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Original Article

Using IoT and Machine Learning for Enhanced Home Energy Management in Somalia

Ubaid Mohamed Dahir[1], Abdirahman Osman Hashi[1], Abdullahi Ahmed Abdirahman[1], Mohamed Abdirahman Elmi[1], Octavio Ernest Romo Rodriguez[2]

[1]*Faculty of Computing, SIMAD University, Mogadishu, Somalia.*
[2]*Department of Computer Science, Faculty of Informatics, Istanbul Teknik Universitesi, Istanbul, Turkey.*

[1]*Corresponding Author : engubaid@simad.edu.so*

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Abstract *- This paper presents a novel approach to home energy management in Somalia by integrating Internet of Things (IoT) technology with machine learning algorithms to optimize energy consumption in residential settings. The proposed system, Optimizing Home Energy Management in Somalia with IoT Technology, utilizes real-time data analytics to manage the operation of home appliances efficiently. By leveraging data on electricity price fluctuations and renewable energy availability, the system intelligently determines the most cost-effective and sustainable energy sources to utilize at any given time. It provides recommendations on which appliances to operate or turn off to minimize energy use and costs. The methodology involves the deployment of IoT sensors and devices across various home appliances to monitor and control energy consumption dynamically. Machine learning algorithms analyze patterns in energy usage and predict future trends to optimize the scheduling of appliance operations, thus enhancing energy efficiency and reducing dependency on non-renewable energy sources. The study's findings demonstrate significant improvements in energy management, highlighting reductions in energy consumption and costs and contributing to environmental sustainability. This research contributes to the growing field of smart energy solutions in developing countries, offering a scalable model that can be adapted to different regional settings beyond Somalia.*

Keywords *- Home energy management, Renewable energy, Energy efficiency, Machine Learning, Internet of Things.*

1. Introduction

The advent of smart technologies, such as smart power meters and wireless networks, has the potential to transform the traditional electric power infrastructure into one that operates with greater efficacy and efficiency. These innovations are pivotal in enhancing the energy utilization patterns of both providers and consumers by bringing about more finely tuned energy distribution and management [1].

In this context, Somalia, a country with a complex history of conflict and climatic challenges, stands on the brink of technological transformation that could significantly enhance its socioeconomic landscape. Among the myriad of issues faced by the country, energy management remains a critical concern, not only due to the scarcity of resources but also because of the inefficiencies in energy distribution and consumption. As Somalia progresses towards stabilization and development, innovative solutions are needed to address these persistent energy issues [2].

In many parts of the world, the Internet of Things (IoT) has emerged as a revolutionary technology, offering novel solutions to optimize energy usage. IoT involves the interconnection via the internet of computing devices embedded in everyday objects, enabling them to send and receive data. This technology is particularly promising for developing regions like Somalia, where it can be leveraged to monitor and manage energy consumption in homes more efficiently. The need for energy efficiency in Somali homes is driven by several factors, such as limited energy infrastructure, which is susceptible to frequent disruptions and is often unavailable to rural and remote communities, and the high cost of energy, when available, places a significant burden on households [3].

Implementing IoT could mitigate these issues by providing real-time data on energy use, identifying inefficiencies, and suggesting or automating adjustments to reduce waste. Moreover, Somalia's climate, characterized by variable rainfall and frequent droughts, underscores the importance of sustainable energy solutions. With a majority of the Somali population relying on biomass and imported oil for energy, the environmental impact is substantial [4].

Adopting IoT technology in energy management not only promises improved efficiency but also supports broader environmental sustainability goals. However, the implementation of such technology in Somalia faces unique challenges. These include the lack of a stable and widespread electrical grid, limited internet connectivity in many areas, and a general scarcity of technical expertise and financial resources to support the widespread deployment of IoT solutions. Addressing these challenges requires a carefully structured approach that considers the local context and available resources [5].

Therefore, to tackle these issues, the strategy of smart energy monitoring and the scheduling of appliances hinges on the optimization of electricity usage and the automation of systems to aid homeowners in reducing their energy footprints. In many Somalian households, electricity meters are inconspicuously placed and typically consulted only when there is a power shortage. These meters provide a cumulative account of electricity usage for all household appliances rather than detailing the consumption of individual devices. For a more granular understanding of how energy savings are realized, it is imperative to establish a system where end-users can visually monitor each appliance separately [6].

