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Energy and Industry 4.0: an Application of ProKnow-C Method

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Abstract: Industry 4.0 brings new challenges to the organizations and integrate energy management and its technologies are one of them. The possibility of real-time monitoring and more accurate data are some of the advantages of this integration. The present study aims to realize a literature review integrating the terms "energy" and "industry 4.0" to identify research gaps in the literature. The method used was ProKnow-C (Knowledge Development Process – Constructivist). As a result, a bibliographic portfolio of 26 articles was obtained and a bibliometric analysis was executed to identify year of publication, local of publication and the most used terms. Some of the literature gaps were identified like the intensive use of the Internet of Things and a lack of conceptual models that conciliate both themes.

Keywords: Energy, Industry 4.0, ProKnow-C.

1 Introduction

Industry 4.0 or fourth industrial revolution was only possible due to the advances in information and communication technologies (ICTs)[10]. Tesh da Silva et al. [41] emphasizes its importance to the flexibility of manufacturing resources and the increase of productivity. In this context, energy management is a very important aspect of production because it can lead to a decrease in costs and have business implications [33, 37]

Production activities of industry consume about 35% of the entire global electricity supply and are responsible for 20% of total carbon emissions [30]. In this scenario, energy-efficient manufacturing is a key factor for the sustainable and rational use of energy, because enterprises are looking for a solution to substitute fossil fuels and to deal with the rise of energy prices [11, 27].

In this scenario, Industry 4.0 has a close relationship with energy management due to the continuous improvement of energy consumption leading to an optimization of the energetic resources [43].

So, based on the importance of the topic to the efficiency of industries, how is it the current scientific scenario regarding energy and industry 4.0?

This study is justified by the relevance of the theme to the scientific community, serving as one more source of research to the specialists. The research is part of a bigger study to develop a model of energy management and Industry 4.0 to fill a gap discussed by Bunse et al. [4] between the solutions to energy efficiency and how they are implemented at industries. So, the specific objectives were divided into two: (i) select a relevant portfolio of articles on energy industry 4.0; (ii) carry out the bibliometric analysis on the portfolio.

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2 Literature Review

This section brings definitions of industry 4.0 and energy management.

2.1 Energy Management

The definition of energy management is proposed by Fiedler and Mircea [12] as the sum of all measures and activities planned or executed to minimize the energy consumption of a company or institution. Perroni et al. [27] highlight that energy management discusses dynamic factors that can impact energy performance for better or worse.

Sola and Mota [38] define energy management as a way to improve energetic performance and to reduce the emissions in the organizations.

Energy information is important to improve energy-efficient measures [21]. Fiedler and Mircea [12] affirm that the information can be obtained by an energy management system (EMS) which helps in the acquisition of relevant data.

The scarcity of models from performance indicators to this area is identified in Bunse et al. [4]. The ISO 50001 provides a framework for industrial plants considering all the aspects of processes, although it will not state specific performance criteria [7].

The industry is facing a major transformation related to energy management since it is changing from traditional sources to renewable energy sources [35]. Renewable energies are considered clean sources of energy that minimize environmental impacts, produce minimum secondary wastes, and are sustainable considering the triple bottom line aspect [26]. The transition to renewable energy sources increasing the complexity of the system and the utilization of a digital or a smart energy system is necessary to surpass this obstacle [35].

2.2. Industry 4.0

Industry 4.0 or the Fourth Industrial Revolution is the development of self-learning factories with the utilization of the internet of things (IoT), big data, and cyber-physical systems (CPS) [41]. Organizations are implementing this type of technology due to the challenges of manufacturing, like increasing productivity [18, 41].

This environment is the scenario for transformations in industry value chains, production value chains, and business models [22]. Roblek et al. [31] point out some of the characteristics of industry 4.0 like increased competitiveness through smart equipment, use of information, demographic changes, etc. Medojevic et al. [22] presents some technologies used in industry 4.0, like the Internet of Things (IoT), Big Data, Augmented Reality (AR), Blockchain, and Rapid Prototyping

Energy management is a part of Industry 4.0 since it is a central part of the operation and the implementation of energy management in this scenario must follow a series of steps, including the understanding of energy flows, allowing the identification of the unnecessary or excessive flows and consumers [22]. Industry 4.0 also contributes to sustainability in the energy scenario since the Sustainable Development Goals number 7 and 9 affirm that digital industrial development will support the growth of industrial sustainable energy [14].

