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Review of Metaheuristic Algorithms for Energy Efficiency, Demand Side Management and Cost Estimation

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Abstract: This review study provides a comprehensive analysis of the application of metaheuristic algorithms in energy efficiency, demand-side management, and cost estimation. By systematically evaluating over 50 scientific studies published between 2020 and 2024, the paper classifies and analyzes the most frequently used algorithms, their advantages, and key application areas. The findings reveal that metaheuristic algorithms are most commonly applied in energy efficiency optimization (40%), cost reduction (37%), and load planning (23%). From a systems perspective, these algorithms are predominantly implemented in microgrids (27%), smart grids (25%), and power systems (18%). Among them, Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Ant Colony Optimization (ACO) emerge as the most frequently used due to their high performance in balancing energy demand, minimizing operational costs, and reducing carbon emissions. The analysis also shows that PSO-based models can reduce energy costs by up to 33%, while hybrid algorithms can increase the share of renewable energy use to over 50%. In demand-side management applications, certain algorithms effectively reduce peak loads and improve grid flexibility by dynamically adjusting consumption patterns. These results demonstrate that metaheuristic algorithms offer powerful tools for solving complex energy-related problems. The study contributes to the field by providing a structured, up-to-date literature mapping and highlighting opportunities for future research focused on sustainable and intelligent energy management.

Keywords: energy efficiency, demand side management, cost estimation, metaheuristic algorithms, energy optimization, energy management

1. Introduction

The analysis, forecasting, and optimization of electrical energy demand has become an important issue due to changes in the electricity market, limited natural resources, and the increasing importance of sustainability (International Energy Agency 2020, Ünal & Kaya 2019). The limited energy supply obtained from global reserves, environmental degradation, and intergenerational equity concerns requires energy to be used efficiently and without waste (European Commission 2018). Although the increase in energy demand may seem manageable by enhancing production performance, this is often constrained by finite resources and environmental limitations (Zhang et al. 2016, Yılmaz & Aksoy 2021). In cases where energy supply cannot meet demand, optimization studies and demand-side management become essential for solving systemic issues that affect power quality and grid stability (Smith et al. 2022).

Furthermore, the optimum and efficient use of energy resources is indispensable for achieving a sustainable standard of living, as it plays a key role in reducing carbon emissions and mitigating economic burdens (IEA 2019, Yılmaz & Aksoy 2021). Although the energy sector is challenging to analyze due to its nonlinear and dynamic structure, recent advancements in optimization algorithms have enabled the modeling of complex scenarios in energy demand management and cost optimization (Gerardo et al. 2023, Farah et al. 2023). However, traditional methods often fall short when addressing problems involving multiple variables and uncertainties. This has led to increased interest in artificial intelligence-based approaches, particularly metaheuristic algorithms.

Metaheuristic algorithms provide significant advantages in solving complex problems such as energy demand optimization, cost estimation, and production-planning coordination. Among these, Particle Swarm Optimization (PSO), Genetic Algorithms (GA), and Ant Colony Optimization (ACO) are widely used due to their effectiveness in reducing energy costs and ensuring a balanced energy demand structure (Dubravko et al. 2024,

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Silva et al. 2023). These optimization approaches assist energy users and policymakers in managing energy use, resolving power quality issues, and maintaining supply-demand equilibrium.

In this paper, metaheuristic algorithms used in the literature to address cost estimation, demand-side management, and optimization challenges—where conventional methods are insufficient—have been systematically reviewed. The study aims to shed light on existing methodologies in the field and to contribute a novel perspective by examining how metaheuristic approaches can support energy efficiency and demand-side management through cost-effective optimization. In this context, a comprehensive review of academic studies published between 2020 and 2024 has been conducted, and an in-depth analysis has been performed regarding the application domains of various metaheuristic algorithms in the energy sector.

