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REVIEW ARTICLE

Energy Optimization Problems: A Comprehensive Review of Metaheuristic Algorithms and Recent Advances

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ABSTRACT

Introducing renewable energy into contemporary power systems is crucial to guaranteeing sustainable solutions and improving energy performance. Optimizing energy generation, demand forecasting, and system stability have become difficult with the increasing popularity of renewable energy sources like wind and solar energy systems. This literature review explores recent advances in addressing these challenges by applying artificial intelligence (AI), machine learning (ML), and metaheuristic optimization algorithms. Some of those papers are reviewed because they show advancements in forecasting renewable energy generation, controlling hybrid microgrids, and managing energy in smart grids. Particular attention is given to innovative models such as adaptive dynamic grey wolf-dipper throated optimization (ADGWDTO) for wind speed prediction, the Evolutionary Neural Machine Inference Model (ENMIM) for residential energy consumption, and the Wolf-Inspired Optimized Support Vector Regression (WIO-SVR) for building energy forecasts. Further, the review discusses the emergence of hybrid renewable energy systems and evaluates advancements in techno-economic optimization. The works under review explore advancements in prediction performance, system availability, and cost, thus making a real contribution to further developing reliable and effective energy systems. Thus, these findings may be used to change to more sustainable energy systems in urban and off-grid environments. It will also lead to further exploration of new optimization techniques and improved synergistic application of renewable energy into electricity networks worldwide.

Keywords: Renewable energy ▪ Optimization algorithms ▪ Machine learning ▪ Forecasting ▪ Smart grids

1. INTRODUCTION

The use of metaheuristic algorithms in solving energy optimization problems has emerged as an important research focus given the measurement upturn in demand for efficient and effective energy solutions worldwide. Such algorithms mimic natural processes with the ability to function effectively and independently address optimization problems in other disciplines. For example, the relatively recent Greylag Goose Optimization was proposed as a bio-inspired optimization method that is described as promising for addressing energy issues [1]. Likewise, an optimization algorithm is used in other fields, such as classifying roads for self-driving cars using the Adaptive Mutation Dipper Throated Optimization.

Metaheuristic algorithms do not only apply in energy optimization but also environmental conditions and system design aspects. For instance, energy extraction in photovoltaic systems influenced by environmental factors has also been assessed using these algorithms and has demonstrated how these algorithms can improve the performance of actual sys-tems under real-world conditions. Besides, the applicability of the present techniques, namely the Dipper Throated Al-gorithm, which has been employed in feature selection and classification tasks, is also evident through its applicability in electrocardiogram signal processing. In addition, improve-ments in ensemble learning techniques, which are beneficial specifically for estimating sunshine duration in desert areas, have been demonstrated to integrate well with optimization algorithms.

Since optimization challenges are typically complex due to their focus on working with big data, the requirement for scalable algorithms has arisen. In previous years, researchers have been devoted to creating architectures that can improve the efficacy of optimization techniques in the big data context, owing to big data's skewed and unstructured nature. In medi-cal applications,, metaheuristics have been used to diagnoseis of breast cancer; feature selectiovery central in increasing classification accuracy. Similarly, optimization algorithms in engineering functions, such as AI techniques that apply to designing T-shaped monopole antennas, also demonstrate the usage of the algorithms. Another research application concerning telecommunications innovation is in bandwidth parameters for metamaterial antennas, where metaheuristic optimization enhanced prediction accuracy.

Metaheuristic algorithms are also used in supply chain man-agement; dynamic voting classifiers are used in Supply Chain 4.0 environments to identify the risks. In the same way, in agricultural technology, these algorithms have been enhanced to identify the weeds in the wheat field using the images cap-tured by drones. The above study shows that the metaheuristic approach has versatile applications in precision agriculture. Additionally, more innovative fields, including applications of solar energy, also confirm the increasing scale of opti-mization methods in the development of new projects, for instance, a hybrid LSTM model for estimation of direct nor-mal irradiation in hyper-arid areas. In function optimization, chaotic systems have an enhancing ability to be incorporated in metaheuristics to solve unconstrained problems in the case of Chaotic Harris Hawks Optimization.

However, the newly developed metaheuristic, the Waterwheel Plant Algorithm, is used to solve different optimization prob-lems for various fields. Another significant contribution is the Al-Biruni Earth Radius (BER) optimization algorithm, which has been applied in computational systems to solve complex search problems. This algorithm was also taken a step further to improve deep convolutional neural networks, especially in classifying diseases such as Monkeypox. In the field of climate science, new advanced ensemble learning approaches for predicting evapotranspiration under semi-arid conditions have been introduced, which also demonstrate meta-heuristic implementation in environmental monitoring and predictive missions.