Scharl and Praktiknjo [35] present three capabilities of Industry 4.0 that can contribute to renewable energy systems: increase transparency on the status of the energy system; additional flexibility for renewable energy systems; and enhance energy efficiency and decrease energy consumption.

3. Methodology

This article utilizes an adaptation from the ProKnow-C (Knowledge Development Process – Constructivist) methodology to select the portfolio of works. The ProKnow-C appears in Vieira et al. [43] and Rosa et al. [32].

The methodology is based on a list of procedures to select a bibliographic portfolio. Vieira et al. [43] describe a process of seven major steps to select the articles, which are listed in Table 1. The ProKnow-C was utilized due to the familiarity of the authors with the method and because it presents a structured approach easy to follow.

Table 1 Steps of ProKnow-C methodology

Step	Description	Activities
Step 1	To define keywords	Define search axes Set keywords of each axis Define keywords combinations
Step 2	To define database	Define database according to the theme of the research
Step 3	To perform the search in Titles, Abstracts and Keywords	Search databases using the keywords combinations
Step 4	Filtration of the gross article bank	Deleted repeated articles
Step 5	Filtration of the gross articles not repeated	Read the titles Exclude the articles misaligned with the theme
Step 6	Filtration of the bank of gross articles on scientific knowledge	Read abstracts Exclude the articles misaligned with the theme Article availability search Exclude articles not available
Step 7	Filtration to the alignment of the comprehensive article	Read full article Exclude the articles misaligned with the theme

Source: Adapted from Vieira et al. [43]

The procedure idealized proposed a filtration by scientific recognition at step 5 [43]. but this model was not considered in this article due to the date included in the portfolio, which includes articles published in 2020.

With the final portfolio of articles obtained at the final of step 7, was conducted a bibliometric analysis, which is defined by [32] as a form of measurement to evaluate information flows scientifically.

To conduct the research were utilized the software Mendeley to organize the articles and VosViewer to analyze the graphs of references. Were defined three search axes ("Energy Management", "Performance" and "Industry 4.0) and fourteen keywords. The search protocol is presented in Table 2.

The search was performed at Scopus database, without limitation of the period and including journals-type papers and conference proceedings. Were included articles only in English. The Scopus database was used because it is the largest abstract and citation database of peer-reviewed literature, including not only journals but conference proceedings.

Table 2 Search protocol

Search Axes	Keywords
"Energy Management"	"Energy" "Power" "Efficient Manufacturing" "Efficiency"
"Performance"	"Performance" "Measurement" "Measuring Performance" "Monitoring" "Analyze"
"Industry 4.0"	"Industry 4.0" "4.0" "4.0 technology" "Smart Factor" "Smart Manufacturing"

4. Results

The keywords were combined in pairs at the same search axes. The process obtained 11,782 gross articles. Then, were removed the 6,009 duplicates due to the pairing combination, remaining 5,773. After, was conducted the filtration of the articles by title reading, and 809 papers were left in the database since the utilization of simple words at the search protocol resulted in the appearance of articles that were not interesting for the study, like medical and nursing articles. At the abstract reading, 692 were excluded since the approach utilized was focused on hardware solutions to improve energy efficiency without consideration of energy management, and 96 were not available for reading. In the final, the portfolio was composed of 26 articles, which were analysed using bibliometric research. The final portfolio is presented in Table 3.

Table 3 Final portfolio of articles

Articles	Approach used
Adenuga et al. [1]	The article proposes a framework to establish the energy policy, considering the energy cost to determine the economic impacts of energy measurement.
Alharthi et al. [2]	The research focuses on an ecosystem based on IoT and cyber-physical systems to a smart grid. The system impacts the electric grid, delivering better monitoring, efficiency, and optimizing the energy consumption.
Bruton et al. [3]	The paper presents a software as a tool to implement the ISO 50001 in the manufacturing sector. A standard approach was developed to meet the requirements and a web-based software was tested to facilitate the implementation process.
Campo et al. [5]	The study developed a solution based on IoT, that allows the measurement of energy from every machine in a factory.
Cherifi et al. [6]	The paper initiates a process of development of a low-cost energy measurement platform for small objects.

