A BIBLIOMETRIC ANALYSIS ON

SMART ENERGY INTEGRATION AND SYNERGISTIC OPTIMIZATION OF

RENEWABLE AND ENERGY STORAGE SYSTEMS

BANGKOK UNIVERSITY

THE CREATIVE UNIVERSITY

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Xiaokun Zhou

This Independent Study Manuscript Was Presented to

The Graduate School of Bangkok University

in Partial Fulfillment

of the Requirements for the Degree

Master of Management in Business Innovation

2024

This manuscript has been approved by

the Graduate School

Bangkok University

Title : A Bibliometric Analysis of Smart Energy Integration and Synergistic Optimization of Renewable and Conventional Energy.

Author: Xiaokun Zhou

Independent Study Committee:

Advisor: Dr. Ronald Vatananan-Thesenvitz

Field Specialist: Dr. Chulatep Senivongse

Zhou, Xiaokun. Master of Management Business Innovation, July 2024, Graduate School, Bangkok University.

A Bibliometric Analysis of Smart Energy Integration and Synergistic Optimization of Renewable and Conventional Energy. (36pp.)

Advisor: Ronald Vatananan-Thesenvitz, Ph.D.

ABSTRACT

This study explores the integration of renewable energy sources with energy storage systems to create sustainable and reliable energy solutions. The need for such integration is due to the finite nature of fossil fuels and the environmental impact of their use with the potential of renewable technologies like solar, wind, hydroelectric, and biomass to provide cleaner alternatives. Smart energy systems, which combine renewable energy with advanced storage technologies to enhance efficiency, reliability, and sustainability comes with challenges posed by the variability of renewable energy sources and how energy storage can mitigate these issues by storing excess energy during peak production periods for use during low production times. The research involves a bibliometric analysis using RStudio's bibliometrix package to analyze trends, collaborations, and thematic evolution in the field from 2019 to 2024 with the scope limited to academic publications in scholarly databases, focusing on identifying key contributors, institutions, and countries involved in the research. The analysis reveals increasing research interest in smart energy integration and synergistic optimization, with key trends from topics like cybersecurity, low carbon, smart energy meters, and renewable energy systems. The analysis also identifies the emerging areas such as artificial neural networks, cloud computing, and distributed energy storage.

Keywords: Smart Energy Integration, Renewable Energy Sources, Synergistic Optimization, Energy Storage System.

ACKNOWLEDGMENT

In this research paper, I would like to express my sincerest gratitude to the individuals and organizations that have supported and assisted me throughout this research process.

First and I would like to thank my supervisor, Dr. Ronald Vatananan-Thesenvitz, for your guidance and encouragement which was instrumental in helping me to complete this research work. Your expertise and advice helped me to overcome many difficulties and gave me invaluable guidance when I needed it. I would also like to thank all the professors and scholars at Bangkok University, especially my supervising professors, who provided me with significant academic support and guidance throughout my academic journey. In addition, I would like to thank my classmates, Brian, Chen Xi, and Tuan Nguyen, for sharing their thoughts and experiences with me during the research process, which enabled me to look at the problem from different perspectives. Finally, I would like to thank my family and friends for their moral support and encouragement throughout the research process, and for providing me with relevant and specialized knowledge and advice. Their understanding and support enabled me to overcome the difficulties and persevere till the end to complete this work.

In conclusion, I would like to thank all those who have helped and supported me throughout my research career, without your support I would not have been able to complete this research work.

Xiaokun Zhou

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

In this chapter, we delve into integration and storage systems for sustainable and reliable energy. We begin by providing the background and context of our study (Section 1.1), followed by the problem statement (Section 1.2). Subsequently, we outline the research objectives and questions (Section 1.3) and discuss the research scope (Section 1.4). Finally, we explore the significance of our research (Section 1.5) and provide clear definitions of relevant terms (Section 1.6).

1.1 Background and Context of the Study

In recent years, the world has witnessed a significant shift towards the adoption of sustainable and reliable energy sources to address pressing environmental concerns and meet growing energy demands. This transition has been primarily driven by the recognition of the finite nature of fossil fuel reserves and the detrimental impact of their combustion on the environment, including climate change and air pollution (International Energy Agency [IEA], 2020; United Nations, 2019). As a result, there has been a surge in interest and investment in renewable energy technologies, such as solar, wind, hydroelectric, and biomass, which offer cleaner and more sustainable alternatives to traditional fossil fuels (IEA, 2020; United Nations, 2019).

This integration offers the potential to overcome some of the limitations associated with variable and intermittent renewable energy sources, such as solar and wind. By coupling renewable energy generation with energy storage technologies, it becomes possible to store excess energy during peak production periods and utilize it during times of low or no generation (Mbarga et al., 2014). This improves the overall efficiency and reliability of renewable energy systems, while also addressing challenges related to grid stability and power supply variability. The integration of renewable energy sources with energy storage systems is a promising solution to meet the urgent global demand for sustainable and reliable energy (Olatomiwa et al., 2016; Behabtu et al., 2020) since it allows a more flexible and resilient energy infrastructure, reducing reliance on fossil fuels and mitigating the impacts of climate change. According to Mohamed et al., 2015, the synergistic optimization of renewable and energy storage systems can maximize the utilization of renewable resources and minimize the reliance on traditional energy sources (Jurasz et al., 2020)

However, one of the primary challenges associated with renewable energy sources is their inherent variability and intermittent. Unlike fossil fuel-based power plants, which can generate electricity consistently and predictably, renewable energy generation is dependent on factors such as weather conditions, time of day, and geographic location (Lu et al., 2018). This variability introduces challenges for grid operators in balancing supply and demand, leading to issues such as grid instability and power supply variability (Lu et al., 2018). To address these challenges and unlock the full potential of renewable energy sources, there has been a growing interest in integrating them with energy storage systems.

According to Lu et al., (2018), energy storage technologies, such as batteries, pumped hydro storage, and thermal storage, offer the ability to capture and store excess energy generated during periods of high production and release it when demand exceeds supply. This not only helps to smooth out fluctuations in renewable energy generation but also enhances grid stability and reliability. In this milieu, this study seeks to explore and analyze research trends, collaborative networks, and thematic evolution in the field of smart energy integration, with a focus on the synergistic optimization of renewable energy and energy storage technologies.

1.2 Problem Statement

Despite increasing potential benefits of the global demand for sustainable and reliable energy, there is a need for systematic analysis and understanding of the current research landscape in smart energy integration and the synergistic optimization of renewable and energy storage systems. The global transition towards sustainable and reliable energy sources is imperative to mitigate climate change and ensure energy security. The integration of renewable energy sources with energy storage systems offers a promising pathway to meet this urgent demand (Olatomiwa et al., 2016). But the integration of renewable energy sources, such as solar and wind, with energy storage systems presents a solution to the limitations associated with variable and intermittent renewable energy generation (Mbarga et al., 2014).

However, a comprehensive understanding of current research trends, key contributors, and collaborative networks in this field is crucial for informing policymakers, researchers, and industry professionals. Moreover, identifying research gaps and future directions is essential for advancing knowledge and promoting innovation in smart energy integration (Behabtu et al., 2020). By systematically analyzing bibliometric data using RStudio, the study aims to uncover growth patterns, key contributors, and emerging hotspots in renewable energy integration research.

1.3 Research Objective and Questions

This section presents the research objectives of this study is to analyze the current research trends in smart energy integration and the synergistic optimization of renewable and energy storage systems by identifying key contributors and institutions and exploring the countries and trends with main partners in the Smart Energy Integration and renewable energy storage systems.

RQ1: What are the current research trends in smart energy integration and the synergistic optimization of renewable and energy storage systems?

RQ2: Who are the key contributors and institutions involved in research on smart energy integration and synergistic optimization?

RQ3: Which countries/regions are the main partners in the Smart Energy Integration and Co-optimization study?

1.4 Research Scope

This study will focus on conducting a bibliometric analysis of research publications in the field of smart energy integration and the synergistic optimization of renewable and energy storage systems from 2019 to 2024 using the bibliometric analysis tools, such as RStudio's bibliometrix package, will be utilized to process and analyze the collected data systematically. The analysis will encompass research trends, collaborative networks, and thematic evolution. The scope of the study will be limited to academic publications and scholarly databases, with a particular emphasis on identifying key contributors, institutions, and countries/regions involved in research in this area.

Overall, Scopus indexed database will be used to collect the data as such ensuring the inclusion of a wide range of peer-reviewed literature. The research scope aims to provide a comprehensive analysis of the current state of research in smart energy integration and the synergistic optimization of renewable and energy storage systems, offering valuable insights for researchers, policymakers, and industry professionals.

1.5 Significance of the Research

This significance of the research is to understand the current state of research is essential for informing policymakers, researchers, and industry professionals about the latest developments and innovations in smart energy integration and synergistic optimization. By identifying key contributors and institutions, the research can facilitate collaboration and knowledge exchange, driving further advancements in renewable energy technologies.

