IEEE Access
Multidisciplinary ⁝ Rapid Review ⁝ Open Access Journal

Received 5 July 2023, accepted 4 August 2023, date of publication 11 August 2023, date of current version 21 August 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3304332

TOPICAL REVIEW

A Comprehensive Review of Green Computing: Past, Present, and Future Research

SHOWMICK GUHA PAUL[1], ARPA SAHA[1], MOHAMMAD SHAMSUL AREFIN[1,2], (Senior Member, IEEE), TOUHID BHUIYAN[1], AL AMIN BISWAS[3], AHMED WASIF REZA[4], (Member, IEEE), NAIF M. ALOTAIBI[5], SALEM A. ALYAMI[5], (Member, IEEE), AND MOHAMMAD ALI MONI[6]

[1]Department of Computer Science and Engineering, Daffodil International University, Dhaka 1216, Bangladesh
[2]Department of Computer Science and Engineering, Chittagong University of Engineering and Technology, Chattogram 4349, Bangladesh
[3]Department of Computer Science and Engineering, Bangabandhu Sheikh Mujibur Rahman University, Kishoreganj 2300, Bangladesh
[4]Department of Computer Science and Engineering, East West University, Dhaka 1212, Bangladesh
[5]Department of Mathematics and Statistics, Faculty of Science, Imam Mohammad Ibn Saud Islamic University, Riyadh 11564, Saudi Arabia
[6]Artificial Intelligence and Cyber Futures Institute, Charles Stuart University, Bathurst, NSW 2795, Australia

Corresponding authors: Mohammad Ali Moni (mmoni@csu.edu.au) and Mohammad Shamsul Arefin (sarefin@cuet.ac.bd)

This work was supported by the Deanship of Scientific Research, Imam Mohammad Ibn Saud Islamic University (IMSIU), through the Research Partnership Program under Grant RP-21-09-09.

ABSTRACT Green computing, also called sustainable computing, is the process of developing and optimizing computer chips, systems, networks, and software in such a manner that can maximize efficiency by utilizing energy more efficiently and minimizing the negative environmental influence on the surrounding. The term "green computing" refers to practices that lessen the negative effects of technology on the environment. Due to the improvements in modern technology, various devices, mechanisms, and software have been developed, and lots of studies have been conducted to optimize and increase those technologies' green computing abilities. Thus, review and summarization of green computing-based studies are required to identify the current advancements, challenges, and future research opportunities. This study reviewed and summarized green computing in each area studies, by exploring green computing's twelve areas. Current research trends, datasets or testing mechanisms, and the construction or implementation of various technologies to accomplish green computing and sustainable development have been discussed. This study, after conducting a thorough comparison and analysis, provides responses to the proposed state-of-the-art research questions. Furthermore, this study presents the current challenges and future research opportunities with respect to each green computing area. This study will provide organizations, researchers, and institutions conducting research on green computing with insights and ideas. Furthermore, environmental organizations, companies, and government agencies concerned with reducing carbon emissions and energy consumption will also benefit from this review study.

INDEX TERMS Carbon emissions, eco-friendly computing, energy efficiency, green computing, green computing area, sustainable development.

I. INTRODUCTION

Green computing is a concept that emerged in response to growing concerns about the negative environmental impact of information and communication technology (ICT). Green computing term was coined in the early 1990s, and it has since gained widespread acceptance in the IT industry [1]. It refers to the design, development, use, and disposal of computing systems in an environmentally sustainable way [2]. In other words, green computing aims to reduce the computing systems' carbon footprint while ensuring their optimal performance [3].

The phrase "green computing" can also be referred to as the environmentally-friendly aspects of cloud computing,

The associate editor coordinating the review of this manuscript and approving it for publication was Jie Tang.

such as high resource usage, cost savings from not having to construct as many computers, and environmental protection [4]. Green computing has several benefits, including reducing energy consumption, minimizing electronic waste, and lowering operational costs [5]. The domain of green computing includes various aspects of computing systems, such as hardware, software, networks, and data centers. Green computing practices involve optimizing hardware design, reducing power consumption, using renewable energy sources, improving software efficiency, virtualizing servers, and managing e-waste [6], [7], [8], [9]. Green computing has both positive and negative impacts. On the positive side, green computing can reduce energy consumption, lower operational costs, and enhance environmental sustainability. Furthermore, green computing can enhance the effectiveness and dependability of computing systems by optimizing hardware and software. On the negative side, green computing may require additional investments in energy-efficient hardware and renewable energy sources. Furthermore, e-waste disposal and implementing green computing practices may require additional training and resources. Green computing is a broad field that encompasses a range of technologies and practices that aim to mitigate the environmental impact of computing systems. Furthermore, there are several linkages between green computing and other technological fields or domains.

Green ICT and green computing are closely related concepts that share a common goal of promoting environmental sustainability. Green ICT refers to the use of ICT to improve environmental sustainability, while green computing focuses on the design, development, use, and disposal of computing systems in an environmentally sustainable way. Both concepts are critical for promoting environmental sustainability in the digital age, and they complement each other in several ways. Such green ICT can facilitate the deployment of green computing solutions by enabling remote access, virtualization, and cloud computing. Green computing, on the other hand, can enhance the energy efficiency and sustainability of ICT infrastructure by optimizing hardware and software [10]. Moreover, both concepts can contribute to the development of smart and sustainable cities by promoting energy-efficient buildings, transportation systems, and public services. Green ICT taxonomy is a classification system that is used to categorize the different aspects of environmental sustainability in ICT. This taxonomy is essential for identifying the various areas of focus that are critical for promoting environmental sustainability in the digital age. One way to classify the different areas of green ICT is to divide them into three broad categories: data center-related sustainability, distributed ICT-related sustainability, and other ICT-direct sustainability [11]. Fig 1., illustrates the green ICT taxonomy. Data center-related sustainability refers to the usage of energy-efficient data center technologies, such as cooling and power management systems, to reduce data centers' environmental impact. Distributed ICT-related sustainability focuses on the development of energy-efficient distributed computing systems, such as cloud computing and virtualization, to reduce energy consumption and promote environmental sustainability. Finally, other ICT direct sustainability includes a range of practices, such as sustainable software design and green procurement, aimed at reducing the environmental impact of ICT systems. The green ICT taxonomy plays an important role in promoting environmental sustainability in the digital age and advancing the field of green computing.

Green computing differs from traditional IT systems in several ways. Traditional IT systems focus on performance and functionality, whereas green computing emphasizes environmental sustainability. Traditional IT systems may use energy-intensive hardware, consume high amounts of power, and generate significant e-waste. In contrast, green computing systems use energy-efficient hardware, consume less power, and generate minimal e-waste. Furthermore, traditional IT systems may rely on non-renewable energy sources, such as fossil fuels, whereas green computing systems use renewable energy sources. Green computing is good for the environment as it reduces carbon emissions, minimizes electronic waste, and promotes renewable energy sources. By adopting green computing practices, organizations can improve their environmental sustainability and reduce their carbon footprint [12], [13], [14]. Furthermore, green computing can lead to cost savings, improved energy efficiency, and enhanced CSR profile. If we do not adopt green computing, it can lead to increased carbon emissions, e-waste generation, and environmental degradation. Furthermore, organizations may incur higher energy costs, regulatory fines, and reputational damage. By adopting green computing practices, organizations can avoid these negative outcomes and promote environmental sustainability. The necessity of green computing is driven by the increasing use of ICT in various sectors, such as healthcare, finance, education, and manufacturing [15], [16], [17]. ICT accounts for a considerable amount of the world's energy consumption and carbon emissions and its use is projected to increase quickly over the next few years. Therefore, it is essential to adopt green computing practices to reduce the negative environmental impact of ICT and promote sustainable development.

We have taken the initiative to explore and study the area of green computing. This study holds a prominent position within the current technical state of the art in green computing due to its innovative contributions and comprehensive analysis. By critically examining the existing literature and synthesizing key findings, this research adds significant value to the field. Its novel insights, methodologies, and empirical evidence make it a valuable resource for researchers and practitioners seeking to advance the frontiers of green computing. Furthermore, by addressing emerging challenges and identifying novel solutions, this study paves the way for future advancements and sets a new benchmark for excellence in the field of green computing. Some of the contributions that this review study has made include the following:

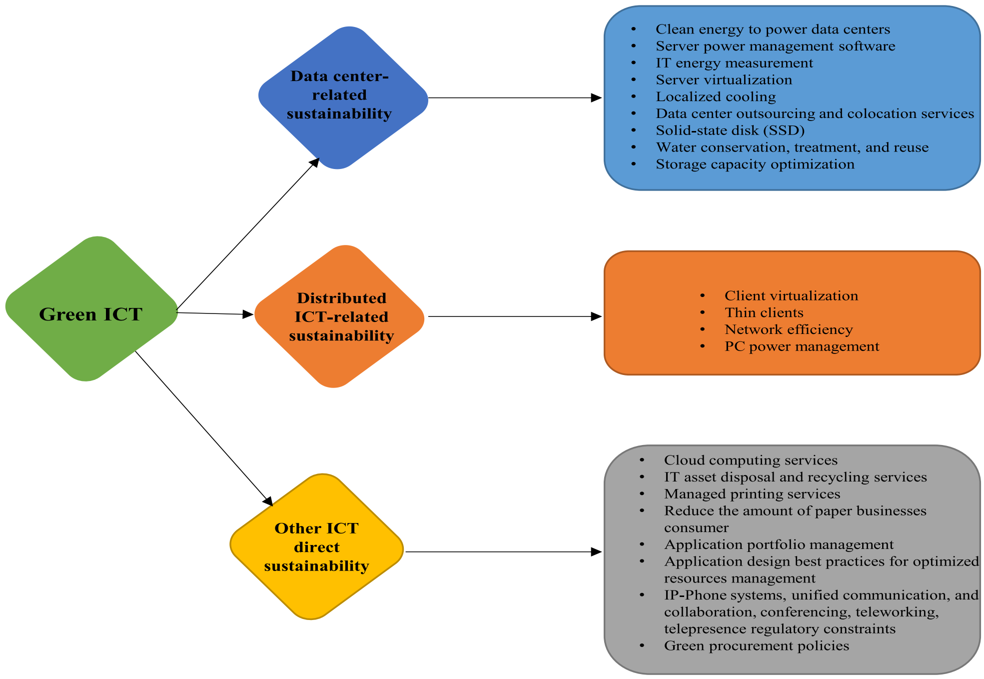

FIGURE 1. Green ICT taxonomy.

I. This study has identified the area of green computing and thoroughly analyzed the current research works in each area.
II. Various technologies and mechanisms that are used in the area of green computing have been explored and the current research trends and most optimal techniques for achieving green computing have been filtered.
III. This study presents a thorough analysis of green computing-related research work, where the most significant contributions and findings, utilized data set and testing mechanism, and current research advancement are presented and summarized.
IV. The study proposed state-of-art questionnaires that uncover the current obstacle and achievement and summarize various other perspectives of green computing-related research works.
V. This study provides future research directions and challenges for researchers in relevant fields.

The research outcomes offer practical implications for industry professionals, policymakers, and researchers working in the field of green computing. This study facilitates the establishment of a framework for forthcoming research in the field of green computing by identifying potential areas of investigation. As such, further study on this subject can enhance understanding of green computing and aid in the further generalization of green computing areas. This study provides a comprehensive analysis of the industry-wide shift towards sustainable computing practices, including the adoption of innovative solutions aimed at mitigating the environmental impact of computing systems. The identified strategies, methodologies, and recommendations can guide the design, implementation, and management of energy-efficient computing systems and infrastructure. Thus, the findings of this study may serve as a catalyst for further research in this area.

The structure of a review study is crucial to convey information to readers effectively. This study is organized into seven sections that follow a logical and structural flow to explore various aspects of green computing. Section I of this study constitutes the introduction, providing an initial overview of green computing. Section II contextualizes the review by discussing related studies and identifying the present research gap. Section III outlines the review methodology, which includes the selection procedure of the studies, and research questions. In section IV, the selected study distribution is analyzed, followed by the exploration of areas of green computing in section V. Section VI presents the findings and analysis of the reviewed studies, highlighting the challenges that emerge in the research on green computing and proposing future research directions. Finally, in section VII, the study has been concluded.

II. RELATED STUDIES

In recent years, numerous studies have been performed in the green computing area. Furthermore, various studies have analyzed the uses of green computing and reviewed the current studies performed in the area of green computing, which are discussed here to identify and explore the current research gap.

Dhaini et al. [18], conducted a review study on green computing based on five areas such as software engineering, cloud computing, mobile computing, data centers, and the educational sector. In the study, a systematic literature review of every area has been conducted, highlighting each area's current research trends, and limitations. However, there has been a lack of discussion regarding the utilization of datasets and their characteristics, testing mechanisms, and contributions in relation to various perspectives on the current technologies' applications in each area.

As green computing is strongly associated with other domains or fields, examining the association between the two fields is necessary to achieve environment-friendly modern computing systems. Castillo and Melin [19] have reviewed the interactions between green computing and computational intelligence. The study reviews and summarizes the current studies performed to find computational intelligence that is environmentally responsible and eco-friendly. In the study, a total of 255 studies have been reviewed, and various distributions related to the reviewed studies have been presented. Furthermore, the study has analyzed the current trends of the existing works and the possibilities of future research trends. Nevertheless, the current technologies utilized in each study, along with their corresponding impacts, approaches, and limitations, have not been underscored.

Hypotheses are the first step toward building and testing the feasibility of any new technology. By implementing and analyzing the hypothesis, advanced and time-appropriate applications or systems can be built. Hamizi et al. [20] have explored the current hypotheses in the green computing field. In the study, the past 11 years of studies have been analyzed, and the associated green computing hypotheses are outlined. Initially, 340 studies had been considered for the study. However, after analyzing the studies, plausible hypotheses were found in only 78 studies. The hypotheses have been categorized into three groups such as tools for estimation, design choice, and platform issues. The review studies are organized into taxonomies, and a comprehensive outlook on potential avenues for future research is provided.

Another study performed by Khelifi et al. [21] analyzed the economic and social contribution of green computing with 5G and blockchain. Studies mainly published from 2016 to 2020, have been analyzed, and a comprehensive analysis of the study's various perspectives has been detailed in the study. A taxonomy of green blockchain and green computing based on 5G has been presented, and a power consumption solution for blockchain 5G computation has been discussed in the study. Moreover, various limitations and future research directions have been detailed. However, other technologies that are closely related to 5G communication technology and blockchain, such as IoT, data centers, and cloud computing, have not been presented.

In another study, Geetha [22] reviewed the application of green computing with bots. In the study, green computing applications across many sectors have been analytically described. Green computing's potential fields, with their limitations, have been deliberated. However, a comprehensive analysis of various green computation integration-based studies with respect to various fields has not been performed.

Sagar and Pradhan [23], in another study, identify the recent trends in green computing. In the study, various algorithms used in the field of green computing have been identified. Furthermore, various perspectives on those algorithms have been discussed. Lastly, a comprehensive analysis of the current limitations has been outlined.

Due to the increased demand for cloud computing, energy consumption is increasing, which can lead to an increase in carbon footprint. Therefore, it is essential to explore techniques that may reduce future energy consumption by utilizing energy efficiently. Aslam and Kaur [24] reviewed studies that proposed energy efficiency techniques in the green cloud computing area. In the study, various techniques that can minimize high operational costs and be more energy efficient, reducing the carbon footprint, have been explored and analyzed. Furthermore, future research guidance has been provided by analyzing the current relevant studies. Nonetheless, only a small number of studies have been analyzed to uncover energy-efficient cloud computing techniques. Additionally, other green computing areas that can be associated with green cloud computing, such as green data centers and green IoT, have not been explored.

The review of studies related to the implementation of green cloud computing is performed by Radu [25]. In the study, recent green cloud computing-based studies have been summarized, and environmental issues have been discussed. The present study involved a comprehensive examination of 90 studies. An in-depth analysis consisting of green cloud computing benefits, research trends, and current obstacles has been discussed. Furthermore, future research directions and challenges have been presented. Despite the extensive nature of the investigation, the study falls short of providing a comprehensive and comprehensible account of the methods employed, dataset utilization, testing mechanism, and contribution of each individual study. Moreover, the investigation has not delved into the association between green cloud computing and other areas.

In another study, Yuan et al. [26] provided a detailed review of research relating to data centers and multimedia services. In the study, data centers and cloud-based multimedia services, energy efficiency techniques, and approaches have been analyzed. In the study, various perspectives on the energy management of data centers and multimedia services have been addressed by providing a systemic literature review of each perspective. Further, the current challenges in maintaining and designing data centers, as well as future research opportunities for green streaming services, have been outlined.

Benhamaid et al. [27] have performed a comprehensive review of studies on energy management techniques used to achieve green IoT. In the study, current challenges in the field of green IoT for energy consumption have been presented, followed by the approaches that various studies have utilized for energy management. The study provides a comprehensive overview of recent energy management systems for the IoT ecosystem. Furthermore, the present research trends and future perspectives have been described for energy management to achieve green IoT.

Reviewing implementation studies can provide insight, identify current challenges, and provide directions for potential future research work not only in the green computing field but also in other fields. For instance, Showmick et al. [28] summarized the machine learning (ML) and deep learning (DL) technologies utilized during the COVID-19 pandemic. The study delves into six research questions that explore different aspects of ML and DL in relation to the COVID-19 pandemic. Furthermore, the study has outlined current challenges and provided future directions, which can be essential for combating the COVID-19 pandemic.

Mekala and Viswanathan [29] have conducted a survey of X-IoT applications in green computing, where X represents industrial/agriculture/environment. In the study, energy-efficient sensors and virtual machine (VM) selection approaches have been presented. Based on the three research questions, review studies have been selected. Out of an initial sample of 160 studies, 72 were selected based on their quality, and 32 were subsequently identified as potential sources for addressing the research questions. Furthermore, energy-efficient sensors with respect to various technologies and approaches have been discussed. In addition, VM selection approaches based on various criteria have been presented. Finally, the challenges and open issues have been discussed. However, this study contains a limited number of studies and emphasizes specific IoT concerns.

As COVID-19 led to virtualization, Lee et al. [30] have reviewed recent studies on green data centers. In the study, recent engineering-oriented studies on green data centers (GDC) have been reviewed. In the study, the authors found that current technical efforts to create energy-efficient DCs are unable to achieve their goal. Furthermore, although virtualization may help reduce negative environmental effects, GDC needs to be eco-friendlier.

In another study, a green procurement bibliometric review was performed by Masudin et al. [31]. In the study, the implementation of green procurement through supplier selection has been analyzed using 220 studies from 1994 to 2022, and numerous findings have been identified. However, this study doesn't cover the various perspectives related to the area of green procurement.

Massaoudi et al. [32] have explored the usage of DL in smart technology-based studies through a systematic approach. The review and analysis have been conducted on studies conducted between 2015 and 2020, with a total sample size of 220 studies. The study examines the implementation and integration of DL in smart grid systems and outlines DL's major applications in smart grids. Furthermore, many challenges associated with the application and development of DL for smart grids are discussed. However, alternative viewpoints regarding the smart grid, including energy administration, assimilation of renewable sources, and integration of the smart grid in relation to other domains of environmentally-friendly computing, have not been explored.

As green computing is an emerging field, limited studies have been conducted in this field so far. As such, the outline of proper green computing areas has not yet been generalized. Therefore, to understand the progress of green computing-related work, it is necessary to explore all the potential green computing areas. Furthermore, to get a clear understanding of current research achievements and the challenges that researchers face while performing green computing-related research work, there is a need to examine and explore all the potential areas regarding green computing. This study proposed the potential areas of green computing and analyzed the studies with respect to each area to acquire an in-depth knowledge of current trends and limitations as well as furnish researchers with appropriate guidance for future research directions.

III. REVIEW METHODOLOGY

As was described by Brereton et al. [33], a review of studies is a method that involves locating, evaluating, and interpreting all of the data that is readily available on a certain research subject or area of interest. In this investigation, in response to a number of different robust research questions, an exhaustive search of the relevant literature has been carried out. In addition to that, a method that is risk-free, reliable, and measurable has been used in order to offer a response to those issues.

A. SEARCH STRATEGY

Finding relevant research required a number of different academic search engine usage, including Scopus, ERIC, PubMed, DOAJ, Science Direct, Web of Science, IEEE Xplore, and Google Scholar. Table 1 provides a summary of the keywords that were used to retrieve the relevant works from the database. The majority of the time is spent utilizing these keywords in a variety of different combinations to select the relevant studies.

B. INCLUSION AND EXCLUSION CRITERIA

The criteria of inclusion and exclusion for evaluating the relevant studies are as follows:

Inclusion Criteria:

a. Only studies are written in English that were relevant to green computing.
b. Studies that include one or more green computing-related ideas.
c. Studies that address at least one of the environmental concerns related to green computing.
d. Studies include either experimental or analytical work and solving any green computing area problem.

Exclusion Criteria:

a. Research articles not published before 2007 and after 2022.

TABLE 1. Applied keyword.

• green computing	• green e-commerce	• green transportation	• green data mining	• eco-friendly computing
• green machine learning	• smart grid	• green database	• green agriculture	• low-power computing
• green education	• green IoT	• green procurement	• energy efficiency	• carbon-neutral computing
• cloud computing	• green e-government	• technology	• sustainable computing	• power management
• network	• system	• development	• design	• optimization

b. Green computing-related methods are discussed in research journals but are not associated with considered green computing areas.
c. Green computing issues are mentioned in research that does not employ any green computing-related technologies or any analytical work.
d. Studies that review others' green computing-related research work.

C. SELECTION OF THE STUDY

The selection of appropriate studies is essential to conduct a high-quality systematic review. Therefore, the selection of studies for the review should be performed with the utmost care and following a standardized procedure. This study's primary goal is to systematically identify and evaluate the available studies on green computing.

The selection of studies has been carried out through multiple steps outlined in Fig 2. To begin with, an initial pool of 800 studies had been identified using the search strategy. Duplicates had been removed, leaving 680 unique studies for further screening. Abstract and dataset analysis, along with inclusion and exclusion criteria, had been used to narrow down the eligible studies to 328 for full-text review. Of these, 87 studies were removed after examination, resulting in 241 studies for methodological quality evaluation. After careful evaluation, 25 studies were excluded, and only 216 studies had been included in the systematic review.

The selection process helps to ensure that the studies included in the review are of good quality and relevant to the proposed research question. This study employed a rigorous selection procedure, including the use of predefined inclusion and exclusion criteria and multiple levels of screening to identify the most appropriate studies.

D. EXTRACTION OF THE DATA

After studies have been selected, the data extraction step is very vital for accurate analysis and interpretation of the research work. To achieve useful results, the extraction of data from studies has to follow a logical structure. Therefore, tables with predetermined attributes have been generated, and diverse data acquired from the study endeavor has been filled. The first attribute, "References and Year", of the tables contains the study reference and the publication year.