(continued)

Table 3(continued)

Eder et al. [8]	The research focuses on reducing the energy costs of the manufacturing process by utilizing digital measurement techniques. The energy meters were applied at a learning factory, validating the system proposed and the ISO 50001.
Edgar and Pistikopoulos [9]	The article brings an overview of smart manufacturing and how energy productivity can be improved by its elements. The case studies were presented connecting the measurement of energy and smart technologies.
Haas et al. [13]	This study presents a smart platform focusing on energy consumption. The electrical energy consumption indicator (EECI) was utilized to classify all the machines and their processes.
Incipini et al [15]	The work presents an IoT application for energy monitoring. The system was tested on a hydraulic pump with the utilization of sensors.
Javied et al. [16]	The research focuses on a cloud solution for energy monitoring. The solution proposed enhances the measuring and acquisition of data, leading to energy transparency.
Junker and Domann [17]	The authors provided an overview of the systems utilized for energy measurement on industry 4.0.
Li et al. [19]	The study proposes a model of exergy loss as a measure of environmental performance, considering energy and materials flows.
Lins and Oliveira [20]	The paper presents an interface that connects the production controller and the network controller, improving the decision-making process by enhances its speed. The model also shows that is possible to save energy during the production process.
Medojevic et al. [22]	The articles bring an overview of the concepts of industry 4.0 and how its implementation improves energy management.
Munsamy et al. [23]	The research focuses on multinational corporations and their energy models, providing a new approach for a business energy assessment.
Nouiri et al. [24]	The authors developed a smart sustainable tool focused on production scheduling based on renewable energy. An integration happened between the cyber-physical production system and the energy system allowing the monitoring of energy in real-time.
Padma Priya and Menon [25]	The study aimed to demonstrate how machine learning can be utilized to manage and optimize the use of energy.
Pradella et al. [28]	The article identified energy efficiency indicators in the food industry and utilized multi-criteria methods like AHP and PROMETHEE to reveal each sector's performance according to the indicator.
Prudenzi et al. [29]	The paper presents a low-cost device for energy monitoring, allowing the measurement of all characteristics of electricity. The application utilizes a web page that allows graphical visualization.
Satuyeva et al. [34]	The research discusses the applications of IoT technology in the power industry and how they can be applied at Kazakhstan.
Simkoff et al. [36]	The paper discusses the impact of technologies on the process energy efficiency of chemical industries. A relation between the production process and energy efficiency is presented and some recommendations are given.

(continued)

Table 3(continued)

Sun et al. [39]	The article presents a simulation model that integrates energy metrics to production schedules. The model developed was able to reduce the energy consumption and the energy cost considering the production schedule that needed to be followed.
Supekar et al. [40]	The authors proposed a framework to analyze energy productivity through smart manufacturing. The framework focuses on some indicators like the cost of conserving energy along with other economic metrics.
Tokar et al. [42]	The paper discusses the reduction of energy consumption among factories trough the utilization of waste energy recovery solutions.
Vieira et al. [43]	The article presents a review of energy management considering the aspects of industry 4.0. The authors focused on finding performance indicators and through the final portfolio of articles identifying a lack of research in this area.
Wang et al. [44]	The study proposes a strategy to utilizes the buffer status of the machines in an attempt for energy saving. An intelligent system was built to automatize this function.

The bibliometric analysis was initiated by the year evaluation, illustrated in Fig 1.

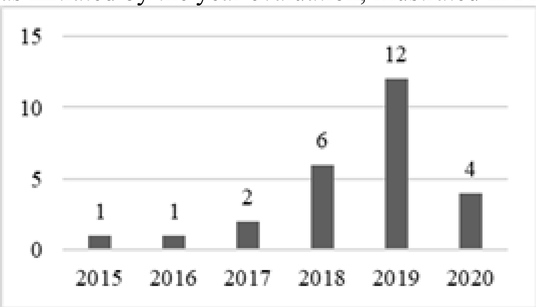

Fig 1 Publications per year

It is possible to observe a crescent tendency since 2017, which is explicable by the creation of the term “industry 4.0” in 2011 at Germany through a proposal of economy development [14, 31]. After the evaluation per year, were analysed the locals of publications of each article. This analysis is illustrated in Fig 2 and the Conference Proceedings are most of the publications founded, which illustrate that the subject is very discussed and have new approaches at every conference.