The findings of this research will have significant implications for businesses and practitioners across industries as tech companies and training providers to use the research findings to develop more effective and advanced sustainable energy solutions and mitigating the impacts of climate change on a global scale and providing energy to large and medium household is the best way possible.

The research will shed light to academia to understand the geographical distribution of research activities and partnerships, highlighting opportunities for international collaboration and resource sharing in the field of smart energy integration (Olatomiwa et al., 2016). By fostering collaboration among researchers and institutions from different regions, the research can accelerate the development and deployment of sustainable energy solutions worldwide.

Finally, the findings of the research can inform policy decisions and investment strategies aimed at promoting energy sustainability and resilience (Behabtu et al., 2020). By identifying research gaps and emerging trends, the research can guide policymakers in allocating resources effectively and steering future research efforts towards addressing critical challenges in smart energy integration.

1.6 Definition of Terms

Smart energy integration: Smart energy integration refers to the incorporation of advanced technologies and strategies to optimize the generation, distribution, and consumption of energy from renewable and traditional sources, enhancing efficiency, reliability, and sustainability (Enabling Technologies and Energy Systems Integration, 2011).

Synergistic optimization: Synergistic optimization involves the combined enhancement of renewable energy generation and energy storage systems to maximize efficiency, reliability, and flexibility in energy production and consumption (Mbarga et al., 2014).

Renewable energy sources: Renewable energy sources are natural resources that are replenished continuously and sustainably, such as solar, wind, hydroelectric, biomass, and geothermal energy (Olatomiwa et al., 2016).

Energy storage systems: Energy storage systems are technologies that capture and store energy for later use, providing flexibility and stability in energy supply and demand management (Behabtu et al., 2020).

CHAPTER 2
LITERATURE REVIEW

This chapter offers a comprehensive review of the literature concerning smart energy integration and the synergistic optimization of renewable and energy storage systems. Additionally, it discusses the methodology employed in conducting bibliometric analysis using RStudio and how this approach was utilized to address the research questions posed in this study.

2.1 Smart Energy

Smart energy encompasses the integration and optimization of renewable energy sources with advanced energy storage systems and smart grid technologies to create a more efficient, reliable, and sustainable energy system. This approach addresses the growing demand for clean energy, reduces greenhouse gas emissions, and enhances energy security (Enabling Technologies and Energy Systems Integration, 2011).

2.1.1 Smart Energy Integration: Concepts and Significance

In Smart energy integration and the optimization of renewable energy sources with energy storage systems have attracted considerable attention in recent years due to their potential to address the growing demand for sustainable and reliable energy (Enabling Technologies and Energy Systems Integration, 2011). The integration of renewable energy sources with energy storage systems represents a key strategy in achieving sustainability goals by reducing reliance on fossil fuels and minimizing greenhouse gas emissions (Olatomiwa et al., 2016; Behabtu et al., 2020).

The transition to smart energy systems is driven by the need to enhance energy efficiency, reduce greenhouse gas emissions, and improve energy security (Mbarga et al., 2014). By integrating renewable energy sources, such as solar and wind power, with energy storage technologies, smart energy systems can effectively manage the variability and intermittency of renewable energy generation. This integration allows for the seamless integration of renewable energy into the existing energy infrastructure, reducing reliance on fossil fuels and mitigating the impacts of climate change (Olatomiwa et al., 2016).

Furthermore, smart energy integration enables the optimization of energy resources and the implementation of demand-response mechanisms to balance supply and demand in real-time. Through advanced data analytics and predictive modeling, smart energy systems can anticipate energy demand patterns, optimize energy production and consumption schedules, and enhance grid stability and resilience (Behabtu et al., 2020). This proactive approach to energy management not only reduces energy costs for consumers but also improves the overall efficiency and reliability of the energy system.

The concept of smart energy integration represents a paradigm shift in the way we generate, distribute, and consume energy. By leveraging advanced technologies and innovative strategies, smart energy systems offer a pathway towards a more sustainable and resilient energy future. Through a comprehensive review of the literature, this section highlights the importance of smart energy integration in addressing the challenges of energy transition and lays the groundwork for further exploration in this critical area.

The integration of renewable energy sources with energy storage systems has emerged as a critical strategy for addressing the increasing global demand for sustainable and reliable energy (Enabling Technologies and Energy Systems Integration, 2011). Traditional energy sources, such as fossil fuels, are finite and contribute to environmental degradation and climate change. In contrast, renewable energy sources, such as solar, wind, and hydroelectric power, offer clean and abundant alternatives. However, the intermittent nature of renewable energy generation poses challenges to grid stability and energy supply reliability. Energy storage systems play a crucial role in mitigating these challenges by storing excess energy during periods of high generation and supplying energy during times of low generation or high demand.

The synergistic optimization of renewable energy and energy storage systems presents a promising solution to enhance the efficiency, reliability, and sustainability of energy systems. However, despite significant advancements in the field, there remains a need for a systematic analysis of current research trends, key contributors, and collaborative networks in smart energy integration (Mbarga et al., 2014). Additionally, the geographical distribution of research activities and partnerships in this area requires further exploration to identify opportunities for international collaboration and knowledge exchange (Olatomiwa et al., 2016).

2.2 Renewable Energy

Renewable energy refers to energy derived from natural resources that are replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. These sources are abundant, environmentally friendly, and crucial for reducing greenhouse gas emissions and mitigating climate change International Renewable Energy Agency, (2020).

2.2.1 Renewable Energy Storage

Renewable energy storage involves capturing and storing energy generated from renewable sources for later use. This is essential because many renewable energy sources, such as solar and wind, are intermittent and may not align with immediate energy demand. Energy storage systems help address this variability by storing excess energy during periods of high generation and releasing it during times of low generation or high demand (Hossain et al., 2021).

2.2.2 Renewable Energy Storage Systems

Renewable energy storage systems encompass a variety of technologies and approaches designed to store energy efficiently and effectively. These systems include:

Battery Storage: Utilizes rechargeable batteries to store excess electricity generated from renewable sources, such as solar and wind power (International Energy Agency [IEA], 2021).

Pumped Hydro Storage: Involves pumping water to a higher elevation during periods of low demand and releasing it through turbines to generate electricity during peak demand (IEA, 2021).

Thermal Energy Storage: Stores heat generated from solar thermal power plants or other renewable sources for later use in heating or electricity generation (IEA, 2021).

Hydrogen Storage: Involves converting excess renewable electricity into hydrogen through electrolysis, which can be stored and used later for various applications, including energy generation and transportation (IEA, 2021).

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

This chapter is dedicated to elucidating the approach employed in this study, encompassing the research setup, sampling techniques, and data collection methods. Additionally, a detailed outline of the data analysis procedures will be provided to offer a comprehensive understanding of the systematic approach undertaken.

3.1 Research Setup

Bibliometric analysis will be employed in this study, utilizing a quantitative method to examine and understand the landscape of AI integration in online education. This approach involves collecting data from academic literature found in Scopus-indexed journals and academic proceedings. By adopting this design, we can monitor publication trends, analyze citation patterns, and map co-authorship networks, thereby identifying significant works and influential authors within the field over a specific time frame. Leveraging the power of bibliometrics allows researchers to gain a deeper understanding of complex phenomena, and to identify trends and relational patterns over time. The data will be gathered quantitatively, focusing not only on the frequency of publications and citations but also on identifying thematic patterns and trends within scholarly discourse, achieving harmonization in the field.

3.2 Sampling and Data Collection

Sampling and data collection methodologies are crucial aspects of bibliometric research (Donthu et al., 2021), as they dictate the comprehensiveness and reliability of the dataset under analysis. This section elucidates the strategies employed to identify relevant publications, authors, and affiliations within the field of smart energy integration. The sampling techniques utilized in this study will involve a systematic approach to identifying and selecting publications that meet the specific criteria for inclusion. This may include utilizing databases Scopus to ensure a comprehensive representation of the literature within the field of interest (Berndt, 2020). Additionally, snowball sampling techniques will be employed to capture relevant works that may not be readily available in traditional academic databases.

Data collection methods will encompass the extraction of pertinent information from the selected publications, including details on authors, affiliations, publication dates, and keywords (Yedla & Dorius, 2016) from 2019 to 2024. Moreover, considerations regarding the inclusion/exclusion criteria and data validation procedures are addressed to ensure the accuracy and validity of the collected data. The meticulous approach to sampling and data collection aims to provide a robust foundation for the subsequent bibliometric analysis (Donthu et al., 2021), ensuring the comprehensive representation of scholarly works pertinent to the study of smart energy integration and synergistic optimization of renewable and energy storage systems.

Table 3.1: Distribution of Articles

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2019:2024
Sources (Journals, Books, etc)	1099
Documents	2356
Annual Growth Rate %	-30.62
Document Average Age	2.84
Average citations per doc	11.3
References	81978
DOCUMENT CONTENTS	
Keywords Plus (ID)	11696
Author's Keywords (DE)	6216
AUTHORS	
Authors	7339
Authors of single-authored docs	108
AUTHORS COLLABORATION	
Single-authored docs	116
Co-Authors per Doc	4.29
International co-authorships %	26.36
DOCUMENT TYPES	
article	1364
conference paper	992

Source: Harzing, A.W. (2007). Publish or Perish

According to Table 3.1 The scope of the study encompasses scholarly articles from various sources within the field of energy and sustainability. The main information picture illustrates the distribution of articles across different sources, highlighting the frequency of publications from each source.

