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Exploring the Dimensions of Energy Security for Sustainable Global Development

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Abstract

Ensuring a stable and sustainable energy supply has become a pressing global priority amidst rising energy demand, worsening environmental degradation, and persistent geopolitical uncertainties. Energy is the backbone of modern economies, serving as a fundamental driver of economic growth, industrial productivity, and technological advancement. Consequently, the availability of a reliable and accessible energy supply is essential for maintaining economic stability and fostering long-term development. The critical nature of energy stems from its pervasive role in supporting infrastructure, powering industries, and enhancing the quality of life. However, the increasing reliance on energy resources has intensified concerns over their environmental and geopolitical implications. Issues such as greenhouse gas emissions, resource depletion, and energy security highlight the urgent need for sustainable energy policies that balance economic needs with environmental preservation. As countries across the globe strive to achieve economic growth and technological progress, ensuring a stable energy supply has become a shared imperative. This requires a multi-faceted approach that incorporates diversification of energy sources, investment in renewable technologies, and international cooperation to address the challenges of energy security and sustainability in an interconnected world. This study seeks to examine the multifaceted nature of energy security, a concept that encompasses the availability, accessibility, affordability, and sustainability of energy resources. By delving into its various dimensions, the research aims to provide a comprehensive understanding of the factors influencing energy security and their implications for economic growth, environmental sustainability, and geopolitical stability. The study not only highlights the immediate challenges related to energy security, such as rising demand, resource depletion, and geopolitical risks, but also identifies derivative topics for further exploration. These include the integration of renewable energy sources, advancements in energy storage technologies, the impact of energy policies on economic development, and the role of international cooperation in mitigating energy crises. By addressing these critical issues, the research aims to lay a foundation for future studies that can contribute to the development of innovative solutions and strategies for achieving energy security. This exploration is particularly relevant in the context of an increasingly interconnected global economy where energy security remains a cornerstone of sustainable development and international stability. This research employs a hybrid methodology, combining bibliometric analysis and the Analytical Hierarchy Process (AHP), to explore and analyze the derivatives of the energy security concept. Through this innovative approach, the study identifies three priority topics with significant potential to contribute novel insights to the future development of energy security: clean energy, energy harvesting, and energy equity. The findings emphasize the critical importance of transitioning toward a sustainable energy system that not only ensures a stable and reliable energy supply but also aligns with broader goals of environmental preservation and social well-being. Clean energy focuses on reducing environmental impacts through the adoption of renewable energy sources and low-carbon technologies. Energy harvesting highlights advancements in capturing and utilizing ambient energy, contributing to efficiency and resilience in energy systems. Energy equity addresses the fair distribution of energy resources, ensuring accessibility and affordability for all, particularly marginalized and underserved populations. These priority areas underscore the need for integrated strategies that balance economic growth, environmental stewardship, and social inclusion. By focusing on these transformative topics, the study provides a roadmap for future research and policy development aimed at fostering a secure, equitable, and sustainable global energy system.

Keywords: Energy Security, Clean Energy, Energy Harvesting, Energy Equity

JEL Codes: Q40, Q42, Q48, Q56

1. INTRODUCTION

In recent years, studies on energy security across various countries have garnered significant attention from experts, with a notable focus on renewable energy advancements over the past five years. This trend reflects the growing urgency to address the complexities of energy security within the context of sustainable development and environmental preservation. National energy security is increasingly viewed as a fundamental aspect of a state's capacity to ensure the availability of reliable and affordable energy resources, capable of meeting the energy demands of its citizens in a sustainable manner. The application

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of the energy security concept emphasizes its dual role as a critical factor in promoting environmental sustainability and as a cornerstone for economic development (Khan & Hassan, 2019; Petrakis, 2021). By ensuring a stable and resilient energy supply, nations can foster industrial growth, enhance productivity, and support technological innovation while simultaneously reducing environmental impacts through the integration of renewable energy solutions. This shift toward renewable energy as a central element of energy security highlights the global commitment to transitioning from traditional fossil fuel reliance to cleaner and more sustainable energy systems. Such efforts not only address immediate concerns of energy availability and affordability but also align with long-term goals of reducing carbon emissions and mitigating climate change (Porro & Gia, 201). The evolving discourse underscores energy security's critical importance as both a policy priority and a strategic reference point for achieving balanced and sustainable development. Renewable energy policies are increasingly being developed in response to potential threats to energy security, with the achievement of energy security at an optimal level serving as a critical foundation for advancing renewable energy initiatives (Ahmad & Ali, 2019; Sattich et al., 2022). The concept of energy security is intrinsically linked to the essential needs of human life and overall productivity, underscoring its central role in ensuring economic stability and societal well-being (Durbin & Filer, 2021; Diaz & Weber, 2020). Over the past few decades, the fragility of energy systems has been exposed by extreme natural events, such as hurricanes, floods, and wildfires, which have disrupted energy supplies and highlighted vulnerabilities in traditional energy infrastructures. These disruptions emphasize the urgent need for resilient energy systems that incorporate renewable energy solutions to reduce dependence on non-renewable resources and enhance adaptability to environmental challenges (William & Adam, 2018). Additionally, energy security has frequently served as a catalyst for international conflicts, as nations compete for control over limited energy resources or leverage energy as a geopolitical tool. These dynamic underscores the importance of transitioning to diversified and sustainable energy systems that minimize vulnerabilities and foster cooperation rather than conflict. By prioritizing renewable energy policies, countries can address the dual challenges of achieving energy security and mitigating the impacts of climate change, paving the way for a more stable and sustainable future. Studies on energy security generally focus on three primary dimensions: the availability of energy sources, the affordability of energy supply, and the sustained development of renewable energy (Allen, 2021; Zhang, 2021; Ali & Audi, 2016; Ali et al., 2021). While significant research has been conducted on these aspects, numerous challenges remain that continue to draw the attention of academics and researchers globally. These challenges highlight the complexities and interdependencies inherent in achieving comprehensive energy security.