Optimization algorithms have also played an important role in the development of the metamaterial antenna, where an optimized set of ensemble methods greatly enhanced the pre-diction capability.

Further, in smart cities, traffic flow control based on soft GRU-based recurrent neural networks has been deemed important, with deep learning methods improving congestion prediction. For instance, a grid search method ofmodel optimization has been used in water management to predict water quality.

Integrating stochastic fractal search and the particle swarm optimization improves the K-Nearest Neighbors algorithm, particularly for Wireless Sensor networks. Several meta-heuristic algorithms are included in the development of en-ergy efficiency forecasting; features of the Waterwheel Plant Algorithm to hyperparameters of multilayer perceptron mod-els enhance the energy prediction model. In addition, better runtime wireless sensor network optimization has been expe-rienced based on using the Al-Biruni Earth Radius Optimiza-tion algorithm, highlighting the importance of the algorithm in multiple domains.

In educational technology, the Greylag Goose Optimization algorithm has proven useful in better student performance prediction, indicating the possibilities of metaheuristic algo-rithms in Educational Data Mining. Moreover, the application of machine learning for predictive analytics of students' per-formance has also been seen to improve the performance and reliability of educational analysis. Another contribution of this study to the environmental protection sector is the appli-cation of machine learning in satellite image classification to identify oil spills, where optimization algorithms are critical in improving the efficiency of the detection systems. Last but not least, in the case of road maintenance, a recent model, including AlexNet, has been used for pothole detection, indi-cating the universal application of optimization algorithms in structure and infrastructure management.

Lastly, metaheuristic algorithms are useful for a wide va-riety of optimization problems across different domains of specialization, including energy and environmental, medical, educational, and infrastructural. Such algorithms' constant innovation and implementation remain essential for address-ing ever-evolving and challenging optimization issues in an evolving world with limited resources.

To provide a clearer overview of the reviewed studies, Fig-ure 1 summarizes the distribution of research applications discussed in this manuscript. The chart shows that the largest proportion of the reviewed literature focuses on energy fore-casting and renewable energy systems, which reflects the central role of artificial intelligence, machine learning, and metaheuristic optimization in improving energy prediction, renewable resource integration, and sustainable energy man-agement. Other important domains, including building energy efficiency, smart grids, wireless sensor networks, healthcare, environmental monitoring, transportation, agriculture, and education, further demonstrate the multidisciplinary nature of optimization algorithms and their ability to support complex decision-making across different real-world applications.

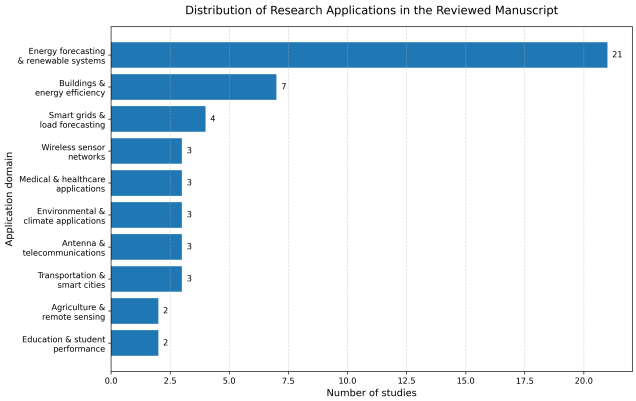

Figure 1. Distribution of research applications covered in the reviewed manuscript.

Figure 2 illustrates the temporal distribution of the reviewed studies according to their publication years. The figure shows a clear concentration of recent studies, particularly in 2022 and 2023, indicating the growing research interest in artificial intelligence, machine learning, and metaheuristic optimization for energy forecasting and renewable energy systems. This trend reflects the rapid development of intelligent computational methods and their increasing relevance in addressing modern energy management, sustainability, and optimization challenges.

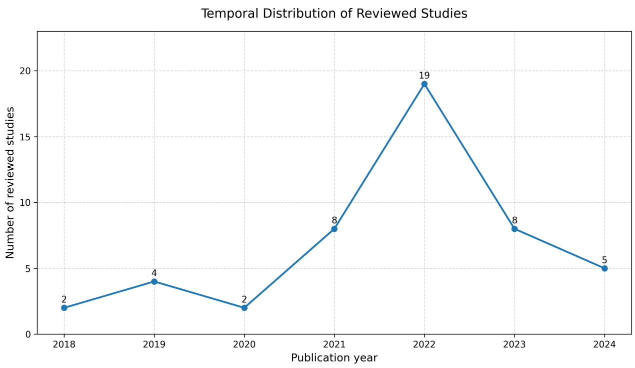

Figure 2. Temporal distribution of the reviewed studies according to publication year.