Current smart solutions are probing into innovative methods to decrease energy consumption by monitoring and managing appliance use through the strategic rescheduling of their operation times, taking various factors into account. Systems like Smartcap automatically regulates the use of household devices by managing the operational schedules of non-essential appliances based on their priority level. Additionally, wireless sensor networks are being used to monitor less critical appliances. These networks utilize Zigbee transmission technologies and smart meters to track energy consumption. This allows users to make informed decisions about the timing of appliance use based on their power requirements, deciding which devices should be used immediately and which can be deferred for later use [7].

The objective of this research is to explore the feasibility and impact of using IoT technology to regulate energy consumption in Somali homes. By examining global case studies and adapting their successes to the Somali context, this study aims to provide a framework for deploying IoT solutions effectively and sustainably. The potential benefits of such an initiative include not only reduced energy consumption and cost but also an enhancement in the quality of life for residents through improved energy reliability and access.

This paper will begin by reviewing the current state of energy infrastructure in Somalia, highlighting the main sources of energy and their associated challenges. Following this, it will delve into the principles of IoT and its applications in energy management, drawing parallels with similar environments where IoT has been successfully implemented. The focus will then shift to a detailed methodology for introducing IoT-based energy solutions in Somali homes, including pilot project designs, data collection methods, and analysis techniques. Anticipated outcomes of this study include a better understanding of energy consumption patterns in Somali households, identification of key areas where energy waste can be reduced, and development of a scalable model for IoT deployment in energy-constrained settings. By providing empirical data and clear insights, this research intends to support policy-makers, donors, and local stakeholders in making informed decisions about energy management technologies.

The following parts of this paper are grouped in this way: In section 2, an outline of linked studies is given. In Section 3, we go into more detail about our suggested method. In section 4, we show the product, the evaluation method, and the result analysis. Last but not least, section 5 sums up our findings.

2. Related Work

The integration of Internet of Things (loT) technology in managing home energy consumption has been an area of intensive research and practical applications around the globe. Developed countries have been pioneers in this field, leveraging advanced loT infrastructures to facilitate smarter energy solutions.

For instance, in many European and North American households, loT-enabled devices like smart thermostats and energy management systems are commonplace [8]. These systems provide users with granular control over their energy consumption, leading to significant savings and efficiency gains. Studies from these regions often show a direct correlation between the use of loT devices and a decrease in energy bills, suggesting that loT technology can play a pivotal role in energy conservation [3].

Transitioning to a broader perspective, the application of loT in energy management reflects a global trend towards more sustainable living. International projects and research initiatives have demonstrated how loT can mitigate issues associated with energy waste. In Asia, for example, smart grids equipped with loT technologies are being rolled out to manage energy distribution better and reduce losses during transmission. Countries like Japan and South Korea have made substantial investments in these technologies, with their governments actively promoting the adoption of loT for energy conservation as a national priority [9].

On the other hand, scholars have proposed a number of methods that make the use of energy more efficient. For instance, author [10] came up with a way to control energy that uses portable sensor networks in their work. A network of portable monitors and a high-tech entrance for the home surroundings make up the two main parts of this system. The clever gateway’s job is to collect data on how much electricity these monitors are using and send it to users. In addition, authors make it easier to control and monitor home electronics from afar. Customers can save energy by monitoring and controlling their home machines through mobile and internet-based apps. This is an innovative feature of the system. Similar to this study, another group of researchers [11] came up with a way to handle home energy that aims to keep people's power costs as low as possible. Their plan involves moving home tools from times when there is much demand for energy to times when there is less demand. This plan uses a system to coordinate appliances, which includes a central unit for managing energy use, a wireless sensor network inside the home, and smart home gadgets that can talk to each other.

In a related study, other researchers [12] designed an energy conservation system for educational settings, using Passive Infrared Radio (PIR) sensors to manage lighting and ventilation. This system functions by deactivating fans and lights when it detects no occupancy, such as during the absence of students in a classroom. As detailed in their findings, the system activates relays that power these appliances on upon sensing motion. If no movement is detected after ten minutes, the system automatically powers down the lights and fans, thereby conserving energy. Building on this concept, different researchers used the best first search technique to regulate demand in systems powered by Photovoltaic (PV) energy. They crafted a model that utilized heuristic search strategies to select the most effective combination of household appliances. This selection was geared towards prioritizing user preferences while concurrently minimizing reliance on the national power grid.

