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Energy efficiency in industrial environments: an updated review and a new research agenda

Eficiência energética em ambientes industriais: uma revisão atualizada e uma nova agenda de pesquisa

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Abstract

Nowadays, discussions about the use of energy efficiency in industries have intensified due to the need to optimize the resources used, especially the high cost in the production process. In this context, a literature review and a research agenda on energy efficiency in industrial environments can assist in the search for solutions and challenges to reduce energy consumption in manufacturing, as well as identify future trends for the topic. Therefore, this article proposes to update the energy efficiency research agenda in industrial environments, through a systematic review of the literature, between the years 2015 and 2020, in search of articles published in journals with current practices and the new strategies used in energy

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management. For the review of the research agenda, one hundred and eighty-five articles were selected, which were read and used in the bibliometric analysis, which was compared to the results obtained and observed in the base article for this update, thus helping in directing the creation of an agenda for studies and practices in energy efficiency in manufacturing environments.

Keywords: Energy Efficiency. Research Agenda. Systematic Literature Review.

Resumo

Atualmente, as discussões sobre o uso da eficiência energética nas indústrias têm se intensificado devido à necessidade de otimizar os recursos utilizados, especialmente o alto custo no processo de produção. Neste contexto, uma revisão da literatura e uma agenda de pesquisa sobre eficiência energética em ambientes industriais pode auxiliar na busca de soluções e desafios para reduzir o consumo de energia na fabricação, bem como identificar tendências futuras para o tema. Portanto, este artigo propõe atualizar a agenda de pesquisa sobre eficiência energética em ambientes industriais, através de uma revisão sistemática da literatura, entre os anos de 2015 e 2020, em busca de artigos publicados em periódicos com as práticas atuais e as novas estratégias utilizadas no gerenciamento de energia. Para a revisão da agenda de pesquisa, foram selecionados cento e oitenta e cinco artigos, que foram lidos e utilizados na análise bibliométrica, que foi comparada aos resultados obtidos e observados no artigo base desta atualização, ajudando assim a orientar a criação de uma agenda para estudos e práticas de eficiência energética em ambientes industriais.

Palavras-chave: Eficiência Energética. Agenda de pesquisa. Revisão Sistemática da Literatura.

Introduction

Industry consumes large amounts of energy to generate goods and services that move modern society. Therefore, investments in energy generation, distribution and transmission should be made to attend industrial demand with reliability.

Thus, a significant amount of energy resources is required for the operation of industrial facilities and equipment. However, a large part of industrial facilities is not operated at an efficient rate, or are unaware of the actual energy consumption, generating opportunities for development a more energy efficient and sustainable manufacturing sector [2].

This subject has been widely researched since the mid-nineties and more intensely from 2007 [1]. However, there were few studies that attempted to outline an appropriate strategy for mitigating loss of efficiency in industries considering the losses encountered during manufacturing processes [2].

The current energy efficiency profile has changed, due to the growing concern about the environmental impacts generated by energy consumption, which directly influences the reduction of energy use [3].

Although the overall efficiency of a plant is related to conversion devices such as motors, lamps, and passive systems (e.g., ovens and steam systems), it is also strongly influenced by manufacturing factors such as production rates, design parameters, and line configurations [4].

Industrial production rates are strongly related to the efficiency of a manufacturing process [5]. According to the International Energy Agency (IEA), despite the continuous demand for energy in the sector, the search of energy efficiency in recent years has prevented an even greater increase in energy use [6].

Energy efficiency practices also provide benefits related to social, environmental, financial and competitiveness issues to companies that implement such practices [7].

In this context, energy efficiency aims to reduce energy use to the minimum level, without reducing production quality and profitability [8]. One of the main barriers to industrial energy efficiency remains the organizational culture in relation to sustainable product development, as many companies still view efficiency requirements as a problem rather than looking for what it really is: a chance to achieve economic and environmental benefits [2].

Given the context presented and to leverage competitiveness in industrial environments through the development and use of manufacturing strategies, sustainable processes, reduction, and control of energy consumption and beyond and disseminate research in the area, the objective of this article is to conduct a bibliometric study and update the research agenda of Fenerich et al. [1] for energy efficiency in industrial environments. Through the bibliometric study, it was possible to identify the strategic and operational models existing in the literature related to the theme, indicators, as well as energy efficiency models.

The article is organized into four sections, so that in section II is presented the methodology of systematic literature review, in section III are demonstrated the results of bibliometric studies and the updating of the research agenda and finally, section IV deals with the final considerations of the study.

Methodology

The research has a basic nature, of qualitative approach [9], due to the realization of steps of understanding the selected texts, as well as the bibliometric analysis. It is also a research of exploratory objectives [9], carried out through systematized bibliographic research, since the literature review aims to identify the concepts and characteristics presented by the authors analyzed on energy performance in productive environments, through the survey of studies and practices carried out on the subject.

The bibliometric analysis describes the characteristics of the scientific content of the articles, to contribute to the production of knowledge [10]. In Fig. 1, the stages of the systematic review process followed to search for the literature pertinent to the theme and the updating of the agenda are highlighted.