The next attribute, "Perform work", indicates the subject of the research works. The third attribute, "Dataset/Testing mechanism" describes the dataset characteristics and utilized testing mechanisms of the studies. Lastly, the last attribute, "Finding and Contribution", mentions the contribution, utilized procedures, and findings of the study.

E. RESEARCH QUESTIONS (RQS)

This exhaustive and in-depth study focuses mostly on summarizing, analyzing, and synthesizing the numerous studies that have been performed in the field of green computing. The primary objective of this investigation is to collect the appropriate response to the following seven research questions through an in-depth analysis and provide an informative, insightful assessment and response. The following are the proposed research questions:

- RQ 1. What are the most recent advancements in the area of green computing research, and how do they stack up against earlier efforts?
- RQ 2. What approaches have shown to be the most successful implementation in the areas of green computing?
- RQ 3. Which areas of green computing are most underdeveloped, and what are the obstacles researchers in those areas are facing?
- RQ 4. How do recent developments in artificial intelligence and machine learning affect the amount of energy saved by computer systems?
- RQ 5. What areas of green computing research are the most promising?
- RQ 6. What will be the most difficult obstacles for those researchers who are now intending to do research on green computing?
- RQ 7. What role does green computing research and development play in achieving the aims of sustainability across the world?

IV. STUDY DISTRIBUTION ANALYSIS

Before analyzing the studies' contributions and achievements towards green computing, it is important to analyze the distribution of the final selected studies. This section presents the final selected studies' various distributions.

From Fig 3., it can be observed that the China performed the highest number of green computing studies, with sixty-four studies published in the field. India is the second-highest study publisher country with twenty-eight research works, followed by the USA with twenty research works. Fourteen studies are contributed by Qatar, Lebanon, Ireland, Brazil, Malta, etc., referred to as "Others". Other nations, most of which are developing countries, have conducted fewer studies on green computing. While some countries have contributed more than others, it is reassuring to see

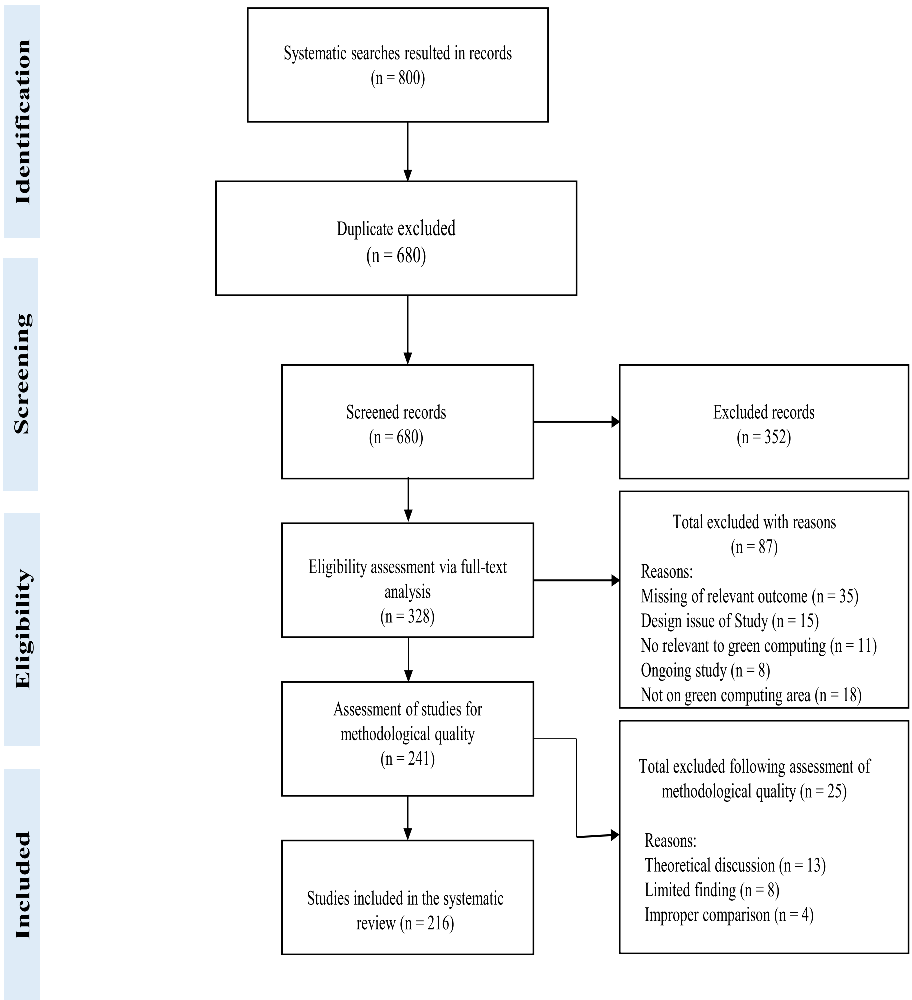

FIGURE 2. Diagram of the study selection procedure.

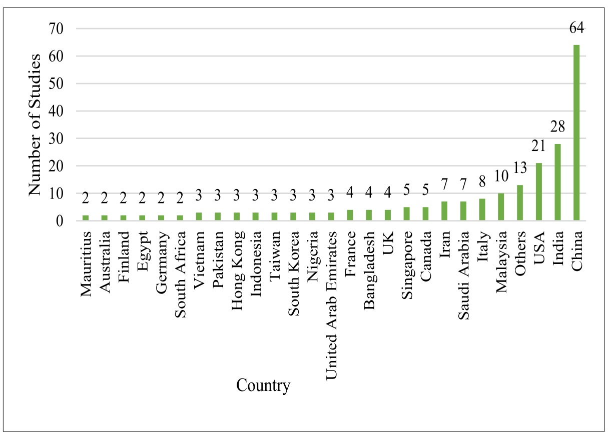

FIGURE 3. Country-wise distribution of green computing area.

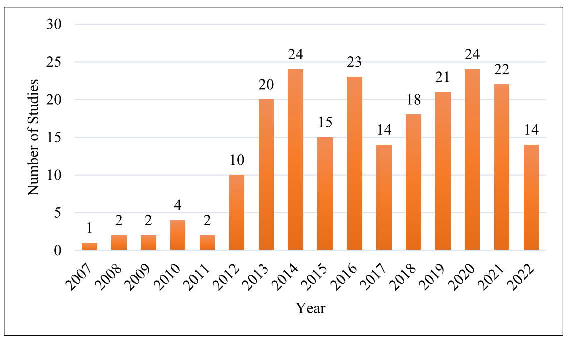

FIGURE 4. Distribution of green computing studies by year.

that nations worldwide are committed to developing a greener future through technology.

Green computing has been a rapidly growing field, with a significant increase in research output in recent years (see Fig 4.), the year 2007 observed one study published in the field, which had been followed by two studies in 2008 and two in 2009. The number of publications started to rise in 2010, with four studies published that year. In 2011, two studies were published, and in 2012, the number increased to ten. The trend continued, with twenty studies published

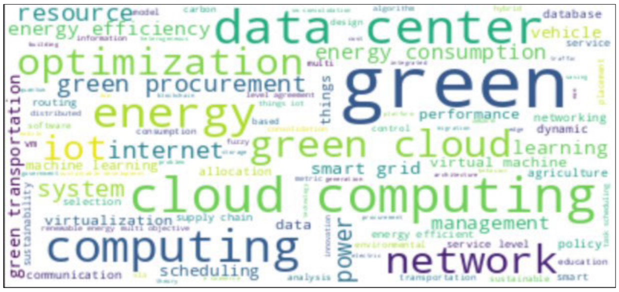

FIGURE 5. Word cloud of studies keyword.

in 2013 and twenty-four in 2014. In 2015, there had been fifteen studies published, and the following year, 2016, there were twenty-three studies published. In 2017, fourteen studies were published, and the number increased to eighteen in 2018. The year 2019 saw twenty-one studies published, and the number increased further to twenty-four in 2020. The year 2021 had twenty-two publications, while fourteen research works were published in 2022. Overall, the field of green computing has seen a steady increase in research output since 2007. The peak of this increase has been observed in the last decade, with the highest number of publications in 2020. This increase in research output is indicative of the growing interest and importance of the field, with researchers actively contributing to developing sustainable computing solutions.

Fig 5. Illustrate the word cloud of selected studies keywords. The keyword analysis demonstrates that the keywords "data-center", "green", "energy", "green cloud", "cloud computing", "computing", "network", and "optimization" were among the most commonly used. These keywords represent various aspects of green computing, such as energy-efficient data centers, cloud computing services with reduced environmental impact, and optimization techniques for energy-efficient computing. On the other hand, the keywords "power", "management", "energy consumption", "green procurement", "green transportation", "virtualization", and "smart grid" were among the least commonly used. These less frequently used keywords reflect the lesser emphasis on areas such as green transportation and energy-efficient procurement in green computing research. Overall, the analysis of keywords used in green computing research provides insights into the research trends and priorities in this field.

Over the years, research in the green computing field has led to the development of various areas, each with its own set of challenges and opportunities. From Fig 6., it can be concluded that the most prominent areas in terms of collected studies are GDC, green cloud computing (GCC), green transportation systems, and green IoT. On the other hand, green machine learning, green data mining (DM) and information retrieval (IR), green e-commerce and e-government, and green databases are some of the most unexplored areas and contain fewer studies.

In the analysis of publication trends in green computing, it is observed that around 63% of the research work

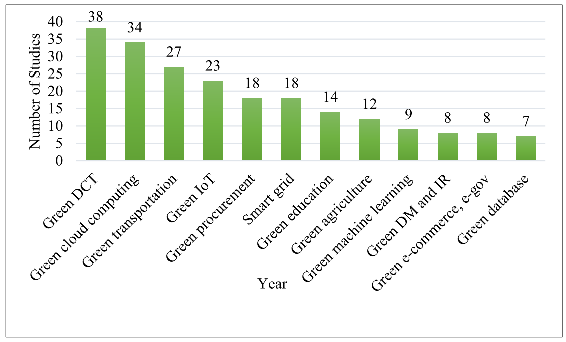

FIGURE 6. Area-wise distribution of green computing studies.

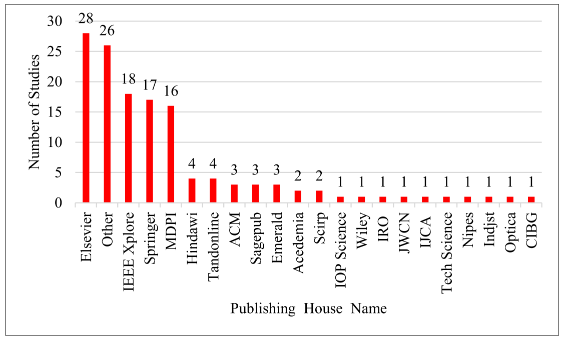

FIGURE 7. Distribution of journal publication related to green computing studies.

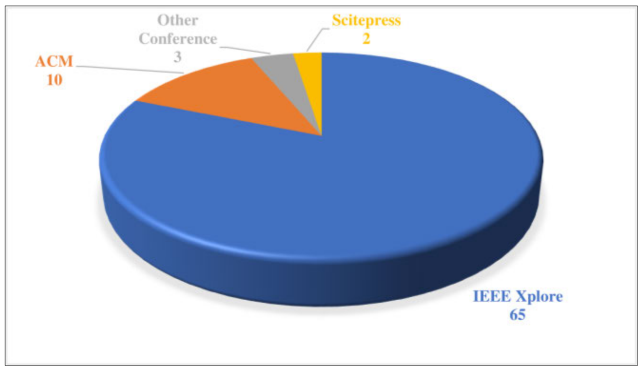

FIGURE 8. Distribution of conference publication related to green computing studies.

is published in journals, while the remaining around 37% are published in conferences. The preference for journal publications over conference studies indicates the growing maturity and stability of the field. Fig 7., presents the journal publication house of green computing's final selected studies. Elsevier, Springer, IEEE Xplore, and MDPI are the leading journal publishing houses in the area of green computing. However, a number of other publishing houses, referred to collectively as "Other," play an important role in the publication of green computing studies. On the other side, Fig 8. depicts the publishing houses of conference studies, with IEEE Xplore playing the dominant role, followed by ACM and other conferences.

FIGURE 9. Categorization of green computing areas.

V. AREAS OF GREEN COMPUTING

Studies of green computing try to lessen the environmental effect of ICT. Green computing covers a wide variety of areas (see Fig 9.). The selection of twelve areas in green computing is driven by their scope, relevance, and the need for comprehensive coverage of key aspects within the field. After gathering numerous research studies, a rigorous application of inclusion-exclusion criteria resulted in the finalization of relevant studies. During the in-depth review process, relevant studies were classified into the same categories, resulting in the formulation of twelve areas of green computing that are more likely to facilitate the alignment of forthcoming studies with one of the twelve specified areas. This approach ensures depth and focus in examining specific challenges, advancements, and implications associated with each area, while also considering practicality, manageability, consensus, and the existing body of research. These identified areas include GDC, GCC, green IoT, green database, green DM and IR, green ML, green e-commerce and green e-government, green procurement, green agriculture, green education, smart grid, and green transportation systems. Each of these areas has its own unique challenges and opportunities for promoting environmental sustainability in the digital age. By focusing on these areas, researchers and practitioners can contribute to the development of sustainable computing systems and help mitigate the negative environmental impact of ICT. The field of green data center technologies focuses on creating and running data centers in an environmentally friendly and resource-conserving manner, using renewable energy sources, and reducing carbon emissions. In the area of green cloud computing, energy efficiency, electronic waste reduction, and increased reliance on renewable energy sources are explored as ways to leverage cloud computing to lessen the environmental impact of IT infrastructure. The green IoT sector examines how to leverage low-power gadgets and improved communication protocols to make the IoT more sustainable and energy-efficient. The design, usage, and administration of databases with regard to energy efficiency is the emphasis of the green database field. The field of green data mining and information retrieval focuses on methods for data mining and information retrieval that are energy-efficient and can help lessen the environmental impact of data processing and decision-making. The field of green machine learning focuses on machine learning methods that are energy-efficient and can help lessen the environmental impact of data processing and decision-making. The field of green e-commerce and green e-government focuses on environmentally friendly and resource-conserving methods of performing e-business and e-government operations. The sustainable purchase of products and services is the focus of the green procurement area. The field of green agriculture focuses on using ICTs to enhance sustainable agricultural methods and decrease farming's environmental effects. The field of green education focuses on using ICTs to encourage environmentally friendly teaching methods. The field of smart grids focuses on using ICTs to optimize and control the electrical grid in a sustainable and energy-efficient manner. The field of green transportation systems focuses on the use of ICTs to manage and improve transportation networks in a manner that is both sustainable and energy-efficient. The overall focus of green computing research is to reduce the environmental impact of ICT systems and to encourage environmentally friendly business practices across a range of sectors, from data centers and cloud computing to transportation and agriculture.

A. GREEN DATA CENTER TECHNOLOGIES

GDC are built with a focus on energy efficiency and low environmental impact. Reducing energy use and carbon footprint while preserving or even enhancing performance and availability is the aim of a GDC. To reduce the need for physical servers and improve energy efficiency, server virtualization is one of the primary technologies used in GDC. Server virtualization enables numerous virtual servers to operate on a single physical server. This is accomplished by dividing a single physical server into many virtual servers, each of which may run its own operating system and applications using virtualization software. According to studies, server virtualization may result in energy savings of at least 50% [34]. Another key technology utilized in green data centers is power management. Using renewable energy sources and dynamic voltage and frequency scaling, which adapts server power consumption depending on workload, are two power management strategies that may help data centers use less energy and have a less negative effect on the environment [35]. Furthermore, a combination of traditional and renewable power sources can effectively reduce CO2 emissions while preserving power security [36].

Table 2, presents some of the key elements of the current studies conducted in the area of the GDC. In the area of GDC, various types of datasets, testing software, and data centers have been utilized for conducting the studies. Among all the testing mechanisms, CloudSim is the most utilized software. However, various types of datasets with respect to the study's objective have been utilized. From Table 2, it can be observed that diverse types of work, such as cooling system development, the design and implementation of green architecture, various types of algorithm development, and server virtualization have been performed in the area of the GDC in recent years. The cooling system is an essential component of green data centers. Green data centers employ methods like liquid cooling and outside air cooling to decrease energy usage. Data centers need extensive cooling to avoid overheating. Traditional air-conditioning systems, which may be a significant source of energy use in data centers, may not be as energy-efficient as these alternatives. Using the nature-based cooling system mechanism can efficiently tackle the overheating problem while reducing energy requirements compared to traditional systems [37]. Another crucial component of green data center is their energy-efficient architecture. Data centers may be built to consume less energy and leave a lower carbon footprint by improving airflow and cutting energy usage. Raised flooring, hot aisle and cold aisle layouts, and other design elements may be used to accomplish this. Furthermore, architecture that is capable of online monitoring, live VM migration, or maximizing network power conservation can be implemented to reduce energy consumption [38], [39]. Evaluating an architecture for the GDC is essential for ensuring the effectiveness of the architecture or framework. Various studies have proposed simulators that can be utilized to validate and identify the system's effectiveness [40]. Storage space optimization is one of the key attributes for achieving a GDC. The multi-valued table structure is an important criterion to optimize the storage space, thus achieving a GDC [41]. The GDC researcher should be concerned not only with decreasing CO2 emissions and energy consumption, but also with strengthening the data center's security while minimizing cost, which can be accomplished by a distributed data center or by building a cyber security solution [42], [43]. Furthermore, developing energy-aware algorithms and task schedulers can aid in optimizing the data center network, and reducing energy consumption is one of the major key components towards achieving a GDC [44], [45]. Profit maximization is an important aspect for industrialists and financial institutes when developing and investing in green data centers, and various

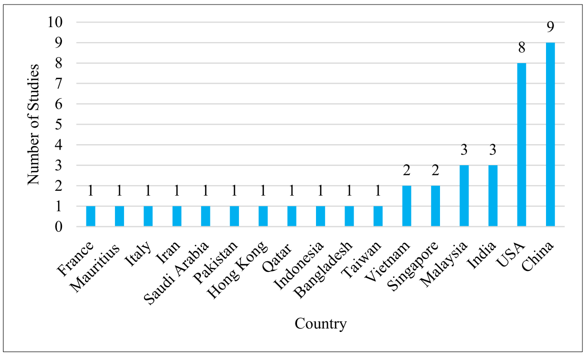

FIGURE 10. **Country-wise distribution of green data center studies.**

studies have been conducted in this context to ensure the maximization of the green data center profit [46], [47].

Lastly, data centers that are run by green energy sources such as biomass, solar, wind, and geothermal energy will assist in lowering the data centers energy consumption as well as the carbon footprint. The needs and peculiarities of various data centers should be taken into consideration, since the best technologies and solutions will vary based on the particular situation. Data center operators must thus carefully evaluate their unique needs and requirements before introducing green data center solutions.

From Fig 10., it is observable that China and USA lead the area with nine and eight studies, respectively. However, other countries are also actively researching sustainable data centers, with India and Malaysia each having three research works. Singapore and Vietnam each having two. Other countries on the list include France, Mauritius, Italy, Iran, Saudi Arabia, Pakistan, Hong Kong, Qatar, Indonesia, Bangladesh, and Taiwan, which each have one green data center-related study, which indicates the global interest in the development of sustainable green data center technology. Fig 11. illustrated the year-wise study publication in the area of GDC. Starting from the lowest, the year 2009 had only one research work published, followed by 2010, and 2012, which also had only one research work each. The most recent year, 2022, had a single research work published, while 2020 and 2021 had two research works each. The years 2015 and 2019 had three research works of each published. Finally, 2013 had the highest number of research works, with eight published.

B. GREEN CLOUD COMPUTING

The purpose of GCC is to lessen the negative effects of cloud computing (CC) on the environment by using sustainable and energy-efficient methods. Data centers, which are significant energy users, are growing in number due to the increasing popularity of CC. This has caused worries about the rising environmental effects of cloud computing. With the fundamental principle of sustainable development, the notion of "green computing" first emerged in 1987, the main

TABLE 2. Summary of green data center technologies studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[41], 2013	Storage space optimization	Microbial datasets from CMR	To optimize the green data center database storage space, a model that mines and utilizes dataset functional dependencies is proposed. The implementation result suggests that to store instances in the proxy mappings, a multi-valued table structure is preferable over a pure relational table structure.
[48], 2020	Combined IT and power supply infrastructure	NSRDB and NREL data	Proposed an algorithm to identify needed IT servers using an adapted binary search and used primary power sources (PS) such as photovoltaic panels and wind turbines to design electrical infrastructure.
[38], 2009	Green cloud architecture (GCA) for reducing data center power consumption	Tested on the tremulous, online real-time game, as a VM application	Present a GCA that enables online monitoring, live VM migration, placement optimization, and can save up to 27% of the energy.
[37], 2010	Ocean thermal energy for air-conditioning	-	To cool the data center using naturally-available cold seawater, its engineering, economic, and environmental implications are examined, and it is found that the energy requirement is 94% less than traditional cooling systems.
[40], 2014	A simulator for GDC design and analysis	Analyzed on different online management schemes	Presented a modeling tool for constructing eco-friendly data centers that captures online resource management systems and data centers' physical behavior inter-dependencies.
[49], 2013	Unified optimization framework green DCN	2 data centers (1024, 3456 servers)	Proposed two algorithms, TE_VMA for VM and TER for routing traffic flows, and had been able to achieve 50% energy savings.
[50], 2017	GDC placement in optical cloud networks	Eclipse standard Luna R IDE	Proposed a cloud network that is VM migration enabled to solve DC placement and addition problems with brown-energy cost and consumption-reducing objectives.
[30], 2016	Space-time scheduling for green DCN	-	To jointly optimize workload and power, two-timescale have been developed.
[51], 2013	Customizable hybrid testbed	Open Flow gigabit routers and mininet	Propose an innovative testbed design that improves scalability, flexibility, and accuracy by combining a virtual emulation test environment with hardware network devices.
[36], 2014	Hybrid green power generation system	-	Proposed a system comprised of solar PV, and a gas turbine with cng-based fuel cell-based hybrid fuel cell system to generate green power. The sequestration technique is used to address CO2 emissions.
[52], 2019	Cost optimization method with dynamic pricing	-	Considering several aspects of energy use, an algorithm for capacity planning with dynamic pricing is proposed.
[53], 2013	Server virtualization impact on energy efficiency	CPU usage, task completion time, power consumption data	To measure the energy usage of servers with various configurations, an empirical approach has been utilized, and the authors find that by aggregating applications from several servers onto a single server and shutting down inactive servers, it is possible to minimize energy usage.
[43], 2017	Cybersecurity based on Li-Fi	Uses an experimental setup to verify cybersecurity solutions	Li-Fi technique-based cyber security solutions for industrial networking of green storage, cloud computing, and data centers are proposed with low-cost energy.
[54], 2015	GDC using Spearman's ranking algorithm	CloudSim, Java	Spearman's rank correlation coefficient technique is utilized to enhance VM scheduling, and it is found that the technique is optimum, efficient, and adaptable.
[55], 2016	Centralized power-management of network and servers	Deploy C# based CPM simulator, used k=8,16 fat-tree topology	Using the DCN idle logic approach with server consolidation, an energy-efficient data center has been constructed that can minimize the energy consumed by network devices as well as servers.
[56], 2016	DCN energy consumption Optimization	Mininet emulator, IPERF traffic generator	By combining resource selective connectedness, consolidation, and energy-proportional computing, a mechanism named adaptive TrimTree is proposed, and it can cope better with traffic anomalies and surges while saving energy.