Taking this idea to the next stage, a modified version of the perceptron learning algorithm was proposed by another research group [13] to supervise and manipulate domestic devices. Their model's objective was to find the most efficient appliance combination that would optimize the use of the available PV system capacity.

To expand upon this, the PIR sensor-based system stands as a straightforward yet effective example of how smart technology can significantly reduce energy waste in public spaces. The application of advanced algorithms like best first search and modified perceptron learning in PV systems represents a leap towards integrating cognitive computing with energy management [14]. These methods are indicative of a trend where AI and machine learning not only make energy systems more efficient but also more responsive to the dynamic patterns of human behavior and environmental conditions. These technologies open up new avenues for energy saving by smartly aligning energy production with consumption patterns, thereby reducing the load on traditional energy grids and fostering a more sustainable use of resources.

In the context of Africa, the potential of loT is just beginning to be tapped. African nations, with their rapidly growing populations and urbanization rates, face unique energy challenges [15]. The need for robust and efficient energy management systems is more pressing than ever. Several studies across the continent have highlighted the importance of adopting loT to overcome these challenges. In South Africa, for instance, loT is being used to address the energy supply crisis by enabling real-time monitoring and load balancing on the grid.

Similarly, pilot projects in countries like Kenya have demonstrated the benefits of smart metering in tracking and reducing household energy consumption. Focusing on Somalia, the landscape is different, yet the potential for loT in energy management is equally promising. Somalia's energy sector is characterized by its reliance on imported fossil fuels and a lack of widespread, stable electrical infrastructure. This makes the nation particularly vulnerable to fluctuations in global oil prices and presents a barrier to achieving energy security. Research on Somalia's energy issues suggests that adopting loT could be transformative, offering a way to bypass some of the infrastructural hurdles and leapfrog directly to advanced energy management solutions. However, studies also indicate the need for a careful, context-aware implementation strategy that takes into account the country's unique challenges, such as limited internet connectivity and ongoing security concerns [16].

In a study [17] aiming to optimize energy consumption during periods of high demand, researchers introduced a model that managed the energy usage of household appliances. This was particularly focused on times when renewable energy sources were available. Their model incorporated a sophisticated algorithm that not only regulated the usage of renewable energy but also automatically reduced the load of heavy appliances during peak hours to balance demand and supply effectively.

Furthering the quest for energy efficiency, the author [18] designed a prototype system that possessed the capabilities to control, monitor, and troubleshoot the power consumption of household electrical devices. This system was notable for its potential to decrease the energy use of these appliances by a significant margin up to 59%. One of the distinguishing features of the prototype was its diagnostic feedback mechanism, which was instrumental in detecting and reporting failures in electrical appliances. It sought to diminish the energy footprint of these devices by severing power completely when they were not in active use, thereby eliminating the standby energy draw.

Addressing the subtle yet prevalent issue of energy wastage in standby mode, another author [19] proposed a smart energy management system that incorporated a power strip with an integrated ZigBee communication module. This system served a dual purpose: it utilized motion sensors to ascertain presence in the vicinity of the test bed and allowed for the scheduling of power usage. In a similar vein, the author [20] put forward a design that aimed to cut the standby power consumption of home appliances to zero. Their system involved a smart socket that would disconnect power when appliances were not in use. The central component of this design was a Micro Controller Unit (MCU), which received inputs from both a Core Balanced Current Transformer (CBCT) and a Pyroelectric Infrared (PIR) sensor. The latter was responsible for detecting when a user was near the socket. The MCU's role was crucial, as it managed the activation and deactivation of a relay that functioned as an appliance switch, thereby eliminating standby power consumption [21].

In Somalia, the deployment of loT in the energy sector is still in its infancy. Nonetheless, the few existing initiatives provide valuable insights into the transformative power of this technology [22]. One such initiative involved the use of solar-powered loT systems to provide real-time data on energy production and consumption in off-grid communities, as can be seen in Figure 1. The results were promising, showing not only an increase in energy efficiency but also an enhancement in the residents' quality of life. These findings support the notion that, even in the most challenging environments, loT can deliver tangible benefits.

Furthermore, it is essential to consider the socio-economic context when examining the application of loT in Somalia. The affordability and accessibility of technology are major factors that influence the adoption rate of loT solutions. Studies from other African contexts have shown that cost-effective loT implementation can result in widespread adoption, suggesting a similar approach could be effective in Somalia. Partnerships with international development agencies and the private sector could facilitate the deployment of affordable loT devices, thereby promoting energy efficiency among Somali households.