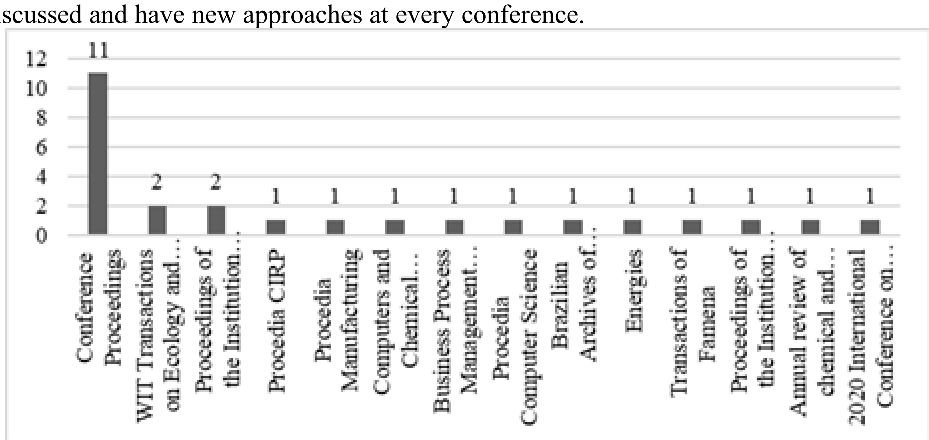

Fig 2 Number of articles by local of publication

The country of the authors was another analysis performed and it is designed in Fig 3. The United States is the leader in publications, and it is possible to observe collaborations between more than one country. It is important to mention that despite Germany is the country where the topic was born, the United States also has a leading contribution to the area.

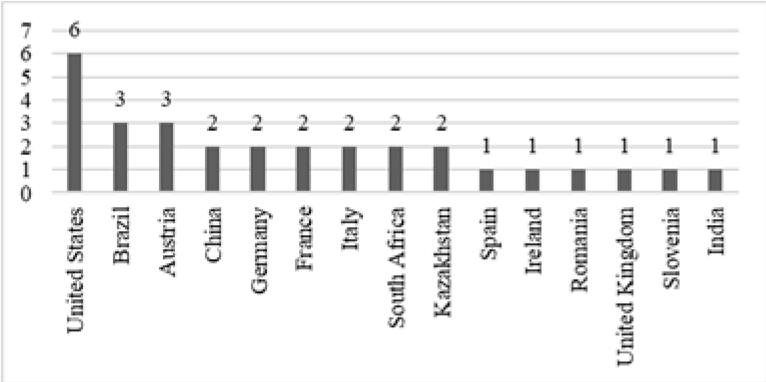

Fig 1 Publications by country

The next analysis was performed at VosViewer. It was observed that the authors with more citations were Edgar and Pistikopoulos [9] with an overview of smart manufacturing and how its elements can improve energy efficiency as shown in Fig 4.

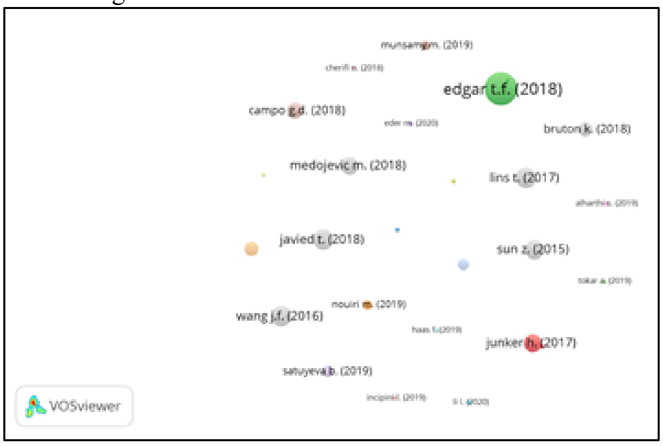

Fig 2 Author’s network

The software also shows the network related to terms used at the title, abstracts, and keywords. Five clusters were formed, and it is possible to visualize their relationships, for example, the term “energy management system” has relations with the terms “control system” and “energy monitoring”. The clusters are illustrated in Fig 5.