One notable issue involves the tension between renewable energy development and public energy preferences. Critics argue that while renewable energy sources are essential for sustainability, their integration into the energy mix may, paradoxically, pose short-term threats to energy security. These concerns often stem from the variability of renewable energy sources, such as wind and solar, and the infrastructural challenges associated with their widespread adoption. Another pressing challenge lies in advancing the broader vision of energy security amid the ongoing global energy transition. This transition, marked by a shift away from fossil fuels toward cleaner energy alternatives, faces obstacles such as geopolitical dependencies and international conflicts. For example, the reliance on Russian energy exports has heightened global tensions, emphasizing the urgent need for strategies to ensure energy security while navigating the complexities of energy transitions (Audi & Ali, 2017; Höysniemi, 2022). Additionally, the energy crisis exacerbated by geopolitical conflicts, such as efforts to reduce natural gas consumption during winter, has intensified the challenges of maintaining energy security. These crises underscore the vulnerability of energy systems to external shocks and highlight the importance of diversification, resilience, and international collaboration in securing future energy supplies. Addressing these interconnected issues requires innovative policies and a balanced approach to transitioning toward sustainable energy systems while ensuring reliable and affordable energy access for all.

Efforts to strengthen energy security have been extensively explored in academic and policy-oriented studies, highlighting various strategies to address the multifaceted challenges of securing energy systems. One prominent approach involves implementing environmental regulatory frameworks, acknowledging regional differences and spatial dependencies in energy needs and resources. Rodríguez-Fernández et al. (2022) propose three innovative perspectives for advancing the concept of energy security: sovereignty, robustness, and resilience. These dimensions emphasize the importance of national energy autonomy, the durability of energy systems under stress, and their capacity to recover from disruptions. The growing complexity of global economies has driven initiatives to enhance energy efficiency, particularly by optimizing energy intensity and reducing carbon intensity. These measures aim to minimize energy use per unit of output while lowering emissions, thus contributing to sustainability. However, such efforts can also introduce energy security risks, as variations in energy intensity and their effects on carbon intensity differ across regions and economic contexts. Middle-income countries, for instance, face heightened instability in managing the trade-offs between energy security risks and renewable energy development.

To improve energy security indicators, several practical measures have been identified. These include enhancing energy governance, expanding generation capacity with a focus on renewable energy sources, increasing energy efficiency, and upgrading power system capacity. Encouraging research and development plays a pivotal role in fostering innovation to address energy challenges. Additionally, integrating environmentally friendly practices into energy policies and behaviors contributes to more sustainable and secure energy systems. Fouladvand (2022) highlights how such measures not only improve technical configurations but also promote affordability and public acceptance of energy security initiatives. Furthermore, while energy security risks can positively influence the adoption of renewable energy, the impact is context-dependent. For middle-income countries, the relationship is often marked by instability, underscoring the need for tailored strategies that address specific economic and environmental conditions. Collectively, these solutions emphasize the importance of a balanced approach that prioritizes resilience, sustainability, and inclusivity in strengthening energy security worldwide. Energy security is a cornerstone of a nation's sustainability, as well as its economic, social, and political stability. It involves ensuring a reliable, affordable, and sustainable energy supply to meet the needs of society and industry, which are crucial for economic growth and development. As the backbone of economic activities, energy security guarantees a stable and uninterrupted energy supply, preventing disruptions in production and distribution that could destabilize economies. A key aspect of energy security is the promotion of energy independence by leveraging domestic energy resources and reducing reliance on imports. This shift minimizes exposure to international energy price fluctuations, enhancing a nation's economic resilience. Moreover, energy security addresses the risk of supply shortages by diversifying energy sources, investing in robust energy infrastructure, and preparing for potential natural or political disruptions that could threaten energy availability. Energy security also plays a pivotal role in climate change mitigation. Transitioning to sustainable energy sources, such as solar, wind, and hydropower, contributes to reducing greenhouse gas emissions, helping to protect the environment and safeguard societies from the adverse impacts of climate change. This transition aligns energy security with environmental sustainability goals. Additionally, energy security drives innovation within the energy sector. The development and adoption of advanced technologies, such as energy storage systems, smart grids, and electric vehicles, enhance energy efficiency and sustainability. These technologies not only improve energy reliability but also create opportunities for economic growth by fostering new industries and technological advancements. In sum, energy security is an integrated approach that ensures economic stability, promotes environmental sustainability, and enhances resilience against geopolitical and natural challenges. By focusing on diversification, innovation, and sustainability, countries can achieve a secure energy future while addressing the pressing global challenges of climate change and resource dependency. Despite the numerous solutions proposed by experts across various fields, approaches to addressing energy security challenges often remain fragmented and narrowly focused. While existing studies offer valuable insights, each with its unique perspective, there is a pressing need for a comprehensive and innovative strategy to redefine the concept of energy security. This strategy must transcend traditional frameworks to address the complex and evolving challenges faced by nearly all nations in ensuring a stable energy supply that supports the continuity of life and economic stability. Given the global nature of energy security concerns, enhancing energy security capabilities has become a critical priority. This requires the development of new theories and constructs that extend the current understanding of energy security. These constructs, as derivatives of the energy security concept, should provide fresh insights and frameworks to guide future policies and practices. By fostering innovation and diversification, these advancements can address emerging risks and promote sustainable energy systems.

