et al., 2017; Hasan et al., 2019).

Some studies have similar positions with regard to the change in the form of evaluation of energy efficiency investments (Cooremans, 2011, 2012; Thollander & Palm, 2015; Aplak & Sogut, 2013; Bhanot et al., 2017), proposing a strategic analysis inserted in a sociotechnical paradigm. However, most studies reinforce that the most used techniques to evaluate energy efficiency investments are based on traditional investment analysis approaches such as Net Present Value (NPV), Internal Rate of Return (IRR) and Payback (PB) (Finnerty et al., 2017; Bunse et al., 2011; Nehler & Rasmussen, 2016; Cooremans, 2012; Knobloch & Mercure, 2016; Lung et al., 2005; Karlsson, 2011; Landini & Sant'Ana, 2017; Alcorta et al., 2014; Rasmussen, 2017; Trianni et al., 2014; Schützenhofer, 2021; Alkaraan, 2020).

Despite this context, there were no studies addressing the evaluation of the impacts and the adoption of initiatives for energy efficiency in companies of non-intensive energy use in a systemic way that consider the dynamic nature of the relationships between variables (internal and external), barriers and drivers. It is possible to show that the studies that deal with non-financial factors for the adoption of energy efficiency measures are scarce and recent, configuring a new field of research and more room for theoretical advances.

The main criticisms on how the energy efficiency gap is being treated in the literature can be summarized in four topics, which are presented in Table 8.

Table 8. Criticism to current approaches.

Problems identified in the literature	Criticism
Artifacts for the evaluation of energy efficiency measures.	Although current techniques for assessing investment in energy efficiency are financially attractive, the level of adoption of energy efficiency initiatives has been low.
Energy efficiency gap	Although the existence of an energy efficiency gap is addressed by the literature, studies do not advance as to *how* to reduce the gap of implementing measures to increase energy efficiency.
Interrelationship between variables (external and internal)	The interrelationship between variables (external and internal) related to barriers and drivers for adopting energy efficiency measures is not addressed in the literature.
Dynamic and systemic understanding of variables	The understanding (systemic and dynamic) of these variables was not mentioned in the literature, although authors emphasize the importance of having a holistic view about the problem.

4 Final considerations

Although energy efficiency positively influences the performance of the industry (Bunse et al., 2011; Knobloch & Mercure, 2016; May et al., 2015; Thollander & Palm, 2015; Adane et al., 2014; Bhanot et al., 2017; Cooremans, 2011), contributing to an increase in competitiveness, the research on the assessment of such benefits is scarce (Fenerich et al., 2017; Rasmussen, 2017). In addition, most studies found are related to energy efficiency of buildings. In industrial environments, studies on thermodynamic and mechanical efficiency in electro-intensive companies have received more attention. However, the context of such companies is different from those of non-intensive energy use, which makes it difficult to generalize or adopt practices in the context of SMEs. Researching this comparison means a research opportunity in the decision-making process for adopting energy efficiency measures in non-energy intensive enterprises.

The practical contributions point to some caveats that non-energy intensive enterprises should observe. First, the variables and artifacts must be tailored specifically to the context of small and micro firms. There is a greater breadth of activities in these companies making it difficult to use the models and artifacts directly. Second, only financial aspects justify non-energy intensive enterprise energy efficiency improvement initiatives. Both the energy market context, including public policies, in which the company finds itself, and the policies of its customers can justify these efforts. For example, the UN recently established 17 sustainable development goals in general and "doubling the global energy efficiency rate by 2030" in particular. As such, adopting initiatives in this direction can potentially serve markets that are aligned with the UN's goals. Third, it is necessary to technically train professionals and decision-makers to understand the advantages and disadvantages of each artifact for evaluating energy efficiency initiatives. The financial artifacts, such as NPV and IRR, are widely known and can limit or invalidate energy efficiency actions in this business segment. Furthermore, ignoring the dynamics of contextual variables reduces the analysis to the short term only, disregarding medium and long-term opportunities. Finally, this study points out the need for public policies and specific metrics for the non-energy intensive Enterprise segment. The implementation of efficiency actions in this segment reduces energy consumption by increasing energy availability for other productive activities. Furthermore, non-energy intensive Enterprises have historically been neglected and, consequently, may present greater opportunities for improvement.