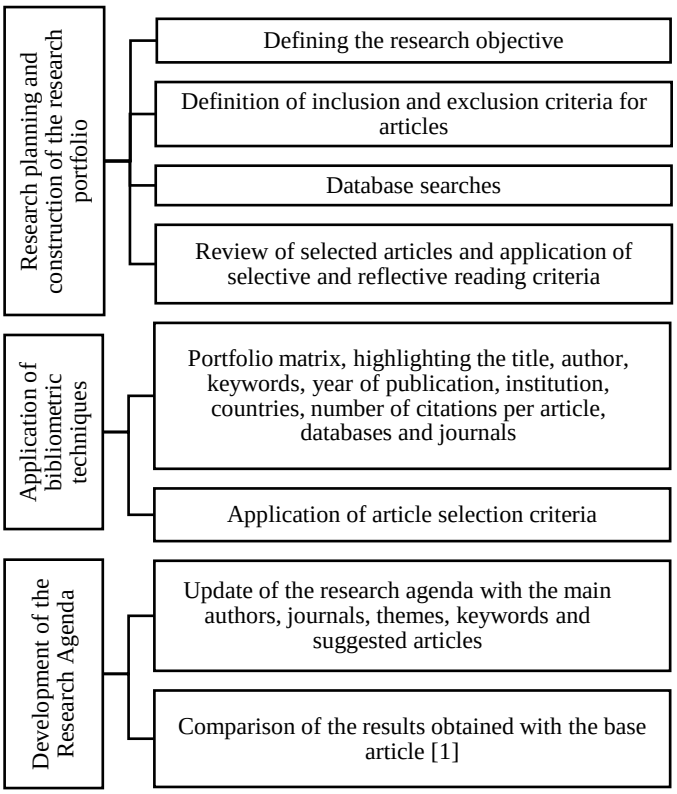

Fig. 1. Systematic Review Process used in the search and analysis of research material, adapted from [1].

The systematized process for the development of research and updating of the systematic review based on the study by Fenerich et al. [1] it was divided into three stages: (1) Research planning and selection of articles to create the research portfolio; (2) the bibliometric analysis of the portfolio; and, finally, (3) the design of the research agenda and the comparison of the results obtained with those observed in Fenerich et al. [1], through

bibliometric indicators.

The construction of the research portfolio began with the definition of search parameters for the theme of energy efficiency (EE) in productive environments, focusing on studies that present indicators, models and references for strategic management and energy operations in industrial environments; articles in English language, whose main sources were the databases: Science Direct, Emerald, Springer, IEEE Xplorer, ISI Web of Knowlegde, Scopus and Cambrigde.

The selection was made by complete scientific articles published in journals, limited to the period from 2015 to 2020 (March 2020), and the time frame was based on the final date of the searches of the base article [1] for this update.

The following search strings were used: “strategy AND energy AND efficiency”; “strategy AND energy AND operations”; “strategy AND energy AND management”; “productivity AND management AND energy” e “productivity AND indicators AND energy”, searches are outlined by title, keywords and abstract.

In order to maintain the ability to analyze the texts and quality of the material, the same steps [1] were used. For reading orientation it was used the orientation by Lima and Mioto [9], starting from the reading of the title, keywords of the bibliographic material, followed by exploratory reading of the abstract to identify whether the information and/or data selected are pertinent to the study to be performed. The next step was to perform a selective reading, through the identification of the article (bibliographic reference and location of the article), characterization (search for the central theme, objectives, concepts used and theoretical framework) and definition of contributions to the present study. Selective reading served to define which articles should undergo a critical reflexive reading. These articles have the following criteria of interest: EE indicators in productive environments; reference model in EE; developed or adopted a procedure to create EE indicators; recommend performance indicators in productive environments; present strategic and / or operational models related to EE in industrial environments.

During the analysis of the articles, the following information was extracted: keywords, year of articles, publication journal versus quantity of selected material, number of citations of each selected article, survey of the most cited authors, number of articles per author, themes, institution, and country of study, which allowed the realization of bibliometric analysis and updating the agenda.

The terms highlighted in bold in the text are the recurrent in relation to the study by Fenerich et al. [1], being a way to show the similarities found in the update in relation to the

base article [1], which also evidences the changes in the research.

In the development of the research, a support software called StArt was used, which is a free tool developed at LaPES (Software Engineering Research Laboratory) of UFSCAR (Federal University of São Carlos) [11], which allows the construction of a research protocol and facilitates the process of reviewing the articles, providing the information of each article such as the name, authors, keywords, journal, year and abstract, allowing some filters to be applied and analyses to be performed.

Results and Discussion

3.1 Bibliometric Analysis

Bibliometric analysis contributes to the identification of historical patterns, trends, and research interests, resulting in accurate predictions of a research field. Bibliometric analysis is often used to evaluate performance at different scientific levels [12].

The initial searches returned in 14,180 articles, of which 7,319 were discarded because they were duplicated and another 6,686, after reading titles and abstract, were discarded because they did not fit the inclusion criteria established. Thus, 185 articles from the established databases were selected for this research, and the number of articles included are mostly belonging to the Scopus and Web of Science databases, considering that these were the first bases on which the searches for material were made. By adding the documents to the other databases, duplication of files was identified, which led to the entry of a minor number of documents from the other bases, as can be observed in Fig. 2.