TABLE 2. *(Continued.)* **Summary of green data center technologies studies.**

[39], 2014	Framework for green DCN	DCNSim simulator	Proposed blocking island paradigm-based framework that can maximize network power conservation by saving 50% power while minimizing sacrifices to the network's performance and reliability.
[45], 2016	Propose a power-aware routing algorithm	Ns-3 simulator	Proposed an algorithm that would only keep the source, destination, and key communication nodes active, minimizing energy usages with a negligible trade-off on performance.
[57], 2017	Joint VM placement and topology adaptation	Two university data centers public traffic tracer	Proposed energy-efficient solution named GreenWay to jointly optimize routing strategy and VM placement in topology-adaptive DCN to enhance the network-wide energy efficiency. GreenWay is able to achieve higher flow performance with lower energy consumption.
[58], 2019	Categorization of metrics	-	Categorize existing metrics that are industry acceptable for data centers and propose carbon emissions, the total cost of ownership, energy intensity, and uptime downtime cost metrics.
[46], 2013	Profit maximization and power management	-	Proposed an optimization-based profit maximizing technique for large-scale data centers to calculate profit in both scenarios, with and without renewable generators.
[59], 2014	Cloud computing management framework	-	The framework ensures minimum cloud computing energy consumption and uses virtual data centers to reduce carbon emissions and maximize providers revenue.
[60], 2022	Energy-saving VM migration algorithm	CloudSim-3.0	Proposed a VM migration method that migrated VM from overloaded data centers across different data centers, thus ensuring service quality and reducing underloaded data centers.
[61], 2012	Transient model for DC prediction	OpenFOAM and BlueTool	Proposed a model that captures the thermal behavior while retaining required the fast-thermal model for the design paradigms of a green data center.
[62], 2014	Flow scheduling method for green DCN	Three representative data center topologies (fat-tree, blocking fat-tree, and bcube)	To arrange traffic flows in the time dimension and let each flow exclusively occupy the link bandwidths on its routing paths a flow scheduling method called EXR has been developed, which can reduce network power consumption and average flow completion time.
[63], 2016	Multi-objective co-evolutionary algorithm for energy-efficient scheduling	-	Proposed OL-PICEA-g uses generalized opposition-based learning technique and smart time scheduling method for multi-objective task scheduling to maximize renewable energy use, task satisfaction rate, and reduce energy consumption.
[42], 2013	Distributed green data centers	-	Multiple distributed networked data centers based on a conceptual approach are presented where data centers are co-located with renewable energy. Which would reduce the security concerns, and require heavy electricity grid infrastructure.
[64], 2020	Direct airside free cooling system based on solar chimney	800 cabinet searches arranged in 3.5 kW	Proposed SC-DAFC system to achieve energy efficiency and, under certain climate conditions, evaluate indoor environments such as thermal, ventilation, and heat recovery.
[65], 2019	Optimization of energy consumption	Simulated on small and large traffic	An artificial bee colony-based energy-saving algorithm that can optimize energy consumption and provide satisfactory paths for fat trees is proposed.
[66], 2021	Design and analysis of sustainable GDC	HOMER software	To reduce net system cost and grid electricity usage, a hybrid energy supply solution is proposed and uses the HOMER software to calculate cost assessment and energy evaluation.
[67], 2013	Metrics for computing performance	Implement in tier level data center	Identify and categorize the data center's metrics into four measurable areas to evaluate their efficiency and performance. Further, power usage effectiveness results can be utilized for evaluating the performance of the data center.
[68], 2015	Real-time power analytics framework	Cloud 3D View	To monitor and optimize the data center subsystem, ICT activities, and power consumption, a real-time power analytics framework is proposed that can enable time shifting of workloads and minimize power usage.
[69], 2021	Minimizing energy cost	Five data centers executing a hybrid workload	To minimize energy costs, and the energy gap generated by data centers powered by multiple types of energy resources and distributed geographically, a fine-grained heterogeneous power distribution model is proposed. Furthermore, to leverage the power supply of each energy source, a two-stage online algorithm is designed.
[70], 2015	Service-oriented VM placement optimization	30 physical servers	The tree and forest heuristic methods, based on service-oriented VM placement and linear time SOVMPO problem solving, were examined and compared to the best-fit algorithm.
[71], 2017	Time-aware multi-application task scheduling	Green energy data, price of grid	To tackle the profit maximization problem and constrained nonlinear optimization problem, a hybrid metaheuristic-based algorithm is proposed that meets delay constraints for all admitted tasks.

TABLE 2. ***(Continued.)*** **Summary of green data center technologies studies.**

[72], 2013	Integrated approach for power management	Production data center access logs	Proposed integrated approach-based power management method for lowering disk, server, and support infrastructure power consumption.
[73], 2017	Power control framework	50 x 250 UPS battery groups, 30000-node cluster, 24-hour data of power generation	To tackle the power fluctuation, renewable energy sources' instability, and to extend the UPS batteries' lives, a novel data center power control framework is designed that can minimize the operating cost of the data center.
[47], 2016	Profit maximization for geographically dispersed	Utilized 2 servers and 2 different classes of service	By considering individual SLA-deadline, multiple classes of service, and geographical electricity price of geographically dispersed data centers a model is developed to maximize profit.

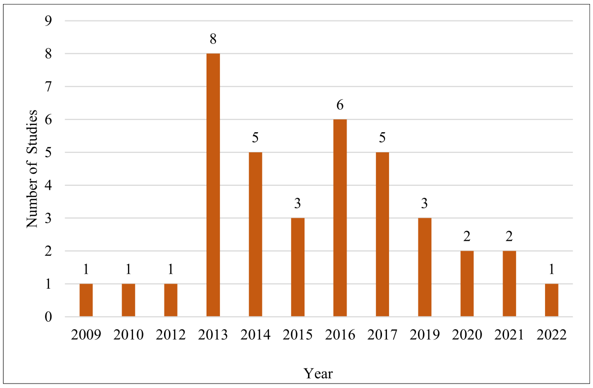

FIGURE 11. **Year-wise distribution of green data center studies.**

aim is to lower energy usage. Green computing refers to the environmentally friendly use of computers and associated technology [74]. Energy consumption and efficiency, power management, greenhouse gas and CO2 emissions, virtualization of servers, and natural resources preservation are some of the main issues with cloud computing. By using ecological and energy-efficient approaches, GCC tackles these issues.

From Table 3, which presents the current studies conducted in the area of GCC, it can be observed that the majority of studies have utilized the CloudSim framework for evaluating the proposed solutions. In the most recent years, there has been a proliferation of research in the development of energy-efficient hybrid frameworks, as well as the creation of algorithms for VM migration and selection policies, and optimization algorithms. GCC studies have considered renewable energy sources usages to power data centers, the optimization of data center energy consumption through server virtualization, framework modeling, power management strategies, effective cooling systems, task and job scheduling algorithms, the creation of energy-efficient algorithms, and protocols for cloud computing. Renewable energy usages to power up the data center responsible for providing cloud computing service is one of the basic and effective approaches. The usage of various cost and energy-aware algorithms can reduce energy consumption while maintaining the quality of services (QoS). Allocation of resources and management of power using algorithms can optimized server response time, meet service level agreements, and improve power efficiency [75], [76]. Task scheduling is one of the key components of cloud computing, therefore, optimization and improvement of task scheduling algorithms can aid to achieved green cloud computing. Using various mechanism based task scheduling algorithms, resource load balancing can achieve, and execution time and resource consumption can reduce while delivering better performance [77], [78], [79]. Furthermore, job scheduling algorithms can save energy usage, and improved resource utilization. Cloud computing's other key components such as VM migration, using various techniques such as Ant Colony Optimization and constraints such as traffic-aware VMs migration can reduce energy usage and improve resource utilization [80], [81]. These various procedures may improve network traffic, cut down on data center energy use, and lessen the environmental impact of cloud services. Organizations may lessen their negative environment effects and increase the overall sustainability of their operations by employing green cloud computing techniques. This may include lowering the energy requirements of data centers, lowering the environmental impact of cloud services, and raising the general energy effectiveness of cloud computing.

Furthermore, the development of an energy-efficient framework and management system for cloud computing can assist to achieve green computing. Green cloud computing has advantages for the economy as well as the environment. Organizations may reduce operational expenses and boost profitability by lowering their energy use.

Fig 12. illustrates the country-wise green cloud computing study distributions, which include eighteen different countries. Among the countries, the Netherlands, Australia, Italy, Mauritius, France, Bangladesh, Singapore, Lebanon, South Korea, Ireland, and Brazil have one study each on the area of green cloud computing. Meanwhile, the USA, Finland, Saudi Arabia, and Egypt have two studies each. Iran stands out with three research works, while China and India have the highest number of publications with six studies each. The research efforts of these countries highlight the growing

TABLE 3. Summary green cloud computing studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[74], 2019	Environmental impact and operational cost reduction	-	To overcome the issue of operational cost reduction and to decrease issue of carbon footprint, DM tools and auto-scaling with constraint satisfaction problems based GCC solutions have been proposed.
[75], 2014	Energy-efficient resource allocation algorithm	CloudSim	Based on the CC environment on the time cost and energy consumption models, an improved clonal selection algorithm is proposed that offers improved response time and make span, showcases the energy efficiency of the data center, and meets the service level agreement.
[77], 2016	Parallel task scheduling optimization	CloudSim	To enhance resource utilization and scheduling efficiency, a green clonal scheduling optimization algorithm is proposed, which can reduce execution time, achieve resource load balancing and minimize energy consumption.
[82], 2018	Consolidating VMs in green cloud computing	Used 2 kinds of heterogeneous pms in 800 quantities	For energy consumption reduction, live migrations quantity, SLA violation, and energy SLA violation multiplication, a meta-heuristic harmony search algorithm is presented that offers improvements compared to previous methods, from a to a maximum of 1988.23% to minimum of 18.56% in ESV in migrations.
[83], 2016	Integrated energy efficient data center management	GC simulator	An integrated energy management system and architecture are present for green cloud computing data centers, which has energy savings potential and can save up to 40% energy in some cases by integrating workload and thermal management.
[84], 2014	Dynamic VM placement with deterministic and stochastic demands	A cloud data center with 200 servers	Dynamic placement of VMs is presented with deterministic and stochastic demands, where MEAGLE reduces the required server's number and assures stochastic resource availability with a probability.
[85], 2011	Framework for improving carbon efficiency in clouds	-	A green-policy-based, carbon-efficient, user-oriented cloud architectural framework capable of reducing carbon footprint and saving energy is proposed, which can reduce 23% energy consumption, and 25% carbon footprint.
[86], 2012	Automated power and performance management	Use discrete-event simulation	To manage cloud computing resources infrastructure automatically, a framework is proposed that would dynamically adapt to time-varying workloads, reduce QoS violations, and reduce energy consumption.
[87], 2012	Integrated green cloud computing architecture	-	To fulfill enterprise requirements by selecting energy-efficient appropriate local or cloud access and satisfies client-side proposed an integrated green cloud architecture (IGCA).
[78], 2017	ACO-based task scheduling	4 data centers	Using some ant system features, an energy-aware scheme for task scheduling is proposed,which can demonstrate its effectiveness by delivering better performance.
[80], 2016	Traffic-aware VM migration	CloudSim	To migrate VMs by considering energy consumed in migration, computing, and host reactivating, three highly efficient VM migration schemes are proposed, and usage of migration energy drops 32%, saving 23% energy, with little SLA violation compared to VM migration without clustering.
[79], 2014	Improved binary PSO-based task scheduling algorithm	-	Green cloud task-scheduling technique based on enhanced binary particle swarm optimization that can reduce resource consumption and execution time is proposed.
[88], 2015	Utilization prediction-based VM consolidation	Two server, 800 heterogeneous hosts	A dynamic VM consolidation approach is proposed, which can reduce energy consumption, have fewer SLA violations, and increase VM migrations compared to other heuristic algorithms.
[89], 2016	Preemptive priority-based job scheduling algorithm	DVFS Controller	To create a balance between server load and energy consumption, a preemptive priority-based job scheduling algorithm is proposed.
[90], 2020	Energy-efficient hybrid framework	200 virtual VMs, 20 servers and 3000 computing resources-based data center	To improve electrical energy consumption efficiency, researchers proposed an energy-efficient hybrid framework that can increase data center energy productivity, reduce power consumption, and save costs.
[81], 2020	Ant colony optimization-based VM migration for consolidation	CloudSim 3.0.3	An Active and Idle virtual machine migration algorithm based on the ant colony system is proposed, which can improve resource utilization, minimize thermal throttle, and reduce excessive energy consumption.

TABLE 3. ***(Continued.)*** **Summary green cloud computing studies.**

[91], 2015	Service level agreement-based optimization of energy efficiency	-	To minimize the energy cost, a dynamic migration algorithm is proposed in consideration of SLAs, which can reduce power consumption and effectively use cloud resources, and can coexist with SLAs.
[92], 2013	An auction-based resource allocation model	Java language, lp_solve version 5.5	To allocate and price cloud resources, a green greedy algorithm using combinatorial auction mechanisms is proposed, which can reduce energy consumption while ensuring cloud providers higher revenue generation.
[76], 2014	Policies and algorithms for data center power management	CloudSim	To select the placement of VMs and identify VM allocation and selection for migration, an FRBS VM placement policy-based fuzzy logic-based management algorithm is proposed, which can improve power efficiency by 40% compared to other policies.
[93], 2013	Energy efficient workflow job scheduling	Experiment with 10 different sizes of workflows represented by a two-tuple (n, $\|Em\|$)	To make workflow scheduling energy efficient, an energy-efficient scientific workflow scheduling algorithm is proposed that can save 30% energy, increase resource utilization by 25%, and reduce CO2 emissions.
[94], 2021	Strong agile response task scheduling optimization	CloudSim	Based on peak energy use and the time span of task scheduling, proposed a strong agile response task scheduling optimization algorithm that can achieve task scheduling stability, and efficiency and improve the cloud computing system.
[95], 2015	Efficient approach for green cloud computing	-	The genetic algorithm-based hybrid energy-aware algorithm is proposed, which can reduce SLA violations, and reduce energy consumption.
[96], 2012	Resource allocation technique	CloudSim	Based on the distributed resource processing capacity and bandwidth that return on an hourly basis, an optimal resource allocation method is proposed that can diminish the request loss possibility.
[97], 2015	Energy-aware service routing protocol	Amazon EC2 cloud platform	To construct energy-efficient provider paths that can select the optimal set of composite service components, an autonomic service routing protocol is proposed that can reduce collaborative cloud services' overall energy requirements.
[98], 2017	Task scheduling algorithm	CloudSim	To address the green cloud computing energy consumption problem, a load-balancing global optimization algorithm which is energy-efficient for task scheduling is proposed that can reduce energy consumption.
[99], 2013	Performance analysis-based resource allocation	CloudSim	To allocate VMs on cloud infrastructure, a resource allocation scheme based on performance analysis is proposed, which can improve resource utilization, and without compromising allocation time to serve a large number of requests.
[100], 2017	Adaptive task allocation technique	CloudSim	To reduce energy consumption, and minimize cloud system makespan for heterogeneous cloud environments, an adaptive task allocation algorithm is proposed.
[101], 2020	Energy-aware VM selection policy design and development	CloudSim	To perform minimum SLA violation-based energy-efficient VM selection, a power-aware VM selection policy is proposed. The policy includes host overload condition, VM's current state.
[102], 2019	Green cloud model for mobile edge computing	NS2 green cloud simulator	To reduce energy waste, reduce latency, and serve efficiently in the cloud and on mobile devices, an active queue management-based green cloud model for mobile edge computing is proposed that can reduce latency more than the conventional cloud and Femtolet model.
[103], 2020	Improved chaotic binary grey wolf optimization algorithm	CloudSim	By using chaos theory and the hill-climbing method, an improved GWO algorithm named IGWO is proposed, which can increase GWO convergence speed and prevent falling into the local optimum.
[104], 2012	Energy-aware layer in software architecture	-	To evaluate data centers' energy consumption using micro and macro metrics, an energy-aware layer in software architecture is proposed, which migrates services to energy-consuming hosts.
[105], 2014	Ant colony system to consolidate VMs	CloudSim	To minimize energy consumption and perform dynamic VM consolidation while maintaining QoS, an ACS-based distributed system architecture is presented that can maintain the required performance and reduce energy consumption.
[106], 2018	Predictive anti-correlated VM placement algorithm	CloudSim	A predictive anti-correlated VM placement approach is proposed that can reduce energy consumption by 18% and reduce service violations by 47% compared to some common VM placement algorithms.
[107], 2014	Hybrid optimization model	REALcloudSim	To optimize the energy efficiency and network quality jointly in data centers by the cloud service provider, a hybrid optimization model is presented, which has higher parallelism capability.

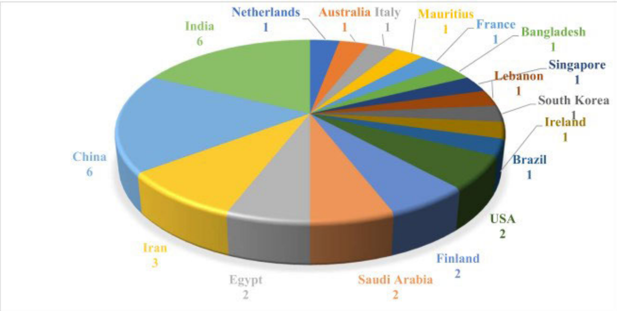

FIGURE 12. Country-wise distribution of green cloud computing studies.

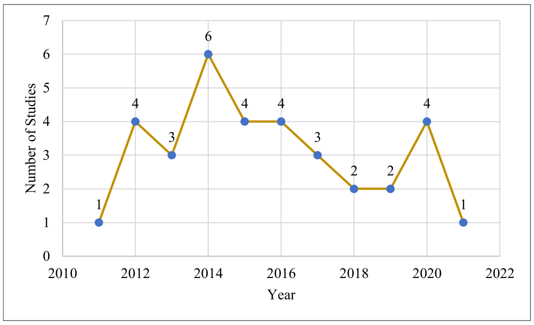

FIGURE 13. Year-wise distribution of green cloud computing studies.

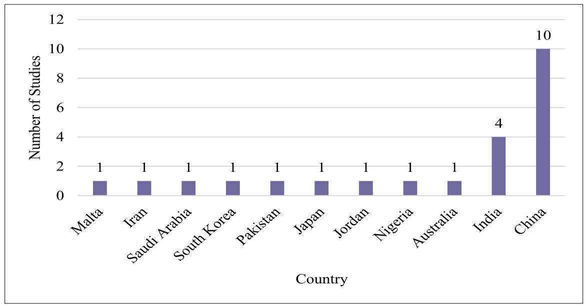

FIGURE 14. Country-wise distribution of green IoT studies.

importance of green cloud computing as an emerging field and its potential to address the environmental challenges posed by the massive energy consumption of cloud computing services and systems.

Among the years presented in Fig 13., the least number of studies were published in 2011 and 2021, with only one study each year. In contrast, 2014 had the highest number of studies, with six publications. Years 2012, 2015, 2016, and 2020 had the highest number of studies after 2014, with four green cloud computing-related studies. The focus on sustainability and eco-friendliness cloud computing is driving research in this area, leading to new technologies development and strategies for energy-efficient and environmentally-friendly cloud computing.

C. GREEN IoT

Green IoT are the development and implementation of IoT systems using sustainable and energy-efficient approaches. The usages of low-power gadgets, the adoption of energy-efficient communication protocols, and the use of renewable energy sources to power IoT gadgets are some examples of these best practices. It is crucial to create green IoT techniques to reduce these devices' negative environmental effects since the energy consumption in IoT devices has increased drastically. Green IoT may also lead to cost reductions and enhanced system performance. Green IoT computing is a field of study that deals with the difficulties of lowering energy use and carbon footprint while preserving the performance and functionality of IoT devices. Designing energy-efficient protocols and algorithms that may be used on IoT devices and networks is one of the main difficulties in this sector. Different strategies have been put forward by researchers to lower the energy use and carbon footprint of IoT networks and devices [108].

Table 4, presents the current studies performed in the field of green IoT in recent years. In recent years, various control schemes and design methods, including energy-efficient caching, spectrum sharing, and offloading computation studies, have been conducted. MATLAB and NS2 have been commonly utilized software in the studies of green IoT. However, based on the studies' objectives, various other datasets and testing mechanisms, such as sensor data, responses, and software, have also been employed. The performed work in the area of green IoT includes developing control schemes, designing, energy-related management systems, power management, monitoring systems, energy- efficient communication protocols, and green IoT networks. Using IoT systems, various control mechanisms, such as smart congestion, energy consumption, and monitoring systems, have been developed. To reduce and optimize energy consumption, various energy management and harvesting schemes have been developed. To create a more sustainable future for IoT systems, green IoT computing strives to achieve a balance between environmental sustainability and technical growth.

The field of green IoT is growing rapidly, as evidenced by the country's involvement and the number of studies published on the subject. From Fig 14., China has emerged as a leader in green IoT research, with ten studies published in the area. India is also making significant contributions, with four studies published. Other countries have a smaller but still noteworthy number of studies in the field. Furthermore, in 2007, 2015, 2017, and 2022, only one study per year has been published (see Fig 15.). Two studies had been published in 2018, while four studies had been published in both 2019 and 2021. However, the highest number of studies, a total of nine had been published in 2020.

This indicates a global interest in the potential of IoT to support sustainability initiatives.

D. GREEN PROCUREMENT

Green procurement is the process of buying products and services that have a less negative effect on the environment.