Fig. 1 Implemented solar energy in somalia

The evolution of loT in Somalia also depends on capacity building and education. Research from other developing nations highlights the importance of equipping local populations with the necessary skills to manage and maintain loT systems. Training programs and educational initiatives could empower Somali citizens to harness the potential of loT for energy fully management. This approach not only fosters local expertise but also ensures the sustainability of loT solutions in the long term. Given the nascent state of loT in Somalia, the exploration of related works from around the world and across Africa provides a valuable foundation for understanding the potential and challenges of this technology. The experiences of other countries offer lessons and models that can be adapted and applied to the Somali context. By building on the global body of knowledge and tailoring solutions to local conditions, loT has the potential to improve energy management in Somali homes [23] significantly.

3. Methodology

To effectively manage and regulate home appliance energy consumption using IoT, a combination of rule-based machine learning and neural networks for predictive analytics is our proposed methodology. This integrated approach optimizes energy usage by predicting consumption patterns and automatically adjusting appliance operations based on a set of predefined rules.

3.1. System Design and Data Collection

The initial phase focuses on the design and deployment of the IoT system architecture, including the selection and installation of appropriate IoT sensors and smart meters within homes; we used Sonoff Pow R2 and eGauge EG4115, as can be seen in Figures 2 and 3, respectively. These devices are critical for gathering both real-time and historical data on energy consumption, which includes detailed metrics such as usage frequency, duration of use, peak usage times, and the energy consumed by each cycle. We know that establishing a robust network of sensors ensures comprehensive coverage and accurate data capture, which is essential for the effective operation of the subsequent phases.

Fig. 2 Sonoff POW R2

Fig. 3 eGauge EG4115 data logger

Simultaneously, a central control unit is set up to serve as the hub of communication and data processing. This unit is responsible for collecting data from all sensors, processing this data, and sending commands back to the appliances based on real-time analytics. The control unit will use advanced communication protocols of Wi-Fi to ensure seamless interaction between different components of the IoT system.

3.2. Rule Definition and Neural Network Integration

Once the data collection infrastructure is in place, the next phase involves defining specific rules for energy consumption and integrating a neural network for predictive analytics. The rule-based system will operate according to a series of predefined parameters, such as minimizing energy usage during peak tariff periods and controlling the power state of appliances based on user habits and environmental conditions. These rules are programmed to ensure that energy consumption is kept within optimal limits without sacrificing user comfort and convenience.

In parallel, a neural network, particularly a Multilayer Perceptron (MLP), is going to be developed and trained with the historical data collected from the homes. This neural network will analyse patterns in energy usage to predict future demands and possible peaks in energy consumption. By understanding these patterns, the system can pre-emptively adjust the operational rules of the appliances, thereby ensuring more efficient energy use. The integration of machine learning not only enhances the system's ability to adapt to changing conditions but also supports more nuanced and dynamic management of energy resources.

3.3. System Deployment and Real-Time Operation

With the rules set and the predictive model in place, the system is now ready for deployment and real-time operation. During this phase, the IoT system actively monitors incoming data from the network of sensors. It applies the established rules and machine learning insights to manage appliance operations dynamically, as can be seen in Figure 4. This real-time application is critical for adapting to immediate changes in energy usage patterns and reacting to unforeseen conditions, such as an unexpected increase in appliance use or changes in the external energy supply.

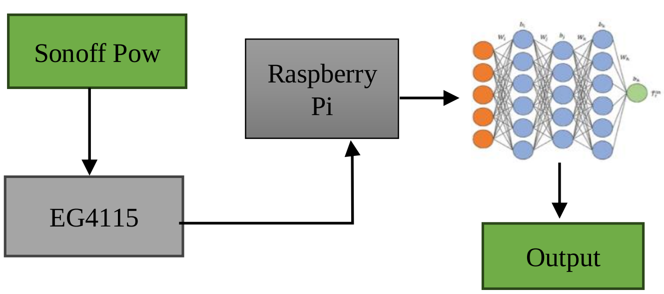


Fig. 4 Proposed methodology

This phase also involves continuous monitoring and adjustment, where the system's performance is regularly assessed to ensure it meets the predefined energy efficiency goals. Adjustments to the rules or the predictive model might be necessary to refine the system's responses and improve its overall energy management capabilities.