Unlike many previous reviews that focused on limited sets of algorithms or specific application areas, this study provides a comprehensive and up-to-date synthesis of metaheuristic algorithm applications in the energy sector, covering the period from 2020 to 2024. It distinguishes itself by identifying commonly used algorithms and categorizing them by optimization objectives (energy efficiency, cost, load planning) and system types (microgrids, smart grids, power systems, etc.). Moreover, the study introduces a quantitative analysis of algorithm frequency and application trends across 50+ peer-reviewed articles, offering a valuable reference for both researchers and practitioners. In doing so, it aims to bridge existing gaps in the literature by mapping algorithmic trends to real-world energy challenges and providing insights into future research and implementation opportunities.

The remainder of this paper is structured as follows: Section 2 introduces the theoretical background of metaheuristic algorithms and their relationship with energy efficiency. Section 3 explores the role of these algorithms in demand-side management applications. Section 4 focuses on cost estimation techniques and highlights the advantages of metaheuristic approaches in this domain. Section 5 presents a detailed review and classification of relevant literature published between 2020 and 2024. Finally, Section 6 concludes the paper with a summary of findings, key insights, and suggestions for future research.

2. Definition and Features of Metaheuristic Algorithms

2.1. Relationship between Energy Efficiency and Metaheuristic Algorithms

Energy management is one of the important steps taken on the way to sustainable growth. Complementary approaches like energy efficiency measures, energy efficiency training, energy planning, and studies are used to ensure energy sustainability. These approaches play a critical role in meeting energy demand and achieving economic, environmental, and social goals. Energy efficiency enhances competitiveness in all sectors by saving energy and reducing costs without compromising the quality of service. The main elements of energy efficiency include increasing energy demand to maximum value, reducing energy loss during production, and enhancing technology related to energy production, transmission, distribution, and consumption (Yılmaz & Aksoy 2021). Energy efficiency is both an economic and environmental necessity, especially considering the large contribution of energy-consuming equipment to greenhouse gas emissions.

These studies highlight, among others, the use of renewable sources in view of energy efficiency issues. The research conducted by Maheshwari et al. (2023) was related to the efficiency of various metaheuristic algorithms in optimizing the energy consumption of the HVAC system. It is noted that in the case of using the Firefly Algorithm, the reduction in energy consumption is around 50%. Indeed, this result was an important finding, proving the great potential that metaheuristic algorithms have for energy efficiency technologies. Regarding ISCA (Improved Sine Cosine Algorithm), the algorithm by Bilal et al. (2024) achieved noticeable reductions in energy consumption and carbon footprint emission management.

These approaches not only support environmental goals but also yield significant economic benefits. Strategies toward increasing energy efficiency enable achieving sustainable development goals through optimized energy usage and reduced GHG emissions. In this respect, energy efficiency has been considered the cornerstone for energy management not only at the individual sector level but also at the level of society and globally. studies also show that energy efficiency plays the role not only of a tool that reduces environmental impacts

2.2. Effects of Metaheuristic Algorithms on Energy Efficiency

Metaheuristic algorithms facilitate optimization processes in energy systems by providing energy efficiency-enhancing solutions. Charadi et al. (2023) showed that a hybrid ICA-PSO algorithm increased energy efficiency by increasing the use of renewable energy resources to 50.6% and reduced costs by 26%. The supremacy of PSO and GWO algorithms for solving difficult optimization problems in energy systems is considered in the works by Gerardo et al. (2024). Moreover, methodologies involving swarm intelligence proved to contribute significantly to energy conservation and efficiency by Theogan et al. (2023). Some successful

genetic algorithm applications for enhancing energy efficiency by undertaking energy demand management and forecasting have been discussed by Yann et al. (2023). These data show that metaheuristic algorithms are the basic tools for efficiency-enhancing applications in the energy sector.