2. RELATED WORK

Renewable energy can be effectively incorporated into today's energy systems to support the population and promote sustainable power. However, as renewable energy sources get integrated into the system, generating more energy and predicting the energy consumption rate is necessary. Energy management, demand forecasting, and balance and stability of the energy system have turned into a multifaceted problem. Recent research has focused on leveraging artificial intelligence (AI), machine learning (ML) techniques, and metaheuristic optimization algorithms to address these challenges. This literature review includes papers focusing on new approaches to forecast renewable energy, optimize the design of hybrid renewable energy systems, and on the development of enhanced energy management in smart grids. Observations obtained from these works provide worthwhile inputs towards approbation to effective and resilient energy systems, especially concerning smart grid and off-grid fields.

Specifically, the technology for forecasting wind speed is paramount to improve the prospects for further safety and stability of power networks, especially in the systems with a big share of renewables in generation. Further, it is shown in the analysis carried out that wind itself is a random, aleatory variable and prediction of power and speed of wind energy is a difficult process. Several techniques have been created to enhance the accuracy of the forecast, some of which are designed for working with time series data. This research proposes a novel approach using a weighted ensemble model for wind speed prediction, with weight values optimized by an adaptive dynamic grey wolf-dipper throated optimization (ADGWDTO) algorithm. The traditional Grey Wolf Optimizer (GWO) was modified to emulate the dynamic group-based cooperation observed in nature, balancing exploration and exploitation more effectively. The quick bowing movements of the dipper-throated bird and the white breast led to the enhancement of the comprehension's exploration functions. The ADGWDTO algorithm was used to optimize the hyperparameters of three key regression models: multilayer perceptron (MLP), K-nearest regressor (KNR), and Long Short-Term Memory (LSTM). When applied to the Global Energy Forecasting Competition 2012 data from Kaggle, the method has higher accuracy than state-of-the-art wind speed forecasting algorithms. The binary version of ADGWDTO yielded feature selection with an average fitness of 0.9209 and SD of 0.7432. Additionally, the ensemble model optimized with ADGWDTO achieved a root mean square error (RMSE) of 0.0035, showcasing its advantage over other models. Further analysis by one-way ANOVA and Wilcoxon's rank-sum test both showed significant robustness and stability, thus verifying the general practicability of the model.

Since the available energy sources are finite as the global economy grows, the energy requirements of commercial and residential buildings rise correspondingly on the global scale, thus calling for efficient energy simulations and forecasts in formulating energy policies and development initiatives. In the research presented in [2], a novel ensemble model named the Evolutionary Neural Machine Inference Model (ENMIM) was developed to estimate energy consumption in residential buildings based on real-world data. This ensemble model integrates two supervised learning methods—least squares support vector regression (LSSVR) and radial basis function neural networks (RBFNN)—and optimizes its tuning parameters using symbiotic organism search (SOS). To ensure the ENMIM's reliability, parametric and experimental datasets collected from residential buildings in Ho Chi Minh City, Vietnam, and other experiments reported in the extant literature were employed. These comparative evaluations suggest that ENMIM reconstructs all inputs more effectively than other benchmark models regarding predicting accuracy. This study advances the ENMIM as a viable method for planning energy management, and the excellence of ENMIM's incisive prediction over other AI methodologies implies its fitness to different domains.

The building sector consumes forty percent of the world's energy and, therefore, is the biggest energy consumer. In [3], the authors highlight the importance of energy forecasting models for providing decision-makers with the right information in order to run efficient electric utility systems. A major problem in this regard is the selection of the most appropriate hyperparameters when constructing the prediction models. To address this, a novel time-series Wolf-Inspired Optimized Support Vector Regression (WIO-SVR) model was developed to predict 48-step-ahead energy consumption in buildings. This model integrates support vector regression (SVR) as the prediction engine, with the grey wolf optimizer (GWO) employed to fine-tune the SVR's hyperparameters. The developed model was calibrated and tested using 30-minute energy data from a sample of buildings in Vietnam, which can be commercial buildings, hospitals, authorities, university buildings, and offices. The dataset was split for learning and testing purposes. The performance of the WIO-SVR surpassed that of baseline models such as SVR, random forests (RF), M5P, and decision tree learner (REPTree). Specifically, the WIO-SVR achieved the highest correlation coefficient (R) of 0.90 and demonstrated an average root-mean-square error (RMSE) of 2.02 kWh, significantly outperforming the SVR model (10.95 kWh), RF model (16.27 kWh), M5P model (17.73 kWh), and REPTree model (26.44 kWh). The RMSE performance achieved better accuracy. The WIO-SVR model enhanced this aspect by 442.0–1207.9%, hence applicable for building managers seeking to enhance energy management.