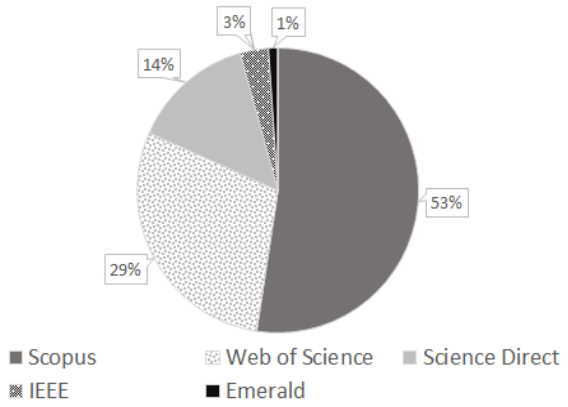

Fig. 2. Classification of accepted articles by database.

Exclusion criteria are related to articles that do not have the full version available, gray publications or that do not reach the research objective.

Table I shows the criteria used for material inclusion and the number of articles selected for each inclusion criteria. As can be verified, most of the selected articles have a correlation between EE, strategy, and operations.

The accepted articles were classified into three categories, some of which were identified in more than one inclusion criterion (I). Most articles were identified as in the Strategy category (43.24%), followed by the Practices category (35.14%) and the Indicators category (24.32%), demonstrating that there are few articles related to indicators, even representing an important part of the development of EE, because it stimulates the practice of energy control and management in reducing consumption and efficient use of this resource.

Criteria	frequency
(I) Studies that correlate EE, strategy, or operation.	122
(I) Studies presenting strategic or operational models of EE.	40
(I) Studies describing EE indicators.	33
(I) Studies describing practices and/or procedures for calculating energy performance in production systems.	21
(I) Studies describing productive performance indicators that address energy use.	17
(I) Studies describing procedures adopted for the development of EE indicators.	14

TABLE I Publications in Relation to the Criteria of Inclusion (I).

After criteria evaluation, the number of articles published per year in the databases is shown in Fig. 3, including the analysis carried out by Fenerich et al. [1] (period until 2014) and in the current survey (2015 to 2020). There has been a growth trend of related research from 2007, especially in 2019, with 58 articles, reflecting that the academic environment is looking for alternatives for the rational use of energy resources, to provide greater efficiency to industries, to remain competitive in the current economic scenario and achieve sustainable development.

Fenerich et al. [1] identified 186 articles during the period 1994 to 2014 (10 years). In the period from 2015 to 2020 (5 years), 185 articles were identified. Considering the periods of the articles, we found that between 2015 and 2020, the average is 37 articles per year, which

is 25.13% higher than in the period from 1994 to 2014, with an average of 11 papers per year. This demonstrates the growing interest on the subject to improve production conditions, with better use of resources and sustainable development.

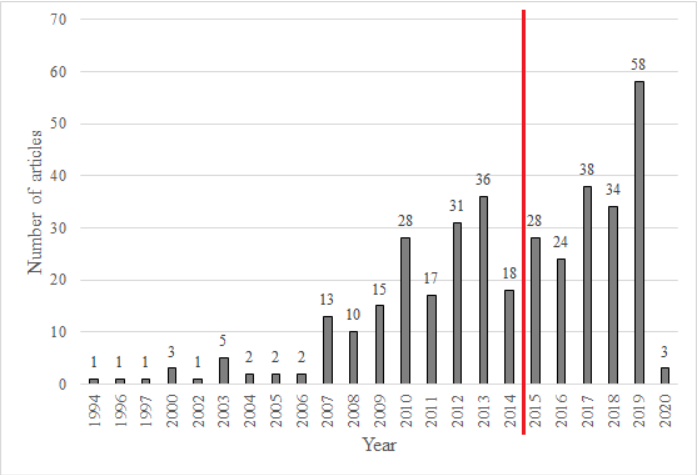

Fig. 3. Number of articles per year.

We used indexes described in the literature for bibliometric analysis [10] to quantify the data in the articles. The indexes are: (1) number of articles per year (TP); (2) number of authors in the articles per year (AU); (3) number of times the articles are cited (NR); (4) average number of authors per article (AU/TP); and (5) average number of times that articles are cited (NR/TP). The referred indexes of the selected articles can be seen in Table II.

Year	TP	AU	NR	AU/TP	NR/TP
2015	28	90	713	3,2	25,5
2016	24	78	583	3,3	24,3
2017	38	128	605	3,4	15,9
2018	34	125	337	3,7	9,9
2019	58	237	277	4,1	4,8
2020	3	13	2	4,3	0,7
Average	36,4	131,6	503,0	3,5	16,1
Article average [1]	11,1	27,2	155,4	2,3	44,1

TABLE II Characteristics of Articles in EE Industrial Environments from 2015 to 2020
For the calculation of the average, the 2020 publications were not considered, because this period was not closed during the conclusion of the research and thus did not represent the annual totality of articles as in the other years evaluated.

