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Energy Efficiency Trends in Petroleum Extraction: A Bibliometric Study

Dauren A. Yessengaliyev [1,2], Yerlan U. Zhumagaliyev [1,2,*], Adilbek A. Tazhibayev [1,*], Zhomart A. Bekbossynov [1,3], Zhadyrassyn S. Sarkulova [4], Gulya A. Issengaliyeva [5], Zheniskul U. Zhubandykova [4], Viktor V. Semenikhin [4], Kuralai T. Yeskalina [2] and Arystanbek E. Ansapov [6]

1 "TRENCO R&D" LLP, Astana 010000, Kazakhstan; dauralga@mail.ru (D.A.Y.); zh.bekbossynov@alageum.com (Z.A.B.)
2 Department of Metallurgy and Mining, K.Zhubanov Aktobe Regional University, Aktobe 030000, Kazakhstan; kuralai.tulegenovna@gmail.com
3 "Kentau Transformer Plant" JSC, Kentau 160400, Kazakhstan
4 Department of Oil and Gas Industry, K.Zhubanov Aktobe Regional University, Aktobe 030000, Kazakhstan; zhadi_0691@mail.ru (Z.S.S.); tima2001@inbox.ru (Z.U.Z.); viktorsemenihin445@gmail.com (V.V.S.)
5 Department of Ecology, K.Zhubanov Aktobe Regional University, Aktobe 030000, Kazakhstan; isengul@mail.ru
6 Department of Operation and Equipment, S.Seifullin Kazakh Agrotechnical Research University, Astana 010000, Kazakhstan; ansapov95@mail.ru
* Correspondence: yzhumagaliyev@zhubanov.edu.kz (Y.U.Z.); adilbek@trencontc.kz (A.A.T.); Tel.: +7-701-304-8400 (Y.U.Z.); +7-771-001-6888 (A.A.T.)

Abstract: This comprehensive bibliometric analysis investigates energy-saving strategies in petroleum extraction, shedding light on key research areas, trends, and collaborations. The analysis covers 98 research articles spanning from 2003 to 2024, sourced from the Web of Science (WOS) database and analyzed using the Bibliometrics R package v.4.1.3, including descriptive statistics, network analysis, and factorial analysis. Findings reveal significant contributions from China, Canada, Russia, and the USA, with notable collaborations and thematic clusters identified. Top journals, prolific authors, and leading institutions are highlighted, showcasing global efforts in advancing sustainability in the oil industry. Institutions like the University of Calgary and authors such as Gates ID, Ren SR, and Zhang L play significant roles in advancing knowledge in this domain. Keyword analysis underscores prevalent themes such as optimization, simulation, and energy efficiency. Technological innovations, process optimization, and organizational strategies emerge as crucial avenues for reducing electrical energy consumption in oil extraction operations. However, limitations include database constraints and language bias. Overall, this study offers valuable insights for researchers, policymakers, and industry stakeholders, informing future research directions and policy initiatives for enhancing energy efficiency and sustainability in petroleum extraction.

Keywords: energy efficiency; oil extraction; sustainability; bibliometric analysis

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1. Introduction

The primary imminent challenge facing humanity concerns satisfying the global energy demand. Nonetheless, the escalation of energy consumption and depletion of resources in industrial operations pose substantial challenges [1]. Additionally, the primary cost component of oil production stems from the energy consumption of oil pumping units [2]. Thus, considering the projected growth in oil production and the corresponding energy consumption, the analysis and development of measures to reduce the level of energy consumption in oil extraction systems appear to be a highly relevant task [3].

Preserving electrical energy resources and improving their efficiency of utilization are vital goals in modern manufacturing. According to United Nations statistics, higher per capita energy consumption is correlated with improved standard of living, and the widespread adoption of advanced industrial technologies follows suit. Conversely, inefficient energy usage is directly linked to a proportional decline in the national income of a country, leading to a reduction in the overall quality of life [4].

Expenditure on electricity consumption in the course of oil production constitutes a substantial cost factor for industrial enterprises. As outlined in official records, a primary objective of state energy policy in mineral extraction is to enhance energy efficiency at oil production sites [5].

Enhancing energy efficiency across production, transformation, transportation, distribution, and consumption stages is a central focus in the energy sector, referred to as energy conservation. Energy management, a comprehensive strategy incorporating information, analytics, organizational, technical, and regulatory measures, serves as a pivotal tool in achieving effective energy conservation.

The extraction of oil stands as a pivotal component in meeting global energy demands, serving as the lifeblood of numerous industries [6]. The perpetual demand for oil underscores the need for efficient and sustainable methods in its extraction, considering the inherent challenges and the energy-intensive nature of the process [7]. As the sand in the hourglass of finite fossil fuel resources continues to dwindle, the need to optimize energy consumption becomes increasingly pronounced [8].