Key sources include 'ENERGIES' with 122 articles, followed by 'ENERGY' with 88 articles, 'IEEE ACCESS' with 44 articles, and others such as 'APPLIED ENERGY,' 'SMART ENERGY,' and 'SUSTAINABILITY (SWITZERLAND)' contributing significantly to the dataset. These sources serve as primary inputs for bibliometric analysis, providing a diverse range of publications for comprehensive research insights.

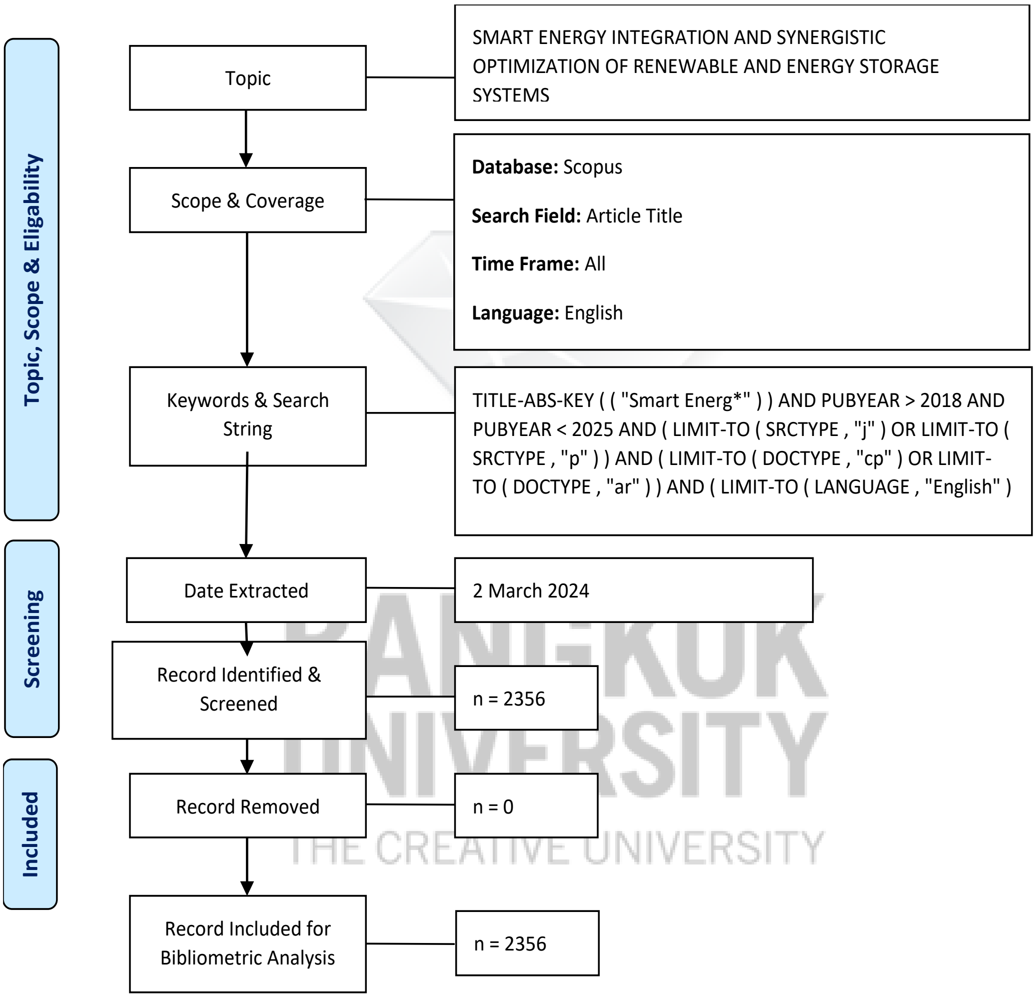
3.3 Research Methods

Quantitative data analysis techniques, such as the interpretation of emergent themes and discourse analysis, will be employed to construct a comprehensive narrative. adopts a quantitative approach to analyze publication output, citation metrics, and collaborative networks among authors and institutions. By quantifying research productivity and impact, this method facilitates the identification of key contributors and influential publications.

The term "bibliometric" was originally introduced by the French author Paul Olet (1934), signifying its French origin. Pritchard (1969) expanded upon this concept, defining bibliometrics as a statistical and mathematical application applicable to books and other scenarios. Raw data collection and analysis are facilitated by software tools such as Sitkis (Schildt et al., 2006). The integration of these methods will provide a comprehensive and multi-faceted analysis of the trends and developments in smart energy integration, contributing to a deeper understanding of the research landscape in this field (Tang, 2021). The bibliometric on smart energy integration and the synergistic optimization of renewable and energy storage systems requires a robust research design and methodology to ensure the systematic exploration of the field.

Figure 3.1 shows the data analysis overview that provides a roadmap of the analytical procedures employed to derive insights from the collected bibliometric data. This includes data preprocessing steps, statistical analyses, visualization techniques, and interpretation frameworks utilized to elucidate patterns and trends within the dataset. Additionally, considerations regarding data validation, reliability, and sensitivity analyses are discussed to ensure the integrity and rigor of the findings. Moving forward, the next step involves conducting a thorough data preprocessing phase to clean and prepare the bibliometric data for analysis. This may include standardizing author names, unifying keywords, and addressing any inconsistencies in the dataset.

Figure 3.1 Flow Diagram of the Search Strategy



Source: Zakaria, A. A., Azni, A. H., Ridzuan, F., Zakaria, N. H., & Daud, M. (2023). Systematic literature review: trend analysis on the design of lightweight block cipher. *Journal of King Saud University-Computer and Information Sciences*, *35*(5), 101550.

3.4 Data Analysis Overview

Following data preprocessing, statistical analyses will be applied to quantify and assess various bibliometric indicators such as publication trends, citation patterns, and collaboration networks (Olejniczak et al., 2022). These analyses will provide quantitative insights into the research landscape of smart energy integration, offering valuable information on publication output, impact factors, and collaborative relationships among researchers and institutions.

Moreover, visualization techniques will be employed to present the findings in a clear and understandable manner. This may involve creating visualizations such as co-authorship networks, keyword co-occurrence maps, and trend visualizations to illustrate the relationships and patterns identified in the data (Isenberg et al., 2014).

Finally, interpretation frameworks will be utilized to derive meaningful insights as seen in table 3.2 from the analyzed data, unveiling patterns, emerging topics, and shifts in research focus within the field over the specified period (Kawalek & Jayaratna, 2003). Considerations regarding data validation, reliability, and sensitivity analyses will also be addressed to ensure the robustness and integrity of the research findings.

Table 3.2: Analysis Methods Regarding RQs

Research Question	Bibliometric analysis method	Biblioshiny function
1. What are the current research trends in smart energy integration and the synergistic optimization of renewable and energy storage systems?	Identify the evolution of keywords and topics over time. Documents under words	Trend Topics KW+ author's keyword. Thematic Map kw+ for application. Co-occurrence networks kw+ technology

Table 3.2: Analysis Methods Regarding RQs (Continued)

Research Question	**Bibliometric analysis method**	**Biblioshiny function**
2. Who are the key contributors and institutions involved in research on smart energy integration and synergistic optimization?	Identify top authors and visualize collaboration networks.	Most Relevant Authors Author Collaboration Network and author co-citation network
3. Which countries/regions are the main partners in the Smart Energy Integration and Co-optimization study?	Visualize international collaboration and analyze corresponding author's country.	Country Collaboration Map. Corresponding Author's. Country most cited country

CHAPTER 4
FINDINGS

In this chapter, we present the findings of our analysis on smart energy integration and synergistic optimization research trends from 2019 to 2024. Through a comprehensive examination of publications, authors, affiliations, and collaboration networks, we aim to address the research questions posed in the introduction. Our analysis provides insights into the current landscape of research in this field, identifies key contributors and institutions, and highlights collaborative partnerships among countries and regions. Additionally, we discuss emerging trends, challenges, and future directions based on the findings presented in this chapter.