TABLE 4. Summary of green IoT studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[109], 2021	Adaptive duty cycle control scheme	-	By incorporating dynamic duty cycle adjustment and total use of residual energy a real-time processing scheme and congestion avoidance scheme is proposed.
[110], 2021	IRS and AmBC joint design method	MATLAB	On the basis of a joint design of an iterative beamforming vector, IRS phase shift, reflection coefficient, and IRS phase shift, to reduce the AP's transmit power, a joint design of IRS and AmBC are presented, which effectively reduces the access point transmission power.
[111], 2020	IoT-based parking system	Malta realistic market data	By using an unoccupied garage parking space, a pay-as-you-go smart parking system based on green IoT-based is proposed, and by matching private garages' pricing portfolio with a garage's current demand, the system presents the most favorable prices to its users.
[112], 2022	Offloading offline/online computation	Cooja and TensorFlow	To tackle the IoT-edge offloading-enabled blockchain problem new deep Q-learning approach using Markov Decision Process is employed while maintaining privacy and security.
[113], 2019	Building reliable routing infrastructure	Castalia	By creating a rendezvous region in the middle of the network area and using clustering and multipath techniques, for IoT sensing infrastructure a reliable routing protocol is proposed, and it is able to reduce energy consumption while assisting in boosting the IoT infrastructure network lifetime.
[114], 2020	Energy management scheme	NS2 network simulator	By using energy-constrained nodes of heterogeneous types, an IoT energy management scheme is proposed that can reduce the node's failures and energy consumption.
[115], 2020	Cellular networks with energy efficient and energy harvesting schemes	-	An energy-efficient and energy-harvesting scheme based on the three-layer structured C-IoT architecture for machine-type communication is proposed.
[116], 2020	Relationship between employee's well-being and green IoT	Response of 500 IT employees	The impact of green IoT on employee well-being is analyzed in the study using a survey of 500 IT employees, and it is found that green IoT affects employee loyalty and commitment to the organization.
[117], 2020	Hybrid seismic electrical data acquisition station	-	Cloud technology platforms and green IoT-based hybrid seismic-electrical data acquisition system designs are proposed. Further, electrical data acquisition, master control, and a front-end seismic data acquisition circuit are designed and implemented.
[118], 2015	System model for energy efficient green-IoT network	Small real IoT testbed environment	By using energy-efficient routing, sleep scheduling, adaptive data aggregation, energy harvesting, and a QoS-aware resource allocation, a system model is proposed to reduce the energy consumption of IoT devices while maintaining the QoS of the network.
[119], 2019	Backscatter communication for green IoT networks	Monte-Carlo simulation	To improve the spectral efficiency of IoT sensor networks deployed in the field, a hybrid TDMA-based PD-NOMA multiplexing method has been developed that can accommodate a large number of sensor nodes and outperform the TDMA scheme.
[120], 2020	Joint resource allocation	4 secondary users, 8 subcarriers	The NOMA technique is applied to cognitive orthogonal frequency division multiplexing systems, along with SWIPT, to enhance G-IoT nodes' capacity and lifetime.
[121], 2020	Link selection in buffer-aided cooperative networks	-	Investigated the buffer-aided cooperative networks with multiple co-channel interference link selection algorithms for G-IoT and found that preponderant contribution to the total outage probability of the system is the outage probability of the buffer being either empty or filled.
[122], 2019	Framework for wildfire monitoring	21852 data values	For early prediction of wildfires, an IoT framework backed by fog-cloud computing technology that is energy-efficient is proposed and can collect data based on IoT sensors, predicting the spread of the wildfire as well as identifying potential hazards.
[123], 2018	Scalable and energy-efficient scheme	5000 nodes	G-IoT-based heterogeneous wireless nodes are proposed and include a multi-stage weighted election heuristic, a zone-based hybrid placement scheme, and a minimum-cost cross-layer transmission model.
[124], 2018	Smart congestion control mechanism	ndnSIM	To reduce sensor power consumption, reduce network congestion rates, and enhance the ICN network's performance, a smart congestion control mechanism that can outline a green and efficient ICN-based sensor networking model is proposed.
[125], 2021	Energy efficient caching	NDN traffic generator	To make predictions based on the spatial and temporal request patterns in blockchain-based IoT networks, a request graph convolutional LSTM is proposed, and to develop a pre-caching strategy heuristic algorithm based on the predictions is proposed.
[126], 2021	Energy-efficient cross-layer spectrum sharing	MATLAB	A non-persistent CSMA access scheme-based distributed cross-layer design with soft-delay constraints is proposed to improve spectrum utilization, efficient green IoT networking, and network lifetime.

TABLE 4. ***(Continued.)*** **Summary of green IoT studies.**

[127], 2017	Performance optimization	NS-2 platform	To improve the transmission efficiency, in the IoT core network an adaptive network coding scheme and a polynomial-time optimal storage allocation scheme have been proposed, which can distribute the n data components into N data centers.
[128], 2019	Dynamic access control with battery prediction	10 MEC servers, one IoT device, an SDN controller	For the IoT device an intelligent LSDQN-based access control algorithm is proposed to obtain the optimal access control strategy in an IoT system where to determine the optimal access control decision by DQN with the target of maximizing the average uplink rate whilst minimizing the energy consumption, the LSTM model is used to predict the battery status for assisting the IoT device.
[129], 2020	Wireless communication design with energy constraint	MATLAB	Design space-air-ground integrated IoT network of V2N communication architecture to maximize the vehicle's attainable speed by simultaneously optimizing the transmit power and UAV trajectory under UAV energy constraints and UAV mobility constraints.
[130], 2020	IoT based energy consumption monitoring and controlling device	4 different electrical appliances over a duration of 4 hours	Used an Atmega328 microcontroller for presenting the smart home automated energy and billing-aware metering system architecture and found that the performance accuracy exhibited by the system is 95%.
[131], 2007	Real-time smart waste management system	Waste collection dataset from 2003-2007 in the city of Casey	To design a real-time waste management system, an RFID and sensor model is proposed. Using the system, service providers can track waste identity, missing or stolen bins, and weight quickly and accurately.

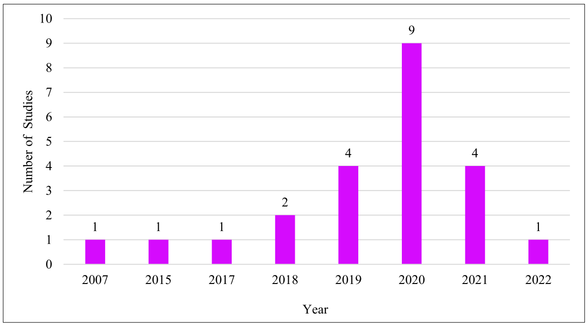

FIGURE 15. **Year-wise distribution of green IoT studies.**

Products with a smaller carbon footprint, items made of recycled materials, and services that support sustainable practices may all fall under this category. Green procurement's two main goals are to reduce the environmental impact of the procurement process while also encouraging sustainable development. Along with helping businesses comply with regulations, green procurement may also help them gain favor with consumers and other stakeholders. Green procurement methods include life cycle thinking, eco-labeling, and environmentally preferred purchasing. A product or service's environmental effect is taken into account throughout its entire lifespan, from the procurement of raw materials through disposal. The process of eco-labeling involves confirming that items adhere to strict environmental criteria. Choosing goods or services that have less of an effect on the environment than those that are already on the market is known as environmentally preferred purchasing. Organizations may find it difficult to implement green procurement since it often calls for a change in perspective and in the way that procurement procedures are performed. However, it may also bring about financial savings and other advantages, like a boost to reputation and more creativity. Additionally, many businesses are already using green procurement as a means of achieving sustainability objectives and staying compliant with international environmental requirements [132], [133]. In order to achieve an ecologically sustainable future, green procurement is critical, and it is also important to analyze the currently performed studies in the area.

Table 5, presents the current studies conducted in the area of green procurement. In the most recent years, various factors that impact green procurement, such as leadership style, top management support, and green procurement practices with respect to various industries, have been examined. By examining the overall studies, it is noticeable that for most of the studies related to green procurement, the researchers collected data from people or companies. Most of the studies' primary goal is to identify the drivers and barriers related to various industries and sectors. The furniture, real estate, construction, and photovoltaic industries' green procurements have been analyzed by the researcher, and the barriers and drivers for green procurement among those industries have been outlined. Lack of knowledge and awareness, lack of green building materials, little market benefit, and insufficient incentive policies are the major and most common barriers to achieving green procurement in the real estate industry and construction projects. Furthermore, green procurement relations with leadership style, financial performance, buyer-supplier relationships, and management support have been analyzed by various studies. Various other works, such as a process model for green procurement based on IoT, supplier selection, and government green procurement, have been performed in recent years.

China leads the world with eight studies in the field of green procurement, followed by the United Arab Emirates and South Africa with two studies each (see Fig 16.). Other countries with one study each include India, Italy, Malaysia, Thailand, Hong Kong, and Saudi Arabia. Overall, the studies in the green procurement area are still limited, but the

TABLE 5. Summary of green procurement studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[134], 2017	Green procurement drivers and their interrelationship identification	12 drivers	The systematic review of literature and experts' opinions with interviews of the South African manufacturing sector was conducted to first identify and then refine the leading drivers. The interpretive logic of pairwise comparison and the TISM model was developed using the comments of these experts.
[135], 2021	Exploring the impact of leadership style on green procurement	Sample of 213, SurveyMonkey software	By viewing green procurement through a natural resource-based theoretical lens, the influence of innovation capability and leadership styles on green procurement is explored, and it is found that transactional or transformational leadership styles do influence innovation capability but do not influence green procurement.
[136], 2016	Stakeholder satisfaction and operational performance	206 Chinese A-share companies data	The relationship between firm performance and green procurement is analyzed using the natural resource-based view, and it is found that green procurement, whether of products or processes, has a beneficial impact on firm performance.
[137], 2019	Green procurement process model based on blockchain–IoT integrated architecture	Cronbach's α used for reliability test, MICMAC analysis	The usages of IoT and blockchain for green procurement activities have been analyzed, and current challenges have been identified through surveys and interviews with procurement managers from various industries. To overcome the challenges, the architecture for blockchain and IoT-based green supply chains has been developed for a sustainable business.
[138], 2019	Green procurement practices among mining companies' hospitals	7 mining hospitals	Through interviews with 7 mining hospitals' procurement officers, their practices of procurement, procedures, and policies have been analyzed, and found that constant practice increases green procurement tendency rather than just training.
[139], 2020	Green procurement and financial performance	122 firms over a seven-year period	To analyze the link between financial performance, green procurement, and tourists' green purchasing behavior, a time-series cross-sectional regression model has been used and found that financial performance does not directly affect green procurement.
[140], 2015	Supplier selection in green procurement	Compare with LT-TOPSIS	To select the green suppliers, a 2-tuple linguistic assessment-based optimization decision method is designed, and against the background of the low carbon economy and green supply chain management, a new evaluation system for green procurement is proposed.
[141], 2014	Government green procurement	12 barriers used	To identify factors that negatively influence the municipal level Chinese government's green procurement and their significance and relative relationship, a fuzzy-based DEMATEL and fuzzy clustering approach is employed, and it is found that corrupt behaviors and poor quality of the green product are the major barriers.
[142], 2018	Green procurement practices and barriers in furniture manufacturing	118 procurement officers and managers	The SPSS version 20.0 software has been used to analyze current practices in green procurement and determine barriers. Assuring the safety and incoming movement of products to facilities, followed by ensuring that suppliers' locations are operated in a safe manner, are the current practices, and the time consumption for the implementation of green procurement is the major barrier.
[143], 2010	Carbon-sensitive supply chain network	49-node dataset	To minimize emissions along the supply chain by considering green procurement, the MIP model has been developed and finds that introducing the carbon price, supply chain decentralization, and multi-sourcing will reduce carbon emissions.
[144], 2008	Green procurement adoption for successful green supply chain management	137 companies	Statistical package has been utilized to investigate Thai electronic companies' adaptation to green procurement and find that ODM and OEM companies have adopted green procurement practices.
[145], 2016	Trust theory and supplier-buyer relationship	50 South African manufacturing companies	Exploratory factor analysis and an overall measurement model have been assessed with mediating regression analysis using SPSS 22.0 to test the reliability and validity of items to analyze the contribution to innovative green procurement through buyer-supplier relationship management and find that trust plays a critical and mediating role.
[146], 2016	Key factors affecting green procurement in real estate development	39 real estate developers	To identify key factors in GP behavior, a one-way analysis of variance technique is used and finds that marketing benefits and pressure, as well as organization-internal pressure, are influencing the developers to adopt GP.
[147], 2016	Construction projects in effective green procurement	84 participants	By performing expert interviews and a questionnaire survey, this study analyzed and identified "Regulations and standards of green procurement by the government" and "Life-cycle considerations and green construction technology" as the most important factor for GP in the construction process.
[148], 2019	Photovoltaic industry barriers to green procurement	6 experts	To examine the barriers of China's PV industry to GP, proposed a rough weighted technique that combines the benefits of DEMATEL and ISM and finds that internal obstacles, such as the company's unawareness, are more major barriers than external obstacles. However, weak incentive policies, which is an external obstacle, should be solved first.

TABLE 5. ***(Continued.)*** **Summary of green procurement studies.**

[149], 2019	Impact mechanism between green procurement and top management support	171 questionnaires	A moderated multiple mediation model has been developed to examine the influence mechanism between GP and top management support in Chinese manufacturing enterprises. The study finds that top management support is positively associated with GP.
[150], 2017	Real estate development green procurement barriers identification	78 participants	Utilize the hierarchical cluster analysis technique on Chinese real estate developers to identify the barriers to GP in the industry and find that less knowledge about GP, green building materials, as well as little market benefit and insufficient incentive policies, are the major barriers.
[151], 2021	Enhancing factors for the adoption of green procurement in the Pakistani construction sector	77 participants	Using a conceptual model validated with a partial least squares' structural equation modeling technique with SmartPLS V3 software, factors that can improve the adoption of GP in a construction project have been analyzed, and it was found that a lack of knowledge and awareness about GP are the major barriers.

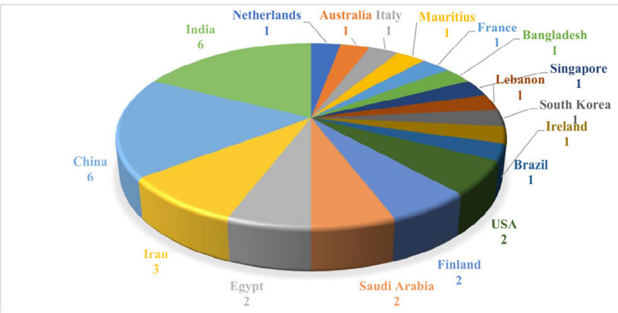

FIGURE 16. **Country-wise distribution of green procurement studies.**

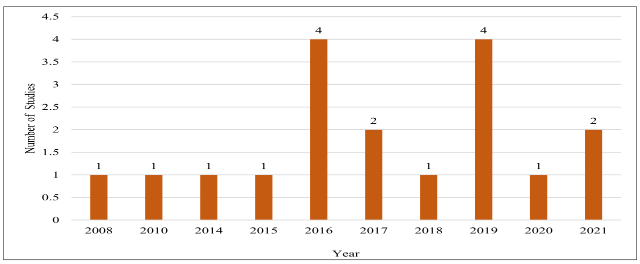

FIGURE 17. **Year-wise distribution of green procurement studies.**

diverse countries' involvement demonstrates that interest in this area is growing globally. In the area of green procurement, research has been relatively limited, with only a few studies published each year (see Fig 17.). The earliest study has been published in 2008, and there has been a steady stream of research in this area over the years. In 2008, 2010, 2014, 2015, 2018, and 2020, a single study was published on a variety of sustainable procurement-related issues. In 2017 and 2021, there were two research works published in the area of green procurements. The years with the highest number of studies published have been 2016 and 2019, with four studies published in each of these years.

E. SMART GRID

A modernized electrical grid, commonly known as the ''smart grid'', makes use of digital technology to improve the dependability, efficiency, and sustainability of the power system [152]. Smart grids collect and analyze power use data using modern metering infrastructure, communications, and control systems, and then utilize that data to enhance grid performance. One of the main advantages of a smart grid is that it may enable utilities to better control the supply and demand of power, which can assist in lowering energy usage and prices [153]. Power usage trends can be observed and altered by deploying smart meters that monitor power consumption in real-time. This approach may lessen the requirement for costly peak power production and increase the grid's general effectiveness. Smart grids also make it possible for renewable energy sources like solar and wind power to be integrated more effectively into the power system. Advanced control systems may be used in smart grids to automatically alter the flow of power from renewable sources. This may enhance renewable energy usage and decrease the demand for fossil fuels. The capacity of smart grids to increase the resilience and dependability of the electrical system is another significant feature. Smart grids may utilize sophisticated monitoring and control systems to swiftly identify and react to power outages, decreasing the length and severity of service disruptions. To increase the dependability of the power supply during crises, the smart grid may also deploy distributed energy resources like battery storage and microgrids. In general, smart grids have the potential to greatly increase the effectiveness, dependability, and sustainability of the electricity system. Furthermore, smart grids are crucial for tackling environmental problems and can aid in sustainable development.

Several smart grid studies have been conducted in recent years that cover various aspects of smart grid systems. Table 6, presents the recent studies conducted in the area of smart grids. In the most recent years, renewable energy trading schemes, downlink communication schemes, and data processing frameworks have been developed. Various simulator-based software and numerical evaluations have been performed to evaluate the smart grid system's development and implementation. Among the used software, MATLAB is the most common, with other software such as Castalia and Simulink being used based on the study's objective. Furthermore, various types of studies have been conducted in the area of the smart grid, such as energy management, resource management, security requirements analysis, protocol and algorithm development, and frame-

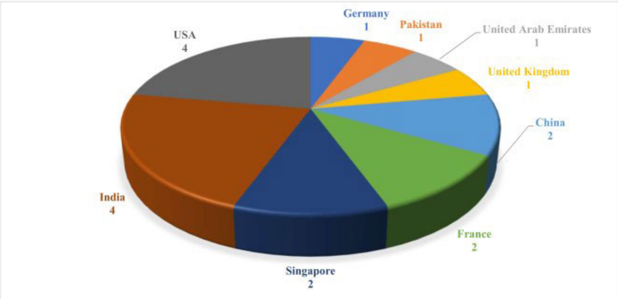

FIGURE 18. Country-wise distribution of smart grid studies.

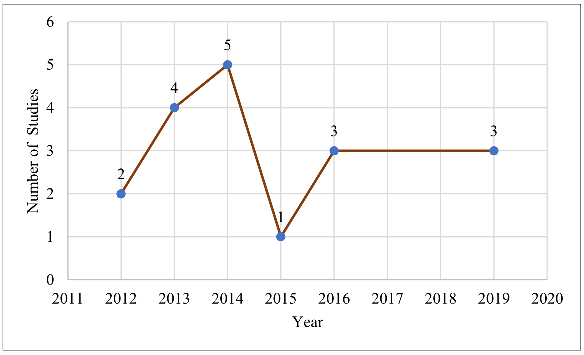

FIGURE 19. Year-wise distribution of smart grid studies.

work design. Energy management is one of the key attributes of smart grids, and various studies have been conducted focusing on the issue. Furthermore, resource management and distribution and residential energy management are some of the common applications of smart grid systems. Other studies focusing on developing efficient authentication protocols, monitoring and controlling algorithms, and renewable energy trading schemes have a great impact on achieving secure smart grid systems that can reduce energy consumption and are environmentally friendly. However, the adoption of smart grids requires cooperation among several parties, including the government, the business community, and consumers.

In the context of the smart grid, Germany, Pakistan, the United Arab Emirates, and the United Kingdom have each contributed one study to this area of research (see Fig 18.). China, France, and Singapore each have two studies on the area, while India and the USA both have four studies. From Fig 19., it can be observed that research in the smart grid area has been ongoing for several years, with studies published in various years. Four studies were published in 2013, while the highest number of studies was published in 2014 with count of five studies. A single study has been published in 2015, whereas two were published in 2012. In 2016 and 2019, three studies were published, respectively.

F. GREEN TRANSPORTATION SYSTEMS

Green transportation systems are those that employ sustainable and energy-saving technology and procedures to reduce the negative environmental effects of transportation. These systems seek to increase overall sustainability in the transportation industry while reducing carbon emissions and air pollution brought on by conventional modes of transportation [172]. Electric and hybrid cars, clean fuel substitutes, and intelligent transportation systems used to ease traffic and boost energy efficiency are some of the technologies and procedures employed in green transportation systems. Aside from integrating public transportation systems, green transportation systems can also incorporate active transportation options such as bicycling and walking. Green transportation systems aim to provide the same level of accessibility and mobility as conventional systems while reducing the environmental impact of transportation. Green transportation systems include electric cars, bike-sharing programs, and high-speed rail networks [173]. While offering a more sustainable and energy-efficient alternative, these systems have the potential to drastically reduce the carbon emissions and air pollution caused by conventional transportation systems.