Against this backdrop, this bibliometric analysis embarks on an exploration of the scholarly landscape surrounding energy-saving strategies and innovations within the domain of oil extraction. By employing bibliometric methods, which are analytical tools in the realm of scientific literature, we aim to systematically evaluate and quantify the research output, trends, and impact of studies devoted to energy conservation in oil production. This research endeavor involves the classification and examination of diverse types of bibliometric data, including citation analyses, co-authorship networks, and thematic content analysis, providing a comprehensive understanding of the evolving discourse in this crucial field of study. Through the lens of bibliometrics, we seek to uncover patterns, identify influential research contributions, and contribute valuable insights to the ongoing discourse on sustainable practices in oil extraction [9].

2. Materials and Methods

2.1. Research Steps for Bibliometric Analysis

In this bibliometric analysis, our focus is on exploring the scholarly landscape surrounding energy-saving strategies and innovations within the realm of oil extraction. Utilizing bibliometric methods as analytical tools within scientific literature, our objective is to systematically assess and quantify the research output, trends, and impact of studies devoted to energy conservation in oil production. To guide our investigation, we formulated a series of research questions aimed at unraveling key aspects of this domain. These questions encompass inquiries into the evolution of research themes over time, the geographical distribution of research contributions, the identification of influential authors and publications, and the examination of collaboration networks among researchers and institutions. Additionally, we seek to understand the methodological approaches employed in studying energy-saving strategies in oil extraction and to identify emerging topics that may shape future research agendas. By addressing these research questions, we aim to provide a comprehensive understanding of the current state of research in this field and to offer insights that can inform industry practices, policy-making efforts, and future research directions in the pursuit of sustainable energy solutions within the oil sector. Through rigorous analysis and interpretation of bibliometric data, we endeavor to contribute meaningfully to the ongoing discourse on sustainable practices in oil extraction. Figure 1 represents the steps to investigate bibliometric analysis.

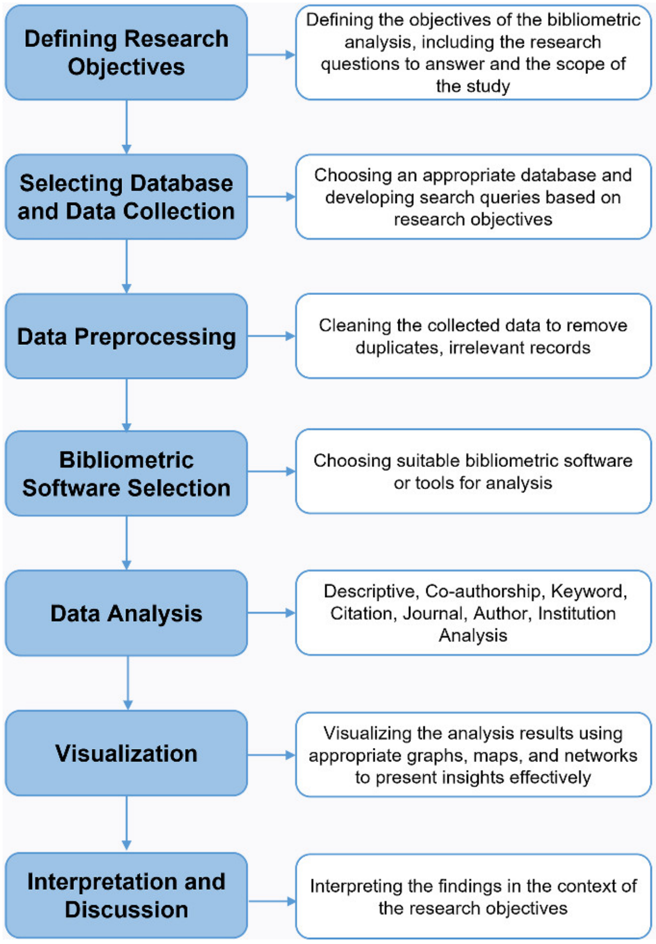


Figure 1. Procedure for bibliometrics analysis.

2.2. Bibliometric Analysis Tool

We employ "Biblioshiny," a component of the Bibliometrics R package v.4.1.3, to conduct bibliometric analysis [10]. Tailored specifically for bibliometric and scientometric investigations, this tool offers detailed categorization into intellectual, social, and conceptual structures while also providing valuable insights into authors, documents, and sources. Distinguished from other bibliometric software, Biblioshiny stands out with its diverse range of results presented through visually engaging graphs and informative tables, offering unique and comprehensive features for analysis.

3. Results

3.1. Main Information about the Data

We have concluded the examination of 98 research articles contributed by 367 researchers. Notably, 11 publications were authored by a single individual, underscoring a significant level of research collaboration within the dataset. With an average of 1.75 documents per author, it is evident that many authors have contributed to more than one research paper, indicating a pattern of prolific publication among individuals (Table 1).