The presentation of results using the SNA, especially the density of co-authorship and the networks of terms formed over time, represents an advance in relation to works of this nature. The co-authorship density allowed the identification of the main research clusters on the subject, something that was not found in literature. Accordingly, the network of terms shows an unprecedented vision, as it illustrates the importance and evolution of each research subject in the studied situations, allowing to relate the most recent terms and locate this study in the knowledge frontier.

The literature understands the potential of energy efficiency by these companies, recognizes the gap between the potential and the adoption of measures, and highlights the need to understand this. However, more research is needed to assess the involved factors by using a holistic approach. Existing studies address the issue in a segmented and isolated way.

In this sense, the understanding of the decision process regarding the adoption of initiatives to increase energy efficiency in non-energy intensive companies, especially in the Brazilian context, is necessary. It is possible to observe the limitation of traditional approaches (NPV, IRR and Payback) to evaluate the adoption of these initiatives, mainly because they do not incorporate factors other than technical and financial factors.

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References

Adane, T. F., Nafisi, M., Asif, F. M. A., Semere, D. T., & Nicolescu, M. (2014). System dynamics analysis of energy usage: case studies in automotive manufacturing. *International Journal of Manufacturing Research*, *9*(2), 131-156.

Adler, M. J., & van Doren, C. (2010). *Como ler livros: o guia clássico para a leitura inteligente*. É Realizações.

Alcorta, L., Bazilian, M., De Simone, G., & Pedersen, A. (2014). Return on investment from industrial energy efficiency: evidence from developing countries. *Energy Efficiency*, *7*(1), 43-53.

Alkaraan, F. (2020). Strategic investment decision-making practices in large manufacturing companies: a role for emergent analysis techniques? *Meditari Accountancy Research*, *28*, 633-653.

Andrei, M., Thollander, P., Pierre, I., Gindroz, B., & Rohdin, P. (2021). Decarbonization of industry: Guidelines towards a harmonized energy efficiency policy program impact evaluation methodology. *Energy Reports*, *7*, 1385-1395. http://dx.doi.org/10.1016/j.egyr.2021.02.067.

Antunes, P., Carreira, P., & Silva, M. M. (2014). Towards an energy management maturity model. *Energy Policy*, *73*, 803-814. http://dx.doi.org/10.1016/j.enpol.2014.06.011.

Aplak, H. S., & Sogut, M. Z. (2013). Game theory approach in decisional process of energy management for industrial sector. *Energy Conversion and Management*, *74*, 70-80.

Bardin, L. (2015). *Análise de conteúdo*. São Paulo: Edições 70.

Bhanot, N., Rao, P. V., & Deshmukh, S. G. (2017). An integrated approach for analysing the enablers and barriers of sustainable manufacturing. *Journal of Cleaner Production*, *142*(4), 4412-4439. http://dx.doi.org/10.1016/j.jclepro.2016.11.123.

Boehner, J. (2015). Multi criteria decision making enhancing sustainable energy management. *Applied Mechanics and Materials*, *805*, 32-37. http://dx.doi.org/10.4028/www.scientific.net/AMM.805.32.

Bunse, K., Vodicka, M., Schönsleben, P., Brülhart, M., & Ernst, F. O. (2011). Integrating energy efficiency performance in production management: gap analysis between industrial needs and scientific literature. *Journal of Cleaner Production*, *19*(6-7), 667-679.

Buccieri, G. P., Balestieri, J. A. P., & Matelli, J. A. (2020). Energy efficiency in Brazilian industrial plants: knowledge management and applications through an expert system. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *42*(11), 1-12.

Cagno, E., Neri, A., & Trianni, A. (2018). Broadening to sustainability the perspective of industrial decision-makers on the energy efficiency measures adoption: some empirical evidence. *Energy Efficiency*, *11*, 1193-1210. http://dx.doi.org/10.1007/s12053-018-9621-0.