3.3. Evaluation and System Enhancement

The final phase focuses on the comprehensive evaluation of the system's performance and its impact on energy consumption. Efficiency metrics such as the total energy saved and reductions in energy costs are analysed to determine the effectiveness of the IoT system.

Based on the outcomes of this evaluation, the system may be enhanced or scaled to include more advanced features, such as integration with renewable energy sources or expanded predictive capabilities that account for a broader range of variables. The goal of this phase is not only to confirm the system's success in achieving its objectives but also to ensure its adaptability and scalability for future needs and technologies. This phase solidifies the foundation for a sustainable and intelligent energy management system that can evolve with advancements in IoT and smart home technologies.

4. Results and Discussions

In order to explain the implementation of the proposed methodology, the analysis begins by detailing the characteristics and operational data of test home appliances used within the study's IoT-based energy management system. This information is crucial for understanding how each appliance contributes to the overall energy consumption and how it can be effectively managed through the system.

4.1. Results

As seen in Figure 5, we have categorized various appliances into three types based on their operational characteristics and energy consumption profiles: Non-Shiftable (NS), Programmable Shiftable (PS), and Time Shiftable (TS). These categories are crucial for understanding how each appliance can be managed within an IoT-based energy management system to optimize energy usage and reduce costs.

Non-shiftable appliances, like the Refrigerator (Ref) and Air Scrubber (AS), are essential for continuous operation and have high dissipation coefficients (100.00), indicating significant energy use. They operate within a fixed power rating-0.3 kWh for the refrigerator and 0.4 kWh for the air scrubber across all time slots from 1 to 8. This category of appliances is typically not adjusted in response to energy price fluctuations due to their necessity.

Programmable Shiftable appliances include Heaters (H) and Air Conditioners (AC1, AC2), which allow for adjustable power settings. For example, the heater has a variable power range from 0.5 to 1.5 kWh, adjustable in increments of 0.1 kWh. These appliances can be programmed to operate at lower power during peak price times or shut off when unnecessary, providing flexibility in energy management. Their operational adjustments can significantly impact overall energy consumption, especially during times of high electricity prices.

	Name	Type	Diss. Coeff	Power Rating (kWh)	Time Slot
0	Ref	NS	100.00	0.3	[1, 8]
1	AS	NS	100.00	0.4	[1, 8]
4	H	PS	70.00	[0.5, 1.5, 0.1]	[1, 8]
3	AC2	PS	60.00	[0.4, 1.8, 0.4]	[1, 8]
2	AC1	PS	40.00	[0.3, 1.5, 0.2]	[1, 8]
7	WM	TS	0.09	0.2	[9, 2]
5	L1	TS	0.04	0.6	[3, 5]
8	DW	TS	0.03	0.7	[1, 8]
6	L2	TS	0.02	0.2	[8, 5]

Fig. 5 Categorization of appliance

Time-shiftable appliances, such as the Washing Machine (WM), Lights (L1, L2), and Dishwasher (DW), have the lowest energy requirements but can be entirely shifted in operation time. Their power ratings are relatively low, and they are scheduled to run during specific hours such as the washing machine, which operates between slots 9 and 2 - to take advantage of lower energy prices or high green energy availability. It can be seen in Figure 6 that the blue line represents the fluctuation of electricity prices across different time slots throughout the day. These fluctuations are critical data points for an IoT-based energy management system designed to optimize household energy consumption in response to dynamic pricing.

This figure clearly illustrates several peaks in electricity prices, notably around slots 5, 10, 15, 20, 25, and just before 30, where the cost reaches or exceeds $30/MWh. These peaks likely correspond to high-demand periods, possibly during morning and evening hours when residential energy usage typically increases. Conversely, the valleys in the figure, such as those seen around slots 8, 13, 18, 23, and 28, where prices dip to their lowest points, suggest times of reduced energy demand. As it can be seen, the orange line, which is the 'distribution,' represents the average expected price distribution based on historical data, predictions and typical energy market behaviour. This line allows us to contextualize the actual price fluctuations. It can be a valuable forecast for the energy management system, allowing it to anticipate and react to potential rises or falls in electricity costs.

Based on this fluctuation, we can see that the IoT system can make informed decisions about when it is most cost-effective to operate high-energy-consuming appliances or to store energy in home battery systems if available. For example, the system might delay the operation of a dishwasher or washing machine to align with the next anticipated low-price period, thus avoiding high costs associated with peak times. This strategic adjustment not only optimizes financial savings on energy bills but also contributes to a more balanced and efficient grid operation by reducing consumption during peak periods.