This study aims to contribute to this endeavor by identifying and developing new theories and constructs related to energy security. The focus is on supporting energy diversification strategies, which are essential for reducing dependence on limited energy sources and enhancing resilience against supply disruptions. Emphasizing knowledge development, this research underscores the importance of disseminating findings through scientific journals, as highlighted by Sarjana et al. (2022), to ensure broad accessibility and stimulate further academic and practical advancements. Ultimately, by integrating novel constructs and fostering interdisciplinary collaboration, this study seeks to pave the way for more robust, adaptive, and sustainable energy security strategies that can meet the demands of an increasingly interconnected and dynamic global landscape.

2. METHODOLOGY

The methodology employed in this study adopts a hybrid approach that combines qualitative analysis and bibliometric analysis, providing a comprehensive framework for exploring the concept of energy security. This approach integrates the depth and contextual understanding of qualitative research with the systematic insights of bibliometric analysis, enabling a nuanced examination of patterns and trends in the scientific literature. The first step involved collecting bibliometric data from scientific publications relevant to energy security, including article titles, authors, published journals, years of publication, citation counts, and other relevant metrics. The data collection spanned from 2018 to 2022, capturing recent developments in the field. A total of 4,685 journal articles were gathered, resulting in 138,976 citations sourced primarily through searches on Google Scholar. This dataset formed the basis for further analysis. Bibliometric analysis, as described by Raharjo and Sarjana (2022), employed VOSviewer software to visualize citation networks, analyze collaboration among authors, and identify frequently occurring keywords. Additionally, the analysis highlighted influential topics within the field and uncovered underexplored areas with the potential for novel contributions to energy security concepts. This systematic approach facilitated the identification of relationships between researchers and emerging trends, offering a detailed picture of the research landscape in energy security.

The qualitative analysis complemented these findings by interpreting the bibliometric results to uncover deeper insights into patterns and their broader implications for energy security. This integration of findings enabled the identification of derivative topics, trends, and relationships that extend the conceptual understanding of energy security. For example, the study pinpointed rarely discussed topics with potential for novel theoretical contributions, bridging gaps in current research and offering directions for further inquiry. The combined approach provided rich insights into the relationships between researchers, influential topics, and emerging trends in the field. By integrating bibliometric tools with qualitative interpretations, the study contextualized its findings, enhancing their relevance and applicability. This methodology not only advances the understanding of energy security but also demonstrates the potential of a hybrid analytical framework to enrich academic research and identify opportunities for both theoretical and practical advancements in the field. The subsequent phase of the study involves applying the Analytical Hierarchy Process (AHP) for decision-making, particularly suited to addressing complex problems that involve multiple criteria and alternatives. AHP is widely used across various domains, including the analysis of energy security concepts, to prioritize existing alternatives based on predefined criteria. The primary objective of this analysis is to identify derivative topics that hold potential for novelty within the broader framework of energy security. The criteria employed in the analysis include availability, affordability, efficiency, acceptability, and accessibility, while the alternatives considered are energy harvesting, energy independence, energy equity, energy trilemma, energy sustainability, clean energy, and energy hubs. The process begins by creating a hierarchy of the identified criteria and alternatives, outlining the relationships between each element. The hierarchy structure defines the primary goal at the upper level, with subsequent levels representing the contributing criteria and alternatives that support achieving this goal. Pairwise comparison matrices are then constructed for each level of the hierarchy. These matrices compare the relative importance of criteria and alternatives, enabling precise measurements of their significance in achieving energy security objectives. The pairwise comparison values are assigned based on the perceived importance of each criterion or alternative in relation to others. Using the AHP method, the relative weights of the criteria are calculated, reflecting their importance in the context of energy security. This weighting guides the prioritization of alternatives, helping to identify which options are most effective in supporting energy security goals. The alternative with the highest score is deemed the most suitable for addressing the objectives and is prioritized for decision-making. This systematic approach ensures that the chosen alternative aligns closely with the defined criteria, enhancing the relevance and impact of the analysis. The application of AHP in the context of energy security analysis provides a robust framework for evaluating and prioritizing complex issues related to energy availability and sustainability. By offering a structured method for identifying key factors and assessing their contributions, AHP facilitates the development of targeted strategies and policies. This ensures that policy-making is not only accurate but also effective in addressing the multifaceted energy challenges faced by nations, paving the way for sustainable and resilient energy systems.