Cassettari, L., Bendato, I., Mosca, M., & Mosca, R. (2017). Energy Resources Intelligent Management using online real-time simulation: a decision support tool for sustainable manufacturing. *Applied Energy*, *190*, 841-851.

Çoban, V., Onar, E., Oztaysi, B., & Kahraman, C. (2020). Energy management maturity model based on fuzzy probabilistic linguistic term sets. *Journal of Multiple-Valued Logic & Soft Computing*, *35*(1-2), 217-237.

Cooremans, C. (2011). Make it strategic! Financial investment logic is not enough. *Energy Efficiency*, *4*(4), 473-492.

Cooremans, C. (2012). Investment in energy efficiency: Do the characteristics of investments matter? *Energy Efficiency*, *5*(4), 497-518.

Dong, J., & Huo, H. (2017). Identification of financing barriers to energy efficiency in small and medium-sized enterprises by integrating the fuzzy delphi and fuzzy DEMATEL approaches. *Energies*, *10*(8), 1172.

Dresch, A., Lacerda, D., & Antunes Junior, J. (2015). *Design science research: a method for science and technology advancement*. Cham: Springer.

Ermel, A. P. C., Lacerda, D. P., Morandi, M. I. W. M., & Gauss, L. (2021). *Literature reviews: modern methods for investigating scientific and technological knowledge*. Cham: Springer.

Fenerich, F. C., Costa, S. G., & Lima, E. P. (2017). Energy efficiency in industrial environments: overview and research agenda. *IEEE Latin America Transactions*, *15*(3), 415-422.

Finnerty, N., Sterling, R., Coakley, D., Contreras, S., Coffey, R., & Keane, M. M. (2017). Development of a Global Energy Management System for non-energy intensive multi-site industrial organisations: a methodology. *Energy*, *136*, 16-31. http://dx.doi.org/10.1016/j.energy.2016.10.049.

Fresner, J., Morea, F., Krenn, C., Aranda Uson, J., & Tomasi, F. (2017). Energy efficiency in small and medium enterprises: lessons learned from 280 energy audits across Europe. *Journal of Cleaner Production*, *142*, 1650-1660.

Hasan, A. S. M. M., & Trianni, A. (2020). A review of energy management assessment models for industrial energy efficiency. *Energies*, *13*(21), 5713. http://dx.doi.org/10.3390/en13215713.

Hasan, A. S. M. M., Hossain, R., Tuhin, R. A., Sakib, T. H., & Thollander, P. (2019). Empirical investigation of barriers and driving forces for efficient energy management practices in non-energy-intensive manufacturing industries of Bangladesh. *Sustainability*, *11*(9), 2671. http://dx.doi.org/10.3390/su11092671.

Henriques, J., & Catarino, J. (2016). Motivating towards energy efficiency in small and medium enterprises. *Journal of Cleaner Production*, *139*, 42-50.

Ho, W., & Ma, X. (2018). The state-of-the-art integrations and applications of the analytic hierarchy process. *European Journal of Operational Research*, *267*(2), 399-414. http://dx.doi.org/10.1016/j.ejor.2017.09.007.

Horschig, T., & Thrän, D. (2017). Are decisions well supported for the energy transition? A review on modeling approaches for renewable energy policy evaluation. *Energy, Sustainability and Society*, *7*(1), 5.

International Energy Agency – IEA. (2016). *Energy efficiency market report.* Paris: IEA.

Ionescu, C. V., & Darie, G. 2020. Energy Effectiveness-New Energy Performance Indicator to optimize the Industrial Energy Consumptions. In *EPE 2020 - Proceedings of the 2020 11th International Conference and Exposition on Electrical And Power Engineering* (pp. 462-465). Piscataway: Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/EPE50722.2020.9305663.

Karlsson, M. (2011). The MIND method: a decision support for optimization of industrial energy systems: principles and case studies. *Applied Energy*, *88*(3), 577-589.

Kim, K. T., Lee, D. J., Park, S. J., Zhang, Y., & Sultanov, A. (2015). Measuring the efficiency of the investment for renewable energy in Korea using data envelopment analysis. *Renewable & Sustainable Energy Reviews*, *47*, 694-702.