We chose to source research articles from the Web of Science (WOS) database due to its extensive coverage of scientific findings. WOS has detailed citation data, which is particularly beneficial for conducting extensive bibliometric analysis and evaluating the influence of research outputs. Crafting a refined search query aligned with our research objectives, we applied filters to ensure the selection of pertinent literature. Our final search query consisted of (TS = ("Oil Production" OR "Petroleum Extraction" OR "Hydrocarbon Harvesting" OR "Oil Well Pumping" OR "Drilling Operations" OR "Oil Field Operations" OR "Crude Oil Recovery")) AND (TS = ("Energy Saving" OR "Energy Efficiency" OR

"Power Conservation" OR "Resource Optimization" OR "Sustainable Energy" OR "Energy Management" OR "Efficient Power Usage" OR "Electricity Conservation")). The final search outcomes consisted of 327 articles. To facilitate bibliometric analysis, we restricted our search to original English-language articles. Subsequently, we manually reviewed the articles, excluding articles to align with our research objectives, resulting in a final sample size of 98 articles (Figure 2).

Table 1. Descriptive statistics.

Description	Results
Main information	
Timespan	2003:2024
Sources	52
Documents	98
Annual growth rate %	5.37
Document average age	6.02
Average citations per doc	14.08
References	3487
Document contents	
Keywords plus (ID)	282
Author's keywords (DE)	346
Authors and collaboration	
Authors	367
Authors of single-authored docs	11
Co-authors per doc	4.16
International co-authorships %	20.41

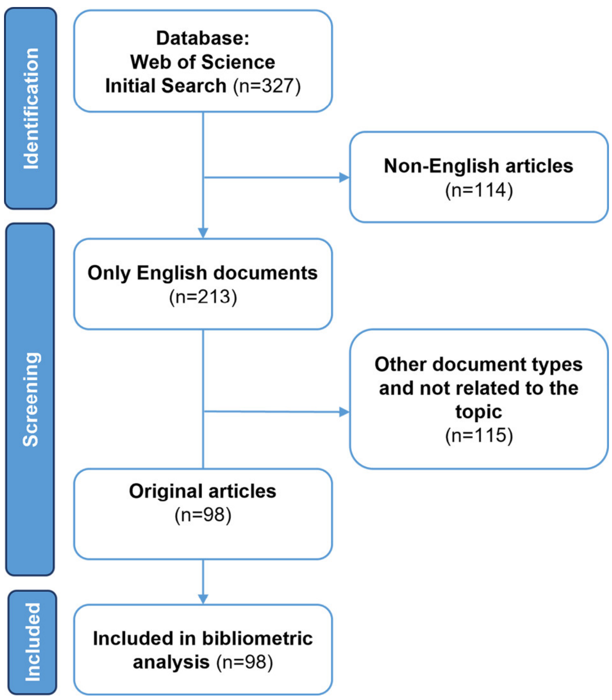


Figure 2. A flow chart of the screening process using PRISMA.

3.2. Descriptive Statistics, Network, Citation, Trend, and Cluster Analysis

We initiated our bibliometric analysis by conducting descriptive statistics to comprehensively understand the characteristics of the scholarly literature dataset. We constructed co-authorship networks to identify prominent authors and collaborative patterns within the selected literature. This analysis aimed to unveil research communities and highlight influential contributors. By examining keyword networks, we intended to uncover thematic clusters and emergent trends in the field. This analysis provides insights into the evolving vocabulary and focal points of research. An exploration of temporal trends was conducted to discern shifts in research focus over time. This analysis aids in understanding the dynamic nature of the field. Cluster analysis categorized articles into thematic clusters, offering a nuanced perspective on the interconnectedness of research topics. This segmentation enhances our ability to identify key themes and subdomains. We also employed descriptive statistics to characterize the dataset, including mean publication years, citation counts, and authorship patterns. These measures provided a quantitative overview of the selected literature. Citation analysis was be conducted to assess the impact and influence of selected articles. This step contributed to evaluating the scholarly significance of the literature.

Figures 3 and 4 illustrate the trends over time regarding annual publication rates and citations. The number of publications per year fluctuates throughout the observed period, with a notable increase in publications from 2010 onwards, peaking in 2019 and 2022 with 13 and 14 articles, respectively. The average total citations per year show varying trends over the observed period. Notably, there are fluctuations in the mean citation rates, with some years experiencing higher averages than others. For example, the mean total citations per year ranged from 0.33 in 2007 to 5.46 in 2021, suggesting fluctuations in the impact or recognition of published work across different years.