3. RESULTS AND DISCUSSIONS

The collection of bibliometric data relevant to energy security focuses on information such as article titles, authors, journals, years of publication, and citation counts. Once the data is gathered, the next step involves preprocessing to organize the dataset, including checking for duplicate entries and removing irrelevant data. The cleaned data is then imported into VOSviewer, a software tool used for bibliometric analysis, to generate network visualizations of citations and collaborations between authors, as well as to analyze keywords that frequently appear in scientific articles related to energy security. Using VOSviewer's analytical features, the study identifies the main themes in the literature on energy security. These themes provide insights into patterns of collaboration among authors and research groups actively engaged in this field. The visualizations produced by VOSviewer facilitate the interpretation of findings, highlighting developments, trends, and emerging needs within the concept of energy security. These findings help delineate the trajectory of research in this area and reveal opportunities for further exploration and innovation.

Citation metrics, a critical component of the analysis, measure how frequently scientific journals are cited by other articles or journals. These metrics serve as indicators of the influence and relevance of scientific publications. However, it is emphasized that citation metrics should be viewed as one of several evaluation tools rather than the sole determinant of a paper's quality. The keywords used to search for journal articles on energy security span the last five years, as presented in Table 1. The data also include information on the number of citations per year, average citations per paper, and the number of authors contributing to the publications. It is observed that older scientific journals tend to have higher citation counts due to their longer exposure, while newer publications are still gaining traction. Trends in the data indicate an increase in the average number of authors per paper over recent years, reflecting a growing emphasis on collaborative research. The quality of journal publications is assessed using metrics such as the h-index, g-index, and hA-index. The h-index measures the productivity and citation impact of researchers based on the number of citations their publications receive. The g-index represents the average citations across all publications, offering a broader view of research impact, while the hA-index focuses on the actual impact created by individual researchers.

This comprehensive bibliometric analysis provides valuable insights into the evolution of energy security research. It highlights influential studies, identifies collaboration patterns, and uncovers areas for further exploration. By combining citation metrics with network visualizations, the study evaluates the productivity and influence of research in this field, offering a foundation for advancing the understanding and application of energy security concepts. Citation trends are a key metric in evaluating the impact and relevance of scientific publications, playing a significant role in shaping research and influencing researchers. The frequency with which an article is cited serves as a primary indicator of its impact within the academic community.

Articles that receive numerous citations are generally considered to hold significant value, contributing meaningfully to their respective fields. This makes citation trends a measure of prestige for both researchers and journals. Researchers with highly cited works are often regarded as influential figures in their disciplines, while journals with frequently cited articles tend to enjoy higher reputations among academics.

Beyond prestige, citation trends also facilitate the dissemination of research and ideas. When an article is cited, it indicates that the research has been acknowledged and used as a reference, helping to spread scientific thought and broaden the impact of research across various fields. Citations thus play a pivotal role in advancing knowledge, promoting dialogue within the scientific community, and guiding future research directions. Citation trends are also instrumental in assessing the quality of research. Frequently cited articles are often viewed as having undergone rigorous peer review and validation, signifying that they contribute important findings or perspectives to their field. Furthermore, citation trends serve as a valuable tool for researchers to discover relevant studies. References within a highly cited article can guide readers to other influential works, enriching their understanding of a particular topic. For researchers, the recognition associated with high citation counts can be rewarding, fostering motivation to pursue further studies. Citations can also open doors to collaboration, bringing together researchers with shared interests and fostering innovative partnerships. However, it is essential to recognize that citation trends are influenced by factors beyond academic merit, such as social media visibility, active promotion, or strong collaboration networks. These factors can amplify an article's reach and citation count, underscoring the need to contextualize citation trends when using them as an indicator of quality or impact.