From Table 7, it can be observed that various types of studies have been conducted in the area of green transportation. In the most recent years, green transportation various policy developments, factor analyses, scheduling problem solutions, urban transportation system development, and analyses of the regional companies' green transportation have been performed. To perform overall studies in this field, various types of datasets containing data about people's opinions and surveys, field studies, traffic data, industry data, city data, and CO2 emission data have been utilized. Moreover, various software such as MATLAB, TransCAD, HOMER, VISSIM, and GAMS has been utilized. Using those datasets and software, various types of research work, such as analysis of the regional company adaptation of green transportation, the cyber-physical bike system, social systems for vehicles, strategy and framework development, ecological highway development, algorithms, and mechanism development have been conducted in the area of green transportation. Various green transportation policies have been taken into consideration in recent years, such as motorcycle bans and subsidizing electric scooters, which can reduce city pollution effectively, reduce social congestion, and deter social crime. Furthermore, to reduce the usage of traditionally fueled vehicles in the city, renting motorcycles for short distances and electric vehicles for medium and long distances is a more environmentally friendly solution. Traffic management and ecological highway development are some major factors in green transportation systems, which not only save non-renewable resources, cost, and time but also ensure safe, eco-friendly, sustainable development. Overall, researchers in this area are concentrated on the creation of new technologies and regulations that promote the use of environmentally friendly transportation methods, as well as the assessment of current methods to ascertain their efficacy. Therefore, green transportation systems can aid in building a sustainable future and

TABLE 6. Summary of smart grid studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[154], 2014	Greedy backpressure routing	IEEE P802.11s	For multigate mesh networks, proposed a greedy backpressure routing protocol, that used periodic beacon exchange to collect information iteratively and realize the effect of traffic load. Thus, the proposed protocol can achieve better network reliability, latency, and performance.
[155], 2014	Distributed energy resources	Numerical evaluations with 9 parameters	To dynamically optimize the profit and trade energy of DGSs differential game-based oligopolistic market model has been developed. which can maximize the DGSs' aggregate profits over fixed-quantity schemes.
[156], 2014	Smart energy management at cell-sites	-	To manage energy optimally for single-cell sites and multiple cell-site networks, a theoretical framework is proposed, and the results showcase that electricity costs can be drastically reduced by the proposed algorithms.
[157], 2016	Balanced energy distribution mechanism	-	To optimize payoff and self-utility for rational agents with hidden private information, an energy allocation mechanism is proposed that can perform energy trading among competing consumers and prosumers.
[158], 2013	Analysis of smart grid wireless network security requirements	43 security requirements	The GSM-enabled intelligent electronic devices with GPS support can be implemented to provide solutions found by analyzing the result of SREP on the SG wireless network.
[159], 2013	Residential smart grid energy management	10 HEMUs, and one CEMU, MATLAB software	To minimize customer expenses, an MDP-based scheduling mechanism for REM in a smart grid is proposed. CEMU reduced its energy expenses by using a dynamic pricing mechanism, and HEMU interacts with CEMU to fulfill its energy requests within its desired budget.
[160], 2013	Protocol for robust and efficient authentication	-	To accomplish mutual authentication and key agreement between the substation and the smart appliances, a robust and efficient authentication mechanism based on elliptic curve cryptography is presented, which can resist replay, man-in-middle, and impersonation attacks as well as provide session key security.
[161], 2013	Smart grid-based framework	MATLAB	To provide an optimized reservation schedule and energy-efficient services for exascale applications, a smart and energy-aware service-oriented architecture manager is presented. The design of a smart grid and a multicriteria green job scheduler are the new features of the system, and the proposed multi-criteria job scheduler is able to save energy consumption, CO2 emissions, and financial costs.
[162], 2012	Tree balancing in smart grid	RPL code base and Cooja emulator	To determine the concentrator by smart meter nodes utilizing the information about the state of concentrators, a tree balancing algorithm called TREEB is proposed which operates in a distributed manner, reduces disparity, and helps to balance the networks.
[163], 2012	Substation monitoring and control	Castalia simulator	To report import value and identify faulty components, a PBCoop cooperative agent-based approach algorithm is proposed, which is capable of reducing energy consumption in sensor nodes and ensuring that sensed data are managed intelligently.
[164], 2019	Safe and effective renewable energy trading scheme	-	By dividing the electricity market trading model into two levels, a blockchain-based security and efficient energy trading scheme is proposed that can balance power demand and supply and provide privacy.
[165], 2016	Smart grid using the IoT	-	To timely provide service delivery for power generation, utilization, and distribution with IoT-based intelligent collaborative data processing, a collaborative service-oriented smart grid using IoT is presented.
[166], 2014	Demand response in smart grid	Matlab and Simulink	To perform load modeling of the power gain from the demand response of aggregated TCL units for AGC, a load model using coupled Fokker-Planck equations have been utilized, and the result demonstrated that AGC improves economic operation in a single area system and system performance.
[167], 2014	Energy-efficient and economically efficient P2P network protocol	EEP2P protocol and the traditional P2P protocols	Combining the TOU model and P2P protocol, presents a framework that switches between a dormant state and an active state in accordance with a time schedule sequence by using the TOU pricing model automatically to adjust their energy consumption per unit time. Various file sizes on different systems can be transferred both economically and energy efficiently using the proposed protocol.
[168], 2016	Key management protocols for smart grids	-	To secure smart grid communication, management, and control, a security key agreement and update protocol based on smart grid topologies and symmetric-key primitives is presented, which can detect and revoke compromised IEDs efficiently.
[169], 2019	Smart grid downlink communication	Python charm cryptographic library	To secure SG downlink multicast communication, an attribute-based signcryption scheme is proposed, which can achieve message nonrepudiation, data confidentiality, message source authentication, and immediate attribute revocation.
[170], 2019	Adaptive data processing framework	495 nodes, 800 edges	A framework that is aware of edge nodes is presented in order to intelligently analyze IoT and related data segments and to empower nodes. The framework can efficiently organize and store data segments in a smart grid repository.
[171], 2015	Decentral smart grid control	-	A decentralized and direct frequency-price coupling-based decentralized smart grid control is presented, where the price is directly connected to the local grid frequency at each customer, to achieve a dependable DR in the collective network dynamics of power grids.

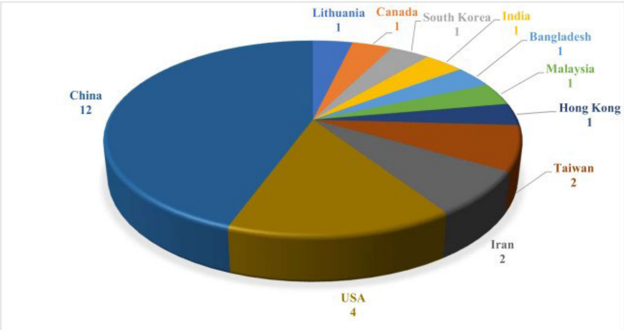

FIGURE 20. Country-wise distribution of green transportation systems studies.

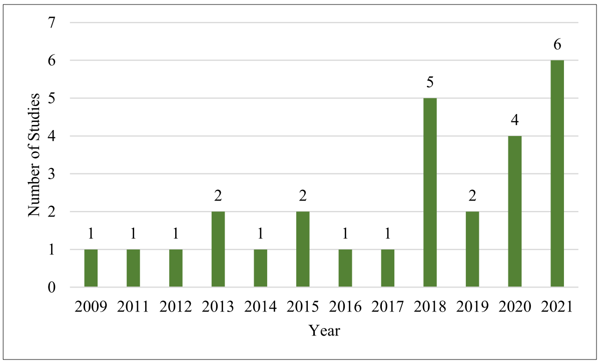

FIGURE 21. Year-wise distribution of green transportation systems studies.

reducing CO2 and greenhouse gas emissions, thus minimizing and solving climate change issues.

Fig 20. illustrates the fact that various countries have performed green transportation-related research, where China dominates the area with a total study count of twelve, followed by the USA with four studies. Iran and Taiwan have performed two studies each. On the other hand, other countries have performed one study each.

In the area of the green transportation system, research has been conducted over the years with increasing attention in recent times. From Fig 21., it can be observed that the least number of studies have been recorded in 2009, 2011, 2012, 2014, 2016, and 2017 with one study each year, while the year 2021 recorded the highest number of studies with six publications. Similarly, 2018 had five studies, 2020 had four, and 2013, 2015, and 2019 recorded two studies each. The results indicate that research in green transportation is gradually gaining momentum, with a significant number of publications emerging in recent years, especially in 2018 and 2021. Overall, the research indicates a global interest in developing sustainable transportation systems to reduce carbon emissions and help mitigate climate change.

G. GREEN DATABASE

The phrase "green database" refers to the administration and upkeep of databases that make use of eco-friendly technology and procedures. Due to the growth of technologies and data, green databases (GDB) are becoming more popular and essential. The green database objective is to reduce the negative effects of data management on the surrounding ecosystem as much as possible while simultaneously preserving or enhancing the database's performance and availability. Green database techniques include the use of energy-efficient hardware, the application of power management methods, the use of cloud computing and virtualization technologies, and so on.

Table 8, presents the studies conducted in the green database area that solve various issues. However, due to relatively new and evolving fields, very limited studies have been conducted in the area. Energy consumption benchmark platform, GDB model and management for the stock market, integration of GDB in software development, and GDB assignment in green manufacturing are some of the topics that have been explored by the researcher in the area of green databases. Additionally, the green database also comprises the use of sustainable data management strategies, such as data compression and de-duplication, in order to reduce the amount of energy that is necessary for the storing and retrieving of data.

H. GREEN DATA MINING AND INFORMATION RETRIEVAL

Green data mining and information retrieval is the process of gathering, storing, and analyzing data using ecologically friendly practices. This entails using energy-efficient gear, putting power management strategies into practice, as well as employing renewable energy sources. Green data mining and information retrieval aim to reduce the environmental impact of these activities while still delivering meaningful insights from the data by implementing carbon footprint management strategies into practice, as well as employing renewable energy sources [208]. The sustainable disposal of electronic waste produced by data mining operations is also regarded as a component of green information retrieval and data mining.

Table 9, presents the studies conducted in recent years to tackle green data mining and information retrieval area's various issues. Cost-sensitive learning-based framework for data mining, the latency/power tradeoff model, CPU power management, the energy operational cost reduction model, data-aware and efficient data mining services and Web service recommender systems, and the green data mining principle are some of the concepts that have been explored in recent studies. Numerous strategies and methods for making data mining more ecologically friendly have been studied, but various issues have not yet been properly addressed.

I. GREEN MACHINE LEARNING

Green machine learning is the application of low-cost and efficient machine learning techniques to promote energy efficiency and reduce carbon emissions in various industries. This field of study aims to develop algorithms and models

TABLE 7. Summary of green transportation system studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[174], 2021	Green transportation in regional companies	402 workers	Analyze collected transportation worker data via survey from companies of Šiauliai regional responsible for transportation and find that the importance of green transport can be understood by the regional company. Combining several means of transport, cargo consolidation by combining small and large orders, and ecological driving are the green transportation measures most commonly implemented in regional companies.
[175], 2009	Mobile tool for tracking and supporting green transportation habits	3 weeks, 13 persons field study	To semi-automatically sense and reveal transportation behavior information, a mobile phone application has been developed that can give users feedback about self-reported and sensed transportation behaviors.
[176], 2011	Cyber-physical bike	C/C++ using the NVIDIA CUDA library (v2.3) and an open-source optical flow library	To solve biker safety problems, a design for a video processing technique-based cyber-physical bicycle system that can automatically detect vehicles is present, and a prototype implementation has been done to showcase the system's feasibility. The proposed system can operate with good accuracy at normal frame rates, and perform real-time detection at reduced frame rates.
[177], 2013	Vehicular social networking system	-	To provide economic solutions to users via a mobile application, a novel crowdsourcing-based vehicular social networking system is presented that utilizes commercial social networks and cloud computing.
[178], 2021	Eco-friendly effects on green transportation demand management	Cameras at 45 locations, 22 public parking lots	The eco-friendly and non-environmental transportation modes, such as the usage of public bicycles, reducing air pollution, and parking costs, are considered to analyze the green transportation area policy and find that reducing air pollution, and reducing parking costs 42.5 B KRW/y, and 18.2 B KRW cost benefits can be achieved respectively.
[179], 2015	Strategies for green transportation	Monte Carlo simulation to sample thousands of OD pairs	To seamlessly transition Taipei to green transportation through densely distributed convenience shops, a proposal has been presented that finds that rented motorcycles can be used for short trips, while electric motorcycles can be used for medium and long trips.
[180], 2021	Green transportation scheme of municipal solid waste	One depot, 105 waste collection points, and one transfer station	Based on real-time traffic conditions to minimize energy consumption, a mathematical planning model is proposed to solve the green transportation route problem of municipal solid waste. Vehicle load, speed, driving distance, and road gradient condition is incorporated, for the shortest path which has more fuel-saving potential.
[181], 2018	Traffic structure optimization	TransCAD software	To achieve green transportation and sustainable development, a generalized cost method to quantify all the factors that influence the travel mode selection has been used to establish a logit model reflecting the sharing rate of the traffic mode.
[182], 2020	Sustainable urban transportation system	-	For smart cities, smart transport systems demand a framework to integrate SLAM with power distribution network is proposed, which implements cloud-based centralized SLAM on GIS technologies.
[183], 2020	Ecological highway	-	To build an ecological highway, define the ecological highway construction life cycle, planning, design, construction to operation, management, and maintenance, propose the implementation scheme of the ecological highway, and elaborate the safeguard measures.
[184], 2018	Optimization of solar energy system for the electric vehicle	HOMER software	To build an ecological highway, define the ecological highway construction life cycle, from planning, design, and construction to management, operation and maintenance. Further, propose the implementation scheme of the ecological highway and elaborate on the safeguard measures.
[185], 2015	Green transportation development policy	Objective index data from 2007-2011 Dongguan statistical yearbooks	To analyze the Dongguan "motorcycle ban" policy-based case study, utilized a fuzzy comprehensive evaluation mode and constructed the second-grade evaluation index and found that the "motorcycle ban" policy can effectively reduce city pollution, reduce social congestion, deter social crime, and promote the development of public transportation system.
[186], 2013	Social-network-enabled green transportation system	VISSIM software	To establish communication between electric vehicles, information gathering, monitoring, traffic flow control, and assistant driving, design and demonstrate a social network-enabled transportation system prototype. For transportation agencies and travellers, the proposed system provides affordable cost solutions and reduces energy consumption, traffic congestion, and pollution impact.
[187], 2020	Maximize renewable generation, incentivize battery deployment, and promote green transportation	MATLAB	To design energy storage battery systems capable of being deployed along with renewable energy farms, an optimization framework is demonstrated. To obtain optimal design parameters, a simulation-based optimization framework is established.

TABLE 7. ***(Continued.)*** **Summary of green transportation system studies.**

[188], 2018	Bi-level closed-loop supply chain	GAMS software, BARON solver	To coordinate retail price, the ratio of transportation mode selection, and collection effort-related decisions, mathematical modelling is developed for a two-echelon closed-loop supply chain where the manufacturer acts as the Stackelberg leader and a retailer plays the follower role.
[189], 2021	Multi-vehicle and one-cargo green transportation scheduling	T20F4 (19,1) contains twenty tasks, four flatcars, and one heavy-duty task	To solve the MVOC green transportation scheduling problem, minimize time cost, and reduce CO2 emission bi-objective mathematical model is developed. The proposed MOTS can outperform the classic algorithm and solve the problem even on a large scale.
[190], 2019	Control of traffic lights in cooperative green vehicle routing	Singapore traffic data, SUMO platform	To reduce transportation-related emissions by threefold means, a pheromone-based GTS is proposed. The system uses support vector regression to forecast traffic congestion, uses CTLC to move traffic in downstream paths, and uses CGVR to prevent upstream vehicles from entering congested roads.
[191], 2012	Model for evaluating low carbon island policy	-	To analyze Penghu Island's green transportation policy, a system dynamics approach is designed and finds the policy effect of replacing gasoline motorcycles with electric scooters, limiting the use of two-stroke and four-stroke gasoline motorcycles,and reducing the issue of vehicle licenses.
[192], 2014	Green transportation optimization model	-	To design economically and environmentally cost-efficient forward and reverse logistics, a genetic algorithm-based optimization model is proposed, which can suggest guidance and deal with green operations.
[193], 2018	Distance-based road pricing	OD data collected by the Taiwan freeway ET system	To improve safety and environmental concerns in freeway management, both static and dynamic context-based GSI-based road pricing models are proposed that can provide off-peak discounts to the road user, maintain government revenue, and offer higher profit to ETC agents.
[194], 2016	Scheduling green transportation with pick-up time and mode options	MTO clothing manufacturing company data	An evolution-strategy-based memetic Pareto optimization approach is used to solve the bi-objective green transportation scheduling problem. The model considers transport mode selections and pickup time, and a multi-objective local search process is proposed.
[195], 2020	Push-pull-mooring factors In GT	854 participants	Analyze the effects of push, pull, and mooring factors and the role of information provision. The study finds that push factors shift away mood from private cars, and attract individual mode towards GT by pull factor, while the mooring factor can negatively moderate the push and pull factors effects.
[196], 2018	Green transportation problem with two objectives	10 test problems	Simulated annealing and an NSGA-II algorithm have been implemented to optimize a multi-objective linear integer fuzzy programming technique simulated, two-objective fuzzy transportation problem. where the SA algorithm can come up with better-quality Pareto solutions in a shorter time.
[197], 2021	The development of green transportation infrastructure and fiscal policy	Chinese cities from 2003 to 2018, and manual collection of 2,640 high-speed railway station samples	Analyze the environmental and economic effects of high-speed rail construction for urban development, as well as the effectiveness of fiscal policy in resolving financing issues for high-speed railway construction. The study found that urban productivity, industrial structure upgrades, and investment scale are directly promoted by investment in high-speed rail construction, and the financing cost of high-speed railway construction projects can be reduced by taking fiscal policy measures.
[198], 2017	Production and green transportation coordination	8 order and 38 product batch, 10 order and 43 product batch, 1 order and 40 product batch	To solve the coordination problem of production and green transportation, such as reducing the total cost of the supply chain, which can be reduced by 9.60% to 21.90%, and carbon emission penalties, a combined hybrid genetic algorithm and heuristic procedure are proposed.
[199], 2019	Improved composite index	World energy statistics data, 112 country CO2 emission data	To assess the 112 countries' performance in green transportation and logistics practices, the environmental logistics performance index has been developed. Using RAM and DEA, the index is measured by LPI, transport sector oil consumption, and CO2 emissions.
[200], 2021	Green transportation planning strategy for heavy-haul coal railways	Train trajectory data	To estimate train energy usage and optimize plans based on capacity and energy aspects, a combined data mining and optimization framework that uses a mixed integer programming model is proposed. Utilize a Gaussian distribution for the energy consumption feature, and using a branch-and-bound algorithm, the optimized model has been solved.

that can optimize energy consumption and reduce the environmental impact of machine learning systems. Research in this area includes developing energy-efficient architectures for neural networks, reducing the energy consumption of data preprocessing and models' training, and incorporating environmental factors into the decision-making process of machine learning models. In recent years, green ML has been applied in various industries, such as transportation,

TABLE 8. Summary of green database studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[201], 2013	Energy consumption benchmark for database systems	DB2, Oracle, open source database system, IO datasets	To measure database energy consumption, design the DBPower benchmark platform by integrating software and hardware. The platform utilizes a modular architecture and is capable of understanding the relationship between performance and energy consumption in DBMS.
[202], 2016	Green database design in software development	Two different servers	Proposed a green software database design model to contemplate the energy usage during the database design phase. Further, the model is designed to estimate the collision of software applications based on their source utilization.
[203], 2014	Green database model for Indian stock market	Data of 10 different companies	Proposed a green database model for the stock market of India that can be integrated with cloud computing and is efficient and accurate in forecasting.
[204], 2014	Green database management for Indian stock market	Online data set of SBI, NSE from Jan/2000 to Dec/2012	To save space, time, and power consumption, this study deals with integer value datasets for the stock market and can save more than 50.586%.
[205], 2017	Dashboard for measuring green software design	PhpStorm	To measure green software design via a web-based dashboard, a system named Green Dash is proposed for software developers. The system is able to calculate sustainability for green software design.
[206], 2008	DBMS for green manufacturing	-	For green manufacturing, a three-level structure-based web database support system is proposed, that can provide a green assessment for the production process.
[207], 2021	Green simulation with database Monte Carlo	-	Green database Monte Carlo named green simulation procedure has been proposed that uses quasi-control variates and finds that the proposed GDB estimator is successful in improving estimation accuracy compared to standard Monte Carlo.

agriculture, and manufacturing, to improve energy efficiency and reduce carbon emissions.

Due to a relatively new and evolving field, very limited studies have been conducted in the area, leaving most of its potential unexplored. Table 10, presents the current studies conducted in the area of green machine learning. Multi-information source optimization, green and energy-efficient hyperparameter optimization, knowledge-aware ML, an energy and carbon footprint analysis framework, and energy-efficient reinforcement learning are some of the topics that have been explored by various researchers. Moreover, MAGIC, ADULT, COMPAS, and various other benchmark datasets have been utilized for the evaluation of the study's mechanism.

J. GREEN E-COMMERCE AND GREEN E-GOVERNMENT

Green e-commerce is the practice of using environmentally responsible and sustainable methods in the world of electronic commerce. Green e-commerce includes instituting recycling and waste reduction initiatives, employing eco-friendly packaging materials, and running e-commerce operations on renewable energy sources. Green e-commerce also includes measures such as building energy-efficient structures and establishing green transportation networks to reduce its carbon footprint. Green e-commerce benefits businesses by lowering energy and trash disposal expenses, in addition to promoting environmental protection. A favorable brand image and increased customer loyalty may result from the use of green principles in online commerce. Furthermore, incorporating sustainability principles into e-commerce can have long-term positive effects.

Green e-government refers to the use of environmentally sustainable practices by various organizations of government. This might include switching to paperless processes to cut waste, utilizing energy-efficient technologies in providing e-government services to lower emissions, and powering government facilities using renewable energy sources. In order to enhance decision-making and overall sustainability in public services, green e-government can also incorporate the use of data analysis and modeling. Implementing green e-government services will reduce the negative effects of government activities on the environment and boost sustainable development.

Table 11, presents the studies conducted on green e-commerce and green e-government in recent years. To achieve sustainable e-commerce, various studies have been conducted on issues such as green supply chain and risk management, feasibility assessment, assessing market readiness, supply chain coordination, and decision-making. Due to the relatively new area concept, green e-commerce studies mainly focus on performing feasibility analysis and exploring public response and willingness to adopt green e-commerce ecosystems. However, very few studies have been conducted on green e-government which mainly focuses on green government procurement practices across various public enterprises and projects.

TABLE 9. Summary of green data mining and information retrieval studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[209], 2016	Ensemble-based data stream mining	Waveform (5000 data), Spambase (4601 data), Chess (3196 data) and Australian (690 data)	For data stream mining, proposed an online active learning framework that uses an active online ensemble algorithm, which can build accurate models with much smaller ensemble sizes and present cost-sensitive learning.
[210], 2022	ML classification on tiny printed circuits	10 datasets of the UCI ML repository	Obtain area-efficient and Pareto-optimal solutions by introducing leverage approximate computing principles on bespoke architectures, which can be suitable for tiny circuits and applications with extreme resource constraints.
[211], 2014	A self-adaptive latency/power compromise paradigm for replicated search engines	50M web documents from ClueWeb09	A novel self-adapting model capable of saving 33% energy is proposed to analyze distributed search engines trade-off between power consumption and latency.
[212], 2015	CPU energy management for internet search engines	MSN 2006 query log, Terrier IR platform	Propose to delegate CPU power management, which may use information derived from querying operations, such as query server use, to load suitably and control CPU frequency, therefore decreasing query server energy usage.
[213], 2016	Using renewable energy to lower the operating expenses of multi-center online search engines	Six different frontends of the Yahoo web search engine, spanning one week	To minimize multi-center web search engines' operational costs, a mathematical model is proposed that can reduce energy operational costs by 25% while maintaining acceptable service quality.
[214], 2019	Recommending data-driven energy-efficient data mining services	13 users from different locations in 8 countries	To represent dataset information as contextual factors, various ways have been explored, and their impacts on recommendation accuracy have been investigated, which outperforms the baseline model.
[215], 2018	Energy-efficient data mining web service recommender	13 users from different locations in 8 countries	Proposed web service recommender system, which considers data as a contextual factor. The system increases the accuracy of QoS value prediction by 61% and of recommendation by 32%.
[208], 2018	Principles of green data mining	-	Using CRISP-DM methodology, a set of principles for green data mining is developed that cover various phases of the process, including impacting managerial decisions as well as technical questions.