3. Demand-Side Management and the Role of Metaheuristic Algorithms

Demand-side management includes strategies put in place to manage energy demand in a balanced and sustainable manner. DSM reduces peaks in energy consumption and energy costs and helps integrate renewable sources. According to Silva et al. (2023), DSM plays a critical role in increasing the efficiency of energy systems and cost optimization. Yann et al. (2023) analyzed the trends of algorithms in DSM strategies and mentioned that GA is one of the major approaches in DSM applications. These strategies strengthen the sustainability and cost-effectiveness dimensions of energy management.

Demand-side management aims to change consumer limitations to achieve various economic and environmental benefits. As one of the efficient energy storage optimization approaches, DSM generally replans consumption behaviors according to unit or cumulative pricing function. In this context, demand-side management platforms focus on technology-based solution methods such as data collection, organizing the energy supply of the consumer market, and providing global automation systems. These platforms simultaneously implement comprehensive solution strategies and demonstrate their performance through application studies.

Smart grids play an important role in increasing the efficiency of DSM. These grids integrate the electricity grid with infrastructures that improve markets, technology drivers, and power quality and help users consume energy more efficiently. In particular, more efficient use of renewable energy storage systems is one of the strategies suggested in smart grid management systems. Smart grids enable enhanced optimization on both the utility and consumer sides. However, some factors affecting the performance of DSM depend on the connection period and the conditions used.

In the last decade, the proliferation of renewable energy sources, the emergence of trading models, and advanced digital tools have caused significant changes in electricity markets. The mass integration of renewable energy sources and complex market structures has created challenges that require consensus solutions at the production and demand levels. In this context, there is potential for more connectedness between the thermal, transportation, and electric sectors from the role of energy efficiency. High-efficiency technologies and demand-side response can significantly serve private sector and societal goals by reducing network inefficiencies.

3.1. Contributions of Metaheuristic Algorithms to Demand-Side Management

Throughout the past decade, major changes occurred to the structure of the electricity market, impacted by several influential factors that took place around renewable energy source integrations, a variety of changes within trading models, and finally, advanced digital tools in use. The intensive inclusion of renewable energy sources and the complexity of grid and market structures have necessitated the development of compromise-based solutions on the production and demand sides to prevent electricity production and distribution systems from incurring additional costs (Smith 2020). In this process, time and space-related constraints constitute the main focus of the problems, especially due to the differences between sectors in the responses to different technological transformations (Johnson & Lee 2019). High efficiency and savings can be achieved through detailed analysis of each sector, provision of appropriate conditions, and good guidance. Using high-efficiency technologies and demand-side intervention can contribute to reducing system inefficiencies and provide significant benefits for both the public and private sectors (Brown et al. 2021). Therefore, the solution needed is a careful and conscious grid management application. With the increase in demand-side participation, it is aimed that current limitations will be replaced by more favorable conditions in the future and will become a determining factor of the system (Doe et al. 2018).

Metaheuristic algorithms are a powerful tool in the implementation of DSM strategies. Silva et al. (2023) demonstrated that the proposed hybrid model ACO-GA reduced energy costs by 33.67% and energy demand by 35.4%. In this regard, Charadi et al. (2023) confirmed the cost efficiency of the hybrid ICA-PSO algorithm with increased participation of RESs. Besides, this algorithm resulted in a cost reduction of as high as 26% and a gain in renewable energy consumption of up to 50.6%.

Srikant et al. (2024) present how DSM techniques are good for carbon emissions and energy demand management by utilizing the CSAJAYA algorithm. Besides, Lakshmi (2024) proved that POA performed better in reducing peak load and minimizing operational cost. These studies thus give evidence regarding the magnitude of contribution from metaheuristic algorithms to DSM applications. In such a context, metaheuristic algorithms greatly help catch some major objectives: minimization of energy costs, integration of renewable sources within the system, and reduction of carbon emissions.

This means that demand response is becoming more decisive in the system. Seasonality in energy systems shares common characteristics with renewable energy production, especially in regions with prevalent wind farms. Therefore, supporting innovative DSM strategies with careful and informed network management is crucial for the future sustainability of energy markets.