Introducing renewable energy sources into smart grids can be seen as the solution to developing efficient energy systems. According to [4], studying how to optimize synergistic systems of renewable energy is still a problem in solving the main problem of energy outlook, which is how to predict and control energy output. To overcome these challenges, this work suggests a broad method for integrating artificial intelligence algorithm techniques and metaheuristic optimization methods in smart grids. The Hybrid LSTM-RL model, which yielded 0.92 precision, 0.93 recall, and 0.92 accuracy to forecast energy demand patterns,, outperformed existing algorithms. Furthermore, with 0.91 accuracy, the RL-SA algorithm accurately estimates load balancing, increasing grid stability. The CNN-PSO algorithm also had lower error rates in predicting renewable energy generation with MSE, MAE, R-squared, RMSE, and MAPE values of 345.12, 15.07, 0.78, 18.57, and 7.83, respectively. These outcomes signify a major improvement in integrating hybrid renewable energy systems for improved energy production and distribution using smart grid approaches. Furthermore, the solution presented may be effective in rural and off-grid systems, accommodating the solution for various energy control challenges.

Renewable energy systems, particularly hybrid renewable energy systems, are difficult to develop because of the inherent variability of renewable resources and the technology multi-dimensionality of such systems: technical and economical. Although much work has been devoted to hybrid renewable energy systems, there is a lack of studies on creating useful models or methods in the context identified in [5]. But now metaheuristic algorithms are gaining recognition for optimizing complex systems such as hybrid renewable energy systems because of their efficiency and provide accurate and optimal solutions in less time. This study aims to obtain a techno-economically feasible optimum design for a hybrid ocomprising aich comprises aa solar photovoltaic system, biogas generator, pumped hydro energy storage and battery system powering a radio transmitter station in India. Two metaheuristic optimization techniques—the water cycle algorithm (WCA) and moth-flame optimization (MFO)—are evaluated and compared with the Genetic Algorithm (GA), which has served as a benchmark in previous studies. The objective function of the study is to reduce the total net present cost, subject to design constraints and an elaborate modeling approach adopted. A sensitivity analysis based on the loss of load probability criteria is performed to determine the feasibility of the design. Statistical outcomes reveal WCA and MFO as efficient heuristics, with WCA giving a better design solution to the margin. The optimal configuration obtained by WCA includes a solar photovoltaic panel area of 548.67 m² (69.2 kW), a 16 kW biogas generator, a battery bank of 21 units, a 30 kW converter, and an upper reservoir volume of 2081.5 m³, with a total net present cost of $0.813 million. Based on these findings, this study reviews the literature in order to show that metaheuristic optimization adopts a low-cost, efficient hybrid renewable energy system

Increasingncreasing hydrocarbon fuel consumption has led to numerous environmental issues, prompting the integration of renewable energy systems (RES) into the grid. In the article denoted as [6], solar photovoltaic (PV) and wind energy emerge as the most advanced hybrid renewable energy system (HRES) alternatives to conventional fossil fuels due to their pollution-free nature, widespread availability, and low cost. In addition, the daily and seasonal variability of solar irradiation and wind speed reduces the accuracy in the determination of the system size, thus making HRES either oversized or undersized, leading to high costs or low efficiency. This has resulted in an intense need to source optimization strategies that would help reduce HRES costs while still delivering on their intended use. This paper critically reviews different optimization techniques categorized as past and current, as well as combines methodologies by objective function, decision variable, and evaluation measure. The majority of HRES research in the present day tends to emphasize the technical reliability and the economic considerations of this subject. In contrast, the present study pays particular attention to the cardinal environmental specifications. It is observed that hybrid metaheuristic optimization methods are on the rise within engineering disciplines and their application because of flexibility and versatility. In addition, the application of economic indicators is more developed than reliability and environmental indicators. However, multi-criteria functions involving the economic and reliability indicators in the optimal design of HRES are growing in their usage.