When observing the indicators in Table II, it is verified that the ratio of the number of authors and the number of articles per year (AU/TP), indicates an average of 3.5 authors per article, an increase of 52.1% when compared to the average of 2.3 authors identified by Fenerich et al. [1], which indicates an increase in the number of researchers on the subject. NR/TP allows to verify that the articles from the years 2015 to 2017 are more cited, as it is a

fact that more recent articles tend to be less cited. If compared to the study by Fenerich et al. [1], there is a progressive increase in the number of articles and authors with studies in the area per year. In Fenerich et al. [1], the year 2013 presented the highest index in relation to TP (37) and AU (73), which shows a growth of 56.7% in the number of articles and 224.6% in the increase of authors if compared to the year 2019 (the most representative year in the survey), demonstrating a significant growth of research and researchers in EE.

Another issue observed was the number of articles published by country during the period from 2015 to 2020. **China** stands out with the highest representation, followed by **USA**, **UK, Italy**, **Germany**, **Sweden, South Africa,** Brazil, **Spain, India,** Portugal, Russia, South Korea, **Ireland,** and Nigeria, totaling 82.2% of articles, as can be seen in Fig. 4. Fig. 4 was developed through the Pareto curve and presents a cutout with countries representing 82.2% of the total articles and published three or more articles. The countries with two articles in the period analyzed are Australia, Belgium, Colombia, France, Iran, Malaysia, Mexico, Switzerland, Turkey, and 15 other countries with only 1 article each.

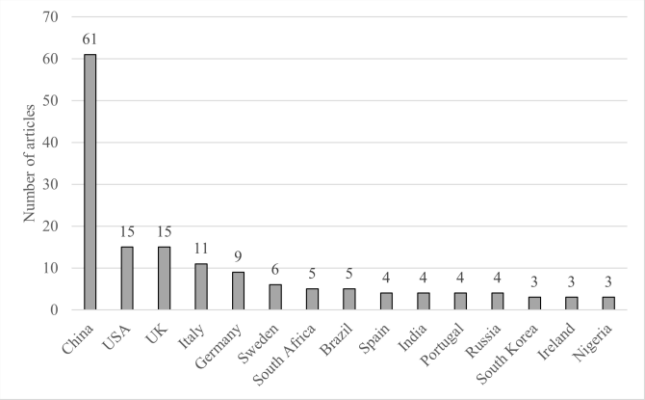

Fig. 4. Number of articles by country.

In Fenerich et al. [1] survey, USA was the leader in number of articles, with China appearing in second place. The number of articles in each year published by China are: 2020, 1 article; 2019, 21 articles; 2018, 13 articles; 2017, 13 articles; 2016, 8 articles; and 2015, 5 articles.

After we analyzed the most cited articles, we identified that 33 articles in the portfolio (with more than 25 citations per article) are responsible for 55.26% of the citations. The 3 most cited articles (more than 70 citations) are: (1) “Energy management in industry - a systematic review of previous findings and an integrative conceptual framework”, written by Mike Schulze, Henrik Nehler, Mikael Ottosson and Patrik Thollander in 2016 and published by Journal of Cleaner Production with 129 citations [13]; (2) “A performance evaluation of

the energy, environmental, and economic efficiency and productivity in China: An application of global data envelopment analysis", written by Zhaohua Wang and Chao Feng, in 2015 and published by Applied Energy with 87 citations [14]; (3) "Sources of production inefficiency and productivity growth in China: A global data envelopment analysis" also written by Zhaohua Wang and Chao Feng, in 2015 and published by Energy Economics with 76 citations [15].

The journals with the highest number of articles related in our portfolio are: Journal of Cleaner Production (IF-JCR: 3.844), Applied Energy (IF-JCR: 5.613), Energy Policy (IF-JCR: 2.575) and Energy (IF-JCR: 4.159). Compared to Fenerich et al. [1], the journal Energy Efficiency (IF-JCR: 1.060) was the one that presented the largest number of articles until 2014, followed by Energy Policy, Applied Energy, and International Journal of Energy Sector Management. It is possible to note that 2 journals remain on the list of most published research in EE, where currently the Journal of Cleaner Production emerges with most published articles. Table III presents a section of the journals that published more than 6 papers, the number of articles in the analyzed period, as well as the accumulated percentage.

Journals	Number of Articles	% Accumulated
Journal of Cleaner Production	62	33.51%
Applied Energy	23	45.95%
Energy Policy	17	55.14%
Energy	16	63.78%
Energy Efficiency	7	67.57%
International Journal of Advanced Manufacturing Technology	6	70.81%
TOTAL	131	70.81%

TABLE III Journals With More Articles in Portfolio.

The institutions that developed more studies in the area are Beijing Institute of Technology, with 6 articles and Chongqing University with 4 published articles. **Linköping University**, Northwestern Polytechnical University, Xiamen University, and Zhejiang University presented 3 articles each. The other institutions presented only one or two articles from 2015 to 2020. When compared to Fenerich et al. [1], it is noted that until 2014, Linköping University (Sweden) was the institution with the highest number of articles (6 papers),

followed by Tsinghua University, and Universidad de Sevilla, with 3 papers each, being possible to verify that Chinese institutions are at the forefront of research in EE.