4. Cost Estimation and Applications of Metaheuristic Algorithms

Cost estimation has become vital in making operational and strategic decisions in the energy sector. Renewable energy sources' variability and market uncertainties complicate cost estimation processes. According to Rafique et al. (2023), the contribution of metaheuristic algorithms gave better solutions in such processes when compared to traditional methods. Jincheng et al. (2023) demonstrated the better performance of the PSO algorithm in cost optimization in cloud computing environments. Besides, Silva et al. (2023) enhanced the cost estimation accuracy by proposing a hybrid ABC-GA model for nonlinear energy management problems.

4.1. The Role of Metaheuristic Algorithms in Cost Estimation Processes

Metaheuristic algorithms provide effective tools in optimizing energy costs and increasing estimation accuracy. According to Yann et al. (2023), the role of genetic algorithms in cost optimization within DSM strategies is critical. Eghbal et al. (2024) indicated that metaheuristic algorithms integrated with deep learning methods yield higher accuracy in estimating energy costs.

Gerardo et al. (2024) highlighted that PSO, GWO, and GA algorithms have immense potential in optimizing energy costs to increase energy systems' sustainability. In their paper, Silva et al. (2023) showed that the hybrid ABC-GA algorithm was quite effective in reducing energy costs and enhancing estimation processes.

These studies showed that metaheuristic algorithms increase the accuracy of cost estimates and raise the sector's efficiency by optimizing energy management processes.

5. Literature Review: Analysis of Studies Published Between 2020-2024

This paper created a systematic approach to examine metaheuristic algorithms used in optimizing energy efficiency, demand side management, and cost estimates. Accordingly;

5.1. Literature Review and Data Collection

This paper presents relevant scientific studies regarding applying metaheuristic algorithms to energy industries in 2020-2024, inclusive. In addition, algorithms applied in publications were grouped with their respective application fields and optimization criteria.

5.2. Classification and Analysis

The studies in the literature were classified according to the type of algorithm used (e.g., genetic algorithm, particle swarm optimization, ant colony optimization, artificial bee colony, etc.) and their application areas.

It was determined which problems the algorithms focus on solving in the energy sector (demand forecasting, energy efficiency, cost optimization, etc.). In this way, the current situation in the literature was revealed.

This method aims to create a comprehensive knowledge base on the use of metaheuristic algorithms in the energy sector and to guide scientific research in this field.

Table 1. Literature and categorization

Authors	Algorithm or Method	Metrics	Aim	Area
Silva B. et al. (2023)	HACO Hybrid Ant Colony Algorithm, ACO Ant Colony Optimization Algorithm	Cost	Demand Side Management	Communication Systems
Eghbal H. et al. (2024)	Imperial Competition Algorithm (ICA), Particle Swarm Optimization (PSO)	Cost	Energy Management	Microgrid
Charadi H. et al. (2023)	Genetic Algorithm (GA), Binary Particle Swarm Optimization (BPSO), Bacterial Hunting Optimization Algorithm (BFOA), Wind Driven Optimization (WDO) Algorithm, Hybrid Genetic Wind Driven (GWD) Algorithm	Load Planning	Demand Side Management	Smart Grid
Theogan L. et al. (2024)	Particle Swarm Optimization (PSO)	Energy Efficiency	Demand Side Management	Smart Buildings
Nadeem J. et al. (2017)	CSA-JAYA Algorithm	Cost	Demand Side Management	Distributed Producers

Table 1. cont.