Knobloch, F., & Mercure, J. F. (2016). The behavioural aspect of green technology investments: a general positive model in the context of heterogeneous agents. *Environmental Innovation and Societal Transitions*, *21*, 39-55.

König, W. (2020). Energy efficiency in industrial organizations: a cultural-institutional framework of decision making. *Energy Research & Social Science*, *60*, 101314. http://dx.doi.org/10.1016/j.erss.2019.101314.

König, W., Löbbe, S., Büttner, S., & Schneider, C. (2020). Establishing energy efficiency⇔drivers for energy efficiency in german manufacturing small- and medium-sized enterprises. *Energies*, *13*(19), 5144. http://dx.doi.org/10.3390/en13195144.

Lacerda, D. P., Dresch, A., Proença, A., Antunes Júnior, J., & Valle, J. A. (2013). Design Science Research: método de pesquisa para a engenharia de produção. *Gestão & Produção*, *20*(4), 741-761. http://dx.doi.org/10.1590/S0104-530X2013005000014.

Landini, C. L., & Sant'Ana, P. H. M. (2017). Technical, economic, and regulatory analysis of the implementation of micro-cogeneration technology in the Brazilian manufacturing sector. *Energy Efficiency*, *10*(4), 957-971.

Lawrence, A., Thollander, P., Andrei, M., & Karlsson, M. (2019). Specific energy consumption/use (SEC) in energy management for improving energy efficiency in industry: meaning, usage and differences. *Energies*, *12*(2), 247. http://dx.doi.org/10.3390/en12020247.

Li, T., Li, A., & Guo, X. (2020). The sustainable development-oriented development and utilization of renewable energy industry: a comprehensive analysis of MCDM methods. *Energy*, *212*, 118694. http://dx.doi.org/10.1016/j.energy.2020.118694.

Lopes, J. R., Ávila, S., Kalid, R., & Rodríguez, J. L. M. (2018). Energy efficiency improvement in non-intensive energy enterprises: a framework proposal. *Energies*, *11*(5), 1271. http://dx.doi.org/10.3390/en11051271.

Lung, R. B., Mckane, A., Leach, R. & Marsh, D. (2005). Ancillary savings and production benefits in the evaluation of industrial energy efficiency measures. In *ACEEE Summer Study on Energy Efficiency in Industry* (pp. 103-114). Washington: ACEEE.

Lyubchenko, V. Y., Iskhakov, A. F., & Pavlyuchenko, D. A. (2020). Rating of organization's energy efficiency based on Harrington's desirability function. In *2020 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2020.* Piscataway: Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/FarEastCon50210.2020.9271239.

Martins, J. C., Lacerda, D. P., Wolf Motta Morandi, M. I., Goldmeyer, D., & Piran, F. S. (2020). Systems dynamic modeling to analyze the systemic viability of the combined use of regenerative converters and energy storage in a UPS manufacturer. *Journal of Cleaner Production*, *246*, 118950. http://dx.doi.org/10.1016/j.jclepro.2019.118950.

Martins, J. C., Morandi, M. I. W. M., & Lacerda, D. P. (2019). Estimating the long-term financial impact of solar microgeneration and energy efficiency for a brazilian medium-sized enterprise. *IEEE Latin America Transactions*, *17*(10), 1607-1615. http://dx.doi.org/10.1109/TLA.2019.8986438.

Mawson, V. J., & Hughes, B. R. (2019). The development of modelling tools to improve energy efficiency in manufacturing processes and systems. *Journal of Manufacturing Systems*, *51*, 95-105. http://dx.doi.org/10.1016/j.jmsy.2019.04.008.

May, G., Barletta, I., Stahl, B., & Taisch, M. (2015). Energy management in production: a novel method to develop key performance indicators for improving energy efficiency. *Applied Energy*, *149*, 46-61.

May, G., Stahl, B., Taisch, M., & Kiritsis, D. (2017). Energy management in manufacturing: from literature review to a conceptual framework. *Journal of Cleaner Production*, *167*, 1464-1489. http://dx.doi.org/10.1016/j.jclepro.2016.10.191.