As shown in Table 2, the highest citation trends over the past five years are associated with articles published in reputable journals owned by globally recognized publishers. This underscores the importance of publishing high-quality research in well-established journals with reputable indexing, as these platforms significantly enhance the visibility and perceived value of scientific work. While citation trends are a powerful tool for measuring research impact, it is vital to consider the broader context and underlying factors that influence citation dynamics. This table provides an overview of journal publication metrics related to the concept of energy security from 2017 to 2021. The metrics include data on the number of papers, citations, and various indices, offering insights into the publication trends and academic impact over the years. The number of papers published each year remained relatively stable, with a noticeable increase from 740 in 2017 to a peak of 993 in 2019, followed by slight declines in subsequent years. Despite this consistency in publication numbers, the total citations show a more dynamic trend. Citations reached their highest in 2018, with 42,681, reflecting strong academic engagement with the publications from earlier years. However, citations declined sharply in later years, dropping to 7,790 by 2021. This decline could indicate either a reduced academic interest in newer works or the shorter time frame available for recent papers to accumulate citations.

The cites per year metric, which measures average citations received per year, peaked in 2019 at 11,717.33 but decreased steadily afterward, mirroring the overall citation trend. Similarly, cites per paper, which reflects the average number of citations each paper received, declined over time, from 43.52 in 2017 to just 7.96 in 2021. This trend suggests that papers published in earlier years were more widely cited than recent ones, which might be due to the inherent lag in citation accumulation for newer publications. The cites per author metric, which provides an average of citations attributed to each contributing author, shows a declining pattern over the years, peaking in 2018 at 15,809.76 and dropping to 2,836.95 by 2021. Conversely, the papers per author metric shows a relatively stable trend, with minor fluctuations, indicating that individual authors maintained a consistent publication rate despite variations in citation impact. The authors per paper metric reveals a gradual increase over the years, from 2.79 in 2017 to 3.23 in 2021, suggesting a growing tendency toward collaborative research in the field of energy security. This trend reflects a broader shift in academic publishing where multi-author papers are becoming more common, likely due to the interdisciplinary nature of energy security research.

Table 1: Journal publication period metrics on the concept of energy security

Citation metric	2017	2018	2019	2020	2021
Papers	740	991	993	982	979
Citations	32203	42681	35152	21150	7790
Cites/year	6440.60	10670.25	11717.33	10575.00	7790.00
Cites/paper	43.52	43.07	35.40	21.54	7.96
Cites/author	12940.01	15809.76	12322.79	7301.86	2836.95
Papers/author	366.88	440.11	446.94	408.18	418.15
Authors/paper	2.79	3.04	3.05	3.24	3.23
h-index	89	98	92	68	35
g-index	148	161	138	95	51
hA-index	34	43	44	42	35

The h-index, which measures the number of papers with at least hhh citations, peaked at 98 in 2018 before decreasing to 35 by 2021. The g-index, which gives more weight to highly-cited articles, shows a similar trend, reaching its highest value of

161 in 2018 and declining sharply to 51 in 2021. The hA-index, which adjusts the h-index to account for author contributions, remained relatively stable, fluctuating between 34 and 44 over the five years. Overall, these metrics illustrate a dynamic academic landscape for energy security research, with peaks in productivity and impact occurring around 2018 and 2019, followed by a gradual decline in citation-related metrics. This could be attributed to the time-dependent nature of citations and evolving research interests within the academic community. The consistent growth in collaborative research, as evidenced by the increasing authors per paper, highlights the interdisciplinary and team-oriented approach in this field.

Network visualization using VOSviewer offers a powerful approach to analyzing relationships between various elements within a specific concept, such as energy security. This method provides a clearer representation of the connections and interactions among topics relevant to energy security, enabling a deeper understanding of the structure and dynamics underlying the concept. By visualizing these relationships, researchers can identify key themes, uncover hidden patterns, and gain new insights that might not be apparent through traditional data analysis techniques. Once the bibliometric data is imported and configured, VOSviewer generates network visualizations in the form of node maps and cluster maps. These visualizations allow researchers to explore how different topics are interrelated and grouped into clusters, providing a comprehensive overview of the research landscape. The node maps highlight individual topics or keywords, while the cluster maps group them based on their degree of interconnection, offering a structured view of thematic areas within the field.

Through the network visualization of energy security, it is observed that several topics are frequently published and well-established in the literature. These include renewable energy, energy efficiency, food security, climate change, water security, and smart grids. These widely studied topics reflect their centrality to current discourse on energy security and their recognized importance in addressing global challenges. In contrast, the analysis reveals several emerging topics that are less frequently published and hold the potential for novel research contributions. These include energy harvesting, energy independence, energy equity, energy trilemma, energy sustainability, clean energy, and energy hubs. These underexplored areas present opportunities for further investigation and development, as they represent critical components of energy security that have yet to be fully integrated into mainstream research. By leveraging network visualization, researchers can not only map the current state of knowledge on energy security but also identify gaps and opportunities for advancing the field. This approach facilitates a more strategic allocation of research efforts, encouraging the exploration of novel topics while continuing to build on established themes. Such insights are invaluable for driving innovation and addressing the complex challenges associated with ensuring a secure and sustainable energy future. This table showcases citation trends in prominent journal publications, highlighting the most-cited works across various energy security, IoT, and technological domains. The total citations (TC) provide insight into the academic impact and relevance of each article, reflecting the significance of their contributions to their respective fields. The most-cited publication is "Hydrogen energy, economy and storage: Review and recommendation" by Abe et al. (2019), published in the *International Journal of Hydrogen Energy* by Elsevier, with 1,505 citations. This paper underscores the growing focus on hydrogen as a key element in energy transition strategies, discussing its potential in energy storage and economic viability. Following closely is the survey by Li et al. (2018) titled "5G Internet of Things: A survey," published in the *Journal of Industrial Information Integration* by Elsevier, with 1,293 citations. This work emphasizes the transformative potential of 5G technology in IoT applications, aligning with the increasing integration of IoT in industrial and everyday contexts.