Regarding the authors, Yingfeng Zhang published 4 articles, followed by Boqiang Lin, Chao Feng, Congbo Li, Haidong Yang, Jianjun Ouyang, João Henriques, Justina Catarino, Wei Cai, and Yi-Ming Wei with 3 articles each. There is also a list of 42 authors who published 2 articles each, while the others presented only one article.

Table IV presents the authors with the highest number of articles, the corresponding institution, and the country of origin. There is a change in relation to the main authors of Fenerich et al. [1] that identified the following main authors: Ernst Worrell (Utrecht University) with 5 articles, Charles Goldman (The Hong Kong Polytechnic University) with 3 articles and Clara Inés Pardo Martínez (University of Wuppertal), also with 3 articles. These authors did not show prominence in relation to the number of articles after 2015, a fact that may be related to the migration of reference institutions in EE research.

Authors	Number of Articles	Institution	Country
Yingfeng Zhang	4	Northwestern Polytechnical University	China
Boqiang Lin	3	Xiamen University	China
Chao Feng	3	Beijing Institute of Technology	China
Congbo Li	3	Chongqing University	China
Haidong Yang	3	Guangdong University of Technology	China
Jianjun Ouyang	3	Shandong Technology and Business University	China
João Henriques	3	Laboratório Nacional de Energia e Geologia	Portugal
Justina Catarino	3	Laboratório Nacional de Energia e Geologia	Portugal
Wei Cai	3	Southwest University	China
Yi-Ming Wei	3	Beijing Institute of Technology	China

TABLE IV Authors With More Articles in Portfolio.

Analyzing the recurrent keywords of the articles, the term "**energy efficiency**" presented the highest occurrence, followed by: "**energy management**", "**energy consumption**", "sustainable manufacturing", "industry", "**energy conservation**",

"**sustainability**", "data envelopment analysis (DEA)", "optimization", "**China**", "energy policy", "**barriers**", "cleaner production", "CNC", "demand response", "**energy**", "**energy saving**", "**industrial energy efficiency**", "ISO 50001", "resource efficiency" and "small and medium-sized enterprises". When compared to Fenerich et al. [1] (highlighted in bold), it is noted that there are more articles with a bias towards sustainability, manufacturing development and its relationship with EE.

The articles were classified considering the keywords to identify the research focus of each article, being considered only the articles with more than 7 citations, which represents 52.97% of the total articles. The classification of the articles is presented in Table V, which describes the groups and a brief description of the related topics.

It is noteworthy that a considerable number of articles are attributed to the issues of consumption, cost and energy savings, environmental causes, and sustainability, representing 35.67% of the articles. We found that some articles refer to more than one group. The studies were classified according to the theme and then grouped according to the similarity of each research to associate with similar studies.

Year	Keywords
2015	**Energy efficiency**, Sustainable Manufacturing, **Energy**, **Energy management**, Innovation, Machining feature, Production inefficiency, SME and **Sustainability**.
2016	**Energy efficiency**, **Energy management**, **Barriers**, **Energy saving**, Industry and Pulp and paper industry.
2017	**Energy efficiency**, CNC machining, **Energy conservation, Energy consumption**, Industry, Demand side management, eco-efficiency, emissions footprints, **Energy management**, Energy performance contracting, Game model, **Industrial energy efficiency**, production, Small and medium-sized enterprises, SOA, **Sustainability** and Sustainable manufacturing.
2018	**Energy efficiency**, **Energy management**, Sustainable manufacturing, **Energy conservation**, energy policy, Energy-saving strategy, Industry, multi objective optimization, Resource efficiency, Small and medium-sized companies and Sustainability.
2019	**Energy efficiency**, **Energy consumption**, Optimization, **Energy management**, Energy policy, Productivity, Cleaner production, Cyber physical systems (CPSs), Distributed energy system, Energy monitoring, Energy performance, **Energy saving**, Energy service company, Environmental sustainability, Ethylene production, Exergy analysis, Industry, Industry 4.0, Lean

	manufacturing, Life cycle assessment, Production Scheduling e **Sustainability**.
2020	Cigarette companies, Clean energy, CO_2 emission reduction potential, Corporate Energy Strategy, Data envelopment analysis, Emerging economy, **Energy**, Energy and environmental efficiency, **Energy Efficiency**, Energy system development and management, Energy-saving potential, Grey DEMATEL, Russian Energy Strategy, Sensitivity analysis e Sustainability assessment indicators.

TABLE V Classification of Themes.

The themes are grouped into: Group 1 (Economics), Group 2 (Performance), Group 3 (Processes), Group 4 (Environmental), Group 5 (Management), Group 6 (Strategy), Group 7 (Policies) and Group 8 (Control).

Based on the keywords and the analysis of the related studies, it was possible to delineate the trends of EE research. Table VI presents the recurring keywords per year, which allows evaluating trends in relation to EE surveys. In 2015, we noted that the focus of research on sustainability [93] and new forms of production to make consumption more efficient, focused on economic issues, energy management [101] and the reduction of consumption, emerging proposals for practices to reduce consumption [102] and the development of lean processes [60].