Morandi, M. I. W. M., & Camargo, L. F. (2015). Revisão sistemática da literatura. In A. Dresch, D. P. Lacerda & J. A. V. Júnior Antunes (Eds.), *Design Science Research: método de pesquisa para a engenharia de produção* (pp. 141-175). Porto Alegre: Bookman.

Mozzato, A. R., & Grzybovski, D. (2011). Análise de conteúdo como técnica de análise de dados qualitativos no campo da administração: potencial e desafios. *Revista de Administração Contemporânea*, *15*(4), 731-747.

Nehler, T., & Rasmussen, J. (2016). How do firms consider non-energy benefits? Empirical findings on energy-efficiency investments in Swedish industry. *Journal of Cleaner Production*, *113*, 472-482.

Neri, A., Cagno, E., di Sebastiano, G., & Trianni, A. (2018). Industrial sustainability: modelling drivers and mechanisms with barriers. *Journal of Cleaner Production*, *194*, 452-472. http://dx.doi.org/10.1016/j.jclepro.2018.05.140.

Never, B. (2016). Behave and save? Behaviour, energy efficiency and performance of micro and small enterprises in Uganda. *Energy Research & Social Science*, *15*, 34-44.

Olanrewaju, O. A., & Jimoh, A. A. (2014). Review of energy models to the development of an efficient industrial energy model. *Renewable & Sustainable Energy Reviews*, *30*, 661-671.

Otte, E., & Rousseau, R. (2002). Social network analysis: a powerful strategy, also for the information sciences. *Journal of Information Science*, *28*(6), 441-453.

Palm, J., & Thollander, P. (2010). An interdisciplinary perspective on industrial energy efficiency. *Applied Energy*, *87*(10), 3255-3261.

Palm, J., & Thollander, P. 2019. Reframing energy efficiency in industry: a discussion of definitions, rationales, and management practices. In M. Lopes, C. H. Antunes & K. B. Janda (Eds.), *Energy and behaviour: towards a low carbon future* (pp. 153-175). London: Elsevier. https://doi.org/10.1016/B978-0-12-818567-4.00007-7.

Paramonova, S., & Thollander, P. (2016). Energy-efficiency networks for SMEs: learning from the Swedish experience. *Renewable & Sustainable Energy Reviews*, *65*, 295-307.

Patterson, M. G. (1996). What is energy efficiency? Concepts, indicators and methodological issues. *Energy Policy*, *24*(5), 377-390.

Perroni, M. G., Gouvea, S. E. C., Pinheiro, E. de L., & Silva, W. V. (2016). The relationship between enterprize efficiency in resource use and energy efficiency practices adoption. *International Journal of Production Economics*, *190*, 108-119.

Piovezan, L. B., & Fujita, M. S. L. (2015). Análise de cocitação de autores: uma aplicação em estudos de indexação. *Em Questão*, *21*(1), 110-129.

Pusnik, M., Al-Mansour, F., Sucic, B., & Gubina, A. F. (2016). Gap analysis of industrial energy management systems in Slovenia. *Energy*, *108*, 41-49.

Rasmussen, J. (2017). The additional benefits of energy efficiency investments: a systematic literature review and a framework for categorisation. *Energy Efficiency*, *10*(6), 1401-1418. http://dx.doi.org/10.1007/s12053-017-9528-1.

Reddy, B. S. (2013). Barriers and drivers to energy efficiency: a new taxonomical approach. *Energy Conversion and Management*, *74*, 403-416.

Roemer, A. C., & Strassburger, S. (2019). Hybrid system modeling approach for the depiction of the energy consumption in production simulations. In *Proceedings of the 2019 Winter Simulation Conference.* New York: IEEE.

Rotzek, J. N., Scope, C., & Günther, E. (2018). What energy management practice can learn from research on energy culture? Sustainability accounting. *Management and Policy Journal*, *9*(4), 515-551. http://dx.doi.org/10.1108/SAMPJ-07-2017-0067.