Modernizing the power grid is a vision of a future smart grid due to the integration of almost every innovative technology visible today, such as AI, big data analytics, and IoT, among others, with digital transformation as the backbone of the energy market. As described in [7], this transformation enhances the extent to which energy managers require the reliability and security of electric power systems. To achieve sustainable development of these systems, energy planning employs several approaches such as demand-side electrification, electricity demand forecasting models, stochastic optimization and simulation. Among all the load forecasts, short-term load forecasting is especially important since it allows for predicting energy demand from one hour to 24 hours and assists in the stable restoration of power systems.

In this work, several machine learning methods were analyzed with the help of a complex and rather difficult case based in Panama. Of all these machine learning paradigms, deep learning, considered a recent powerful machine learning model, has emerged as a promising approach in relevant fields such as electricity forecasting, object detection, speech recognition, etc. These elements were found to predict short-term electricity demand: the previous week's load factor, the previous day's load factor, and temperature. The presented deep learning regression model can be regarded as the most effective, with R^2 of 0.93 and MAPE of 2.9, while the lowest results were obtained with the AdaBoost model with R^2 of 0.75 and MAPE of 5.70. These emerging studies underscore the necessity of deep learning to improve short-term load forecasting to build more precise power systems.

Industry 4.0 is the fourth industrial revolution that combines automation, machines, and the Internet through network sensors, creating big data. Based on the research done in [8], it is clear that both Machine Learning (ML) and Deep Learning (DL), two subcategories of Artificial Intelligence (AI), are very vital in examining this data and getting insights for manufacturing companies. This change brings Industrial AI (IAI) into the foreground, and it is at the center of improving industrial operations. This paper focuses on understanding Industry 4.0 and presents the major characteristics, specifications and concerns or issues, including scalability, security and many data issues. Furthermore, a new architecture to incorporate IAI has been established, and the most useful ML and DL algorithms in the Industry 4.0 environment are presented in detail, along with their features, applications, and performances. The paper also explores the application of ML and DL models in one of the most critical areas of Industry 4.0: the smart grid. Based on these models, the efficiency and effectiveness of enhancing smart grid operations are determined. Last but not least, the paper discusses potential trends and concerns in data analysis based on its application to Industry 4.0; these include, but are not limited to, issues such as the ability to scale up big data and cybersecurity.

This article reviews recent advances and prospects in forecasting renewable energy generation using machine learning (ML) and deep learning (DL) techniques. As discussed in [9], with the growing integration of renewable energy sources (RES) into electricity grids, accurate forecasting is essential for ensuring efficient grid operation and energy management. Several challenges with traditional forecasting techniques have led to using more modern techniques, such as ML and DL algorithms, to feed big data and make precise estimates. The paper considers possible methods of forecasting used in the RE generation and their effectiveness within different models. Furthermore, it identifies some of the research issues and opportunities in the field, including fluctuations in the renewable energy generation form, lack of data, and interpretability of models. The review also emphasizes the need to put in place strong and accurate forecasting models to enhance the integration of RES into power grids to move towards a cleaner energy framework from the current outdated traditional ways.

For machine learning problems such as classification and regression, feature selection is a key challenge essential to renewable energy concerns. In the work done in [10], selecting features is a crucial step in enhancing the overall prediction systems of the important renewable energy sources, such as wind, solar, and marine energy. This research also presents the objectives, the current overall picture of most of the major prediction systems that require feature selection, and a detailed discussion of most of the issues and challenges. The results show that wrapper feature selection techniques are used more frequently with improved performance and fast training algorithms generate good results. However, there is no unified approach to the classification of tasks addressed by the finalists, and the wide range of the addressed issues prevents a systematic assessment of the methods used. To address this problem, the authors suggest concurrently employing several global search strategies. The second part of the study presents novel feature selection using the Coral Reefs Optimization algorithm with Substrate Layer. This method combines the various search methods in a single Glover algorithm to allow a sound approach to global search. When the same system was implemented using an Extreme Learning Machine for wind speed during the real dataset of the wind farm located in Spain, the proposed model proved to achieve an accuracy of up to 20% for the wind speed prediction of an hour and a day if the feature selection process was excluded.