4.1 What Are the Current Research Trends, Technology, and Application in Smart Energy Integration and the Synergistic Optimization of Renewable and Energy Storage Systems (RQ1)

Figure 4.1: Trend on Authors Keyword

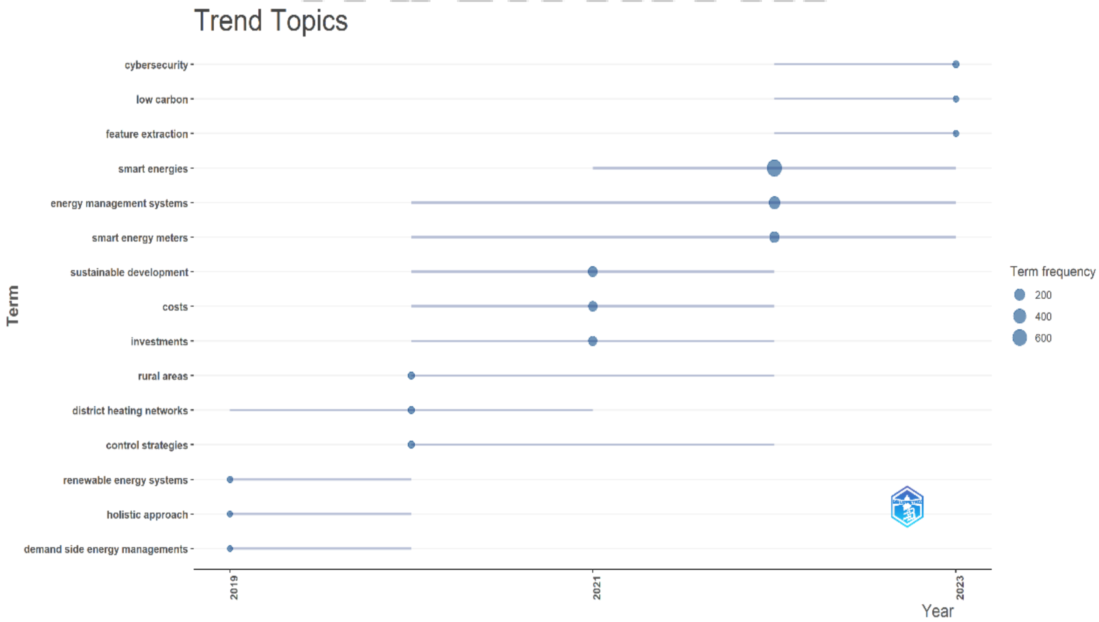


Figure 4.2: Trend Topic

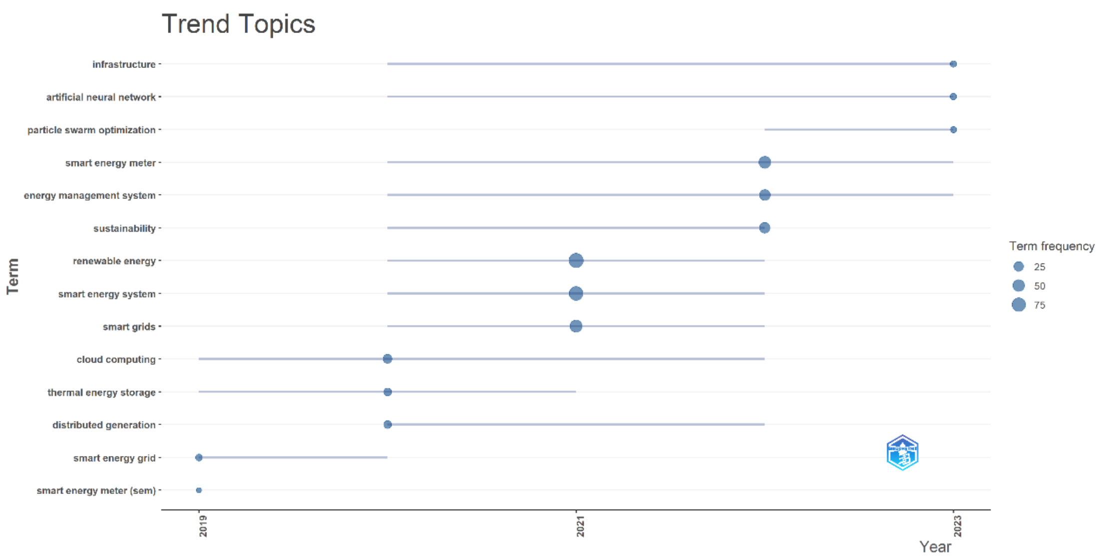


Figure 4.1 (authors keyword) and 4.2 (keyword+) shows the "Trend Topics" visualization with the evolution of various research terms related to smart energy integration and synergistic optimization over time. X-Axis (Year): Represents the timeline from 2019 to 2023 while the Y-Axis (Term): Lists the key research terms that have been analyzed. Term Frequency (Bubble Size): Indicates the frequency of each term in the literature, with larger bubbles representing higher frequencies. The lines in the visualization provide a clear representation of when specific research topics started gaining attention, how continuously they have been researched over time, and how the frequency of publications has changed.

According to the figure above, most terms show increasing frequencies over the years, particularly from 2021 onwards, suggesting growing research interest and activity in these areas. Emerging Topics: Terms like "cybersecurity", "low carbon", "smart energy meters", and "renewable energy systems" indicate newer areas of focus or heightened recent interest. Consistent Themes: Terms like "sustainable development" and "energy management systems" show consistent interest, emphasizing their foundational role in the field. Also, newer topic in figure 4.2 such as “infrastructure network,” “artificial neural network,” “surface water optimization,” “energy management system,” “sustainability,” “cloud computing,” “smart grids,” and “distributed energy storage.” bringing in key trends and emerging research topics in smart energy integration and synergistic optimization of renewable and energy storage systems.

Figure 4.3: Thematic Map Application

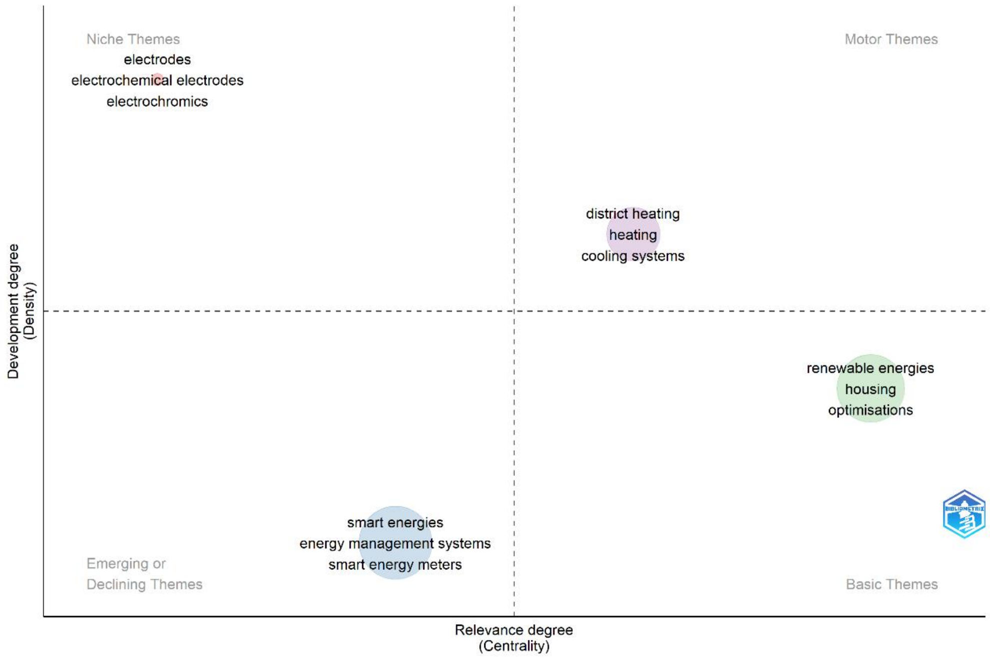
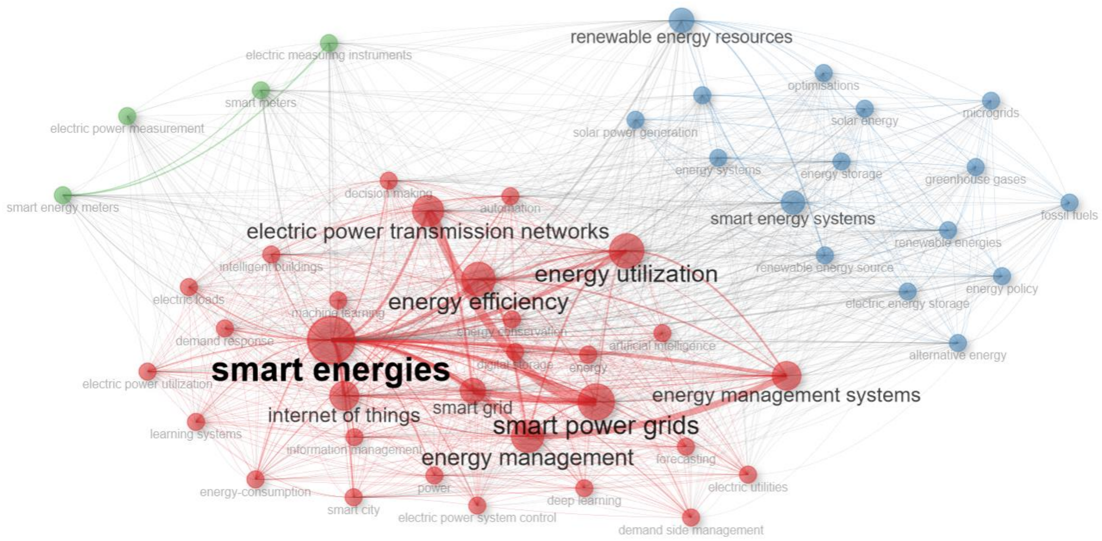


Figure 4.3 is a Thematic map visualization, which helps to categorize research themes based on their development degree (density) and relevance degree (centrality). X-Axis (Relevance degree or Centrality) measures the importance or centrality of the themes within the field. Themes on the right are more central and relevant. Y-Axis (Development degree or Density) which measures the development or internal cohesion of the themes. Themes at the top are more developed and have higher internal coherence.