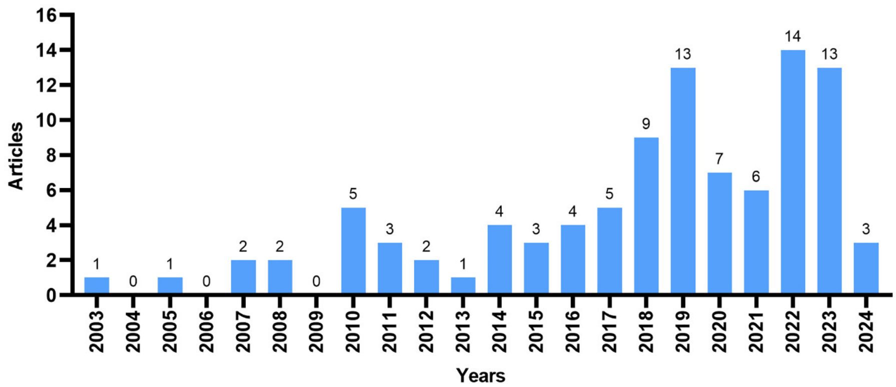


Figure 3. Annual publications trend.

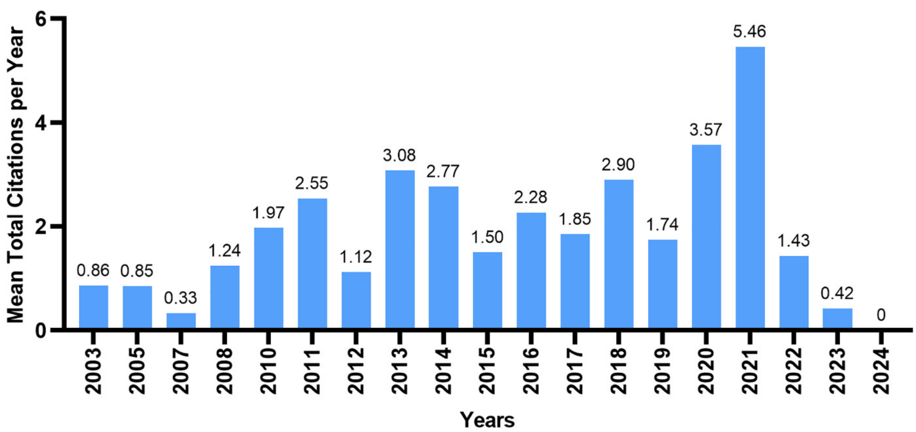


Figure 4. Annual citations trend.

3.3. Highly Impactful Research Journals

To assess the impact of influential research journals, we utilized source impact and Bradford law [11–13]. Table 2 outlines the top 10 research journals ranked by total publications. Bradford's law categorizes academic journals into three zones, with Zone 1 comprising core research journals that predominantly publish literature pertinent to energy efficiency trends in petroleum extraction (Figure 5). This zone is deemed as the nuclear zone, contributing significantly to research. From a pool of 52 research journals, our analysis revealed that 5 journals fell within Zone 1, indicating their primary focus on core research in this domain, while 15 journals were classified under Zone 2, and 32 journals were categorized under Zone 3.

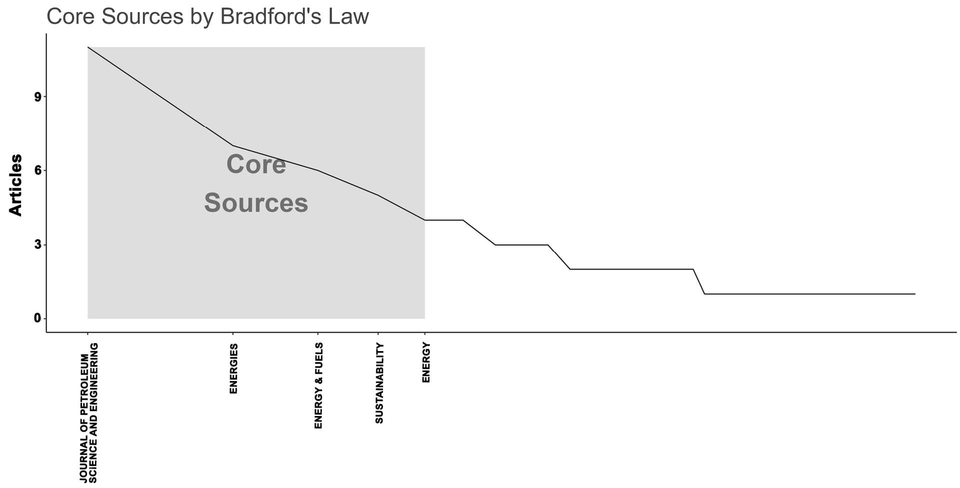


Figure 5. Core sources by Bradford's law.

Table 2. Top 10 journals according to source impact.