Dawood et al. (2020) contributed the third most-cited work, "Hydrogen production for energy: An overview," also in the *International Journal of Hydrogen Energy* by Elsevier, with 1,103 citations. This further highlights the critical role of hydrogen in future energy solutions, particularly in addressing energy security and sustainability challenges. Another highly-cited paper, "A comprehensive survey on Internet of Things (IoT) toward 5G wireless systems" by Chettri and Bera (2020), garnered 881 citations. Published in the *IEEE Internet of Things Journal* by IEEE, it delves into the technological advancements and integration of IoT within 5G networks, addressing the evolving needs of wireless systems. Pata (2018) examined renewable energy consumption and its interplay with urbanization, financial development, income, and CO_2 emissions in Turkey. Published in the *Journal of Cleaner Production* by Elsevier, the paper has 703 citations and tests the Environmental Kuznets Curve (EKC) hypothesis, emphasizing the role of structural breaks in environmental studies.

Chowdhury et al. (2020) addressed future communication technologies in their work, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," published in the *IEEE Open Journal of the Communications Society* by IEEE, with 673 citations. This article offers a forward-looking perspective on 6G, establishing its role as a successor to 5G. Wu et al. (2018), with 624 citations, explored security techniques for 5G wireless networks in their survey published in the *IEEE Journal on Selected Areas in Communications*. This work highlights the ongoing concerns about the physical layer security of wireless systems. Ferrag et al. (2019) and Sengupta et al. (2020) focused on blockchain technologies and their implications for IoT and Industrial IoT (IIoT). Published in the *IEEE Internet of Things Journal* and the *Journal of Network and Computer Applications* respectively, these papers emphasize the critical role of blockchain in addressing IoT security challenges, with 593 and 526 citations. Lastly, Gai et al. (2018) explored FinTech in their survey published in the *Journal of Network and Computer Applications* by Elsevier, accruing 516 citations. Their work sheds light on the intersection of finance and technology, emphasizing innovative applications in a rapidly evolving field.These citation trends reflect the diverse yet interconnected themes of energy security, IoT, blockchain, and wireless communication technologies. The prominence of Elsevier and IEEE as publishers also highlights their pivotal role in disseminating impactful research.

Bibliometric data-based visualization and network analysis provide an effective means of visually analyzing co-authorship in scientific publications, offering insights into collaboration patterns within the research community. The network visualization results, represent authors as nodes and their relationships as edges. By interpreting these patterns, it is possible to identify prominent authors, assess their influence on the topic of energy security, and understand the dynamics of research collaboration. The analysis reveals that the majority of dominant authors are concentrated in specific countries, indicating an uneven global distribution of studies on energy security. This highlights the need for broader, more geographically inclusive research to ensure energy sustainability and security across diverse regions. In the context of energy security, this analytical approach can also prioritize factors contributing to energy security based on their significance. The hierarchical structure aims to identify three main alternatives as priority topics for the development of energy security. The criteria used to assess energy security include availability, affordability, efficiency, acceptability, and accessibility. The alternative options under consideration are energy harvesting, energy independence, energy equity, energy trilemma, energy sustainability, clean energy, and energy hubs. Among these, clean energy, energy equity, and energy harvesting emerged as the top three priorities based on the evaluation.

Table 2: Citation trends in journal publications

Authors (Year)	Title	Source Journal	Publisher
(Abe et al., 2019)	Hydrogen energy, economy and storage: Review and recommendation	International Journal of Hydrogen Energy	Elsevier
(Li et al., 2018)	5G Internet of Things: A survey	Journal of Industrial Information Integration	Elsevier
(Dawood et al., 2020)	Hydrogen production for energy: An overview	International Journal of Hydrogen Energy	Elsevier
(Chettri and Bera, 2020)	A comprehensive survey on Internet of Things (IoT) toward 5G wireless systems	IEEE Internet of Things Journal	IEEE
(Pata, 2018)	Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: testing EKC hypothesis with structural breaks	Journal of cleaner production	Elsevier
(Chowdhury et al., 2020)	6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions	IEEE Open Journal of the Communications Society	IEEE
(Wu et al., 2018)	A survey of physical layer security techniques for 5G wireless networks and challenges ahead	IEEE Journal on Selected Areas in Communications	IEEE
(Ferrag et al., 2019)	Blockchain technologies for the internet of things: Research issues and challenges	IEEE Internet of Things Journal	IEEE
(Sengupta et al., 2020)	A comprehensive survey on attacks, security issues and blockchain solutions for IoT and IIoT	Journal of Network and Computer Applications	Elsevier
(Gai et al., 2018)	A survey on FinTech	Journal of Network and Computer Applications	Elsevier