Year	Keywords
2015	**Energy efficiency**, Sustainable Manufacturing, **Energy**, **Energy management**, Innovation, Machining feature, Production inefficiency, SME and **Sustainability**.
2016	**Energy efficiency**, **Energy management**, **Barriers**, **Energy saving**, Industry e Pulp and paper industry.
2017	**Energy efficiency**, CNC machining, **Energy conservation, Energy consumption**, Industry, Demand side management, eco-efficiency, emissions footprints, **Energy management**, Energy performance contracting, Game model, **Industrial energy efficiency**, production, Small and medium-sized enterprises, SOA, **Sustainability** and Sustainable manufacturing.
2018	**Energy efficiency**, **Energy management**, Sustainable manufacturing, **Energy conservation**, energy policy, Energy-saving strategy, Industry, multi objective optimization, Resource efficiency, Small and medium-sized companies and Sustainability.

2019	**Energy efficiency**, **Energy consumption**, Optimization, **Energy management**, Energy policy, Productivity, Cleaner production, Cyber physical systems (CPSs), Distributed energy system, Energy monitoring, Energy performance, **Energy saving**, Energy service company, Environmental sustainability, Ethylene production, Exergy analysis, Industry, Industry 4.0, Lean manufacturing, Life cycle assessment, Production Scheduling e **Sustainability**.
2020	Cigarette companies, Clean energy, CO_2 emission reduction potential, Corporate Energy Strategy, Data envelopment analysis, Emerging economy, **Energy**, Energy and environmental efficiency, **Energy Efficiency**, Energy system development and management, Energy-saving potential, Grey DEMATEL, Russian Energy Strategy, Sensitivity analysis e Sustainability assessment indicators.

TABLE VI Most Frequent Keywords Per Year.

In 2015, there was concern about the company's image and compliance with legislation [55], because with the increasing increase in energy consumption, there is a need to weigh the impacts caused by the emission of greenhouse effect gases. Thus, the relationship of EE is perceived as the trend of a more sustainable future, being necessary to seek innovations that can contribute to meet the demand for energy in the industry [33]; [24], considering the need to reduce carbon emissions.

In 2016, there was concern about the barriers imposed by both the energy market and companies to achieve EE [36]. Topics such as greenhouse effect gas emissions and sustainable production are correlated with proposed use of technologies to assist in decision-making related to energy management [57], suggesting structured approaches to controlling consumption and analyzing environmental impacts [103].

In 2017, there is a search for energy sources that are at the same time more economical, renewable, and low carbon dioxide emissions [92]. Propositions are on ways of storing the energy generated and reducing waste, seeking new technologies capable of providing greater storage at a viable cost [17].

The year 2018 emerges with policy concerns [104] and EE strategies in relation to countries and companies for the promotion and prioritization of EE, remaining the sustainability bias, and addresses the importance of sustainable manufacturing for sustainable development [65].

The focus of the 2019 studies is related to the trends of Industry 4.0 [95] and Artificial Intelligence as a possibility to control micro networks, in order to provide greater energy savings, energy independence and efficiency by integrating various solutions, such as wind

and photovoltaic system, load control and storage [105], in addition to indicating waste situations with the use of tools such as IoT, seeking in addition to process optimization, cleaner production and improvement of energy performance [106].

The few studies available so far in 2020 are heading towards the search for corporate strategies [107] for cleaner production and reduction of CO_2 emissions.

With the keywords analysis, it is possible to understand how EE has developed in the last 5 years in industrial environments, while other topics present opportunities to be better explored in the coming years as the development of sustainable services and products and industry 4.0.

3.2 New Research Agenda

The improvement of production processes, as well as awareness in the use of systems, are key points for sustainability in relation to EE, promoting an optimization of energy resources in operations. One of the relevant possibilities for a diagnosis of EE is the elaboration of research agendas, in order to map studies that envision the adoption of strategies in EE, as well as the use of indicators that evidence a situation with opportunities for improvement and practices that direct actions to achieve strategic objectives.

The research agenda presented in Table VII is divided into the categories Sustainability and Operations, with the dismemberment of the subcategories: strategy, indicators and practices, with the objective of identifying the journals present in each category and subcategory, the main authors, themes, keywords and relevant articles as a reading suggestion.

Energy Efficiency in Operations: Research Agenda	
Strategy	
Journals	**Journal of Cleaner Production**, **Applied Energy**, International journal of advanced manufacturing technology, International Journal of Applied Engineering Research, **Energy**, **Energy Policy**, European journal of industrial engineering, International journal of precision engineering and manufacturing-green technology.
Topics	**Energy management**, **Energy efficiency**, energy consumption, energy efficiency in the industry, Energy performance, systems operation strategy, energy policy, energy conservation in industry, renewable energy, worker behavior, energy consumption and greenhouse gas emissions greenhouse effect, energy consumption in factories, operation