K. GREEN EDUCATION

The term "green education" describes the incorporation of environmental and sustainability concepts into the curriculum and daily operations of educational institutions. It aims to encourage sustainable practices in the management of educational institutions and to educate students about environmental challenges and their role in building a sustainable future. Environmental education may be included in current subjects, among other approaches to green education. It may also include implementing sustainable principles into how educational institutions run, such as lowering energy and water use, encouraging recycling and waste minimization, and using green building design. There are several advantages to green education. It may aid in the growth of students' critical thinking and problem-solving abilities as well as their comprehension of the interconnection of social, economic, and environmental concerns. Additionally, it encourages children to take action to preserve the environment by fostering a feeling of environmental responsibility. Additionally, implementing sustainable practices in educational institutions may result in financial savings, better indoor air quality, and a lower environmental impact. Green education is essential for tackling the current environmental issues on a worldwide scale. Sustainable development requires a populace that is more ecologically aware and active, which may be accomplished through green education. Additionally, it may aid in the growth of the next generation of sustainability leaders. Many educational institutions have begun to incorporate green education into their programs and daily operations in recent years. To guarantee that every student has access to environmental education, additional work must be done to properly integrate green education into the educational system.

Table 12, presents the current studies that have been conducted in recent years in the area of green education. The studies have been mainly focused on analyzing various issues in green education using data collected from students, and academics. Various studies have been conducted on analyzing students' knowledge, awareness, and practices toward green education and green computing. Some studies have found that there is no interconnection between green computing knowledge and gender. However, female students have more positive attitudes toward green computing than male students. To promote and spread green education and e-learning,

TABLE 10. Summary of green machine learning studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[216], 2018	Balancing optical network energy costs and emissions	808,024 records	To determine the effective solution for a static set of requests that reduces the power cost of the RWA while keeping emissions below a defined limit, mixed-integer linear programming and machine learning are used, where the logistic regression model 92.50% accurately predicts the most cost-efficient path.
[217], 2021	Multi-information source optimization and augmented gaussian processes	"MAGIC Gamma Telescope" dataset	Proposed is an augmented Gaussian process approach that utilizes various information sources, in which only "reliable" information is trained from the accessible sources.
[218], 2022	Green hyperparameter optimization	ADULT, COMPAS dataset	To search for an accurate and fair ML model while using a small portion of the dataset, less computational time, and energy consumption, both multi-objective and multiple information sources Bayesian optimizations-based, a fair and green hyperparameter optimization approach has been proposed.
[219], 2022	Knowledge-aware machine learning	-	The PyKale API is designed to be pipeline-based to integrate all ML workflows into six standard phases that harness information from numerous sources for accurate and interpretable prediction, especially multimodal learning and transfer learning.
[220], 2022	Carbon footprint and energy analysis framework	MNIST, CIFAR10 datasets	To examine the energy and carbon footprints of distributed and federated learning, an unique paradigm is proposed that quantifies the energy footprints and carbon equivalent emissions for vanilla FL techniques and fully decentralized, consensus-based approaches.
[221], 2022	Smart glasses with a smart application and arduino	5 classes of data obtain from LidSonic	To identify obstacles, a smart glasses pair named LidSonic is developed, which utilizes machine learning, LiDAR, and ultrasonic sensors. An Arduino Uno device located in the smart glasses and a smartphone is employed to collect data, detect objects, and manage sensors by communicating data using Bluetooth.
[222], 2021	Power profile and thresholding	REDD dataset	Various ML methods have been utilized to optimize household appliances energy consumption by NILM. Furthermore, to increase trained algorithms performance, two novel concepts, thresholding/occurrence per million, along with power windowing, were utilized.
[223], 2020	Energy efficient hyperparameters tuning	MAGIC dataset	To drastically reduce computational time and energy consumption, multi-information source optimization is proposed, which uses only available "reliable" information.
[224], 2018	Energy efficient reinforcement learning for wireless sensor networks	SPHERE challenge dataset	Presents a method utilizing Reinforcement Learning (RL) techniques that leverage the energy consumption and algorithm's performance and are cheap in terms of work hours, calibration, and energy usage.

various energy-efficient green computing architectures, systems, and infrastructures have been developed over the years. Furthermore, to implement sustainable education, various green university models have been developed and case studies have been analyzed.

L. GREEN AGRICULTURE

The goal of green agricultural technology is to minimize the harmful effects of agricultural operations on the environment. This is accomplished by implementing measures for environmentally friendly agricultural production, such as employing renewable energy sources, energy-efficient smart agricultural devices, utilizing resources more efficiently, integrating modern technologies into agricultural practices, drastically reducing the use of chemical fertilizers and pesticides, and boosting the use of organic farming methods. Precision agriculture, which makes use of tools like GPS and remote sensing to increase agricultural yields, can lessen the effect on the environment. Vertical farming mechanisms that involve growing crops in stacked layers are very cost and resource efficient for preserving land and water. Green agriculture's overall objective is to produce food in a manner that is ecologically sustainable and less harmful to the environment than conventional agricultural methods. Many studies have been conducted in the area of environmentally friendly green agriculture due to its direct impact on human lifestyle and the economy.

Table 13 represents the studies conducted in the area of green agriculture in the recent year. Policy development and impact analysis, energy management and control systems, pricing determination mechanisms, farmers' credit risk assessment, and renewable energy source-based and IoT-based efficient device development are some of the key subjects that have been examined by various researchers in recent years. Farmers' and experts' opinions, financial issues, sensor data, and government data have been primarily used to conduct the studies. However, various other issues are unexplored in the area of sustainable and green agriculture.

TABLE 11. Summary of green e-commerce and green e-government studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[225], 2020	Green supply chain fairness coordination	-	Presents a green e-commerce supply chain coordination and decision-making model with fairness concerns for green manufacturers and finds that manufacturers' behavior in response to concerns about fairness can result in a decrease in both the greenness and effectiveness of a product or system.
[226], 2022	Feasibility assessment for e-commerce	Total 296 online and offline respondents, SPSS software	Investigate the factors that affect Ethiopia's feasibility and readiness for e-commerce and find that the five-year ICT4D action plan has no significant impact on the e-commerce and e-trade sectors.
[227], 2019	Risk management in e-commerce supply chain	28 people from B2C and B2 organizations	To analyze e-commerce supply chain risks, a statistical analysis of the data obtained from the different supply chains has been performed and found that natural disasters or accidents, theft, or damage at distribution centers or during transportation are the major risks.
[228], 2021	Assessing market readiness and moving to a new competitive landscape	400 consumers	Green marketing impact on online customers is analyzed and finds that consumer awareness, quality green online products availability, infrastructure development, and internet penetration rise are helping to increase the online green products market size.
[229], 2021	E-commerce supply chain coordination and decision making with logistics outsourcing and altruistic preferences	-	Logistics outsourcing's impact on coordination and decision-making in ESC, which is e-platforms dominated, has been examined, and it has been found that dual-channel or conventional supply chains do not always apply to ESC, and that altruistic behavior under ESC is affected by customer preferences.
[230], 2016	Malaysian public enterprises green government procurement practices	274 responses	To explore Malaysian public enterprises' green government procurement practices, procurement officers' perceptions have been analyzed, which finds that the most common GGP practice is to purchase things from local suppliers.
[231], 2021	Green government procurement for green projects	32 respondents	Determine the green project planning phase's important level of life-cycle cost (LCC) components and find that the highest rank of LCC components in green procurement is greenhouse gas savings cost, acquisition cost, energy consumption and simulation cost, and utility cost.
[232], 2022	Enterprise green innovation game analysis	-	An evolutionary game model is created to investigate the dynamic evolution behavior of manufacturers' green innovation strategies and platform green finance methods and finds that green financing and green innovation are beneficial to manufacturers and e-commerce platforms.

VI. FINDING AND ANALYSIS

To understand the review studies' full context, it is necessary to analyze and examine the studies' various perspectives. In the section proposed state-of-the-art research questions reposed have been discussed after performing in-depth analysis. Furthermore, green computing area's challenges and future research directions have been presented.

A. QUESTION RESPONSE

- RQ 1. What are the most recent advancements in the area of green computing research, and how do they stack up against earlier efforts?

Green computing is a rapidly growing research area that has made rapid progress in recent years and attracted lots of attention due to increasing concerns over the carbon footprint and energy consumption of modern technologies. In the green computing domain, many advancements have been made in various areas.

In the area of GDC technologies, one of the most recent advancements is the use of energy-efficient hardware, such as processors and memory devices, that consume less power and result in reducing energy consumption [45], [53], [57], [59], [63], [65] and decreasing the carbon footprint. The renewable energy sources utilization, such as wind and solar power, to power data centers, is an important advancement. Renewable energy sources usages not only reduce dependence on fossil fuels but also decreases data center carbon footprint. Another key advancement is the use of air and water-based cooling systems instead of traditional air conditioning systems, which use less energy and are more environmentally friendly [37]. Furthermore, the use of renewable resource-co-located distributed data centers that are operated by coordinating among themselves can reduce energy consumption, reduce the need for heavy electricity grid infrastructure, and reduce security concerns. In comparison to earlier efforts, these recent advancements in green data center technologies have been much more impactful. Energy-efficient hardware and renewable energy sources have drastically decreased data center carbon footprints. Furthermore, the implementation of air and water-based cooling systems has increased energy efficiency and reduced data center operational costs.

TABLE 12. Summary of green education studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[233], 2019	Implementing green education of urban families	Forty families	A child-centered, family, and urban context of China-based education model is developed by applying a green social work framework, that encourages practitioners to collaborate in the learning process on finding food safety solutions with social and environmental benefits.
[234], 2016	Students' green computing knowledge survey	276 respondents	The knowledge of university students in Nigeria about green computing is investigated, and it is found that conscious use of computing system knowledge is not possessed by the students. Further, there is no significant difference between male or female students and engineering or computer science students' knowledge about green computing.
[235], 2015	University students' attitude toward green computing practices	700 students	Descriptive statistics, independent samples t-test, and PCA techniques are used to analyze students' attitudes toward green computing and the influence of gender on those attitudes. The analysis of the t-test shows that females have a significantly greater difference in positive attitudes toward the green environment than males.
[236], 2020	Green computing-based e-learning system	-	A comparison between the green computer and other computing devices in the e-learning environment has been analyzed. The results show that green computing consumes less energy, is friendly, and is capable of reducing 30% of energy.
[237], 2013	Green computing awareness of Malaysian universities students	224 university students	Students' knowledge of green computing was investigated, taking into account vocabulary and issues, gender influences, and ICT versus non-ICT fields, by employing descriptive statistics, an independent-sample t-test, and PCA. The outcome showed that the study field affects awareness, but findings produced mixed gender effects, and overall, students lack awareness about green computing.
[238], 2014	Cloud-based green computing for e-learning	-	Proposed COGALA named architecture, which can minimize energy usage, cut costs, and assist enterprises with limited IT resources in deploying and maintaining necessary software in a timely way.
[239], 2018	Green computing adoption factors	118 Gulf universities	To identify developing countries' universities' green computing adoption major factors or barriers, an analysis has been performed and found that relative advantage, awareness, top management support, government policy, and adequate resources are the five major factors.
[240], 2018	Proposed model of green computing adoption	26 academics	Proposed a model built on the successful model of green computing adoption for Indonesian higher education that is constructed based on four policies: campus management style, government regulation, supporting technology, and successful adoption of green computing.
[241], 2014	Higher education institution virtual desktop infrastructure	-	To reduce infrastructure costs, energy consumption, and e-waste, PC virtualization has been performed by using N-Computing thin client machines that are connected to the server.
[242], 2013	Low-cost green computing system for education	Run onTinyOS	To empower India's rural parts' education, Arduino and Raspberry Pi combinations are utilized to develop infrastructure that is low-cost, has no external dependencies, and runs on TinyOS.
[243], 2015	Green university initiatives in China	Yearbooks, archives, and statistics examination	Based on document analysis and participant observation, a case study of Tsinghua University is performed to evaluate the initiatives for developing a green university.
[244], 2012	Green university creation in China	Bills and other operating data	To minimize material and energy proposed a green university-integrated model, and Shenyang University is selected to test its feasibility. Significant economic, environmental, and social benefits have been received by applying the model.
[245], 2010	Sustainable computing education for undergraduates	35 students	A green computing course, modules, and evaluation has been developed to include sustainability in computing education at the undergraduate level and find that most students understood green computing techniques, demonstrated enthusiasm, and justified the course's effectiveness.
[246], 2012	Green education using open educational resources	-	Portals that are hosting OER and OER access provider "green" thematic portals are presented and their shortcomings have been discussed.

In the area of GCC, the most recent advancements include energy-efficient green cloud data centers implementation, virtual machine migration and management mechanisms, various types of task schedulers, and the development of more energy-efficient algorithms. The use of virtualization technologies has also become more widespread, allowing for the consolidation [81], [88], [105] of multiple workloads onto a single physical server, reducing energy consumption. Compared to earlier efforts, these advancements have significantly improved the sustainability of cloud computing.

TABLE 13. Summary of green agriculture studies.

Reference and Year	Perform Work	Dataset/Testing mechanism	Finding and Contribution
[247], 2022	Policy influences on the development of green agriculture	Obtained from Sichuan and its Statistical Yearbook 2015–2021	By employing the system dynamics method, the Sichuan Tibetan area green development model in the agricultural sector is presented and proposed three policy simulation scenarios that have a positive effect on the agricultural economic benefits improvements.
[248], 2022	Negative carbon emission energy system	A 150 hm2 agricultural area was used for case study	To satisfy the agricultural negative carbon reduction energy supply need, a DAC-based green agriculture energy system including wind, solar, an electric boiler, and a battery energy storage system is presented, and dry reforming methane and microalgae planting technologies have been employed to capture CO2. The system can achieve negative carbon emissions while achieving economic equipment capacities.
[249], 2020	Optimal pricing of green agriculture products	-	Proposed an optimized dynamic pricing mechanism that can solve the decision-making problem of sellers in the pre-selling and spot selling periods. The result shows that if a product has a prominent driving effect, sellers could raise the price.
[250], 2014	Solar pump irrigation system	4 solar pumps	Solar pumps' field performance has been tested in various locations in Bangladesh and the result shows that 50% of water can be saved using Drip irrigation techniques. Furthermore, wheat cultivation by solar pump irrigation was economically profitable, but Rice is not economically viable.
[251], 2022	Management of the agricultural green supply chain	10 experts	By integrating the fuzzy set, Delphi, the Grey theory, and the weighted influence nonlinear gauge system approaches, a novel hybrid model for calculating the interrelationships between factors in agricultural green supply chain management has been proposed, and it has been found that quality and price of the product, environmental law, and green consciousness are the most sensitive causal elements.
[252], 2017	Agriculture's performance gap in the green economy	22 green agriculture experts	To analyze the gap in aspirations for green agriculture using Q-methodology, expert opinions in Indonesia have been explored, and it has been found that LUP non-synchronization between local and national governments greatly contributes to the gap
[253], 2010	IoT-based green farming products	-	Proposed an innovative business strategy model combining the IoT and analyzing the characteristics of green agricultural products. The IoT system could, to some extent, reduce the informational asymmetry between the producer and consumer.
[254], 2021	Green agricultural production financing behavior in family farms	222 provincial household farm	To analyze the influencing factors of household farm demonstration farms participating in green agricultural production financing behavior TPB and SEM model has been used and found that the financing willingness of the farmers is determined by their attitude, subjective norms, and perceived behavior system of the family farm manager.
[255], 2018	System for green agriculture based on image processing and IoT	Collects data from sensors	An IoT and image processing-based green agriculture system has been developed which can plant and monitor automatically. The system CPU handles irrigation and aftercare and is equipped with several sensors and actuators, while system parameters are updated in the cloud frequently.
[256], 2018	Influencing factors of CO2 emission intensity	Panel data across 30 provinces in China from 1997 to 2014	Simultaneous equation models have been utilized to analyze the influencing elements of Chinese agriculture's CO2 emission intensity from 1997 to 2014 and found that innovation adversely influenced CO2 emission intensity and FDI positively affected innovation.
[257], 2022	Small-scale farmers' preference heterogeneity for green agriculture policy incentives	1032 Chinese farmers	Mixed logit and latent class model regressions were employed to evaluate how small-scale farmers' characteristics and incentive programs affect their desire to participate in ecological fertilization/deinsectization and the study revealed that farmers' choices are most influenced by age, education, family size, and farming organizations.
[258],2022	Sustainable supply chain financing credit risk assessment for farmers	7 bank experts	A risk indicator system for sustainable ASCF and a fuzzy decision procedure that includes decision-maker confidence have been developed to analyze a coffee bean supply chain credit case's risk. Results from NE-BWM and COCOSO indicate that core company credit rating is the most important risk indicator.

In the area of green IoT, recent advancements have focused on improving the energy efficiency of IoT devices and reducing the carbon footprint in production and usage. This includes the development of low-power communication protocols, algorithms, control and management mechanisms, and energy-efficient hardware, such as sensors and microcontrollers. Additionally, initiatives have been undertaken to recycle and reuse IoT devices at the end of their life cycle. Compared to earlier efforts, these advancements have significantly improved the sustainability of IoT. The development of low-power communication protocols, energy-efficient hardware, and algorithms has allowed

IoT devices to operate with reduced energy consumption [113], [114], [118], [128]. Furthermore, recycling and reusing IoT devices have also helped to reduce waste and the negative environmental impact.

Green procurement is the process of purchasing services and products that have a minimal environmental impact. There have been considerable developments in green procurement-related research in recent years. Companies are now considering the environmental impact of their purchases and looking for more sustainable options. Furthermore, recent studies are analyzing the drivers and barriers of green procurement across various industries and projects, which can be beneficial for understanding the current obstacles that companies and organizations are facing towards implementing green procurement. These findings have led to the development of new strategies, technologies, mechanisms, and products that are environmentally friendly and more energy efficient. The use of these technologies helps reduce the carbon footprint of companies, boost green procurement implementation, and contribute to the overall sustainability of the planet.

In recent years, green education has seen significant advancements, particularly in the areas of curriculum development, e-learning system development, awareness analysis, and training programs. The focus has been on incorporating environmentally sustainable practices into the design, development, and use of technology [236]. The goal of green education is to educate individuals and organizations on the importance of reducing the environmental impact of technology and how to implement sustainable practices [238]. Compared to earlier efforts, these advancements have significantly improved the availability of green computing education and increased the number of individuals and organizations that are able to adopt environmentally sustainable green education.

Recent advancements in smart grid technology have focused on improving the reliability, efficiency, and sustainability of the electricity grid. This has been achieved through the use of advanced sensors, energy and resource management, distribution control systems, communication network optimization, and data analytics to better monitor and control the flow of electricity. Smart grid technology also enables renewable energy sources integration, such as wind and solar power, and energy control and management mechanisms into the grid. Compared to earlier efforts, these advancements have greatly increased the efficiency of the electricity grid, reducing energy waste and carbon emissions.

Green transportation systems have seen significant advancements in recent years, with a focus on reducing the carbon footprint of the transportation sector [198]. One of the latest advancements is the increased use of electric vehicles (EVs), improvements in charging infrastructure and battery technology, and plug-in hybrid electric vehicles (PHEVs), which have reduced dependency on fossil fuels. Another advancement is the development of smart traffic management systems, which use real-time data and analytics to optimize traffic flow, reduce congestion, and lower emissions. Furthermore, the development of green transportation policies, ecological highway development, and production and green transportation coordination plays a key role in achieving green transportation and has significantly improved the efficiency and sustainability of the transportation sector, compared to earlier efforts.

Recent advancements in the area of green database research have focused on reducing the energy consumption of databases while maintaining service performance [201], [202]. The use of energy-efficient hardware components, such as solid-state drives (SSDs), which consume less power compared to traditional hard disk drives (HDDs), can provide services more quickly. Additionally, energy-efficient algorithms have been developed to reduce the energy consumption of database operations, such as indexing, sorting, and querying. Furthermore, research has also been conducted on developing various green database models for the stock market and optimizing the use of databases in the cloud, where resources can be shared and dynamically provisioned to reduce overall energy consumption. These efforts have helped to improve the sustainability of database systems and reduce their environmental impact.

In the area of green data mining and information retrieval, recent advancements have focused on reducing the carbon footprint of data centers and optimizing energy usage using energy-efficient data mining techniques. For instance, researchers have been developing algorithms that can minimize energy consumption during data processing and storage [209]. Additionally, researchers have been developing methods to reduce data redundancy and use more energy-efficient information retrieval techniques to minimize the energy footprint.

In recent years, the area of green machine learning has seen significant advancements in reducing the energy consumption and carbon footprint of machine learning techniques [218], [223]. One of the most notable efforts is the development of energy-efficient algorithms that require fewer computational resources and datasets to train models, thus reducing energy consumption. Furthermore, various efficient ML techniques have been deployed to analyze and solve various issues. The development of knowledge-aware ML and the integration of ML in smart IoT devices can reduce resource consumption and thus aid in achieving sustainable development.

In the area of green e-commerce and e-government, recent advancements have focused on reducing the carbon footprint of online transactions, supply chains, and electronic governance processes by analyzing the current issue and developing modern technology-based solutions. The use of more energy-efficient servers, reducing the need for paper-based transactions, and implementing green procurement practices for electronic devices used in e-commerce and e-government are most of the environment-friendly measures. These efforts have resulted in a reduction of energy consumption and a decrease in the amount of waste generated. Additionally, many e-commerce companies are now offering carbon-offset programs for shipping, and e-government agencies are promoting the use of electronic signatures to reduce the need for physical document storage [225]. These advancements demonstrate a commitment to sustainability and a recognition of the important role that technology can play in reducing the environmental impact of e-commerce and governance.

Green agriculture is a recent area of research in green computing that aims to make the agriculture sector more sustainable and environmentally friendly. One of the most recent advancements in this area is the use of IoT-based solutions for precision agriculture. This involves using sensors and other IoT devices to monitor temperature, soil moisture levels, and other factors that affect crop growth [253], [255]. This information is then used to optimize irrigation and fertilization practices, leading to improved yields and reduced resource waste. Furthermore, integrating solar power in agricultural devices such as water pumps, energy management systems, decision-making mechanisms, and policy development are some of the other recent achievements.

In conclusion, the field of green computing has seen significant advancements in recent years. From green data center technologies to green agriculture, researchers and practitioners have been working towards creating more sustainable and energy-efficient systems and frameworks. These advancements have resulted in increased energy efficiency, reduced carbon emissions, reduced resource requirements, and increased cost savings. In comparison to earlier efforts, the current research in green computing has a greater focus on holistic solutions, taking into consideration the entire lifecycle of a system. Overall, green computing is becoming a popular and important area of research and development as the need for sustainable technology solutions has been increasing rapidly.

- RQ 2. What approaches have shown to be the most successful implementations in the areas of green computing?