Performance sensitivity in energy security studies is a critical measure, reflecting the capacity of energy systems and infrastructure to adapt to changing conditions while maintaining functionality. This adaptability is vital for addressing risks and changes that could disrupt energy supply, distribution, or usage. By evaluating performance sensitivity, researchers can identify vulnerabilities and design strategies to mitigate risks. Factors such as climate change, global energy price fluctuations, emerging technologies, and evolving energy policies are integral to understanding and addressing these sensitivities. The three prioritized alternatives—clean energy, energy equity, and energy harvesting—play a pivotal role in enhancing the resilience and sustainability of energy systems. Clean energy focuses on reducing environmental impacts and promoting renewable energy sources. Energy equity emphasizes fair access to energy resources, ensuring that all populations benefit from energy security. Energy harvesting involves innovative technologies to capture and utilize ambient energy, contributing to system efficiency and resilience. By addressing performance sensitivity and prioritizing these alternatives, future studies can focus on strengthening energy security against diverse challenges. These efforts will support the development of robust, adaptable, and sustainable energy systems that align with global goals for energy security and sustainability.

Gradient sensitivity refers to the responsiveness of calculations or outcomes to small changes in specific parameters, providing a critical measure of adaptability and resilience in energy security systems. In the context of energy security, gradient sensitivity evaluates how variations in key criteria—such as availability, affordability, efficiency, acceptability, and accessibility—impact the overall security of the energy supply. By quantifying this responsiveness, gradient sensitivity analysis identifies the most critical elements that significantly influence energy security, enabling more informed decision-making. Measuring gradient sensitivity in energy security is essential for understanding the system's ability to adapt to changes and mitigate potential negative impacts. It helps prioritize criteria and alternatives that are more vulnerable to fluctuations, ensuring that these areas are addressed through targeted interventions. For instance, in this study, energy harvesting has shown an upward trend in its assessment based on the applied criteria, rising to second position in priority. Conversely, energy equity has experienced a downward trend, placing it below energy harvesting in the prioritization hierarchy. These shifts highlight the importance of continuous evaluation and the dynamic nature of energy security challenges.

Gradient sensitivity analysis is particularly valuable for designing risk mitigation strategies and formulating effective energy policies. By analyzing the system's response to changes in the selected criteria, policymakers can develop proactive measures to minimize risks and enhance the resilience of energy systems. For example, understanding how changes in affordability or accessibility affect energy security can guide investments in renewable energy infrastructure, subsidies, or other measures to stabilize supply and demand. Moreover, gradient sensitivity provides insights into how to balance competing priorities, such as promoting sustainable energy sources while ensuring affordability and reliability. By incorporating this analysis into energy policy development, it becomes possible to anticipate and address potential risks, reducing the likelihood of disruptions and safeguarding energy supply security. Ultimately, gradient sensitivity analysis empowers policymakers to create more robust, adaptive, and forward-looking strategies that align with the dynamic needs of energy systems in a rapidly changing world. Two-dimensional sensitivity analysis in energy security studies examines the combined effects of changes in two interacting criteria on the performance and security of the energy system. This approach is particularly relevant when assessing criteria that can have interdependent and complex impacts, such as affordability and availability. Analyzing these two dimensions provides a clearer understanding of how their interplay influences the stability of energy supply, distribution, and usage. Two-dimensional sensitivity analysis allows researchers to evaluate how changes in these criteria affect the prioritization of alternatives and to design strategies that holistically address energy security concerns. In the analysis, positioning nodes highlight three main alternative choices—clean energy, energy harvesting, and energy equity—emerging as the highest-ranked alternatives based on the combined affordability and availability criteria. These alternatives demonstrate their ability to balance the cost-effectiveness of energy supply with its accessibility, positioning them as critical areas for further exploration and investment in energy security. Head-to-head sensitivity analysis, on the other hand, focuses on a direct comparison of alternatives to evaluate their relative performance in securing energy supply, distribution, and use. This approach examines the impact of parameter changes on multiple scenarios to identify which alternatives are most effective in maintaining energy security. In Figure 7, head-to-head sensitivity analysis compares energy harvesting with other alternatives, such as energy independence, energy equity, energy trilemma, energy sustainability, clean energy, and energy hubs.