Sources	Articles
JOURNAL OF PETROLEUM SCIENCE AND ENGINEERING	11
ENERGIES	7
ENERGY & FUELS	6
SUSTAINABILITY	5
ENERGY	4
ENERGY POLICY	4
CHEMISTRY AND TECHNOLOGY OF FUELS AND OILS	3
JOURNAL OF CANADIAN PETROLEUM TECHNOLOGY	3
JOURNAL OF CLEANER PRODUCTION	3
ENERGY REPORTS	2

3.4. Main Researchers and Research Institutions

In the realm of petroleum extraction and energy-saving research, a diverse tapestry of institutions contributes to the scholarly landscape. At the forefront stands the University of Calgary, with a prolific output of 11 articles, showcasing its dedication to advancing knowledge in this field (Table 3). Close behind, the China University of Petroleum and the United States Geological Survey demonstrate their commitment with 10 and 5 articles, respectively. Notably, a constellation of institutions, including the China National Petroleum Corporation and the United States Department of the Interior, among others, contribute significantly, each adding four articles to the discourse. Across continents, from Russia's Gubkin Russian State University of Oil and Gas to Norway's Norwegian University of Science and Technology, the collaborative spirit of research knows no bounds, with each institution enriching the collective understanding of energy efficiency trends in petroleum extraction through their scholarly endeavors.

Table 3. Most proliferative institutions and research organizations.

Affiliation	Articles
UNIVERSITY OF CALGARY	11
CHINA UNIVERSITY OF PETROLEUM	10
UNITED STATES GEOLOGICAL SURVEY	5
CHINA NATIONAL PETROLEUM CORPORATION	4
UNITED STATES DEPARTMENT OF THE INTERIOR	4
PERM NATIONAL RESEARCH POLYTECHNIC UNIVERSITY	4
DELFT UNIVERSITY OF TECHNOLOGY	4
SINTEF	3
GUBKIN RUSSIAN STATE UNIVERSITY OF OIL AND GAS	3
NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY (NTNU)	3

Among the authors contributing significantly to the field, Gates ID emerged as a prolific contributor with five articles, showcasing a robust dedication to advancing knowledge in the domain. Following closely, authors Ren SR and Zhang L demonstrated noteworthy contributions, each with four articles. Production over the time of the 10 most relevant authors is presented in Figure 6.

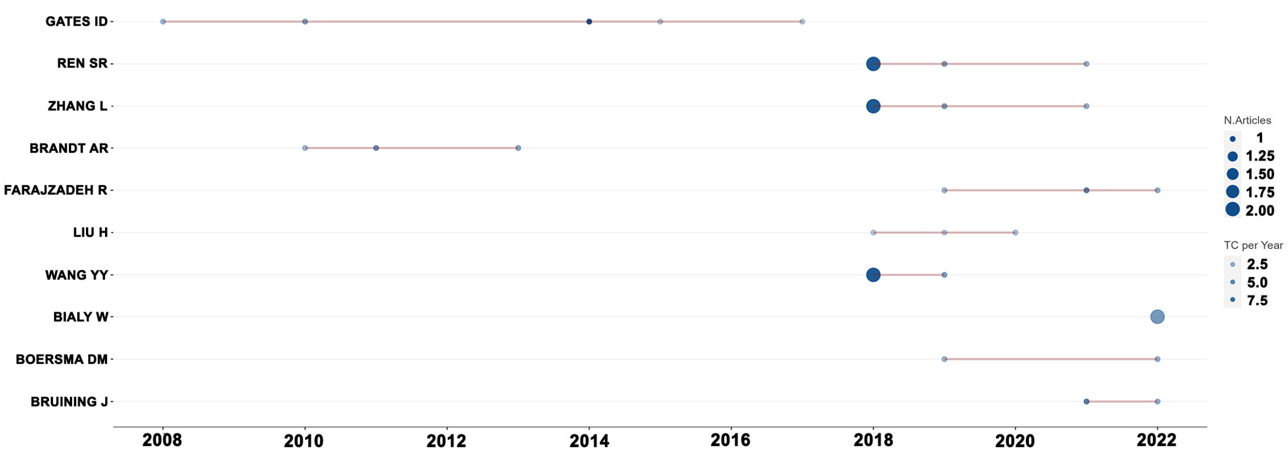
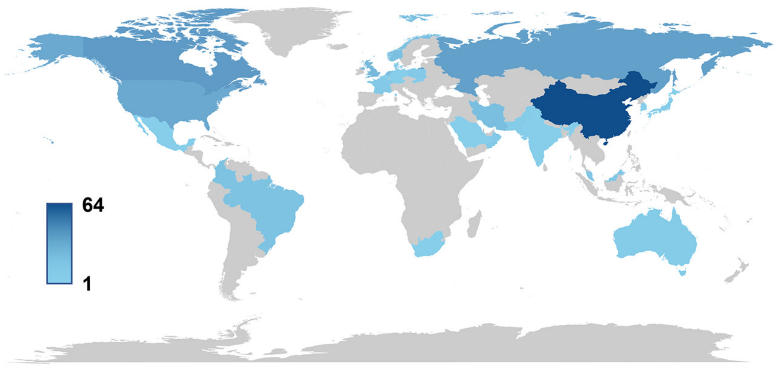