Upper Right (Motor Themes) are highly developed and very important themes such as terms "district heating", "heating", "cooling systems". These themes are crucial to the field and show strong development and high relevance. They drive the research agenda. Upper Left (Niche Themes) are advanced but less important themes. Terms such as "electrodes", "electrochemical electrodes", "electrochromics". These themes are specialized with strong internal development but are less central to the broader field. They might represent specialized research areas. Lower Right (Basic Themes) is an important but less developed theme with terms: "renewable energies", "housing", "optimizations". These themes are fundamental to the field but need further development. They form the base of the research area. Lower Left (Emerging or Declining Themes) are less developed and less important themes. Terms: "smart energies", "energy management systems", "smart energy meters". These themes might be emerging areas of research or could be declining in importance. They show lower centrality and development.

Figure 4.4: Co-Occurrence Network for Technology



In figure 4.4, shows the cooccurrence of word and the size of each node indicates its importance or centrality within the network. Larger fonts suggest greater significance Prominent central nodes include “smart energies,” “energy efficiency,” and “electric power transmission networks.” These terms likely play a crucial role in the context of smart energy technology. The lines connecting nodes represent relationships or connections between these concepts. This visualization provides an overview of how different aspects of smart energy technology are interconnected. These central nodes are connected to other related terms, such as: “Renewable energy resources”, “Smart energy systems”, “Energy management systems”, “Sustainability”, “Alternative energy”, and “Energy utilization”.

We can see three regions, green, red and blue, which represent different energy-related topics. The Green region keywords: electric measuring instruments (electric measuring instruments), smart meters (smart meters), electric power measurement (electric power measurement). This region focuses on technologies and applications related to electric power measurement and smart meters.

The Red Area Keywords: smart energies, smart power grids, energy management, energy efficiency, internet of things. This area focuses on smart energy technologies and systems, including smart grids, energy management systems, and IoT-related applications.

The Blue Area keywords: renewable energy resources, solar power generation, energy systems, smart energy systems, greenhouse gases. greenhouse gases.) This region focuses on renewable energy and smart energy systems, particularly solar power generation and greenhouse gas management.

Connections between the different regions as the red and green areas: the links between these areas show that there is a correlation between smart energy management and electricity measurement, e.g. the importance of smart meters in energy management.

Red and blue zones: the connection between these zones shows a strong link between smart energy technologies and renewable energies, e.g. the role of smart grids in integrating renewable energies.

Blue and green areas: These areas have relatively few links between them, indicating fewer direct connections between them, but still some connections in the overall energy system.

Table 4.1: Summary of Item Frequency and Occurrence Years

Item	Frequency	Year Q1	Year Median	Year Q3
Renewable Energy Systems	10	2019	2019	2020
Holistic Approach	8	2019	2019	2020
Demand Side Energy Managements	7	2019	2019	2020
Electric Utilities	78	2020	2020	2022
Heating	74	2019	2020	2022
Internet of Things (IoT)	54	2019	2020	2020
Energy Efficiency	407	2020	2021	2022
Energy Utilization	377	2020	2021	2022
Smart Power Grids	362	2020	2021	2022
Smart Energies	640	2021	2022	2023

Table 4.1 presents a summary of the frequency of specific items related to smart energy integration and synergistic optimization, along with the years in which they were most prevalent. The years are categorized into quartiles, including the first quartile (Year Q1), the median year (Year Median), and the third quartile (Year Q3), providing insights into the temporal distribution of these items over the period from 2019 to 2024.

Smart Energies is the highest frequency (640), with research hotspots focused on the post-2021 period, shows that this area has received a great deal of attention in recent years, reflecting the importance of smart energy systems in energy management and optimization. For Energy Efficiency and Energy Utilization, they come with a frequency of 407 and 377, respectively, the research hotspots are focused on the period from 2020 to 2022. This indicates that improving energy efficiency and optimizing energy utilization are the focus of current research, in line with the global demand for sustainable energy development. Smart Power Grids has a frequency of 362 and shows the importance of smart grid technologies in integrating renewable energy sources and improving grid stability. While Electric Utilities and Heating have Frequencies of 78 and 74 respectively show that research in intelligence and optimization of these traditional energy systems is still active, especially after 2020. Internet of Things (IoT) with a frequency of 54, it shows that IoT technologies are increasingly used in energy management, especially from 2019, as an important component of smart energy systems.

Through the analysis of the frequency and time distribution of research topics, we can see that the current research trend of smart energy integration and synergistic optimization of renewable energy and energy storage systems is mainly focused on the following aspects: The integrated application and optimization of smart energy systems has become the main trend of research, reflecting a high degree of attention to the intelligence of energy management.

- The enhancement of energy efficiency and energy utilization is at the core of the research, demonstrating the key role of both in realizing sustainable development goals.
- Smart grid technologies are highly researched, demonstrating their importance in integrating renewable energy sources and improving grid efficiency.
- The increasing use of Internet of Things (IoT) technologies in smart energy management reflects the role of technological advances in driving the intelligence of energy systems.

4.2 Who Are the Key Contributors and Institutions Involved in Research on Smart Energy Integration and Synergistic Optimization? (RQ2)

Figure 4.5: Most Relevant Authors

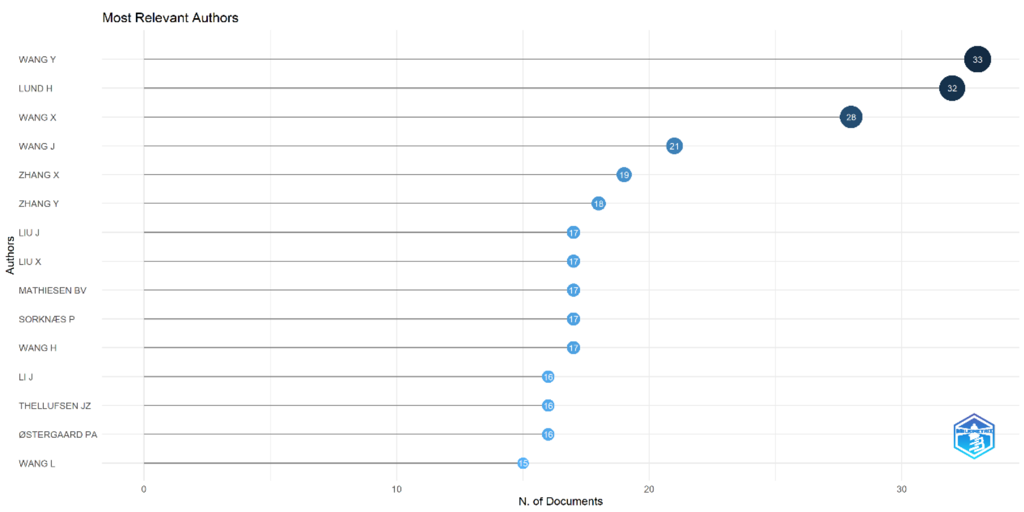


Figure 4.5 represents a scatter plot titled “Most Relevant Authors.” The x-axis ranges from 0 to 30, representing the number of documents associated with each author. It indicates how prolific each author is in terms of research output. The y-axis lists various authors, with their names abbreviated and aligned vertically. Each author corresponds to a specific point on the graph. The size of each point suggests different weights or levels of relevance for each author for example Wang with 33, Lund with 32, and Wang 28. One near the top of the list with approximately 23 documents. Other authors include Li with 16 documents and Liu with 17 documents. WANG Y and WANG X: These two authors are co-authors on several research projects. Their collaborative research focuses on smart energy management, energy storage systems, and power system optimization. Examples: Dynamic Emission Dispatch Considering the Probabilistic Model with Multiple Smart Energy System Players Based on A Developed Fuzzy Theory-Based Harmony Search Algorithm (ENERGY, 2023), Evaluation Of The Maturity Of Urban Energy Internet Development Based On Ahp-Entropy Weight Method And Improved Topics (ENERGIES, 2023). WANG Y and WANG J: Together they have worked on projects on smart grids and energy dispatch optimization, focusing on the optimization of smart energy systems and energy storage technologies. Example: Conducting Polymer Host-Guest Hydrogels with Bicontinuous Electron/Ion Transport for Boosted Thickness-Independent Supercapacitance (CHEMICAL ENGINEERING JOURNAL, 2023), Research on the Analysis and Reasoning Model of Enterprise Bidding Environment of Energy Project Digital Procurement Based on HMM (2022 1ST). International conference on cyber-environment systems and intelligence energy, 2023) SORKNÆS P and MATHIESEN BV: They are co-authors in several research projects, especially in the field of smart energy systems and renewable energy. For example: Beyond Sector Coupling: Utilizing Energy Grids in Sector Coupling to Improve the European Energy Transition (SMART ENERGY, 2023) The Role of Sustainable Bioenergy in A Fully Decarbonized Society (RENEWABLE ENERGY, 2022), The Four Generations Of District Cooling - A Categorization Of The Development In District Cooling From Origin To Future Prospect (ENERGY, 2022). Electrification Of the Industrial Sector In 100% Renewable Energy Scenarios (ENERGY, 2022)

LIU J and LIU X: They co-authored a paper on energy scheduling modelling for three-tier integrated energy systems, using an energy hub model and a hierarchical Stackelberg game approach. Their collaboration focuses on energy management systems and smart city research. For example: WANG Y, WANG X, and WANG J. o They may be affiliated with the same research group: They may be part of the same or closely collaborating research group focusing on smart grid, energy storage and energy management systems. By collaborating on research and co-publishing papers, they increase the number of papers per member. For example, WANG Y and WANG X have co-authored several papers on smart grids and energy scheduling optimization, and WANG Y and WANG J have collaborated several times on energy storage technologies and power system optimization.