Green computing is a process of using computers and related resources in an environmentally friendly manner. Various approaches such as energy-efficient computing, optimizing software, energy-efficient cooling systems, VM placement, etc. are some of the successful implementations in the green computing area. The energy-efficient computing approach aims to minimize the computers, devices, software, and servers' energy consumption by using energy-efficient algorithms, hardware design, and the integration of modern technologies. Optimizing software to reduce power consumption by using low-power processors, power-saving modes, and virtualization techniques to minimize the number of active servers also showcases the efficacy and some of the successful implementation of green computing. The data center optimization approach focuses on optimizing data centers, which are the backbone of many organizations' computing systems and are some of the successful implementations of green cloud computing in green data center areas. By implementing energy-efficient cooling systems, virtualizing servers, and reducing power consumption, data centers can reduce their carbon footprint and energy costs [68], [91]. Cloud computing's successful implementations of the green computing approach involve energy-aware algorithms that can reduce energy consumption while maintaining QoS, resource allocation and management systems, and efficient and low-cost VM migration. IoT includes energy management systems and design development, identifying various industries' green procurement barriers and drivers, analyzing students' awareness and attributes towards green computing, developing eco-friendly smart green universities, developing secure, energy-efficient algorithms, resource and distribution management systems for smart grid, analyzing and developing green transportation policies, smart efficient automatic traffic management and ecological highway and railway development, energy, time, and space optimization for green database model design and development, a cost-sensitive information retrieval system, efficient and data-aware data mining services, green hyperparameter optimization for green ML, an automatic plant monitoring system, and solar power based water pump development are some of the major successful implementations of green computing. By implementing these approaches, organizations can reduce their environmental impact, minimize waste, save resources, and reduce energy costs.

- RQ 3. Which areas of green computing are most underdeveloped, and what are the obstacles researchers in those areas are facing?

Green computing is an important area of research that seeks to develop sustainable and environmentally-friendly technologies in the field of computing. Despite the significant advancements made in recent years, there are still areas that are underdeveloped and face various challenges. Some of the areas that are lagging behind include green education, green databases, green data mining and information retrieval, green machine learning, green e-commerce and e-government, and green agriculture.

The obstacles facing researchers in these areas range from limited funding, a lack of infrastructure, and a lack of technical knowledge to solve the complexity of the problems. Green education research includes building eco-friendly educational infrastructure, energy efficiency e-learning devices, and applications, integrating green computing concepts in the curriculum, and utilizing resources efficiently in the institution. One of the major challenges in conducting research in this area is the cost and awareness associated with green educational infrastructure development, such as green universities. Due to an evolving and new area in green computing, a limited number of studies have been conducted in the area of green databases. Green database's primary research goal is to develop efficient database models and algorithms for storing, searching, and efficiently exchanging data. However, technical understanding and knowledge, funding and awareness of companies, and proper infrastructure and testing mechanisms are some of the obstacles that researchers face in the area of the green database. Green data mining and information retrieval research centers around building energy and other resources efficient data mining and information retrieval systems that can efficiently retrieve data across various sectors. However, proper energy-efficient framework unavailability and technical knowledge requirement for optimizing data mining techniques are some of the major obstacles for researchers. Lack of technical knowledge, funding, and awareness are some of the major obstacles in developing and implementing energy-efficient and optimized green ML across various industries. Green agriculture research includes building energy-efficient IoT devices for farming, smart controlling and monitoring systems, integrating renewable energy in various activities of agriculture, and developing supply chain change management. However, the lack of practical implementation by the farmer due to various constraints such as cost, time, and technical knowledge are the biggest obstacles to motivating researchers to perform green agriculture-related research. Government and e-commerce companies' lack of awareness, willingness, and funding are some of the major obstacles to building a green e-commerce ecosystem and promoting green computing in government organizations and activities. To overcome these challenges, researchers need to collaborate with industry partners, governments, and other stakeholders to create solutions that are not only sustainable but also economically feasible. Furthermore, the lack of standardization in the fields and the lack of a unified approach to green computing research also pose a challenge. Nevertheless, by addressing these challenges, the underdeveloped areas of green computing have the potential to drive innovation and lead to a more sustainable future.

- RQ 4. How do recent developments in artificial intelligence and machine learning affect the amount of energy saved by computer systems?

Artificial intelligence (AI) and ML are rapidly evolving technologies that have the capability to greatly minimize the amount of energy consumed by computer systems. Recent advancements in AI and ML, such as deep learning algorithms and edge computing, are revolutionizing the way that computers process and analyze data. These developments have the capability and potential to minimize the energy consumption of computer systems as well as improve their overall performance and efficiency. By leveraging AI and ML techniques, computer systems can make more intelligent decisions about how to allocate and manage their resources, reducing the energy consumption required to perform a given task.

AI algorithms such as ML can be employed to optimize data centers' and other computing systems' energy usage. For instance, AI can be used to predict the workload demands of a data center and adjust its energy usage accordingly, reducing energy waste. AI could also be employed to monitor individual devices' power consumption and shut down those that are not in use in a data center, further reducing energy consumption. Additionally, AI algorithms can be employed to enhance the energy efficiency of computing devices [65]. AI can be utilized to analyze the energy consumption patterns of individual devices and optimize their power usage accordingly, reducing energy consumption and extending the life of the device. In this sense, AI can be seen as a tool for reducing the environmental impact of technology. Furthermore, AI can be used to develop new green technologies, such as smart grids and green transportation systems. AI algorithms can be used to analyze energy consumption patterns and identify areas where energy savings can be made, leading to the development of new, more efficient systems. AI can also be used to monitor the energy consumption of these systems and optimize their energy usage over time, further reducing their environmental impact.

In recent years, ML significance in green computing fields has grown. ML algorithms has been employed to optimize the energy consumption of computer systems, enabling the reduction of energy waste and the creation of more energy-efficient solutions [210]. One of the main ways machine learning has affected energy savings in computer systems is through the development of smarter energy management techniques. For instance, machine learning algorithms can be used to predict the energy consumption of different parts of a computer system, which can then be used to dynamically adjust the power consumption of these parts to minimize energy waste [216]. Additionally, to optimize the allocation of resources, such as computing power and memory, to save resource consumption and the operation cost of computer systems ML algorithms can be employed. This ML model utilization is important in data centers, where large amounts of energy are consumed by the computing infrastructure. By using machine learning algorithms to optimize resource allocation, data centers can reduce energy consumption and lower their carbon footprint [218]. Furthermore, ML algorithms or models can be utilized to predict failures in computer systems, allowing for proactive maintenance and reducing these systems energy consumption over the long term.

Recent developments in AI and ML have a notable impact on the amount of energy saved by computer systems. These technologies have been integrated into various systems to reduce energy consumption by automating routine tasks and distributing and managing resources properly. AI-based systems can dynamically manage the power consumption of computer systems by adjusting the power usage based on the workload and system requirements. Additionally, ML methods could be used to optimize resource utilization of computer systems, further reducing their energy consumption. As a result, these advancements have the potential to play a crucial role in reducing the carbon footprint of the technology industry and ensuring a more sustainable future.

- RQ 5. What areas of green computing research are the most promising?

Green computing research has made significant progress in recent years, and there are several areas that show significant promise with respect to energy efficiency and sustainability. Some of the most promising green computing areas include the IoT, data centers, cloud computing, and smart grid systems. These areas have the potential to reduce the energy consumption of computer systems, servers, devices, and software, which can reduce greenhouse gas emissions and the overall carbon footprint. Additionally, these areas have the potential to provide new, more sustainable solutions for managing and analyzing large amounts of data, as well as automating processes and reducing energy consumption in the energy sector.

IoT has become an increasingly important aspect of the technology industry, and its growth has been exponential over the past few years. Green IoT is the concept of making IoT devices more energy-efficient and environmentally sustainable, and this area of green computing research has shown great promise [118], [122], [123]. Energy-efficient IoT devices have a major effect on the technology industry's total energy consumption reduction [114], [115]. Additionally, the increasing demand for smart homes and infrastructure is driving the development of more energy-efficient IoT devices, further increasing the potential for energy savings [111]. As the usage of IoT devices continues to grow, the need for more sustainable and energy-efficient technology becomes increasingly important. One of the most promising areas of green computing research is the green IoT, as it has the potential to make a significant impact on reducing the energy consumption of technology while also reducing its environmental impact.

Smart grids are considered one of the most promising areas in green computing due to smart grids' ability to minimize energy efficiency and reduce carbon emissions in the energy sector [161], [163]. The smart grid technologies implementation involves the integration of digital technologies with the traditional power grid system, allowing for real-time monitoring and control of energy generation, distribution, and consumption. This leads to increased energy efficiency, as power grids can dynamically respond to changes in energy demand, reducing the need for additional energy generation. Additionally, renewable energy sources usages such as solar and wind power can be optimized through the use of smart grid technologies, reducing dependence on fossil fuels and decreasing overall carbon emissions. Furthermore, the deployment of smart grid technologies also enables the integration of electric vehicles and other consumer-facing technologies, contributing to a more sustainable energy future. With these advantages, it's not surprising that smart grid technology is considered one of the most promising areas in green computing research.

Due to the adaptation of modern technology, the use of CC is increasing rapidly. Therefore, green cloud computing is a promising research field that can improve the sustainable development of modern CC-based technologies and services. The usage of energy-efficient algorithms, task and job schedulers, and VM migration can maintain QoS and reduce energy in the CC process, thus promoting the sustainability of cloud computing.

The energy control and management system of the data center has a direct impact on energy usage, operational cost, and resource usage, which can affect sustainability and environment-friendly green computing development. Using natural resource-based technology to power and cool data centers can reduce operational costs and reduce CO2 emissions. Distributed data center development and management can reduce the electricity grid infrastructure requirements, which can be beneficial for setting up data centers in developing countries.

In conclusion, green computing research continues to expand as the need for more sustainable and eco-friendly technology becomes increasingly important. From areas such as green IoT, green data centers, green cloud computing, and smart grids, the potential for breakthroughs in reducing the carbon footprint of technology is substantial. With continued innovation and collaboration between academia and industry, the future of green computing looks bright, and the potential to make a significant impact on the environment is real. It's up to all individuals to support and drive these efforts toward a more sustainable future.

- RQ 6. What will be the most difficult obstacles for those researchers who are now intending to do research on green computing?

Conducting research in the field of green computing can be challenging, as there are several obstacles that researchers may face. These obstacles can include a lack of standardization across the field, technical barriers, and limited funding.

Standardization across the field of green computing research is one of the most challenging obstacles for researchers [50], [119], [217]. There are a multitude of devices, technologies, and protocols used in the field of green computing, making it difficult to ensure compatibility and interoperability. Moreover, there is a lack of uniformity in the methods used to evaluate the effectiveness and efficiency of various green computing technologies and solutions. This makes it difficult for researchers to compare their results and draw meaningful conclusions from their studies. In addition, there is a lack of consensus on the best practices for measuring and reporting the energy consumption of computing systems and DC, making it difficult for researchers to accurately compare the energy savings of different solutions. Furthermore, the rapidly evolving nature of technology makes it difficult to standardize the technologies and development process. With new technologies being developed and deployed at an increasingly rapid pace, it can be challenging for researchers to keep up and ensure that their work remains relevant and up-to-date. Additionally, there are often trade-offs between energy efficiency and other performance metrics, such as processing power and data throughput, making it challenging to determine the optimal balance between energy efficiency and performance.

One of the main technical obstacles faced by researchers in green computing is the complexity of designing and implementing energy-efficient systems and algorithms [83], [93]. The complexity arises because energy consumption is a key factor in the design and performance of computer systems, and reducing energy consumption can often result in trade-offs with other performance metrics, such as speed, accuracy, and reliability. Reducing the power consumption of a computer system may result in slower processing times or reduced accuracy, which can negatively impact the overall effectiveness and usefulness of the system. Additionally, the wide range of different devices, platforms, and operating systems that are used in computer systems can make it difficult to design energy-efficient systems that are compatible with a broad range of different devices and configurations. Those issues make it difficult for researchers to develop and implement energy-efficient algorithms and systems that are widely usable and scalable across different platforms. Furthermore, the high pace of technological advancement and the introduction of new devices and platforms can quickly render existing energy-efficient systems and algorithms obsolete, requiring ongoing research and development efforts to stay ahead of the curve. The limited availability of data and resources can also be a major obstacle for researchers in green computing [41], [78], [122]. Collecting and analyzing large amounts of data on energy consumption and performance can be time-consuming and resource-intensive, which can limit the ability of researchers to fully explore and understand the impact of different energy-saving strategies.

Limited funding is a significant obstacle facing researchers in the field of green computing. Government agencies and private sector organizations are increasingly interested in investing in research and development projects aimed at reducing the environmental impact of technology. However, the amount of funding available for these projects is often limited, which can make it difficult for researchers to pursue their work in an impactful manner and scale the developed solution across multiple domains. The competition for funding can be intense, and the process of securing funding is often time-consuming and complicated. In addition to the competition for funding, many researchers in the field of green computing also face a lack of financial stability and job security. Research is often carried out in academic institutions or research labs, which typically do not offer the same level of financial stability as industry positions. Researchers must be prepared to take on a significant amount of risk and uncertainty in order to pursue their work. This lack of financial stability can also make it difficult for researchers to retain top talent, as they may be attracted to more stable and secure positions in the industry. Moreover, limited funding can also restrict the ability of researchers to access the latest technology and resources needed to conduct their work [139], [197], [254]. New technologies are emerging all the time, and researchers must stay up-to-date with these developments in order to make progress in the field. However, the cost of new technologies and equipment can be prohibitively high, and without adequate funding, researchers may struggle to access the resources they need to advance their work.

In closing, the researcher in the field of green computing is facing multiple challenges, including limited funding, a lack of standardization across the field, and technical obstacles. Despite these obstacles, the importance of green computing research is crucial for the future of technology and the environment. By overcoming these challenges, researchers can make significant contributions toward the creation of sustainable and energy-efficient technologies and infrastructures.

- RQ 7. What role does green computing research and development play in achieving the aims of sustainability across the world?

Green computing research and development serves a key role in achieving the aims of sustainability across the world [66], [181], [245],. Due to the rapid technological development and the increasing demand for computing resources, the energy consumption of the ICT sector has also risen, leading to significant carbon emissions and environmental degradation [59], [143]. In this context, green computing provides a means to reduce the environmental impact of the ICT sector while still meeting the growing demand for computing resources. This area of research and development focus on designing and implementing energy-efficient technologies and practices that minimize the environmental footprint of computing systems while maximizing their performance and functionality [55], [57]. The ultimate goal of green computing is to create a more sustainable computing infrastructure that can support the needs of both current and future generations while preserving the environment and natural resources.

The role of research and development in green computing is critical to reaching the objectives of global sustainability. Sustainability refers to the ability of an ecosystem, society, or economy to maintain its function and structure over time. In the context of computing, sustainability involves reducing the environmental impact of computing systems while ensuring their long-term viability and reliability. This requires a focus on energy efficiency, material use, and waste reduction, as well as on creating a sustainable computing infrastructure that supports the development and use of environmentally friendly technologies.

One key area where green computing research and development is having a significant impact is in the optimization of energy use in computing systems [65], [77]. This involves developing hardware and software technologies that reduce the energy consumption of computing systems, both in terms of the amount of energy used by the systems themselves and the energy required to produce and dispose of the systems [51], [66]. Researchers are developing new types of low-power processors and memory technologies, as well as more efficient power management techniques, that can minimize the energy consumption of computing systems [92], [113]. In addition, advances in virtualization and cloud computing are helping to reduce energy consumption by enabling the sharing of computing resources across multiple applications and users.

Another key area where green computing research and development is having an impact is in the reduction of e-waste through the development of new technologies and e-waste management strategies [241]. E-waste refers to the waste generated by electronic devices, such as computers, smartphones, and televisions, that have reached the end of their usable life. This waste can contain toxic materials, such as mercury, lead, and cadmium, that can harm human health and the environment if not properly disposed. Green computing research and development is helping to reduce e-waste by developing technologies that enable the reuse and recycling of electronic components, as well as by promoting the design of devices that are more environmentally friendly and have a longer lifespan.

Therefore, it can be concluded that green computing research and development plays a critical role in achieving the aims of sustainability by reducing the environmental impact of computing systems and ensuring their long-term viability and reliability. Through the development of energy-efficient technologies, the reduction of e-waste, and the promotion of sustainable computing practices, green computing research and development is helping to create a more environmentally friendly and sustainable computing industry that can support the needs of future generations.

B. CHALLENGES

In the process of reviewing studies, various challenges related to green computing have been observed and identified. By overcoming these challenges, green computing can help reduce energy consumption, minimize waste, and mitigate the environmental impact of the technology industry.

The main challenges in the area of GDC include the high levels of energy consumption required to run and cool large amounts of equipment in a data center, as well as the heat generated by the equipment itself. Another challenge is the limited availability of renewable energy sources, which makes it difficult for data centers to operate in a completely carbon-neutral manner. The rapid pace of technological advancements in the data center industry presents challenges in managing equipment obsolescence and the resulting electronic waste. The continuous improvement and upgrades in data center equipment led to shorter lifespans and increased disposal requirements, contributing to environmental impacts. Finding sustainable solutions to minimize electronic waste and reduce the environmental effects of data centers becomes a significant challenge. Implementing effective strategies for equipment reuse, recycling, and responsible disposal is crucial to addressing this challenge.

Green cloud computing challenges include standardization and regulation to ensure that cloud computing is conducted in a responsible and sustainable manner. Evaluating the developed energy-efficient algorithm, task scheduling, and resource management and control system in a standardized way is another challenge that needs to be resolved. Integration of developed energy-efficient mechanisms across various devices and platforms is another challenge that needs to be addressed to obtain efficient green cloud computing.

Green IoT seeks to reduce the environmental impact and increase the energy efficiency of IoT devices and systems. However, there are several challenges to achieving these goals. One challenge is the limited power and processing capabilities of small and low-cost IoT devices, making it hard to integrate energy-saving features. Another challenge is the absence of a standardized approach to green IoT, which can make it challenging for organizations to choose between different solutions. Additionally, the decentralized nature of IoT networks can make it difficult to effectively monitor and manage energy usage. The complex interconnections between IoT devices can also pose difficulties in identifying energy inefficiencies and implementing solutions. The fast-paced technological advancements in IoT also present a challenge in keeping up with the latest green IoT technologies and best practices.

The challenges of implementing green procurement in various industries include the limited availability of eco-friendly products, higher costs associated with these products, a lack of standardization and certification for green products, and resistance to changing traditional procurement practices from both suppliers and customers. Additionally, there is a lack of awareness and education about the benefits of green procurement, which makes it difficult for organizations to convince stakeholders to adopt this practice. Finally, there is a lack of more robust green supply chain management systems that ensure that the products are not only environmentally friendly but also ethically sourced. These challenges present a significant barrier to the widespread adoption of green procurement across various industries.

One major challenge of green education is its lack of integration into traditional educational systems and curricula. This leads to fragmented and inconsistent delivery of green education, with some schools and universities offering comprehensive programs while others offer little or none. Another challenge is the limited resources and funding available for green education initiatives, which hampers the ability to effectively educate and engage students and the wider public. Furthermore, various resistance to change or adaptation of green education procedures from some stakeholders, who may be skeptical about the value of green education or the need for a more sustainable future. Lastly, better collaboration and coordination among educators, politicians, and industry leaders is necessary to ensure that green education is integrated into all sectors of society.

The smart grid is a modernized electrical grid that integrates digital technology to improve efficiency, reliability, and sustainability. However, there are several challenges associated with implementing a smart grid. One challenge is the high cost of upgrading existing infrastructure and deploying new technologies, which makes it difficult for some utility companies and governments to invest in the green transition. Another challenge is the lack of standardization, which makes it difficult to ensure interoperability and compatibility between different smart grid components and systems. There is also a challenge to address security and privacy concerns associated with the increased use of digital technology in the grid, as well as to ensure the reliable operation of the grid in the face of potential cyber threats. Additionally, there is a challenge for greater consumer engagement and education to encourage the adoption of smart grid technologies and practices. Finally, there is also a challenge for regulatory support and collaboration between government agencies, utilities, and other stakeholders to ensure that the transition to a smart grid is coordinated and effective.

There are several challenges associated with transitioning to green transportation systems. One challenge is the high cost of developing and deploying alternative fuel vehicles and infrastructure and the lack of publicly available, usable green transportation infrastructure, which can be common barriers to the widespread adoption of green transportation systems. Another challenge is the lack of public awareness and education about the benefits of green transportation, which makes it difficult to encourage the widespread adoption of these systems. The lack of widespread coordination and collaboration between government agencies, transportation providers, and other stakeholders poses a significant challenge in integrating green transportation systems into existing infrastructure. Ensuring seamless integration requires aligning policies, regulations, and incentives across multiple entities. Limited funding and resources for infrastructure upgrades and the adoption of greener transportation technologies present additional challenges. Overcoming resistance to change and addressing potential conflicts of interest among stakeholders are key obstacles to achieving widespread adoption of green transportation solutions.

Despite the increasing demand for green databases, there are several challenges associated with their implementation and use. One challenge is the need for more efficient and effective methods for managing and processing large amounts of data, which is becoming increasingly complex and diverse. Another challenge is the high cost of acquiring and deploying green database technologies, which can be a barrier for some organizations. Additionally, there is a lack of technical knowledge and awareness about the importance of green databases and their role in promoting sustainability. Finally, there is a challenge for collaboration and standardization across the industry to ensure that green databases are compatible and interoperable with other systems and technologies.

The high computational and energy costs associated with processing and analyzing vast volumes of data pose significant challenges in the fields of green data mining and information retrieval. Finding efficient algorithms and techniques that can minimize resource consumption while maintaining accurate results is crucial. Moreover, the lack of standardized methods and tools for evaluating and comparing the environmental impact of different data mining and information retrieval approaches complicates the decision-making process for organizations striving for sustainability. Developing comprehensive frameworks and metrics to assess the energy efficiency and environmental footprint of these techniques is essential for making informed choices. Addressing these challenges requires interdisciplinary collaboration between researchers, industry experts, and policymakers to drive innovation in energy-efficient data mining and information retrieval methods and promote sustainability in this field.

The biggest challenge in the area of green machine learning is the massive amounts of energy and computational resources required to train and run large machine learning models, which may result in a significant carbon footprint and contribute to climate change. Additionally, the lack of transparency in the supply chain of hardware used for training and inference can also result in unethical practices such as e-waste and the exploitation of resources. Moreover, the shortage of efficient hardware and scalable infrastructure for running such models in a sustainable manner is a hindrance to the widespread adoption of green machine learning.