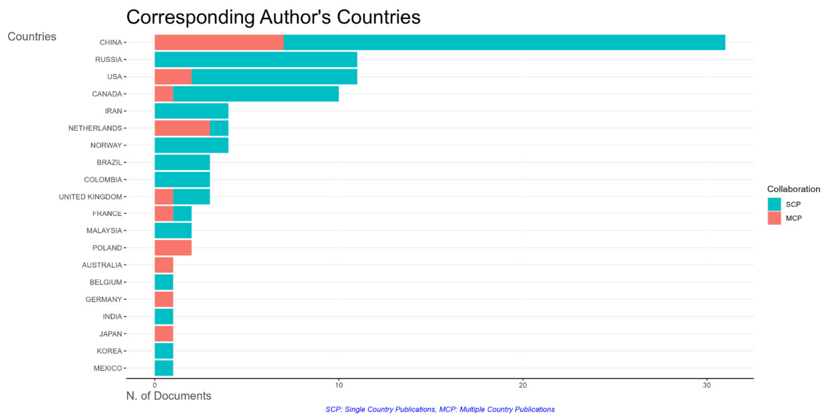
Figure 6. Authors' production over the time.

3.5. Top Ten Countries and Collaboration Network

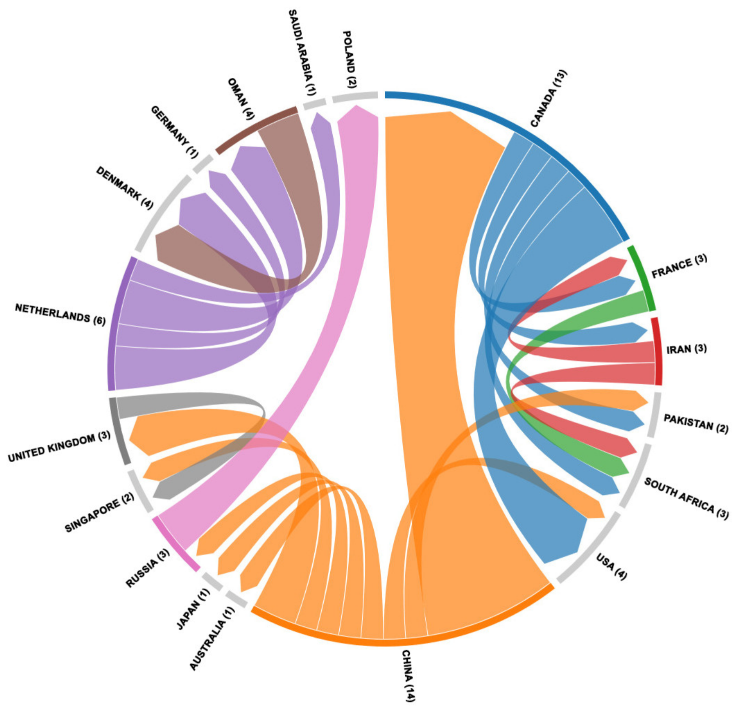
The distribution of contributions to energy-saving in petroleum extraction research reveals a significant presence from China with 64 occurrences, indicating a substantial investment in the field. Following closely, Canada, Russia, and the USA demonstrate notable involvement with frequencies of 25, 22, and 18, respectively. The map and intensity of contribution are indicated in Figure 7A. Additionally, according to the corresponding authors, it is noteworthy that Russia primarily contributed to single-country publications, reflecting a distinct focus on independent research initiatives within the nation's petroleum extraction endeavors (Figure 7B). Deeper collaboration patterns are shown in Figure 7C.



(**A**)



(**B**)



(**C**)

Figure 7. Countries' scientific production (**A**), corresponding author's countries (**B**), and chord diagram of collaboration network (**C**).

3.6. Keyword Analysis and Factorial Analysis

The treemap visualization depicts the frequency distribution of key terms extracted from the bibliometric analysis. It reveals that "model" appeared most frequently, followed by "heavy oil", "bitumen", "design", "optimization", and "simulation", each appearing with notable frequency. Other significant terms included "gas", "oil", "combustion", "energy efficiency", and "injection". Additionally, the visualization highlights important concepts such as "performance", "reservoirs", "viscosity", "water", "diffusion", and "exergy analysis". Notably, variations like "heavy-oil" were also represented. These findings provide valuable insights into the prevalent themes and areas of research within the domain of energy-efficient oil extraction and production (Figure 8).

The results of the factorial analysis reveal clusters of data points along Dimension 2, each associated with specific contributions and total contributions (TC). Cluster 1, for instance, demonstrates a range of contributions from various data points, with TC values spanning from 0 to 105. Within this cluster, contributions vary significantly, indicating diverse levels of impact across the dataset. Furthermore, the analysis identified specific data points within Cluster 1 that exhibited higher contributions, as evidenced by their comparatively higher TC values. These findings offer valuable insights into the underlying structure and patterns within the dataset, aiding in the interpretation and understanding of the analyzed data (Figure 9).

Figure 8. Treemap of the frequent authors' keywords.