Critical innovation in the development of renewable energy materials is vital to meet the ambitious goals of the 2016 Paris Accord to limit global warming to well below 2 °C and on pathways towards future sustainable energy. As mentioned in [11], with the window of opportunity shrinking, so are the needs of the objectives these goals imply- and these can only be met with new research methodologies capable of providing a faster discovery of materials at a pace never before seen. New methods in machine learning have given the scientific and engineering field a versatile and moldable tool to quickly predict material properties and have shown extreme promise for revolutionizing this specialty. The paper outlines numerous machine learning applications in theoretical approaches to renewable energy technologies, including catalysis, batteries, solar cells, and crystal discovery. These approaches have been found to produce remarkable real-world success stories highlighting the potential of machine learning in the evolution of materials science. Nevertheless, critical shortcomings have been identified and will also be crucial to fill if even faster advancement in discovering the materials needed to help the world meet sustainability targets is to be realized.

Treatment of municipal wastewater to meet stringent effluent quality standards is an energy-intensive process, significantly contributing to the operational costs of wastewater treatment plants (WWTPs). As detailed in [12], analyzing and predicting energy consumption (EC) is essential for designing and operating sustainable, energy-efficient WWTPs. In this study, the impact of various parameters—including wastewater characteristics, hydraulic factors, and climate conditions—on the daily EC of the East Melbourne WWTP was examined using six years of data (2014–2019). Data engineering techniques were employed to combine features from multiple sources, and four different feature selection (FS) algorithms were applied to identify the most relevant variables for training machine learning (ML) models. The study specifically analyzed the application of artificial neural networks (ANN), Gradient Boosting Machine (GBM), and Random Forest (RF) algorithms to predict EC. The feature selection results revealed that total nitrogen, chemical oxygen demand (COD), and inflow-flow significantly impacted energy consumption. The regression model evaluation indicated that GBM gave the best prediction of EC. The evaluation of the proposed model for energy consumption prediction for WWTPs showed that a 95 percent confidence interval assessment provided a decent prediction error range of ± 68 MWh/day.

Energy usage forecasting for buildings is useful for energy efficiency management decisions. As discussed in [13], recent developments have seen multiple machine learning models for predicting building energy usage. However, there is a major weakness with any current existing models, and this is its poor incorporation of occupant behavior, which is a major determinant of energy consumption. To fill this research gap, the study suggests a supervised machine learning algorithm that will factor in occupant behavior in energy consumption models. The model was trained using a large data set derived from EnergyPlus simulations; this data set included 3-month accuracy hour's energy use cases of 5760, including but not limited to the building characteristics, type of climate, and occupants' behaviors. Four machine learning algorithms—classification and regression trees (CART), ensemble bagging trees (EBT), artificial neural networks (ANN), and deep neural networks (DNN)—were tested for prediction accuracy and computational efficiency. The results showed that there is significant differentiation in the energy usage pattern, and at the peak, the maximum utilization scenario utilized over 3432 times the minimum. We found that occupancy behavior was the major contributor to variation in energy use, ranging from one to seven times the level. Among the models, the DNN with four hidden layers performed best, achieving a 2.97% coefficient of variation (CV). Such high performance shows the approach's capacity to develop the understanding of the occupant behavior contribution to the building energy consumption, and therefore, chances in the behavioral energy-saving approaches.

The large amount of power used in the structures has raised various effects on the atmosphere that harm human existence. In [14], the authors argue that building energy forecasting is acknowledged as a key approach to energy saving and enhancing the choices towards energy utilization. Furthermore, putting up energy-efficient building systems reduces the overall energy utilization in newly developed structures. Machine learning (ML) methods have been recognized as highly effective for prediction tasks. While ML has been applied to the operational energy consumption of buildings, few studies focus on forecasting potential energy consumption at the early design phase. To address this gap, this paper explores the application of multiple machine learning techniques—including Artificial Neural Networks (ANN), Gradient Boosting (GB), Deep Neural Networks (DNN), Random Forest (RF), Stacking, K-Nearest Neighbors (KNN), Support Vector Machine (SVM), Decision Tree (DT), and Linear Regression (LR)—to predict the annual energy consumption of residential buildings using a large dataset. The paper also analyses the role of building cluster density to model accuracy metrics. The innovation of this study is that the research proposes a model through which designers can feed in the parameters of the building and generate an estimate of energy use in a year during the design phase. The results respectively point out that DNN is the best prediction model for early-stage energy forecasting, which serves as a good reference tool for building designers to make more rational choices, enhance designs and control energy efficiency before building construction begins.