	performance, energy efficiency and environmental awareness, innovation, **energy corporate strategy**, Manufacturing strategy, **ISO 50001**, energy control system, decision support system, distributed energy systems.
Authors	Mike Schulze, Henrik Nehler, Mikael Ottosson, Patrik Thollander, Yong Wang, Lin Li, Pablo Vallejos-Cifuentes, Camilo Ramirez-Gomez, Ana Escudero-Atehortua, Elkin Rodriguez Velasquez, Boqiang Lin, Qingying Zheng, Zeyuan Yang, Xiaohu Xu, Dahu Zhu, Sijie Yan, Han Ding, Min Wei, Seung Ho Hong, Musharraf Alam, Timm Weitzel, Christoph H. Glock, Xiaolei Wang, Boqiang Lin, Arne van Stiphout, Kristof De Vos, Geert Deconinck, Johannes Fresner, Fabio Morea, Christina Krenn, Juan Aranda Uson, Fabio Tomasi, Lujia Feng, Laine Mears, Cleveland Beaufort, Joerg Schulte, Chao Feng, Miao Wang, Yun Zhang, Guan-Chun Liu.
Keywords	**Energy efficiency**, Energy conservation, Energy management, Industry, Optimization, CNC machining, Demand response, Distributed energy system, **Energy**, Energy audit, **Energy management system**, Energy performance contracting, **Energy Saving**, Game model, Non-energy benefits, Production Scheduling, Sustainable machining.
Suggested articles	[43]; [21]; [99]; [13]; [21]; [22]; [31]; [100] ; [30]; [42]; [32];[28]; [37] .

Indicators

Journals	**Energy**, **Journal of Cleaner Production**, **Applied Energy**, **Energy Policy.**
Topics	Energy saving, energy management, energy consumption, energy efficiency, operation performance, energy strategy, energy demand, energy performance, energy-environmental performance, energy savings, emission reduction, system efficiency, energy strategy system operation, **energy efficiency indicator**, innovation in energy efficiency, energy efficiency assessment system.
Authors	Yucel Ozkara, Mehmet Atak, Juan Wang, Tao Zhao, Enrico Cagno, Andres Ramirez-Portilla, AndreaTrianni, Hironori Hibino, Takamasa Horikawa, Makoto Yamaguchi.
Keywords	**Energy efficiency**, Economic analysis, **Energy consumption**, Ethylene production, Evaluation, Industry, ISO 50001, Productivity.
Suggested articles	[78]; [41]; [26]; [27]; [35]; [41].

Practices

Journals	**Journal of Cleaner Production**, **Applied Energy**, Energy Policy, IEEE Transactions on Automation Science and Engineering, South African journal of industrial engineering.
Topics	Energy management, energy consumption, energy efficiency, energy demand, energy efficiency in industry, Energy costs, energy savings, emission reduction, Energy storage,

	energy conservation, energy demand and carbon emissions, renewable energy, thermal management, systems management, innovation in energy efficiency, heat reuse of industrial waste, energy services, manufacturing systems.
Authors	Alessia Arteconi, Eleonora Ciarrocchi, Quanwen Pan, Francesco Carducci, Gabriele Comodi, Fabio Polonara, Ruzhu Wang, Jian-Ya Ding, Shiji Song, Rui Zhang, Raymond Chiong, Cheng Wu, Lingbo Kong, Ali Hasanbeigi, Lynn Price, Maria Teresa Costa-Campi, José García-Quevedo, Agustí Segarra, Minbo Yang, Xiao Feng,
Keywords	**Energy efficiency**, **Energy management**, **Energy consumption**, Energy savings, Industry, Manufacturing, Optimization, scheduling.
Suggested articles	[76]; [68]; [91]; [17]; [19]; [23]; [45].
Energy Efficiency and Sustainability: Research Agenda	
Strategy	
Journals	Journal of Cleaner Production, Energy.
Topics	Energy consumption, energy management, sustainable development in industry, energy saving in manufacturing, energy efficiency, energy efficiency in industry, energy management in manufacturing, industrial carbon emissions, sustainability management, energy policies, environmental pollution in industry, reduction carbon emissions, reduce carbon emissions, energy efficiency assessment system, manufacturing sustainability, sustainability in product development process.
Authors	Wenwen Lin, Shengqiang Liu, Zhanpeng Xie, D.Y. Yu, Chaoyong Zhang, Xun Liu, Sanqiang Zhang, Yuhui Tian, Nevenka Hrovatin, Nives Dolsak, Jelena Zoric, João Henriques, Justina Catarino.
Keywords	**Energy efficiency**, Sustainability, energy management, Sustainable manufacturing, Barriers, Energy consumption, Energy modeling, Green supply chain, Industrial energy efficiency, Small and medium-sized enterprises.
Suggested articles	[98]; [36]; [108]; [41]; [34]; [50].
Indicators	
Journals	Journal of Cleaner Production, Energy Policy, Applied Energy, Energy Conversion and Management, International journal of computer integrated manufacturing.
Topics	Energy consumption, energy development, energy policy, assess the energy sustainability of resources and the environmental sustainability of the pollutant, environmental performance, Energy efficiency performance, energy performance, sustainable development, resource efficiency of manufacturing systems, energy efficiency, energy efficiency in the