4.2. Result of Integration with Green Energy

As we can see in Figure 7, the usage of green energy is crucial, and it presents the variability in green energy production, measured in watt-hours, across various time slots throughout the day. This figure is crucial for understanding how fluctuations in renewable energy availability can influence energy management strategies in smart home systems.

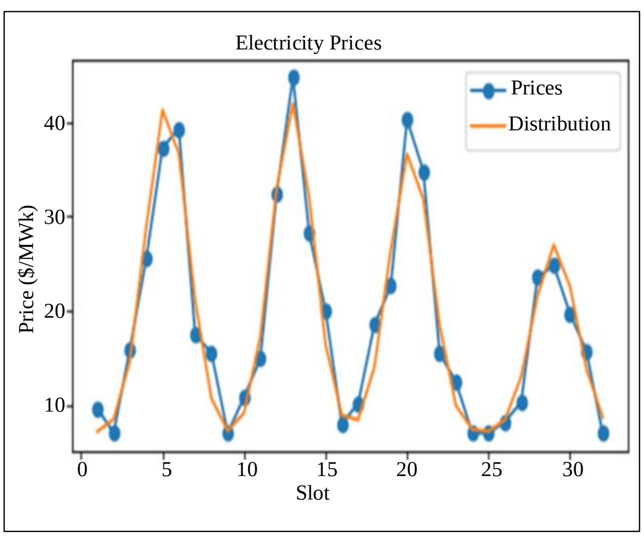


Fig. 6 Fluctuation of electric price

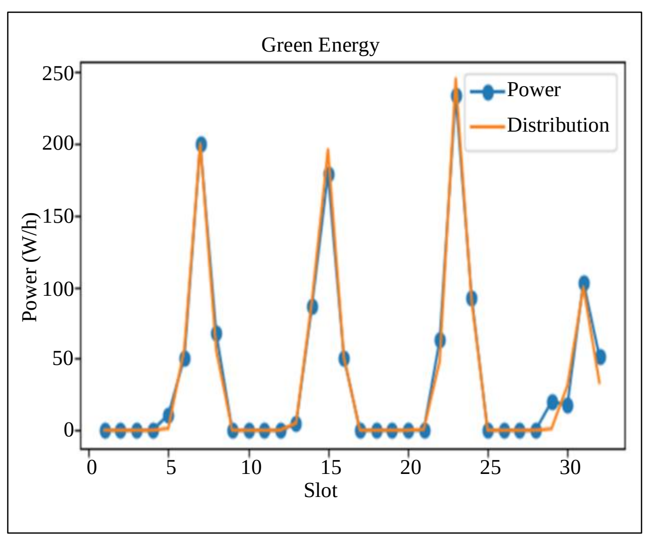
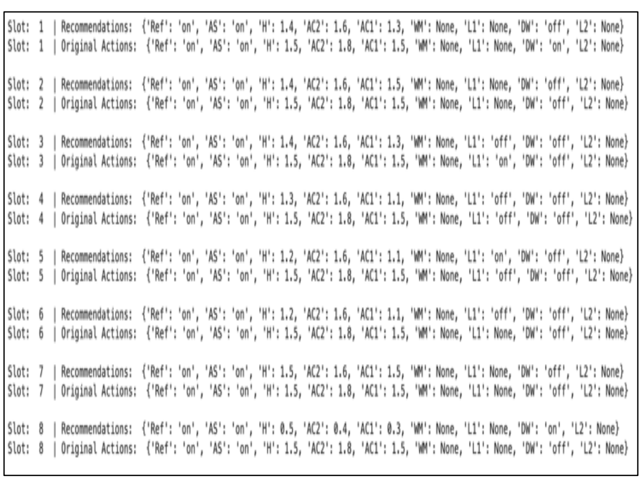


Fig. 7 Heating increased value

The blue line, representing the actual power generated from green energy sources, shows notable peaks at specific times of the day - around slots 10, 15, and just before 25. These peaks suggest times when renewable energy sources are producing at their maximum due to optimal conditions such as peak sunlight hours or favorable wind speeds. The presence of these peaks provides an opportunity for the IoT-based energy management system to leverage this readily available green energy, reducing reliance on non-renewable grid power. Conversely, the valleys indicate periods of low energy production, typically during early morning or late evening, which are times when these renewable sources generate minimal power due to natural limitations like the absence of sunlight or decreased wind activity.