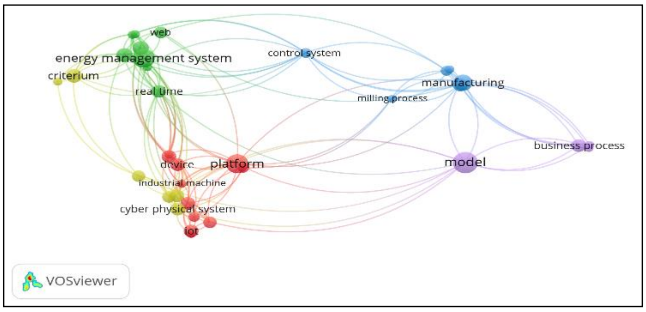

Fig 3 Clusters of terms

When the analysis was only with the keywords, the most used are presented in Fig 6. This analysis showed that other terms should be included in future research like “ISO 50001”, “optimization” and the utilization of IoT should be considered an important technology utilized in the area.

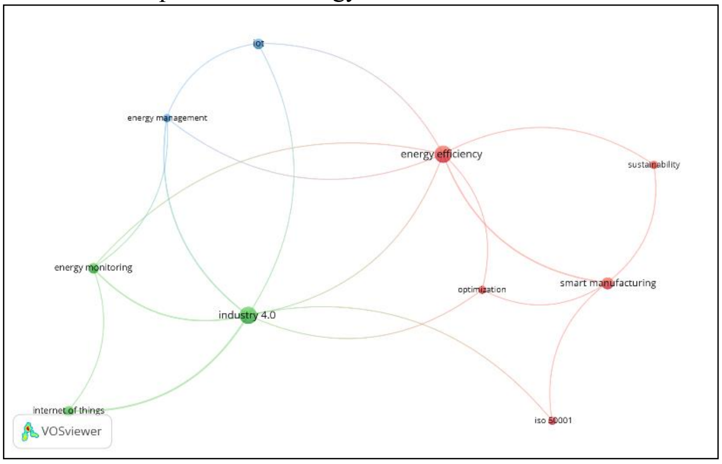

Fig 4 Most common keywords

The use of technology is a frequent topic in the papers analysed. 12 of the 26 articles of the final portfolio, develops technological solution to be utilized at the energy measurement. Alharthi et al. [2], Prudenzi et al. [29], and Wang et al. [45] are some of the examples of the use of technology. However, the development of frameworks and theoretical works are most of the articles analysed, having Adenuga et al. [1], Pradella et al. [28], and Vieira et al. [44] as examples.

5. Conclusions

Energy management is a subject of high relevance to the organizations since it affects their costs and performance. In the scenario of industry 4.0, the measurement can be enhanced by utilizing new technologies and real-time data.

In this article, a bibliographic portfolio of articles was selected using the ProKnow-C method. The final database contains 26 papers that are relevant to the topic and by the bibliometric analysis was possible to consider some pieces of information like year of publication, local of publication, author with most citations, and the terms and keywords more relevant to the area.

Was observed an intense development of technologies to measures systems, and that the IoT is the most common technique utilized. It was also observed a lack of a conceptual models that integrates energy management and industry 4.0, since the existing models are applied at traditional manufacturing systems.

The specific objectives proposed were achieved, since gaps in literature were founded and that a database of 26 articles was obtained for analysis.

The present study is the initial step of major research and should be utilized to introduce the theme “energy management” and “Industry 4.0” to the researchers. It should be noticed that this research is limited to a sample of papers obtained by a combination of specific keywords and that only Scopus was utilized to obtain the articles. For future research, it is suggested that the research protocol, shown here, be replicated to other databases and that new keywords should be included.

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