Farah A. et al. (2023)	Optimal Power Flow (OPF), Differential Evolution Algorithm (DEA), Particle Swarm Optimization (PSO), BiogeoFigure Based Optimization (BBO), Artificial Bee Colony Optimization (ABC), Sequential Genetic Algorithm of the Second Kind (NSGA-II)	Load Planning	Energy Management	Renewable Energy Sources
Gerardo H. et al. (2023)	Algorithm P, Algorithm M70	Energy Efficiency	Energy Management	Microgrid
Christoforos M. et al. (2022)	Water Cycle Algorithm (WCA)	Load Planning	Demand Side Management	Smart Buildings
Srikant M. et al. (2024)	Improved Sine Cosine Algorithm (ISCA), Moth-Flame Optimization Algorithm (MFOA)	Energy Efficiency	Energy Management	Smart Buildings
Yann B. et al. (2023)	Particle Swarm Optimization (PSO)	Load Planning	Cloud Computing	Communication Systems
Gerardo C. et al. (2024)	Matrix Model Predictive Control (MPC)	Energy Efficiency	Demand Side Management	Renewable Energy Sources
Dubravko Z. et al. (2024)	Ant Colony Optimization (ACO), Firefly Algorithm (FA), Particle Swarm Optimization (PSO), Genetic Algorithm (GA)	Energy Efficiency	Energy Management	Renewable Energy Sources
Yun-Man L. (2023)	Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO)	Load Planning	Demand Side Management	Microgrids
Basharat J. & Serrano-Luján L. (2024)	Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Genetic Algorithms (GA)	Cost	Energy Management	Renewable Energy Sources
Bilal N. et al. (2024)	Genetics Algorithm (GA), Teaching Learning-Based Optimization (TLBO), Enhanced Differential Evolution (EDE), Enhanced Differential Teaching Learning Algorithm (EDTLA)	Energy Efficiency	Energy Management	Microgrid
Jincheng Z. et al. (2023)	Ant Colony Optimization (ACO)	Cost	Energy Management	Power Systems
Mingzhou Y. et al. (2024).	Interior Search Algorithm (ISA), Firefly Algorithm (FA), Bat Algorithm (BA)	Cost	Energy Management	Microgrid
Rachida H. et al. (2024)	Whale Optimization Algorithm (WOA), Gray Wolf Optimization (GWO)	Energy Efficiency	Energy Management	Smart Grid
Keshta H. E. et al. (2021)	Particle Swarm Optimization (PSO), Gorilla Troop Optimizer (GTO), Manta Ray Foraging Optimization (MRFO), Bald Eagle Search (BES)	Cost	Energy Management	Smart Grid
Javed MS. et al. (2020)	Particle Swarm Optimization (PSO), Magnetic Optimization Algorithm (MOA), Chimp Optimization Algorithm (ChOA)	Cost	Demand Side Management	Power Systems
Bacanin N. et al. (2023)	Modified Sandpiper Optimization Algorithm (M-SOA)	Cost	Demand Side Management	Microgrid
Mohseni S. et al. (2023)	Crow Search Algorithm, Arithmetic Optimization Algorithm	Cost	Energy Management	Microgrid
Mohseni S. et al. (2020)	Ant Colony Optimization (ACO)	Energy Management	Demand Side Management	Smart Grid
Nutakki M. & Mandava S. (2023)	Class Topper Optimization (CTO)	Cost	Demand Side Management	Smart Grid
Ghaemi Z. et al. (2022)	Archimedes Optimization (AO)	Load Planning	Demand Side Management	Smart Grid
Rahim S. et al. (2016)	Genetics Algorithm (GA)	Energy Efficiency	Demand Side Management	Smart Grids
Javaid N. et al. (2017)	Arithmetic Optimization Algorithm (AOA)	Energy Efficiency	Energy Management	Smart Grids
Batista A. C. & Batista L. S. (2018)	Jellyfish Search Optimizer (JSO) Algorithm	Energy Efficiency	Demand Side Management	Smart Buildings
Silva B. N. et al. (2023)	Particle Swarm Optimization (PSO)	Energy Efficiency	Energy Management	Power Systems
Rezk H. et al. (2023)	Adaptive Coati Optimization Algorithm (ACOA)	Cost	Demand Side Management	Power Systems
Guerraiche K. & Klein M. (2023)	Modified Sandpiper Optimization Algorithm (M-SOA)	Cost	Energy Management	Smart Grids

Table 1. cont.