As we look at social development and urbanization, building energy consumption is increasing. The study carried out in [15] showed that the accurate prediction of building energy consumption is central to advancing energy performance, supporting the sustainability agenda and minimizing the effects of energy wastage and its associated costs. This study comprehensively reviews machine learning (ML) techniques for forecasting energy consumption time series, utilizing real-time data collected from a smart grid installed in an experimental building. The performance of different statistical and ML methods was tested using this real-world data set. The study particularly focuses on analyzing single and ensemble models and a 'hybrid model' that combines forecasting and optimization techniques. Analyzing the results obtained when comparing the single, ensemble, and hybrid models, we can identify that the accuracy of the last one is bigger than that of the others, increasing its reliability for energy consumption forecasting. The results reveal issues related to forecasting and present useful information for energy management planning, which can be useful for users interested in improving energy efficiency and making their buildings more environmentally friendly.

Machine learning-based methods in modern computing resources are applied to maintain the power supply and demand balance. I have described their importance by [16], according to which machine learning is highly effective for energy consumption forecasts. However, the disparity between forecasted and actual energy consumption still remains a problem. as a result, the actual GP may fluctuate and fluctuate and be influenced by weather, holiday time, and weekends. This paper aims to influence prediction accuracy by describing error curve learning and a hybrid model and using actual energy consumption data from Jeju Island in South Korea. Catboost and Xgboost were combined with a multilayer Perceptron model to predict energy consumption. The study focuses on week-ahead (WA) and 48-hour forecasts, revealing a mean error of 2.78% on weekdays, 2.79% on weekends, and 4.28% on special days. The study looks at causes for these errors, including fluctuations in temperature and calamities like typhoons that affect energy usage. Furthermore, the impact of the public holidays and weekend predictions have been considered. The findings of this study may help policymakers develop effective contingencies that address elements causing prediction errors, the results of which will support more accurate energy consumption forecasts.

Thus, the relationship between building energy consumption, greenhouse gases, energy efficiency and sustainability is important. According to [17], Energy prediction has advantages for utility companies, users and facility managers due to increased energy efficiency in buildings. This study introduces a Random Forests (RF)-based prediction model designed to forecast short-term energy consumption hourly across multiple buildings. The model was assessed using five one-year datasets of hourly energy consumption in both the training and the testing stages. Results demonstrated the RF model's superior accuracy, with mean absolute error (MAE) values ranging from 0.430 to 0.501 kWh for 1-step-ahead predictions, 0.612 to 0.940 kWh for 12-steps-ahead predictions, and 0.626 to 0.868 kWh for 24-steps-ahead predictions. The RF model outperformed both the M5P and Random Tree (RT) models, showing an improvement of 49.21% and 46.93% in MAE and mean absolute percentage error (MAPE) compared to the RT model for 1-step-ahead forecasts.

Furthermore, the RF model resulted in a lower MAE of 2.9428 and 3.8743 in the 12-steps-ahead and 24-steps-ahead predictions, greatly improving the M5P by 49.95% and 29.29%. Therefore, these results put the RF model forward as a reasonable method of accurately presenting building energy consumption, and some of them contribute to the development of a new machine-learning model method. The study also contains practical implications in that the building owners and facility managers will have a practical way of improving the energy performance of buildings.

Energy consumption has been a well-researched topic in computer architecture since the early days of ML, but it became a focal point only recently. The analysis presented in [18] shows that most works devoted to machine learning do not take into consideration the computational complexity and, in particular, the energy requirements of algorithms. The cause of this oversight can be attributed to a dearth of awareness of energy evaluation methodologies amongst cognisant machine learning circles. As a result, the paper fills the gap in the literature by presenting an overview of methods used for estimating energy consumption in general and in the context of ML specifically. It is to provide a basis for the ML community to learn and use energy estimation methods and tools to improve the energy efficiency of their algorithms. Besides evaluating approaches, the paper also overviews the recent tools in the software environment that offer energy estimation values and provides two real-world examples that demonstrate how energy consumption can be investigated within machine learning. These recommendations provide pertinent strategies that researchers seeking to develop efficient machines for machine learning should consider in their efforts to develop such machines. These machines factor efficiency in the consumption of energy in addition to the precision of the outcomes.

Industrial Wireless Sensor Networks (WSNs) are increasingly being adopted due to their scalability and cost-effectiveness. They also create issues like energy optimization and network maintenance that the industrial users deal with. As outlined in [19], machine learning techniques have been leveraged to develop an enhanced energy optimization model (EEOM) for Industrial WSNs. The knowledge-based learning is used to reduce energy consumption at the network nodes to the extent necessary for the tasks performed within the system. Secondly, the model evaluates feedback control schemes and estimates the best for achieving enhanced energy performance and network durability. The model investigates the compromise between power consumption and high-speed communication to reduce power consumption. The EEOM model proposed by the author was found to be quite effective in saving energy; the transmission energy savings were 35.28%, the received energy storage was 32.73%, the idle-mode energy storage was 47.84% and the sleep-mode energy storage was 33.69%. It also presented nice degree rates comprising the prevalence threshold of 90.44%, critical success index of 90.33%, and MCC and FMI rates of 90.06% and 92.17% by respective calculations. In addition, the model also detects appropriate nodes and routes for data communication and proposes ways of minimizing the load on the network. Collaborated with the manual interferences, these automated knowledge-based techniques greatly improve the reliability, efficiency and energy cost-effectiveness of Industrial WSNs.