The results indicate that energy harvesting outperforms alternatives such as energy independence, energy trilemma, energy sustainability, and energy hubs, demonstrating a stronger ratio of value in terms of its contribution to energy security. However, energy harvesting shows lower values compared to energy equity and clean energy, indicating that while it is a significant alternative, it may not be as impactful as clean energy and energy equity in specific scenarios. This highlights the importance of tailoring strategies to the context in which these alternatives are applied. Both two-dimensional sensitivity and head-to-head sensitivity analyses provide valuable tools for decision-making in energy security. By examining the interactions between key criteria and directly comparing alternatives, these approaches offer deeper insights into the trade-offs and practical implications of different energy security strategies. This allows policymakers and stakeholders to make informed decisions that enhance the stability, resilience, and sustainability of energy systems while addressing the complex challenges of modern energy demands.

4. CONCLUSION

The growing interest in studying the concept of energy security underscores the need for a more regionally inclusive and comprehensive approach to ensure the continuity of national energy availability. To address this critical need, the study identified three main alternatives as priority topics derived from the broader energy security concept: clean energy, energy harvesting, and energy equity. These alternatives represent essential areas of focus for advancing the understanding and implementation of effective energy security strategies. The prioritization of these topics highlights their potential as novel and impactful areas for further exploration. Clean energy emphasizes the shift towards sustainable and environmentally friendly energy sources to reduce reliance on fossil fuels and mitigate climate change. Energy harvesting involves innovative technologies to capture and utilize ambient energy, contributing to energy system efficiency and resilience. Energy equity focuses on ensuring fair access to energy resources, addressing disparities in energy availability, and promoting inclusivity in energy policies. These priority alternatives offer significant opportunities for researchers, academics, and policymakers to collaborate on developing strategies that align with global sustainability goals. By fostering research and innovation in these areas, governments and other stakeholders can support the transition to renewable energy, enhance energy system resilience, and ensure equitable energy access for all. These efforts are vital for addressing the complex challenges of energy security while paving the way for a more sustainable and inclusive energy future.

Clean energy, energy harvesting, and energy equity are pivotal in fostering a sustainable, efficient, and inclusive approach to strengthening energy security. The adoption of clean energy, particularly renewable sources such as solar, wind, hydro, and sustainable biomass, plays a crucial role in reducing greenhouse gas emissions and mitigating air pollution, which are significant contributors to climate change and public health issues. By transitioning to clean energy, energy systems become more sustainable in the long term and less susceptible to the volatility of global energy prices, enhancing their overall resilience. Energy harvesting technologies further bolster energy security by facilitating the development of decentralized energy systems. These technologies, such as sensors powered by ambient environmental energy, reduce reliance on centralized external energy supplies, making energy systems more adaptable and robust. Decentralized energy resources not only improve efficiency but also enhance resilience in the face of disruptions, providing localized solutions that are both practical and innovative. Energy equity, on the other hand, emphasizes the importance of ensuring equal access to energy resources and services for all individuals. Efforts to promote energy equity address the disparities that often leave vulnerable communities disadvantaged in energy transitions. By prioritizing inclusivity, energy equity ensures that marginalized groups can better withstand changes in energy supply or pricing and fully participate in the benefits of modern energy systems. This focus on equitable access contributes to a more just and resilient energy framework, where all communities can thrive amidst evolving energy challenges.

Together, clean energy, energy harvesting, and energy equity offer a comprehensive approach to achieving sustainable energy security. These pillars not only address environmental and economic challenges but also foster social inclusivity, ensuring that energy transitions benefit society as a whole while paving the way for a resilient and sustainable future. The integration of clean energy, energy harvesting, and energy equity has a synergistic effect on enhancing energy security. The adoption of clean energy mitigates supply risks linked to the volatility of fossil fuel markets and reduces environmental hazards, all while supporting long-term sustainability. By transitioning to renewable energy sources such as solar, wind, and hydro, energy systems become less reliant on finite resources, leading to greater stability and resilience against price fluctuations and supply uncertainties. Energy harvesting complements this by offering a sustainable and decentralized approach to energy generation. Technologies that harness ambient environmental energy reduce dependence on centralized and external energy supplies, increasing the resilience of energy systems to potential disruptions. This decentralized model not only diversifies energy sources but also supports localized solutions, empowering communities and minimizing vulnerabilities associated with energy supply chains. Energy equity ensures that the benefits of these advancements are shared inclusively across all segments of society. By promoting equal access to energy resources and services, energy equity fosters social and economic stability, reducing disparities that could lead to energy-related conflicts. Inclusive energy policies enhance societal cohesion and ensure that vulnerable communities are not left behind in the transition to sustainable energy systems. Together, these three concepts create a comprehensive framework for strengthening energy security. Their combined impact builds a more resilient, sustainable, and equitable energy system that not only addresses environmental and economic challenges but also promotes social stability. This integrated approach ultimately contributes to a robust and secure energy future, capable of meeting the evolving demands of a rapidly changing world.

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