	manufacturing system, greenhouse gas emissions, industrial carbon emissions, energy efficiency strategy, contaminant emissions, energy productivity, sustainable manufacturing systems, sustainability in the management of the energy system, Sustainable value and cleaner production.
Authors	Zhaohua Wang, Chao Feng, Ke Wang, Yi-Ming Wei, Lihong Peng, Xiaoling Zeng, Yejun Wang, Gui-Bing Hong, João Henriques, Justina Catarino, Chi Ung Song, Wankeun Oh.
Keywords	Energy efficiency, Energy conservation, eco-efficiency, Cleaner production, emissions footprints, Energy policy, Environmental sustainability, production, Resource efficiency, SOA, Sustainable manufacturing.
Suggested articles	[14]; [20]; [29]; [18]; [33]; [65].
Practices	
Journals	Journal of Cleaner Production, Applied Energy, **Energy Efficiency**, Energy Policy, Energy, Energy research & social science.
Topics	Energy reduction, energy consumption, Industrial emissions, sustainable management, energy policy, reduction of greenhouse gas emissions, energy conservation in the industry, energy saving performance, Energy performance, energy saving, material efficiency as an instrument energy efficiency in processes, manufacturing strategies, energy management, production inefficiency, sustainable operations in industry, optimization for minimum energy and sustainable manufacturing, energy recovery, cost reductions and carbon from industrial management, emission reduction, sustainability management, transition to sustainable energy.
Authors	Zhaohua Wang, Chao Feng, Giuseppe Ingarao, Yingfeng Zhang, Shuaiyin Ma, Haidong Yang, Jingxiang Lv, Yang Liu, Yansong Guo, Joost R. Duflou, Jun Qian, Hao Tang, Bert Lauwers.
Keywords	**Energy efficiency**, Sustainable manufacturing, Chile, Cleaner production, Energy-intensive manufacturing industries, Industry, Lean manufacturing.
Suggested articles	[39]; [15]; [93]; [38]; [44]; [46].

TABLE VII EE Research Agenda in Industrial Environments

Once the agenda was prepared, it was found that the Operations category presented most of the articles totaling 61.1% of the total. Of these, 45.1% are articles related to strategies used for the EE development in industries, 23% presented practices for EE and 31.9% are related to the use of indicators for energy management in industrial environments.

Through the research agenda, it was possible to observe the direction of research in EE in industrial environments, which presents a view on the research evolution on the subject,

allows the verification of which are the topics, authors and journals that are on the rise compared to the previous research of Fenerich et al. [1].

There was a predominance of energy strategies related to consumption, energy management, emission of pollutants by industry and renewable energy, and also researches that address the issue of energy policies for more efficient production processes, producing more with the same number of resources, which also allows the search for sustainable development.

It is observed that sustainable development is highlighted on the research agenda as a prominent area of research. Energy consumption, cost, and savings, together with emission reduction and sustainability were the most relevant topics in EE research.

In addition, the occurrence of articles with ISO 50001 points out that companies are encouraging policies compatible with the standard, also helping the use of technologies for energy management.

The research agenda contributes to future researchers finding models, practices, strategies, and indicators used in recent EE applications in industrial environments.

Therefore, future studies tend to incorporate characteristics of sustainable development into EE practices and strategies in manufacturing to reduce the difficulties commonly encountered in the implementation of EE in companies.

Final Considerations

EE in industrial environments is aims to optimize energy use, maintaining productivity and reducing energy consumption or increasing productivity without increasing energy consumption. It has the potential to increase competitiveness in the sector and also reduce the negative environmental factors of the production process.

In addition to bibliometric analysis and research agenda, it was verified that the articles in EE in manufacturing follow a growth trend since 2007, reaching higher intensity in 2019. In addition, it was identified some interesting points like China is the country with more published articles (2015-2020), and until 2014, USA led the studies in the area.

Regarding institutions, with the highest volume in articles, currently the Beijing Institute of Technology leads with 6 articles and, before 2015, Linkoping University was the most active in the area. The journal that presented the most articles on the subject was the Journal of Cleaner Production, and in the research of Fenerich et al. [1], Energy Efficiency appeared with more articles on EE according to the chosen criteria.

This article aimed to perform a bibliometric analysis and update the research agenda in EE in manufacturing environments, which were attended after the construction of a portfolio, reading and analysis of 185 articles. The listed articles provide several aspects about EE and the path of research in the area. This article also provides a range of subjects to be studied, which can be defined by various criteria and which can also be identified by the priority of the topic or research.

The paper has some limitations, such as research parameters, which may at some point restrict the list of articles, limitation on databases access, filters used and availability to access the articles.

The main contribution of this research is to present an update of the research agenda in EE in industrial environments, in addition to the discussion of several important issues related to the theme, which can serve as a basis for future research aimed at promoting greater efficiency in the use of energy resources. In addition, the research provides up-to-date information on the subject to industry managers and academia.

As suggestion for future research, it is the continuation of this study, expanding the search databases, to obtain an even richer tracking on the subject, favoring the perception about the evolution of the theme and trends of EE in the industry. Each topic should be analyzed in greater depth, identifying the objectives and techniques applied in the research, as well as a greater emphasis on the area of sustainability. As energy has a fundamental effect on the sustainable development of manufacturing industries, the constant improvement in EE is substantial.

What is proposed in the agenda is not only a list of topics, but a general perspective on the research theme, so attention is paid to the referral and direction of research in EE, since it is necessary to pay attention to the directions of the research.

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