Environmental issues due to emissions of greenhouse gases have become rampant in many countries in recent decades, thus requiring accurate forecasts for management. Following the work in [20], this paper seeks to develop machine learning and mathematical programming to accurately predict GHG emissions despite limited data on CO2, N2O, CH4, and Fluorinated-Gas emissions. Historical data from Iran's energy sector and GHG emissions from 1990 to 2018 and by applying nine algorithms, including ANN, AR, ARIMA, SARIMA, SARIMAX, RF, SVR, KNN, and LSTM, emissions were predicted. For each algorithm, absolute accuracy measures were determined with five performance metrics, and emission projections through to 2028 were made. Next, the results obtained here are introduced to a mathematical model, PSO and GWO, using metaheuristics. These prediction models incorporated into this hybrid model provided enhanced prediction accuracy; the PSO algorithm enhanced by 31.7 % while the GWO algorithm enhanced by 12.8 %. Stepwise Regression was also used to compare and detect data correlations. It expects Iran's total GHG emissions to stand at over 1096 million tonnes per year in 2028. In terms of the practical application of the developed hybrid model, the findings were that this model provided better results than other individual machine learning methodologies.

Hydrogen production and utilization as clean energy have received much attention in the last decade. As described in [21], although the technique of steam methane reforming (SMR) dominates the hydrogen production process, creating an accurate simulation model of the reforming reactor to comprehend the heat transfer characteristics has been quite difficult due to the constraint of theoretical equations. That is why, to optimize the SMR process, the study used an artificial neural network (ANN) model based on 485,710 actual operation datasets. Data cleaning through the removal of outliers and noise was used in order to improve data quality. The resulting model achieved a high accuracy (average R^2 = 0.9987) and was capable of predicting six variables: These include syngas flow rate, the content of CO, CO2, CH4, and H2 and the temperature of steam. For process optimization, the search spaces for nine operating variables were defined, including natural gas flow rate, the hydrogen flow rate for desulfurization, water flow rate and temperature, air flow rate, SMR inlet temperature, and pressure of LT's inlet. These variables were employed to forecast thermal efficiencies for as many as 387,420,489 cases. Introducing five constraints to assess the process feasibility of chosen options to transform the concentrated solar power plant technology, find the following decision variables offered the highest thermal efficiency. The improved process conditions increase the thermal efficiency by up to 85.6%, reflecting the viability of the proposed ANN-based model for optimizing hydrogen production using SMR.

Drawing from the literature under review, it is clear that there is value in improving the advanced optimization and forecasting models for the performance of renewable energy systems. AI and ML methodologies, accompanied by metaheuristic optimization algorithms, are being recognized as efficient approaches to effective energy management, more precisely in hybrid and smart grid systems. Recent research has depicted instances of enhancement in terms of prediction accuracy of the energy anticipated, the dependability of the system, and cost-effectiveness. These results are valuable in the effort to move toward sustainable energy systems for base load, localized, and decentralized utilization in general, both in urban and rural settings and off-grid. Subsequent research is expected to expand elaborate optimization strategies to propel the approaches for integrating renewable energy sources into global power systems.

3. CONCLUSION

This review highlights the significant advancements in optimizing hybrid renewable energy systems and forecasting energy demand through integrating artificial intelligence (AI), machine learning (ML), and metaheuristic optimization algorithms. The studies considered in the incorporation of the mentioned techniques helps simplify the enhancement of energy prediction and enhance the energy MSs and their reliability and efficiency in smart grid and off-grid settings. Somewhat progress has been made in addressing the fluctuation of renewable energy resources and the nature of energy demand. In addition, the integration of AI with optimization algorithms has been ascertained to be commendable for technical and economic optimization. All these innovations are important to the progress in attempts to implement environmentally friendly and enhanced energy systems for energy for the future of energy management, which is important in AI and optimization. However, with these approaches exists the requirement for more papers that would extend such a method and make it enriched, variable and suitable to the shift in energy demand and other environmental occurrences.

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