Singh G. et al. (2024)	Genetics Algorithms (GA)	Cost	Demand Side Management	Microgrid
Achnib A. et al. (2024)	Bacterial Foraging Metaheuristic Optimization Algorithm (BFMO)	Cost	Demand Side Management	Smart Buildings
Mohammedi M. et al. (2024)	Imperialist Competitive Algorithm (ICA), Particle Swarm Optimization (PSO)	Energy Efficiency	Energy Management	Microgrid
Shivani Kumar A. & Tiwari S. (2024).	Bat Optimization Algorithm, African Vulture Optimization, Cuckoo Search Algorithm, Chaotic Harris Hawk Optimization, Chaotic-based Interactive Autodidact School, Slime Mold Algorithm	Load Planning	Energy Management	Power Systems
Praveen M. & Rao V. S. K. (2023)	Pelican Optimization Algorithm (POA)	Load Planning	Demand Side Management	Microgrid
Dey B. et al. (2024)	Ant Colony Optimization (ACO), Firefly Algorithm (FA)	Energy Efficiency	Demand Side Management	Power Systems
Olatunde T. M. et al. (2024)	Back Propagation Neural Network Algorithm (BPNN)	Energy Efficiency	Demand Side Management	Smart Grids

Scientific studies on using metaheuristic algorithms in the energy sector between 2020-2024 were reviewed, and the algorithms, application areas, and optimization criteria used in these studies were examined. The findings are categorized in Table 1. Table 1 summarises the use of metaheuristics in the energy sector by algorithm type, application areas, and optimization objectives.

The data obtained from the studies show the distribution of metaheuristic algorithms in the energy sector according to the optimization objective. According to Figure 1, these algorithms:

- Load Planning by 23 percent,
- 37% Cost Optimization,
- 40% was used for Energy Efficiency Optimization.

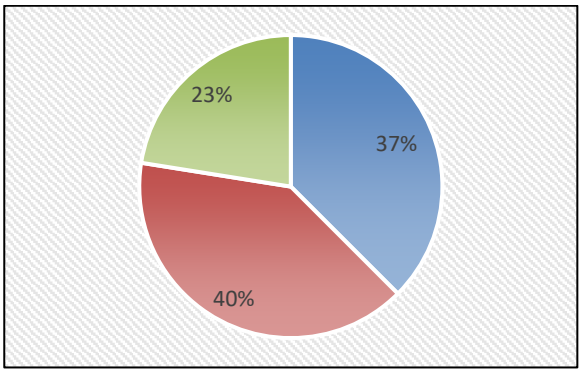


Fig. 1. Metric Chart by Purpose

These results show that optimization studies for energy efficiency issues are the most common in the energy sector, followed by cost and load planning. The extensive use of metaheuristic algorithms in the energy sector once again demonstrates the effectiveness of these algorithms in solving complex optimization problems. For example, load planning optimizes the timing and intensity of electricity consumption, while cost-oriented studies minimize the costs of production and distribution processes. Energy efficiency optimization aims to increase the performance of existing systems by using less energy.

These classifications serve as an important reference for future work in the energy sector and demonstrate the growing role of metaheuristics in energy systems.

As can be seen in Figure 2, the reviewed studies focus predominantly on energy management (48%) and demand-side management (50%), while cloud computing is addressed in a much smaller portion (2%). Note that some studies belong to more than one category, resulting in overlapping percentages exceeding 100%. These data show that energy and demand management are the primary focal points of optimization studies in the energy sector, while cloud computing remains a niche application area.