Sa, A., Thollander, P., & Rafiee, M. (2018). Industrial energy management systems and energy-related decision-making. *Energies*, *11*(10), 2784. http://dx.doi.org/10.3390/en11102784.

Sáenz, J. P., Celik, N., Asfour, S., & Son, Y. J. (2012). Electric utility resource planning using Continuous-Discrete Modular Simulation and Optimization (CoDiMoSO). *Computers & Industrial Engineering*, *63*(3), 671-694.

Sarkar, M., Kim, S., Jemai, J., Ganguly, B., & Sarkar, B. (2019). An application of time-dependent holding costs and system reliability in a multi-item sustainable economic energy efficient reliable manufacturing system. *Energies*, *12*(15), 2857. http://dx.doi.org/10.3390/en12152857.

Schulze, M., Nehler, H., Ottosson, M., & Thollander, P. (2016). Energy management in industry: a systematic review of previous findings and an integrative conceptual framework. *Journal of Cleaner Production*, *112*, 3692-3708.

Schützenhofer, C. (2021). Overcoming the efficiency gap: energy management as a means for overcoming barriers to energy efficiency, empirical support in the case of Austrian large firms. *Energy Efficiency*, *14*, 45. http://dx.doi.org/10.1007/s12053-021-09954-z.

Simeonovski, K., Kaftandzieva, T., & Brock, G. (2021). Energy efficiency management across EU countries: a DEA approach. *Energies*, *4*(9), 2619. http://dx.doi.org/10.3390/en14092619.

Thollander, P., & Palm, J. (2015). Industrial energy management decision making for improved energy efficiency: strategic system perspectives and situated action in combination. *Energies*, *8*(6), 5694-5703.

Trianni, A., Cagno, E., & De Donatis, A. (2014). A framework to characterize energy efficiency measures. *Applied Energy*, *118*, 207-220.

Trianni, A., Cagno, E., & Neri, A. (2017). Modelling barriers to the adoption of industrial sustainability measures. *Journal of Cleaner Production*, *168*, 1482-1504. http://dx.doi.org/10.1016/j.jclepro.2017.07.244.

Trianni, A., Cagno, E., Bertolotti, M., Thollander, P., & Andersson, E. (2019). Energy management: a practice-based assessment model. *Applied Energy*, *235*, 1614-1636. http://dx.doi.org/10.1016/j.apenergy.2018.11.032.

Veit, D. R., Lacerda, D. P., Camargo, L. F. R., Kipper, L. M., & Dresch, A. (2017). Towards Mode 2 knowledge production. *Business Process Management Journal*, *23*, 293-328.

Wang, Z., Xu, G., Lin, R., Wang, H., & Ren, J. (2019). Energy performance contracting, risk factors, and policy implications: Identification and analysis of risks based on the best-worst network method. *Energy*, *170*, 1-13. http://dx.doi.org/10.1016/j.energy.2018.12.140.

Wen, X., Cao, H., Hon, B., Chen, E., & Li, H. (2021). Energy value mapping: a novel lean method to integrate energy efficiency into production management. *Energy*, *217*, 119353. http://dx.doi.org/10.1016/j.energy.2020.119353.

Zanardo, R. P., Siluk, J. C. M., Souza Savian, F., & Schneider, P. S. (2018). Energy audit model based on a performance evaluation system. *Energy*, *154*, 544-552. http://dx.doi.org/10.1016/j.energy.2018.04.179.

Zeng, M., Wang, G., Wang, H., Gao, Y., Guo, L., Zhang, J., & Zhang, H. (2015). Industrial system energy efficiency assessment using system dynamics. In *Proceedings of the 2015 3rd International Conference on Machinery, Materials and Information Technology Applications* (Vol. *35*, pp. 1299-1302). Dordrecht: Atlantis Press.

Zhu, S., Jiang, Z., Zhang, H., Tian, G., & Wang, Y. (2017). A carbon efficiency evaluation method for manufacturing process chain decision-making. *Journal of Cleaner Production*, *148*, 665-680.

Appendix A. LSR Protocol

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CONCEPTUAL FRAMEWORK

Research Topic: Energy Efficiency in Operations

Research object: Decision support tools for Energy Efficiency in industrial environments.