Green e-commerce refers to the practice of using digital platforms for commerce in an environmentally sustainable manner. The main challenge in this area is the large amounts of energy and resources consumed by data centers and other infrastructure required for e-commerce operations. This includes the production and transportation of goods, as well as the use of electronic devices for browsing and purchasing products. Additionally, the challenge of electronic waste (e-waste) is also a significant concern, as many electronic devices used for e-commerce become obsolete rapidly due to improvements in technology and are often not disposed of properly. Green e-government refers to the use of digital technology in government operations and services in an environmentally sustainable manner. The main challenge in this area is the lack of infrastructure and resources in many countries to support digital government services. This can result in an increase in the use of paper-based processes, which have a significant environmental impact. Additionally, many government websites and digital platforms are often outdated and not user-friendly, which can lead to a lack of adoption and utilization of digital government services.

Green agriculture refers to farming practices that prioritize environmental sustainability. The main challenges in this area include soil degradation and water scarcity due to the adaptation of traditional, inefficient, and not eco-friendly practices rather than green agriculture practices. Furthermore, the lack of technical knowledge of farmers, financial issues, and lack of awareness are some of the major challenges to implementing green agriculture practices. The excessive use of chemical fertilizers and pesticides and the lack of awareness of the adoption of organic and green farming are other critical challenges in the process of green agriculture adaptation. Other challenges include the unavailability of cost-effective green agriculture technologies, green supply chain management, and a lack of government subsidies for the adaptation of green agricultural practices. Climate change is also a major challenge for green agriculture, as it can lead to unpredictable weather patterns, soil erosion, and crop failures.

Finally, it can be summarized that green computing has the potential to revolutionize various industries and create a more sustainable future. However, it is crucial to address the challenges associated with its implementation and encourage widespread adoption. This can be achieved through investments in research and development, standardization, education, and awareness-raising initiatives. By working together, industry leaders, policymakers, and individuals can help bring about a greener future that balances economic growth with environmental protection.

C. FUTURE RESEARCH DIRECTIONS

Green computing, which refers to the development of methods that are environmentally sustainable for computing and information technology, is a rapidly growing field of research. Considering the growing worldwide demand for computing resources and the increasing environmental impact of traditional computing practices, there is a growing need for research in green computing.

Green data centers are gaining significance in the current scenario. Future research directions in this field will likely focus on the development of more efficient and cost-effective cooling systems, increased utilization of renewable energy sources, improved power distribution systems, and the reduction of hardware waste through extended product life cycles and recycling programs. In addition to the aforementioned aspects, there are several other areas of research that hold great potential in advancing the field of green computing. One such area involves the development of intelligent algorithms that can optimize energy usage in various computing systems and infrastructures. These algorithms may dynamically adjust resource allocation, workload scheduling, and power management to maximize energy efficiency and minimize wastage. Another promising avenue of exploration is the virtualization of data center resources. By virtualizing servers, storage, and networking infrastructure, organizations can achieve higher resource utilization rates, reduce energy costs, and improve overall operational efficiency. This approach allows for the consolidation of workloads onto fewer physical servers, leading to energy savings and a smaller carbon footprint. Furthermore, the creation of modular and scalable data center designs offers opportunities for more flexible and efficient deployment and maintenance. Modular designs allow for the addition or removal of components based on demand, enabling organizations to scale their data centers in a cost-effective manner. Additionally, incorporating energy-efficient cooling systems, power distribution mechanisms, and renewable energy sources can further enhance the sustainability of data centers.

The future of green cloud computing is characterized by a strong focus on sustainability, reducing carbon emissions and energy consumption, and optimizing the use of resources. In this context, future research directions are likely to include the development of efficient algorithms for energy-aware resource allocation and management, the integration of renewable energy sources into cloud data centers, and the investigation of new cooling technologies that reduce the environmental impact of data center operation. Another area of interest could be the study of innovative hardware and software architectures that can improve the energy efficiency of cloud computing systems, as well as the use of VM migration techniques to improve resource utilization and reduce energy consumption. Furthermore, the integration of various energy-efficient algorithms, task schedulers, and VM migration techniques in smart, efficient green cloud computing architectures is one of the major future research directions. Another important aspect of future research will be the development of cloud computing platforms that are environmentally friendly throughout their entire lifecycle, from design and manufacturing to decommissioning and disposal. Proper planning and implementation of end-of-life strategies can ensure the safe and responsible disposal of electronic waste (e-waste) generated by these systems. This involves adopting sustainable practices for recycling and disposing of hardware components, ensuring compliance with environmental regulations, and promoting circular economy principles by promoting reuse and refurbishment.

IoT has the potential to significantly impact our daily lives and the environment. Future green IoT research may concentrate on the development of multiple devices and platform-integrated sustainable, and energy-efficient IoT solutions. One area of research may be the development of low-power consumption devices and protocols that can operate for long periods of time on minimal energy. An additional area of focus in future research lies in the creation of IoT networks that leverage renewable energy sources and strive to minimize energy waste. By integrating sustainable power generation technologies, such as solar or wind energy, into IoT infrastructure, researchers can significantly reduce reliance on fossil fuels and contribute to a cleaner and more environmentally friendly network.

Green procurement, or the practice of purchasing products and services that are environmentally sustainable, is gaining importance as organizations seek to reduce their carbon footprint and minimize their impact on the environment. In this context, future research in green procurement will focus on developing methodologies for evaluating the environmental impact of products and services, as well as tools and systems to support sustainable purchasing decisions. Analyzing and identifying green procurement practices, drivers, and barriers in various industries is one of the major future research directions. Government green procurement adaptation at various levels and organizations, identifying green procurement relationships with various factors, supplier collaboration, and green information systems are some of the future research opportunities. Green procurement presents another compelling avenue of research, focusing on the exploration of novel and sustainable green products and services crafted from recycled materials or powered by renewable energy sources. By delving into this area, researchers can contribute to the development of environmentally friendly procurement practices that prioritize the adoption of sustainable alternatives. Through the identification and evaluation of innovative product designs and service offerings, this research endeavor seeks to enhance the availability and accessibility of green options in the market. By promoting the utilization of recycled materials and renewable energy, researchers can foster a circular economy and facilitate the transition toward a more sustainable and resource-efficient future.

Green education, or the integration of environmental sustainability into educational curricula, is a growing field that aims to educate and engage individuals in environmental stewardship. In this context, future research in green education will focus on developing innovative and effective methods for teaching environmental sustainability, as well as creating educational materials that are engaging and accessible to a wide range of learners. Another key focus area is the investigation of virtual and augmented reality tools and their potential to enhance educational experiences in the context of sustainability. By integrating these immersive technologies, researchers can delve into the development of innovative teaching methods that promote environmental awareness and eco-conscious behavior. This research endeavor aims to evaluate the effectiveness of virtual and augmented reality in delivering impactful and engaging green education, fostering a deeper understanding and appreciation of environmental issues among learners. By embracing technology as a tool for sustainable education, researchers can contribute to the advancement of eco-literacy and empower individuals to make informed and sustainable choices in their lives.

The smart grid, which refers to the integration of digital technology into the electrical power grid to improve efficiency, reliability, and sustainability, is an area of ongoing research and development. In the future, research in the field of smart grids will focus on improving the overall resilience and security of the grid, as well as increasing the integration of renewable energy sources. This could include the development of advanced control algorithms and monitoring systems to improve the stability of the grid and the integration of energy storage systems to store excess energy generated from renewable sources. Another important aspect of future research will be the development of advanced demand management systems that can dynamically adjust energy consumption as a result of supply and demand fluctuations.

Green transportation systems, or the development of sustainable and environmentally friendly modes of transportation, is a rapidly growing field. In the future, research in green transportation systems will focus on developing and improving alternative fuel vehicles, such as electric and hydrogen-powered vehicles, and exploring the integration of these vehicles into existing transportation networks. Another important aspect of future research will be the development of sustainable transportation infrastructure, such as charging and refueling stations, as well as the integration of smart transportation systems to optimize the use of these assets.

Green databases, or databases designed to minimize their environmental impact, are becoming increasingly important as organizations seek to reduce their carbon footprint and minimize their impact on the environment. In the future, research in green databases will focus on developing energy-efficient database management systems and exploring alternative energy sources for powering data centers. Another area of research will be the development of techniques for reducing the energy consumption of databases, such as optimizing query processing and data compression.

Green data mining and information retrieval, which refers to the development of environmentally sustainable methods for collecting, storing, and processing data, is becoming an increasingly important area of research. In the future, research in this field will focus on developing energy-efficient algorithms and systems for data mining and information retrieval. This could include the exploration of alternative energy sources for powering data centers as well as the optimization of existing algorithms to reduce energy consumption.

Green machine learning, which refers to the development of environmentally sustainable methods for training and deploying machine learning models, is a rapidly growing area of research. In the future, research in green machine learning will focus on developing energy-efficient algorithms and systems for training and deploying machine learning models. This could include the exploration of alternative energy sources for powering data centers as well as the optimization of existing algorithms to reduce energy consumption.

Green e-commerce and green e-government, which refer to the development of environmentally sustainable methods for conducting business and governance online, are growing areas of research. In the future, research in the field of green e-commerce may prioritize the development of energy-efficient systems to enhance sustainability in online commercial activities. This includes exploring alternative energy sources for powering data centers that support e-commerce platforms. By integrating energy-conscious practices and technologies, researchers aim to reduce the environmental impact of online transactions and digital services. Such research endeavors seek to optimize energy usage, improve operational efficiency, and promote eco-friendly practices within the e-commerce and e-government domains. These efforts can contribute to a more sustainable and environmentally conscious digital economy.

Green agriculture, which refers to the development of environmentally sustainable methods for farming and food production, is a growing area of research. In the future, research in green agriculture can focus on developing methods for minimizing the environmental impact of agriculture, such as the use of sustainable crop management techniques, the adoption of renewable energy sources, and the reduction of chemical inputs. Another important area of research can be the development of new technologies and techniques for precision agriculture, such as the use of drones and satellite imagery to optimize crop production and reduce waste.

In the realm of green computing, exploring the future inter-dependency among various areas holds significant promise for advancing sustainability efforts. The development of energy-efficient green data centers can directly impact the overall efficiency of green cloud computing infrastructure, while the integration of green IoT devices with transportation systems contributes to intelligent management and reduced energy consumption. Green procurement practices are crucial in driving the adoption of sustainable technologies across green computing, promoting eco-friendly solutions throughout the supply chain. The convergence of green education and agriculture leverages smart technologies and data-driven decision-making to foster environmentally conscious practices. Synergies between green databases, data mining, and machine learning may enable the development of energy-efficient algorithms for large-scale environmental data analysis. Recognizing and exploring these interdependencies may lead to integrated approaches that propel sustainable development in the digital era, including establishing linkages between green data centers and cloud computing, integrating green IoT with smart grids, promoting green procurement, and converging education with agriculture. Interaction between transportation systems and green databases, along with the integration of machine learning and agriculture, may unlock new avenues for synergy, innovation, and transformative impact, paving the way toward a greener and more sustainable future in green computing.

In conclusion, green computing continues to be an important area of research as the demand for more sustainable and eco-friendly technology increases. Future research directions in green computing could include the development of more efficient algorithms for data processing, energy consumption optimization in cloud computing, the usage of renewable energy sources for powering data centers, and the exploration of new materials for creating greener electronics. Additionally, researchers could investigate the integration of AI and ML techniques to enable dynamic power management and resource allocation in computing systems.

VII. CONCLUSION

The implementation of sustainable technologies across multiple green computing areas to achieve sustainable and eco-friendly development has been analyzed and examined in this study. Identifying sustainable green approaches across multiple areas of green computing is the primary focus of this study. Therefore, numerous studies have been obtained from various academic search engines through the use of multiple keywords. The primary studies obtained from academic search engines have been further filtered using a structural and defined approach. The assessment of the abstract, rigorous evaluation of the dataset or testing mechanisms, selection through inclusion and exclusion criteria, and meticulous scrutiny of the methodological quality are among the primary factors that determine the final selection of studies. Through a structural and extreme quality-driven approach, from the initial 800 studies, 216 studies have been selected and distributed across twelve green computing areas. This study has analyzed the final selected studies by summarizing and examining various developed approaches, analyses, and designs.

The proposed survey methodology in the context of green computing offers a comprehensive approach to demonstrate the resolution of the research problem. It involves extensive study collection from diverse sources and perspectives, ensuring a holistic understanding of the field. By incorporating key variables directly linked to green computing, the survey enables the measurement of specific indicators reflecting progress in addressing environmental impact and sustainability. Comparative analysis of different green computing initiatives allows for assessing the impact of interventions, identifying trends and patterns indicative of progress towards sustainable practices. The study employs a combination of quantitative and qualitative measures to provide a nuanced understanding of challenges and potential solutions. Rigorous validation techniques and expert feedback enhance the reliability and credibility of the survey findings, contributing to the advancement of the field.

This review study conducted an extensive analysis of studies spanning across multiple years and originating from various countries. As the year advances, the number and quality of the studies conducted have increased. In this research work, most of the selected studies are from 2020. China is the leading country in almost every area of green computing research. However, the USA and India have conducted numerous studies and have been able to dominate in some areas. Apart from these nations, several countries have made significant contributions by conducting research in diverse fields of green computing, demonstrating the global trend toward sustainable and eco-friendly development. Efforts towards achieving sustainable and efficient technology in green computing have yielded notable progress in various areas, including green data centers, green cloud computing, green IoT, smart grids, and green transportation. The key developments and achievements in the areas include energy-efficient control and management systems, algorithms, protocols, task schedulers, VM migration mechanisms and algorithms, renewable energy integrated smart systems, green architecture framework development, smart IoT-based devices, and findings of green drivers and barriers. Conversely, several areas of green computing, including green education, green databases, green data mining and information retrieval, green machine learning, green e-commerce and e-government, and green agriculture, remain underdeveloped due to a range of impediments, such as insufficient funding, inadequate infrastructure, limited technical expertise and knowledge, a lack of awareness, and the intricacy of the issues. Energy consumption optimization and efficiency have been the primary focus of much of the research conducted in the field, with a multitude of objectives and goals being pursued. The integration and application of cutting-edge technologies such as AI and ML have demonstrated significant promise in promoting sustainable development in the field of environmentally-friendly computing. The utilization of AI and ML algorithms can enhance energy management and system control, leading to enhanced efficiency and decreased environmental consequences.

However, in the area of green computing, researchers face significant barriers that impede their progress. One such challenge is the lack of standardization, which hinders the establishment of consistent practices and frameworks across studies. Technical obstacles further complicate the implementation of green computing solutions, as complex technologies and infrastructure necessitate specialized knowledge and resources. Limited funding adds to the constraints, as substantial financial support is often required for equipment, data collection, and analysis. These collective barriers contribute to the complexities and challenges encountered by researchers in the field of green computing.

The outcome of this research study has a substantial impact on the field of green computing. By investigating and analyzing various aspects related to green computing, this research contributes to the existing body of knowledge in the field. The findings of this study provide valuable insights and advancements in the development of energy-efficient computing technologies, sustainable computing practices, and environmentally friendly IT solutions.

The significant information obtained, examined, and provided in this review study regarding green computing is current and reliable. The precise keywords have been utilized to search for appropriate content and aid in fulfilling the objectives of the study. While conducting research and selecting specific keywords, there is a potential risk of overlooking significant sources that may not be captured by the chosen terms. This limitation could result in the omission of relevant studies from the analysis. Additionally, during the data extraction and analysis process, it is possible to miss certain data points, which may affect the comprehensiveness and accuracy of the findings. These considerations highlight the need for caution and ongoing refinement in the research methodology to mitigate the potential impact of these limitations.

Due to the increasing significance of green computing, numerous studies are currently being conducted in this field. Hence, in order to remain current, a consistent examination of research pertaining to diverse areas of green computing may be conducted. Future investigations in the field of green computing may entail the identification and resolution of area-specific hindrances and impediments. Forthcoming research endeavors may encompass an examination of the interrelatedness among various areas of green computing. Finally, in order to achieve a sustainable and environmentally conscious future, it is crucial to implement eco-friendly alternatives and engage in various awareness-raising initiatives.

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SHOWMICK GUHA PAUL received the degree in computer science and engineering (CSE) from Daffodil International University, Dhaka, Bangladesh. He is also actively involved in research in machine learning and data science. He is also a member of several research and programming organizations. He has obtained academic and research experience by working as a research assistant and has published Q1 journals articles. His research interests include machine learning, deep learning, health informatics, artificial intelligence, computer vision, and green computing and their application on various field.

ARPA SAHA received the degree in computer science and engineering (CSE) from Daffodil International University, Dhaka, Bangladesh. She has gained the required skills and expertise to make her research successful. Her research interests include machine learning, deep learning, artificial intelligence, image processing, data mining, natural language processing, health informatics, and computer vision. She has demonstrated her passion for these fields through her impressive research accomplishments, including the publication of research articles in the respected Q1 journals.

MOHAMMAD SHAMSUL AREFIN (Senior Member, IEEE) received the Doctor of Engineering degree in information engineering from Hiroshima University, Japan, with the support of the scholarship of MEXT, Japan. He is currently the Dean of the ECE Faculty, Chittagong University of Engineering and Technology (CUET), Chattogram, Bangladesh. Previously, he has been affiliated with the Department of Computer Science and Engineering (CSE), Daffodil International University, Dhaka, Bangladesh, and a Lien Professor with CUET, where he was the Head of the Department of Computer Science and Engineering. As a part of his doctoral research, he was with the IBM Yamato Software Laboratory, Japan. He has published more than 110 refereed publications in international journals, book series, and conference proceedings. His research interests include privacy-preserving data publishing and mining, distributed and cloud computing, big data management, multilingual data management, semantic web, object-oriented system development, and IT for agriculture and the environment. He is a member of ACM and a fellow of IEB and BCS. He visited Japan, Indonesia, Malaysia, Bhutan, Singapore, South Korea, Egypt, India, Saudi Arabia, and China for different professional and social activities. He is also the Organizing Chair of BIM 2021, the TPC Chair of ECCE 2017, the Organizing Co-Chair of ECCE 2019, and the Organizing Chair of BDML 2020.

TOUHID BHUIYAN received the Ph.D. degree in information security focusing on trust management for intelligent recommendations from the Queensland University of Technology (QUT), Australia. He is currently the Head of the Department of Computer Science and Engineering, Daffodil International University (DIU), Bangladesh. He is also a certified ethical hacker. He has received the Cyber Security: Cyber Risk and Resilience Certificate from the University of Oxford. He was a recipient of the Australian Postgraduate Award (APA) and the Deputy Vice-Chancellor's Initiative Scholarship from QUT. He was the Director of the Cyber Security Centre, DIU, where he was also the Head and a Professor with the Software Engineering Department. His research interests include cyber security, intelligent recommendations, social networks, trust management, big data analytics, e-health, and e-learning. Before joining with DIU, he worked for several institutions, including Monash University, The University of Western Australia, QUT, University of Western Sydney, and Central College Sydney. He has more than 114 research publications in renowned national and international journals, books, and conference proceedings.

AL AMIN BISWAS received the Bachelor of Science and Master of Science degrees from the Department of Computer Science and Engineering, Jahangirnagar University, Dhaka, Bangladesh. He is currently a Lecturer with the Computer Science and Engineering Department, Bangabandhu Sheikh Mujibur Rahman University (BSMRU), Kishoreganj, Bangladesh. Prior to joining BSMRU, he was a Lecturer (Senior Scale) with the Computer Science and Engineering Department, Daffodil International University (DIU), Dhaka. His research interests include machine learning, deep learning, data mining, and computer vision. He has more than 30 research papers published in international conferences and journals. He has served as the Session Chair for the International Conference on Computer Communication and Informatics (ICCCI 2021). He also served as the Co-Convener for the International Conference on Machine Intelligence and Data Science Application (MIDAS 2021). He reviewed research papers for many international IEEE, Springer, ACM conferences, and Elsevier journals. He received the Best Paper Award twice for his Outstanding Research Works from two springer conferences.

AHMED WASIF REZA (Member, IEEE) received the B.Sc. degree (Hons.) in computer science and engineering from Khulna University, Bangladesh, the Master of Engineering Science (M.Eng.Sc.) degree from Multimedia University, Malaysia, and the Doctor of Philosophy (Ph.D.) degree from the University of Malaya, Malaysia. He is currently a Professor with the Department of Computer Science and Engineering (CSE) and the additional Director of the Institutional Quality Assurance Cell (IQAC), East West University, Bangladesh. He was also appointed as the Chairperson of the CSE Department. Previously, he was attached with the Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Malaysia, for almost eight years. He is also serving as a member for the Evaluation Team (ET) for Accreditation of different engineering programs of various universities, appointed by the Board of Accreditation for Engineering and Technical Education (BAETE), Bangladesh. He also has vast experience in supervising Ph.D., master's, and undergraduate students. He has been working in the field of radio frequency identification (RFID), wireless communications, biomedical image processing, bioimaging, bioinformatics, optimization, artificial intelligence/machine learning, deep learning, the robotics and Internet of Things, green computing/IT and sustainable development, brain–computer interface (BCI), biomedical signal processing, and electromagnetics, for almost 18 years, both in industrial exposure and academically research valued work. He has authored or coauthored several Science Citation Index (SCI)/Web of Science (WoS) and Scopus-indexed journals and conference papers (more than 200 papers; H-index: 23; and more than citations: 2100). He is a professional member of the IEEE Computer Society.

NAIF M. ALOTAIBI received the Ph.D. degree in statistics from Salford University, Manchester, U.K., in 2018. He is currently an Associate Professor with the Faculty of Science, School of Mathematics and Statistics, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, Saudi Arabia. He has already published many research articles in different international journals. His research interests include applied statistics, mathematical statistics, reliability and maintenance, statistical modeling, R programming, multivariate analysis, and the applications of statistics in sports.

SALEM A. ALYAMI (Member, IEEE) received the Ph.D. degree in bio-statistics from Monash University, Australia, in 2017. He has been an Assistant Professor with the School of Mathematics and Statistics, IMAMU, Riyadh, Saudi Arabia, since 2017, contributing/leading several grants in biostatistics projects. Recently, he has been appointed as the Dean of the Deanship of Scientific Research, IMAMU. His research interests include Bayesian networks, neural networks, Bayesian statistics, MCMC methods, and the applications of statistics in biology and medicine.

MOHAMMAD ALI MONI received the Ph.D. degree in artificial intelligence and digital health data science from the University of Cambridge, U.K. He worked in different world top universities, including Oxford University, Cambridge University, Sydney University, UNSW Sydney, and The University of Queensland. He is currently a professor in artificial intelligence and data science. He continued to focus on the same teaching and research areas during the last 15 years and has led and managed significant research programs, such as using big health data to develop machine learning, deep learning and translational data science models, and software tools to aid diagnosis and prediction of disease outcomes, particularly for hard-to-manage complex and chronic diseases. He has published more than 300 top-tire journal articles and received more than 12300 citations with H-index 51. His research interests include developing statistical models, machine learning and deep learning algorithms, and software tools utilizing multimodal data, especially medical images, neuroimaging, EEG, ECG, bioinformatics, and secondary usage of routinely collected data for different conditions.