SORKNÆS P and MATHIESEN BV: They may belong to the same research group or research team working on district heating, electrification, and sustainable energy systems. By collaborating on research and co-publishing, they increase the number of papers and research impact of each member. For example, they have co-authored multiple high-impact papers on district heating and sustainable bioenergy.

LIU J and LIU X: They may be part of the same or closely collaborating research group focusing on energy management systems and smart cities. By collaborating on research and co-publishing, they have increased the number of papers each member has published. For example, they have co-authored multiple papers on energy scheduling models for three-tier integrated energy systems.

Figure 4.6: Collaboration Network

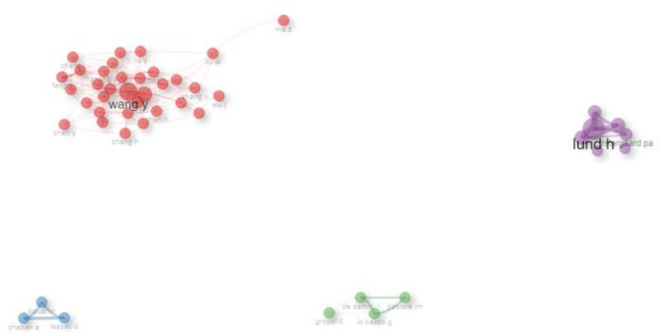


Figure 4.6 represents a collaboration network graph with nodes and connecting lines with authors. There are four distinct clusters, each represented by a different color: red, purple, blue, and green. Red clusters: centered on WANG Y, indicating this author's influence and extensive collaborative network in the field. Many nodes (authors) have collaborations with WANG Y, showing his centrality in the research. Purple cluster: centered on LUND H, indicating LUND H's collaborative network in the field. Although LUND H's collaboration network is relatively independent, it still shows its importance in smart energy integration research. Blue and green clusters: indicate the collaboration networks of other authors, respectively. These clusters show the research work of different authors and their partners in the field.

Researchers such as WANG Y, WANG X and WANG J are from different top universities and research institutions, and they have jointly promoted the development of the field of smart energy integration and cooperative optimization through collaborative research. For example, WANG Y and WANG X are at Tsinghua University and Zhejiang University, respectively, but they have collaborated in several research, showing the close cooperation between top institutions in China.

LUND H, a researcher from Denmark, has collaborations with several prolific authors in China, demonstrating the internationalization trend in the field. For example, the collaborative research between LUND H and WANG Y demonstrates that there is extensive academic exchange and collaboration between European and Chinese researchers in smart energy systems.

By identifying these prolific authors and their affiliations, the research dynamics and academic networks in the field of smart energy integration and co-optimization can be better understood. Cross-institutional and international collaborations facilitate knowledge sharing and technology development, providing valuable references for policy makers, researchers, and industry professionals. Such partnerships not only improve the quality and impact of research, but also drive innovation and progress in the field.

Figure 4.7: Co-Citation Network

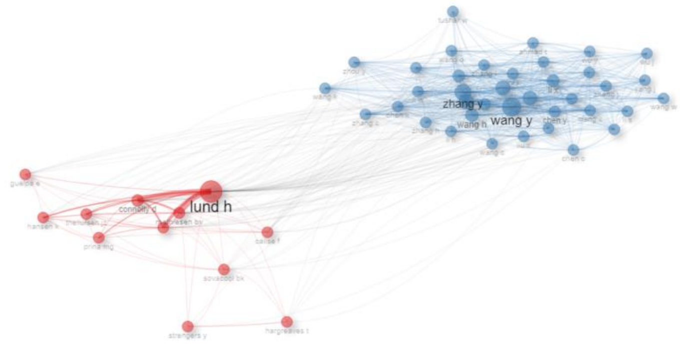


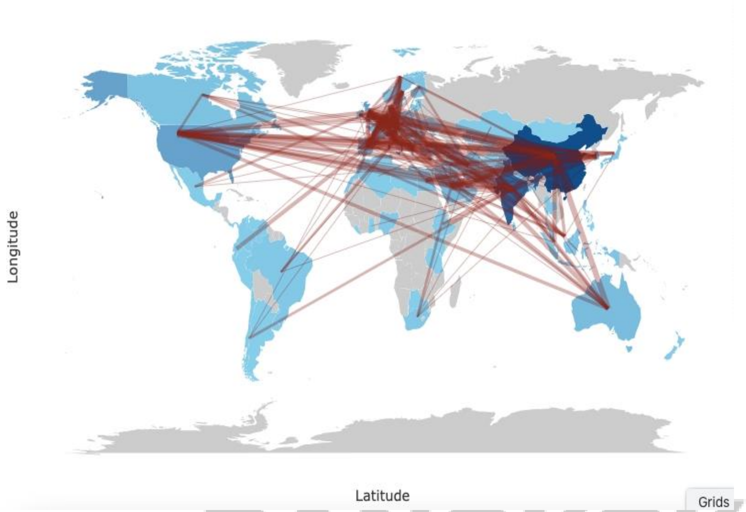
Figure 4.7 represents a collaboration network graph with nodes and connecting lines with authors. There are two distinct clusters, each represented by a different color: Blue and Red. Blue cluster is centered on WANG Y and ZHANG Y, these researchers are mainly from top universities and research institutes in China, such as Tsinghua University and Chinese Academy of Sciences. Researchers in the blue cluster collaborate closely with each other, forming a large research network.

Red Cluster is centered on LUND H, mainly from Aarhus University and Aalborg University in Denmark. The red cluster is smaller but also shows a high level of collaboration density. WANG Y and ZHANG Y are core researchers in the field, and they have a significant impact in the blue cluster. LUND H is a key contributor in the red cluster who also has significant academic contributions in the field of smart energy integration and co-optimization. The blue cluster consists mainly of top Chinese universities and research institutions, including Tsinghua University and the Chinese Academy of Sciences. The red cluster consists mainly of Aarhus University and Aalborg University in Denmark.

This collaborative network diagram shows the key researchers in the field of Smart Energy Integration and Co-optimization and the research institutions they belong to WANG Y and ZHANG Y play an important role in the research network in China, while LUND H has a high influence in the research network in Denmark. The close collaboration between these researchers and institutions has advanced research progress in the field and provides a solid foundation for future research.

4.3 Which Countries/Regions Are the Main Partners in the Smart Energy Integration and Co-Optimization Study? (RQ3)

Figure 4.8: Distribution Collaborations Network



In this section figure 4.8 highlight key patterns in international collaboration observed in the These collaborations signify the global nature of research in the field, showcasing partnerships between Australia and various other countries across continents and the lines connecting the nodes represent connections or interactions. The thickness and density of these lines indicate the strength or frequency of these connections. Such collaborations contribute to the exchange of knowledge, resources, and expertise, fostering advancements in smart energy integration and optimization on an international scale. China and the United States are the main collaborating countries in this field, and the figure shows the dense network of collaboration between them and with other countries. Other important collaborating countries include Germany, Australia, the United Kingdom, and India. Each of these countries has significant cooperation connectivity with China and the United States.

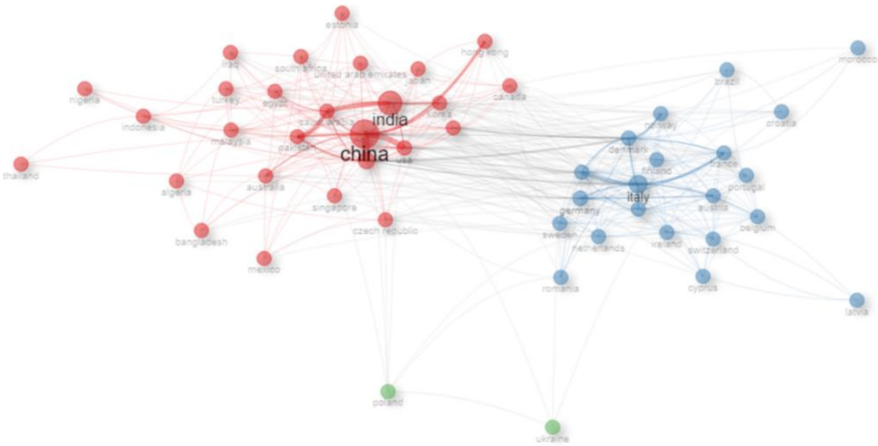
The figure shows many transcontinental collaborative linkages, especially between China and the United States with Europe and Australia. This indicates that research in this field is highly internationalized and collaborative. The largest number of collaboration connectivity is between China and the US, showing the dominance of these two countries in smart energy integration and co-optimization research.