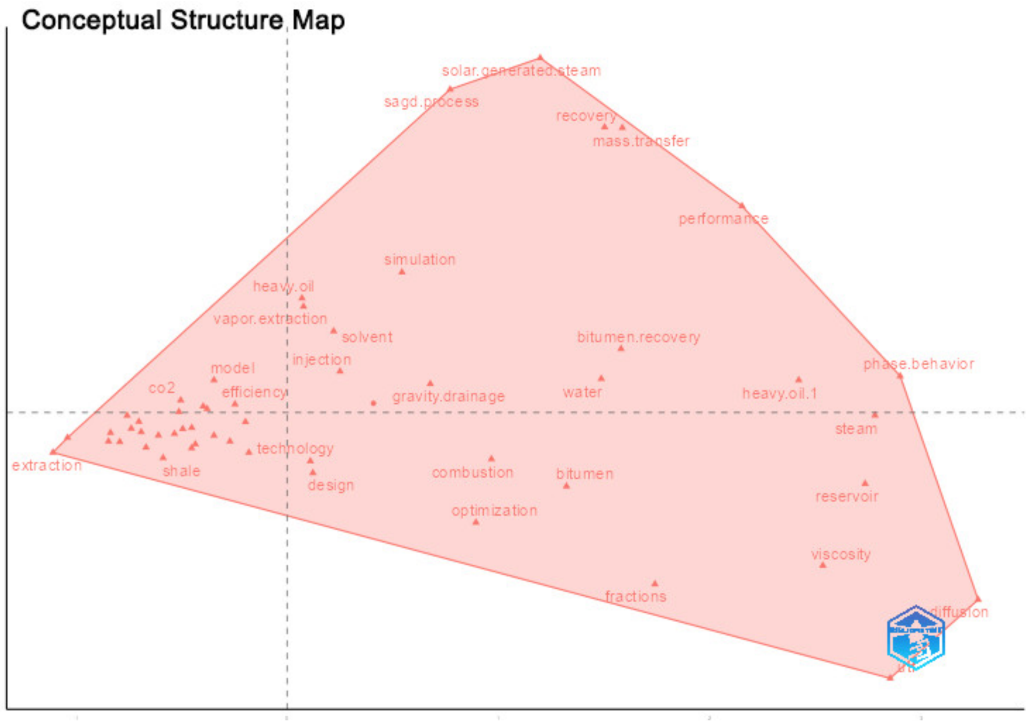


Figure 9. Factorial analysis results.

4. Discussion

In recent times, there has been a notable progression in bibliometric analysis and scientific mapping, driven by increasing interest within the scientific community in the insights derived from such analyses. Through bibliometric analysis, researchers can delve into the impact of research domains, the influence of scholars, and the significance of individual studies, aiding in the identification of influential papers and enriching our comprehension of the broader intellectual terrain within particular research realms [9,14].

One notable observation is the proliferation of research publications in recent years, indicating the increasing awareness of the importance of energy conservation and sustainability within the oil industry. This trend aligns with global efforts to mitigate environmental impact and optimize resource utilization in the energy sector.

The findings of this bibliometric analysis shed light on the landscape of energy-saving research in petroleum extraction and its scholarly contributions. Institutions like the University of Calgary, along with others globally, play a pivotal role in driving research forward and facilitating knowledge dissemination.

The prominence of certain authors, particularly Gates ID, Ren SR, and Zhang L, underscores their dedication and impact within the field. It is crucial to highlight the global reach of energy-saving research in oil extraction, as evidenced by contributions from 28 countries. Notably, countries like China, Canada, Russia, and the USA lead in research output, demonstrating a collective commitment to advancing sustainability in the oil industry. However, it is noteworthy that some significant petroleum-producing countries are notably absent from this list. Countries like Saudi Arabia, the United Arab Emirates, Venezuela, and Kazakhstan, which are major players in the oil industry, should also be active participants in energy-saving research endeavors.

One possible reason for their absence could be attributed to the language barrier, as many research articles might be published in languages other than English. Local language publications might not be captured in databases, leading to under-representation in bibliometric analyses. Therefore, efforts should be made to encourage researchers from these countries to publish their findings in international journals.

By encouraging broader participation and collaboration, we can ensure that energy-saving innovations and best practices are shared and implemented across the global oil industry, leading to more sustainable extraction practices worldwide. This inclusivity is essential for addressing the complex challenges of energy efficiency and environmental sustainability in petroleum extraction on a global scale.

From the comprehensive analysis of articles included in this bibliometric study, it becomes evident that researchers and experts have extensively explored and proposed various interventions aimed at saving electrical energy in oil extraction operations. These interventions encompass a wide range of strategies and technologies designed to optimize energy usage, reduce wastage, and enhance overall efficiency throughout the extraction process.