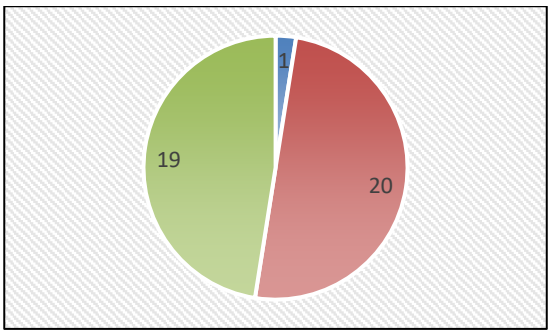


Fig. 2. Distribution of Studies According to Application Systems

These data show that energy and demand management are the primary focal points of optimization studies in the energy sector, while cloud computing applications have a limited application area.

The systems to which metaheuristics are applied represent optimized processes in different areas. According to Figure 3, the distribution of these systems is as follows:

- 5% Communication Systems,
- 2% Distributed Manufacturing Systems,
- 27% Microgrids,
- 10% Renewable Energy Sources,
- 25% Smart Grids,
- 13% Smart Buildings,
- 18% Power Systems.

These results show that microgrids and smart grids are the most common systems where metaheuristic algorithms are applied, with renewable energy sources and smart buildings also playing an important role.

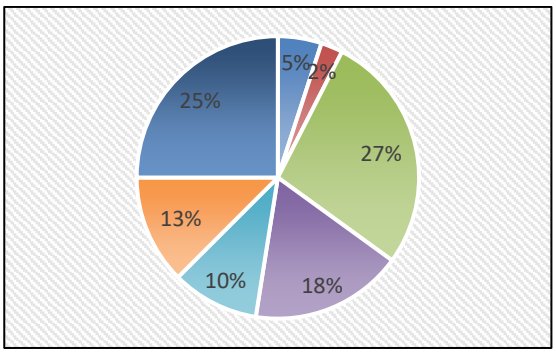


Fig. 3. Preference of Metaheuristic Algorithm over System

In Table 2, the optimization algorithms studied in the literature and found applications in different fields are given in detail.

Accordingly, the three most preferred algorithms are:

- Particle Swarm Optimization (PSO) Algorithm,
- Genetic Algorithm (GA),
- Ant Colony Optimization (ACO) Algorithm.

These algorithms are preferred for their efficiency in solving optimization problems in energy systems. For example:

- Load balancing and cost minimisation in PSO, microgrids and power systems,
- GA in energy distribution and demand management in smart grids,
- ACO has been successfully applied to routing and planning problems in smart buildings and renewable energy sources.

Table 2. Optimization algorithms and usage rates in the literature

Algorithms	Percentage(%)
Adaptive Coat Optimization Algorithm (ACOA)	1%
African Vulture Optimization Algorithm	1%
Algorithm M70	1%
Algorithm P	1%
Ant Colony Optimization (ACO) Algorithm	9%
Archimedes Optimization (AO) Algorithm	3%
Artificial Bee Colony Optimization (ABC) Algorithm	1%
Back Propagation Neural Network Algorithm (BPNN)	1%
Bacterial Nutrition Optimization Algorithm (BFOA)	3%
Bald Eagle Search (BES) Algorithm	1%
Bat Algorithm (BA)	3%
Binary Particle Swarm Optimization (BPSO) Algorithm	1%
BiogeoFigurey-Based Optimization (BBO) Algorithm	1%
Chaotic Harris Hawk Optimization Algorithm	1%
Chaotic Based Interactive Autodidact School Algorithm	1%
Chimpanzee Optimization Algorithm (ChOA)	1%
First in Class Optimization (CTO) Algorithm	1%
Crow Search Algorithm (CSA)	1%
CSA-JAYA Algorithm	1%
Cuckoo Search Algorithm	1%
Differential Evolution (DE) Algorithm	4%
Firefly Algorithm (FA)	4%
Genetic Algorithm (GA)	11%
Gorilla Troupe Optimization (GTO) Algorithm	1%
Grammar Evolution (GE) Algorithm	1%
Grey Wolf Optimization (GWO) Algorithm	1%
Imperialist Competitive Algorithm (ICA)	2%
Improved Sin Cosine Algorithm (ISCA)	1%
Interior Search Algorithm (ISA)	1%
Jellyfish Search Optimization (JSO) Algorithm	1%
Magnetic Optimization Algorithm (MOA)	1%
Manta Ray Feeding Optimization (MRFO) Algorithm	1%
Matrix Model Predictive Control (MPC) Algorithm	1%
Modified Sandpiper Optimization (M-SOA) Algorithm	3%
Moth-Flame Optimization Algorithm (MFOA)	1%
Optimum Power Flow (OPF) Algorithm	1%
Particle Swarm Optimization (PSO) Algorithm	15%
Pelican Optimization Algorithm (POA)	1%
Second Kind of Sequential Genetic Algorithm (NSGA-II)	1%
Slime Mould Algorithm	1%
Teaching-Learning Algorithm (TLA)	3%
Water Cycle Algorithm (WCA)	1%
Whale Optimization Algorithm (WOA)	1%
Wind Driven (WD) Algorithm	3%