There are also many intra-European partnerships, especially between Germany and other European countries. China and the United States are the main collaborating countries in smart energy integration and co-optimization research. These two countries not only have significant research output in their own countries, but also maintain close collaborations with researchers around the world. Germany, the UK and Australia in Europe are also important collaborating countries that have also made significant research contributions in this field.

Figure 4.8 shows the extensive network of collaborations across national boundaries, which contributes to the sharing of knowledge and the advancement of research. The major collaborations are centered between China and the United States, Europe and the United States, reflecting the importance of these regions in smart energy technology research.

This map provides a clear picture of the major collaborating countries and regions in smart energy integration and co-optimization research. These countries have worked together to promote research and technological advancement in this field through close partnerships. Understanding these partnerships can help identify key international partners and future research directions, providing valuable collaboration opportunities and resource sharing platforms for researchers worldwide.

Figure 4.9: Country Collaborations Network



In figure 4.9 the circles in the graph represent nodes corresponding to a specific country. The lines connecting the nodes represent connections or interactions. The thickness and density of these lines indicate the strength or frequency of these connections. Most nodes are in red and blue, with a few in green with China India on one side, Italy on the other side and Ukraine and Poland taking some share of the cluster. China collaborates with most of the clusters and follow by India then Italy. Each node represents a country, and the size of the node indicates the importance of the country in the cooperation network. The red cluster also includes other Asian countries (e.g., South Korea, Japan, Singapore) and some Middle Eastern countries (e.g., UAE, Saudi Arabia).

The Blue Cluster is centered on Italy, European countries (e.g., Germany, France, Netherlands, Denmark) make up this cluster, showing the close cooperation within Europe. The dense cooperation connectivity between these countries shows the highly collaborative nature of Europe in smart energy research.

The Green nodes indicates that Ukraine and Poland, as independent nodes, have some collaborative connections with other countries, but not as close as the countries in the red and blue clusters.

China and India are the main collaborating countries in the Smart Energy Integration and Co-optimization research. They have extensive collaborations in Asia and globally. Italy and other European countries (e.g., Germany, France, Netherlands) cooperate very closely within Europe and are important players in the field.

Figure 4.9 shows a wide network of collaborations across borders, especially between Asia and Europe. Such partnerships contribute to the sharing of knowledge and the progress of research. For example, China and India not only collaborate extensively within Asia, but also have close links with research institutions in Europe and North America.

Through this collaboration network map, we can clearly see the main collaborating countries and regions in smart energy integration and co-optimization research. These countries have worked together to promote research and technological advancement in this field through close partnerships. Understanding these collaborations can help identify key international partners and future research directions, providing valuable collaboration opportunities and resource sharing platforms for researchers worldwide. Proximity: The closer the distance between the nodes, the closer the co-operation between these two countries or regions. This usually means that these countries have more cooperation in research projects and a higher number of papers published together. For example, in the figure, the closer distance between China and India indicates that these two countries have closer cooperation in smart energy system research. Far away: The farther distance between nodes indicates that there is less or no co-operation between these two countries or regions. For example, in the figure, Ukraine and other countries are farther away from each other, indicating that Ukraine has less international cooperation in this field.

Isolated nodes: some nodes are barely connected to other nodes, indicating that these countries or regions are relatively isolated and lack international co-operation in smart energy systems research. For example, Poland and Ukraine in the figure, which are less connected to other countries, show the isolation of these countries in smart energy systems research.

Figure 4.10: Corresponding Authors Country

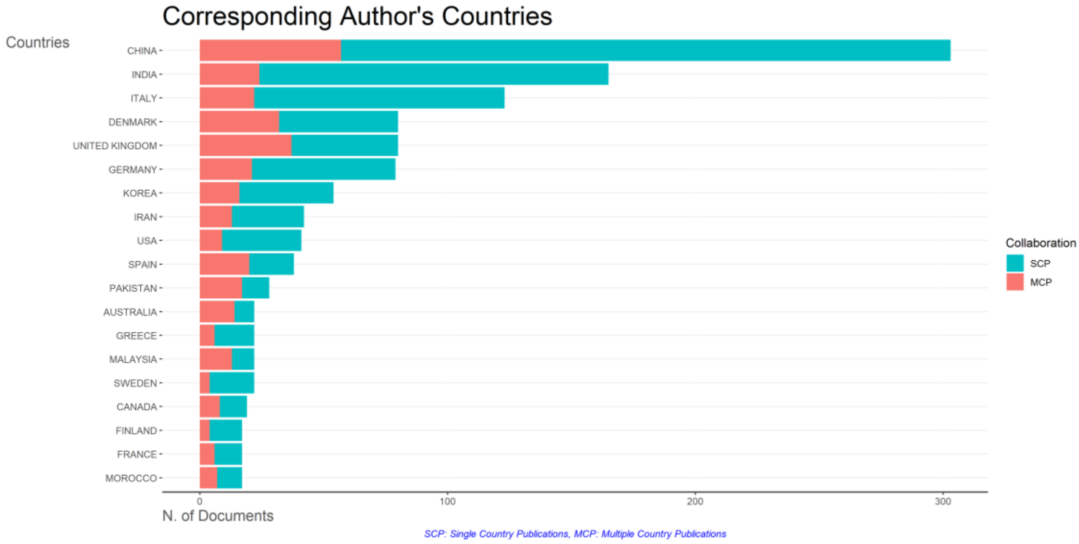


Figure 4.10 is a horizontal bar graph titled “Corresponding Author’s Countries relates to research publications and their corresponding authors. Y-Axis (Countries): The y-axis lists various countries, each representing the origin of corresponding authors. X-Axis (Number of Documents): The x-axis represents the number of research documents associated with each country. Teal Bars (SCP - Single Country Publications): These bars indicate the number of research documents where the corresponding author is from a single country. Red Bars (MCP - Multiple Country Publications): These bars represent the number of research documents involving authors from multiple countries. China has the highest number of documents, followed by India and Italy. Other countries like Denmark, United Kingdom, Germany, Korea, Iran, and USA also contribute significantly. China and India are major players and contributors in smart energy integration and co-optimization research with a large number of single-country and multi-country co-published literature.

European countries such as Italy and Denmark are prominent in multi-country co-publication, demonstrating their importance in international research collaboration. The chart shows the proportion of countries in single-country publishing and multinational co-publishing, revealing the extent of international collaboration.

Multi-country co-publishing (MCP) reflects the activity of these countries in international research collaborations, especially in countries such as Italy, Denmark, the UK, and Germany, which have contributed to the progress of research in the field of smart energy by collaborating with researchers from other countries.

Through this graph, we can clearly see the major collaborating countries and regions in smart energy integration and co-optimization research. China and India dominate the field, and European countries such as Italy and Denmark are prominent in international collaborations. Understanding these collaborations and the distribution of research activities can help identify key international partners and promote knowledge sharing and technological advancement on a global scale.

Figure 4.11: Most Cited Country

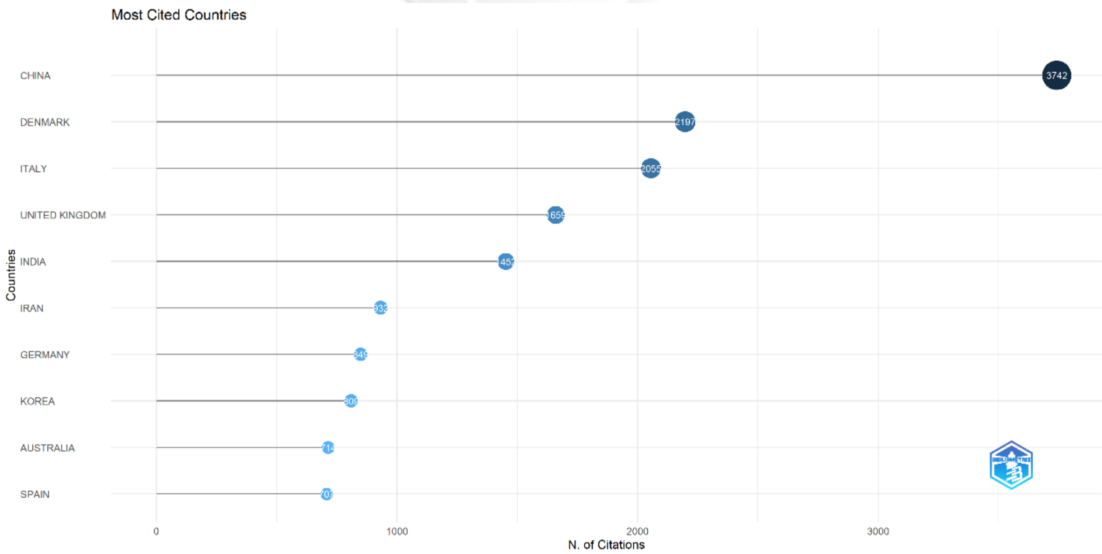


Figure 4.11 Most Cited Countries," indicating that it represents the citation impact of different countries in research publications. Y-Axis (Countries): The y-axis lists various countries, each representing the origin of corresponding authors. X-Axis (Number of Citations): The x-axis represents the number of citations received by research papers from each country. Each dot corresponds to a country. The distance of the dot from the y-axis indicates the number of citations for that country. Notably, the dot associated with China stands out significantly further along the x-axis than all

others, suggesting a much higher citation count for Chinese research. China has a notably higher number of citations compared to other listed countries. Other countries like Denmark, Italy, United Kingdom, France, Canada, Germany, Korea, Australia, and Spain also contribute, but their citation counts are lower.