Summary of the problem situation: Uncertainty in energy supply has awakened the field of energy efficiency research, as the efficient use of energy, as well as the current context (which involves market, economic, political and technological changes) indicate the need for approaches that can help assess the impact of decisions and initiatives used to increase energy efficiency. This need is even more pressing in industrial environments, as the manufacturing industry requires approximately 1/3 of primary energy, being one of the main energy consumers. In other words, in addition to raw material values and changes in demand, energy can also affect businesses and companies' competitiveness.

CONTEXT

Energy efficiency will be considered in the context of Strategies to Meet Future Electric Energy Demand, assuming that this can be achieved through:

(i) Demand-side management;

(ii) Offer Expansion: Distributed Generation and Self-Production.

Decision support tools include any structured and systematized models, methods, techniques, and/or approaches that can be used to support decision-making.

Companies in the industrial segment, manufacturing companies, production systems, manufacturing system.

Non-energy intensive companies.

HORIZON

Studies published since 1973 (Oil Crisis).

THEORETICAL CURRENTS

Approaches used to "evaluate the impacts of decisions and initiatives to increase energy efficiency in industrial environments".

Strategies, Indicators and Practices related to EE.

LANGUAGES

English; Portuguese.

REVIEW QUESTION

How to assess the impacts of decisions and initiatives to increase energy efficiency in industrial environments?

REVIEW STRATEGY

( ) Aggregative (X) Configurative

SEARCH CRITERIA

Inclusion criteria:	Exclusion criteria:
Application in industrial environments;	Do not contain artifact related to evaluation and/or decision making;
Modeling use;	EE of engines, turbines and the like;
I use structured and systematized methods, techniques, and/or approaches;	EE building;
Contain strategies, indicators and/or practices related to EE;	EE related to the use of electric vehicles;
Complete text.	EE chips, memories, etc;
	Energy intensive industries only.

SEARCH TERMS

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P01: "Energy efficiency" AND "Decision support" AND (Manufacturing OR Industri*)

P02: "Energy efficiency" AND "Decision-making" AND (Manufacturing OR Industri*)

P03: "Energy efficiency" AND "Economic evaluation" AND (Manufacturing OR Industr*) P04: "Energy efficiency" AND "Impact assessment" AND (Manufacturing OR Industr*)

P05: "Energy efficiency" AND "Strategic decision" AND (Manufacturing OR Industri*)

P06: "Energy Management" AND "Decision support" AND (Manufacturing OR Industr*) P07: "Energy Management" AND "Decision-making" AND (Manufacturing OR Industr*) P08: "Energy Management" AND

"Economic evaluation" AND (Manufacturing OR Industr*) P09: "Energy Management" AND "Impact assessment" AND (Manufacturing OR Industr*) P10: "Energy Management" AND "Strategic decision" AND (Manufacturing OR Industr*)

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P11: "Industrial energy efficiency" AND "Decision support"
P12: "Industrial energy efficiency" AND "Decision-making"
P13: "Industrial energy efficiency" AND Evaluation
P14: "Industrial energy efficiency" AND Assessment
P15: "Industrial energy efficiency" AND Strateg*
P16: "Industrial energy management" AND "Decision support"
P17: "Industrial energy management" AND "Decision-making"
P18: "Industrial energy management" AND Evaluation
P19: "Industrial energy management" AND Assessment
P20: "Industrial energy management" AND Strateg*

SEARCH SOURCES

Data base:	Internet:
(1) ProQuest|Technology Collection	( ) Google Scholar
(2) Scopus | Elsevier	
(3) Science Direct | Elsevier	Others (Grey Literature):
(4) Web of Science | Main Collection	() National Electric Energy Agency - ANEEL
(5) IEEE Xplore Digital Library	( ) Center for Management and Strategic Studies - CGEE
( ) Compendex | Engineering Village	( ) Energy Research Company - EPE
( ) Emerald Insight	( ) International Energy Agency - IEA
( ) Capes Periodicals	( ) International Renewable Energy Agency – IRENA

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