These analyses show that metaheuristics will continue to play a critical role in future research and application areas in the energy sector.

6. Conclusions

This paper reviews the related literature on the applications of metaheuristics in the energy sector from 2020 to 2024. This work critically reviews the contribution of metaheuristics toward solving optimization problems in the energy sector, application areas, and benefits to energy management processes. The review found that the results indicate that energy management accounts for 48%, and demand management takes 50% in the literature studies. These contribute to achieving crucial objectives like efficient management of energy resources, accurate forecasting of energy demand, and prevention of energy wastage.

The most frequently used metaheuristic algorithms are Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Ant Colony Optimization (ACO). The success of these algorithms is notable for their widespread application in systems such as microgrids (27%), smart grids (25%), and power systems (18%). In particular, the effectiveness of the PSO algorithm in load planning and cost optimization, GA in energy distribution and demand management, and ACO in routing and planning problems explains why these algorithms are preferred in the energy sector.

The analyses also showed that metaheuristic algorithms are effective in different application areas, such as renewable energy sources, smart buildings, and distributed generation systems. For example, applying these algorithms to problems, including energy consumption regulation in smart buildings, generation planning in renewable energy sources, and power flow management in distributed generation systems, has achieved remarkable success.

Therefore, innovative applications of metaheuristic algorithms and further development should be advanced in the energy sector with the help of sustainability goals. In this respect, the role of metaheuristic algorithms becomes highly critical, especially in the energy conversion processes of smart grids, renewable energy sources, and smart buildings. The potential of algorithms in reducing energy costs and further increasing efficiency for environmentally friendly approaches will effectively shape future energy policies and technological innovations.

6.1. Suggestions for Future Studies and Evaluation of Development Opportunities

This paper identifies some gaps in the existing literature. Specifically, studies on areas such as cloud computing and distributed generation systems were observed to be very limited, at 2% each. This means that more research is needed in these areas. Developing hybrid algorithms and increasing the use of adaptive algorithms can enable solving more complex problems in the energy sector. In addition, combining parallel and distributed computing techniques with metaheuristics can provide more effective solutions for processing large-scale systems and complex data sets.

Nevertheless, metaheuristics may become powerful, flexible solutions combined with inventive approaches. A hybrid and/or adaptive algorithm could well be of cardinal importance in all such major roles that reach sustainability objectives in the energy sector, which may involve the development of smart grids, renewable energy integration, and distributed generation.

Consequently, further development and innovative applications of metaheuristic algorithms in the energy sector should be encouraged. Future research will provide significant opportunities to reduce energy costs, increase energy efficiency, and achieve environmental sustainability goals. Advances in this field will contribute to more sustainable, efficient, and environmentally friendly solutions in the energy sector.

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