This graph gives a clear picture of the main collaborating countries and regions in smart energy integration and co-optimization research, as well as the research impact of these countries. China, Denmark, Italy and the UK have significant international impact in this field of research, and these countries have made significant contributions to the development of global smart energy research through high-quality research results. Understanding the research impact of these countries can help identify key international partners and promote knowledge sharing and technological advancement on a global scale.

CHAPTER 5
DISCUSSION & CONCLUSION

In this chapter, we delve into a comprehensive discussion of the findings derived from our analysis of smart energy integration and synergistic optimization research trends. We highlight the key findings, discuss their implications, identify limitations of the research, propose future research directions, and conclude with closing remarks.

5.1 Summary of the Key Findings

Our analysis revealed several significant findings regarding smart energy integration and synergistic optimization. These findings include:

- Firstly, Cybersecurity, Low Carbon, and Feature Extraction: These topics show a significant increase in interest starting around 2021 and continuing through 2023. This suggests a growing focus on the security aspects of energy systems, the need for low-carbon solutions, and the application of advanced data analysis. Also trends like smart energy meters, smart power grid
- Secondly, “India” and “China has a dense clustering indicating high interaction levels. With China has the highest document count, followed by India and Italy these means these countries are highly interested into smart energy. Patterns and trends in collaboration among countries and regions were observed, highlighting the global nature of research in smart energy integration and synergistic optimization.
- Lastly, an analysis of prevalent themes, topics, and keywords in publications allowed us to identify the current focus areas and emerging trends in the field with niche themes like electrochemical electrodes, while less central, are highly developed, indicating the importance of specialized research in addressing specific technical challenges within the broader field.

5.2 Implications and Recommendations

The growing interest in cybersecurity and low carbon solutions indicates a shift towards ensuring secure and environmentally sustainable energy systems. This trend highlights the need for robust security protocols and carbon reduction strategies in future energy projects. These themes are highly developed and central, suggesting their critical role in the field. They represent mature areas that are essential for the efficient distribution and management of energy in urban and regional settings. The focus on costs and investments highlights the ongoing importance of economic factors in the adoption and implementation of smart energy systems. Cost-effective solutions and investment strategies are crucial for the widespread deployment of these technologies.

Based on our analysis, we propose several recommendations for future research directions. Infrastructure Investment: Increase investments in district heating and cooling infrastructure to enhance their efficiency and reach. Prioritize these systems in urban planning and development projects. Innovation: Encourage innovation in these areas to improve their performance and integration with renewable energy sources. Support research on advanced materials and technologies that can optimize these systems. Policy and Regulation: Develop and implement policies that mandate stringent cybersecurity measures for smart energy systems. Encourage research and development of low carbon technologies through incentives and grants. Collaboration: Foster collaborations between cybersecurity experts and energy researchers to integrate security measures seamlessly into energy systems. Promote partnerships between industries and academia to accelerate low carbon innovations.

5.3 Limitations of the Research

It is essential to acknowledge certain limitations of our analysis that may impact the interpretation of the findings and their broader applicability:

- Firstly, the limited availability of comprehensive data may have impacted the scope and depth of our analysis. While we aimed to gather data from diverse sources, including journals and conference series, the lack of complete data sets may have influenced our findings since it was collected just from Scopus within 2019 till date.

- Secondly, potential biases in data collection, such as language bias or publication bias, could have affected the interpretation of results. It is important to recognize the potential limitations imposed by these biases and their impact on the overall insights derived from our analysis.
- Thirdly, Findings from our analysis may not be universally applicable and should be interpreted within the context of the study. The specific focus of our research on smart energy integration and synergistic optimization may limit the generalizability of the findings to other domains within the broader field of sustainable energy systems.

By acknowledging these limitations, we emphasize the importance of carefully considering the scope and context of our analysis when interpreting and utilizing the insights derived from our research.

5.4 Future Research and Next Steps

Future research should focus more on:

To push the boundaries of smart energy systems, it is imperative to delve into the integration of advanced technologies such as artificial intelligence and blockchain. Researching the application of AI in optimizing energy consumption and distribution, as well as exploring the potential of blockchain in ensuring secure and transparent transactions within smart energy systems, can pave the way for groundbreaking advancements (Renewable and Sustainable Energy Reviews Applications of blockchain and artificial intelligence technologies for enabling prosumers in smart grids. Innovative Low Carbon Technologies: Emerging Technologies: Research novel low carbon technologies and their integration into existing energy infrastructures. Focus on advancements in carbon capture, utilization, and storage (CCUS) technologies. Policy Impact: Study the impact of various policy frameworks on the adoption and scalability of low carbon technologies.

Investigating the impact of policy frameworks and regulatory mechanisms on the adoption of smart energy solutions is crucial. Understanding how policies and regulations influence the implementation and uptake of smart energy technologies can provide valuable insights for policymakers and industry stakeholders (Wijayatunga, 2014). Efficiency Improvements: Investigate new materials and technologies to enhance the efficiency of district heating and cooling systems. Explore the integration of renewable energy sources with these systems. Urban Planning: Research the role of urban planning in optimizing the deployment and operation of district heating and cooling networks.

Holistic Approaches: Develop holistic approaches to integrating renewable energies into smart grids. Study the environmental, economic, and social impacts of large-scale renewable energy adoption. Energy Storage Solutions: Research innovative energy storage solutions that complement renewable energy systems. Focus on improving the efficiency and cost-effectiveness of storage technologies. Conducting longitudinal studies is essential to track the evolution of research trends in smart energy integration and assess the long-term impact of interventions. By monitoring changes over an extended period, researchers can gain a deeper understanding of the trajectory of the field and the effectiveness of interventions (Dincer & Acar, 2017; Tang, 2021).

Undertaking in-depth case studies to analyze real-world implementations and identify best practices is pivotal for extracting actionable insights. Examining successful applications of smart energy integration and synergistic optimization in various contexts can offer valuable lessons and guidelines for future implementations (Jing, 2020). Incorporating these future research directions and next steps will contribute to advancing the knowledge and application of smart energy integration and synergistic optimization, fostering innovation and sustainability in the energy sector. Addressing Technological Gaps by investigating challenges related to infrastructure, connectivity, and access. Ensure that AI benefits reach all learners, regardless of socioeconomic status.

Future research and next steps should focus on addressing the emerging challenges and opportunities identified in the current analysis. By fostering interdisciplinary research, promoting innovation, supporting sustainable development, and ensuring economic viability, stakeholders can drive significant advancements in smart energy integration and the synergistic optimization of renewable and energy storage systems. These efforts will contribute to building a more secure, sustainable, and efficient energy future.

5.5 Concluding Remarks

In conclusion, our analysis provides valuable insights into the current landscape of smart energy integration and synergistic optimization research. By addressing key findings, implications, limitations, and future directions, we aim to contribute to the advancement of knowledge in this critical field. We hope that our findings will inspire further research, collaboration, and innovation to address the complex challenges facing the energy sector. By fostering interdisciplinary research, promoting innovation, supporting sustainable development, and ensuring economic viability, stakeholders can drive significant advancements in smart energy integration and the synergistic optimization of renewable and energy storage systems. These efforts will contribute to building a more secure, sustainable, and efficient energy future.

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BIODATA

Name-Last Name: Xiaokun Zhou

Email: samzhou1105@gmail.com

Education Background: Bachelor of Arts, Shanghai Theater Academy

Work Experience:

President, THAI THAI Royal Herbal Products LLP.
Chinese Coordinator,Srinakharinwirot University.
Founder, Shanghai Zhilian Culture Communication Co, Ltd.
Founder, Shanghai Guangyue Culture Media Co,Ltd.
Founder, Shanghai Yimai Internet Technology Company.
Member, Shanghai Dancers' Association.
Consultant&Scenarist/Choreographer-Director, Department of Continuing Education, Shanghai Dancers' Association.
Art Director, Shanghai Changxi Culture &Arts •
Director, Shanghai Xing tuo Alliance.