One key intervention highlighted in the literature is the optimization of drilling techniques. In their study, Ivanova et al. conducted a comprehensive analysis of energy consumption rates during well-drilling processes, proposing electrical energy consumption as a key indicator [15]. They established specific energy consumption rates and introduced a classification system based on the action period and size scale. The authors outlined measures to reduce energy costs, including optimizing drilling parameters and developing a predictive diagram for assessing well performance. These measures aim to achieve significant energy savings of up to 30–40%, enhancing overall energy efficiency in well-drilling operations. Ganzulenko et al. analyzed methods to enhance energy efficiency in sucker rod pumping units for marginal field development. They proposed a linear rack-and-gear drive as the most efficient option and developed an adaptive control system for group operations. Through calculations and testing, they demonstrated significant reductions in power consumption fluctuations and peak values. Integrating these energy-efficient drives and control systems in oil field clusters can yield substantial economic and environmental benefits, enhancing overall production efficiency and automation [16].

Furthermore, the authors underscored the importance of deploying smart well technologies as a means of real-time monitoring and control. Smart well systems enable operators to remotely monitor well performance, adjust production rates, and optimize operating parameters in response to changing reservoir conditions. By leveraging data-driven insights and automation, operators can minimize unnecessary energy usage, mitigate operational inefficiencies, and optimize production output, thereby enhancing overall energy efficiency in oil extraction operations [17].

In addition to technological innovations, the literature emphasizes the significance of upgrading to energy-efficient equipment and integrating renewable energy sources into oil extraction operations. Upgrading energy-efficient pumps, motors, and other machinery can significantly reduce electricity consumption and operating costs. Furthermore, the integration of renewable energy sources such as solar and wind power offers a sustainable alternative to traditional fossil fuel-based energy sources, helping to further reduce carbon emissions and environmental impact.

Oil extraction processes, particularly those involving pumping units, are notorious for their substantial energy requirements. The quest for energy conservation in this sector has become a paramount concern, prompting researchers and engineers to explore innovative technologies and strategies. The intricate dance between energy demand, extraction efficiency, and environmental sustainability necessitates a comprehensive examination of the tools and methodologies employed in the field. Li et al. developed a hydraulic hybrid power system for pumping units to reduce their high energy consumption in oilfields. The system, incorporating a secondary balance mechanism and a controller using multiple populations' genetic algorithms, effectively stabilizes motor operation and reduces energy fluctuations. Simulation results demonstrate substantial energy savings with the implemented system, highlighting its potential for enhancing energy efficiency in oil extraction operations [18].

One such technology at the forefront of enhancing energy efficiency in oil production is the utilization of frequency converters. These devices play a pivotal role in controlling electric motors on pumping units, offering the potential to finely tune and optimize energy consumption. Understanding the impact of frequency converters in this context is essential for navigating the delicate balance between energy conservation and production demands [19,20].

Moreover, authors have proposed the implementation of waste heat recovery systems to capture and utilize excess heat generated during oil extraction processes. By harnessing waste heat for heating purposes or other on-site operations, operators can improve overall energy efficiency and reduce reliance on external energy sources [20,21].

Additionally, the optimization of processes, establishment of energy management systems, and implementation of employee training programs have been identified as crucial components in promoting energy efficiency within oil extraction operations. Process optimization strategies such as controlling equipment speed, reducing friction losses, and minimizing idle time can help optimize energy consumption and improve overall efficiency [22]. Similarly, energy management systems enable operators to track energy usage, identify areas of inefficiency, and implement targeted interventions to reduce energy consumption and operational costs [22].

Overall, the findings from this bibliometric analysis suggest that a comprehensive approach combining technological innovations, process optimization, and organizational strategies is essential for achieving significant reductions in electrical energy consumption in oil extraction operations. By implementing these interventions, operators can enhance energy efficiency, reduce operational costs, and contribute to a more sustainable and environmentally friendly approach to oil extraction.

Nevertheless, it is important to recognize the constraints of this study, which stem from the reliance on a single publication database. WOS encompasses a wide range of publications, but it may not encompass all relevant literature, as databases like Scopus and PubMed may contain additional publications that were not considered in our analysis. Our bibliometric approach, based on empirical data extracted from original articles, prioritized article metadata, such as author details, affiliations, and countries, for productivity, collaboration, and impact assessment rather than analyzing textual content. Additionally, our analysis focused solely on English-language full-text articles, omitting publications in other languages, even if their abstracts were available in English. It is worth noting that the outcomes are contingent on the specific search query utilized in our study.

5. Conclusions

The bibliometric analysis underscores the importance of energy-saving technologies in oil extraction and highlights the collaborative efforts of researchers worldwide to address this critical issue. By identifying key research areas, geographic hotspots, and emerging trends, the analysis informs future research directions and policy initiatives aimed at promoting sustainability and efficiency in the oil industry. Overall, these findings provide valuable insights for researchers, policymakers, and industry stakeholders, informing future directions for research, collaboration, and policy development aimed at enhancing energy efficiency and sustainability in petroleum extraction. While valuable, it is important to note that future research may delve deeper into specific technological innovations, socio-economic impacts, and regulatory frameworks, providing insights beyond the scope of this study and further enriching strategies for enhancing energy efficiency and sustainability in petroleum extraction.

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