The orange line labeled 'distribution' likely represents a predictive model or an average expected output based on historical data. This line helps provide a baseline expectation against which actual power generation can be compared. It assists the energy management system in anticipating changes in green energy production, enabling it to adjust household energy consumption plans proactively. For instance, during expected low production periods, the system might choose to reduce energy usage or draw from stored energy in battery systems.

As the output of the proposed methodology to recommend which energy source should be used and which appliance should be turned off, Figure 8 article illustrates a comparative analysis of original appliance actions versus the recommended actions as suggested by the IoT-based energy management system over a sequence of time slots. This comparison highlights the system's effectiveness in adjusting appliance operations to optimize energy use and reduce costs. In each time slot, the system evaluates the current energy prices, the availability of green energy, and other relevant factors to provide recommendations that either maintain, increase, or decrease the energy consumption of various household appliances.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Slot:  1  | Original Actions:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.8, 'AC1': 1.5, 'WM': None, 'L1': None, 'DW': 'on', 'L2': None}

Slot:  2  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 1.4, 'AC2': 1.6, 'AC1': 1.5, 'WM': None, 'L1': None, 'DW': 'off', 'L2': None}
Slot:  2  | Original Actions:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.8, 'AC1': 1.5, 'WM': None, 'L1': None, 'DW': 'off', 'L2': None}

Slot:  3  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 1.4, 'AC2': 1.6, 'AC1': 1.3, 'WM': None, 'L1': 'off', 'DW': 'off', 'L2': None}
Slot:  3  | Original Actions:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.8, 'AC1': 1.5, 'WM': None, 'L1': 'on', 'DW': 'off', 'L2': None}

Slot:  4  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 1.3, 'AC2': 1.6, 'AC1': 1.1, 'WM': None, 'L1': 'off', 'DW': 'off', 'L2': None}
Slot:  4  | Original Actions:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.8, 'AC1': 1.5, 'WM': None, 'L1': 'off', 'DW': 'off', 'L2': None}

Slot:  5  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 1.2, 'AC2': 1.6, 'AC1': 1.1, 'WM': None, 'L1': 'on', 'DW': 'off', 'L2': None}
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Slot:  6  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 1.2, 'AC2': 1.6, 'AC1': 1.1, 'WM': None, 'L1': 'off', 'DW': 'off', 'L2': None}
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Slot:  7  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.6, 'AC1': 1.5, 'WM': None, 'L1': None, 'DW': 'off', 'L2': None}
Slot:  7  | Original Actions:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.8, 'AC1': 1.5, 'WM': None, 'L1': None, 'DW': 'off', 'L2': None}

Slot:  8  | Recommendations:  {'Ref': 'on', 'AS': 'on', 'H': 0.5, 'AC2': 0.4, 'AC1': 0.3, 'WM': None, 'L1': None, 'DW': 'on', 'L2': None}
Slot:  8  | Original Actions:  {'Ref': 'on', 'AS': 'on', 'H': 1.5, 'AC2': 1.8, 'AC1': 1.5, 'WM': None, 'L1': None, 'DW': 'off', 'L2': None}
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Fig. 8 Recommendation output

For example, in the initial slots, the system recommends slightly reducing the heating unit's energy consumption (from 1.5 to 1.4, 1.3, and eventually 1.2 kW), demonstrating the system's capacity to adapt to changing energy conditions in an effort to conserve energy or reduce costs during peak times. This trend of adjusting appliance settings continues across different slots and appliances, such as air conditioning units and lights, where the recommended actions often include turning off appliances or adjusting their power settings to lower values during less critical periods.

By slot 8, there is a significant change in recommendations for the heater, suggesting a reduction to just 0.5 kW, and for one air conditioner unit, adjusting down to 0.3 kW. This could correlate with a period of either lower energy prices or higher green energy production, where maximizing energy savings becomes feasible without compromising on comfort or utility. The adjustments in recommendations versus original actions not only reflect the system's real-time response to energy cost and availability but also showcase its potential to manage energy consumption intelligently.

Meanwhile, in terms of electricity cost with and without Demand Response (DR), Figure 9 illustrates the economic benefits of utilizing an IoT-based energy management system for the proposed system. This figure provides a clear comparison between the electricity costs incurred when appliances operate under standard conditions without any optimization ("Cost without DR") versus when they operate under an intelligent demand response system ("Cost with DR").

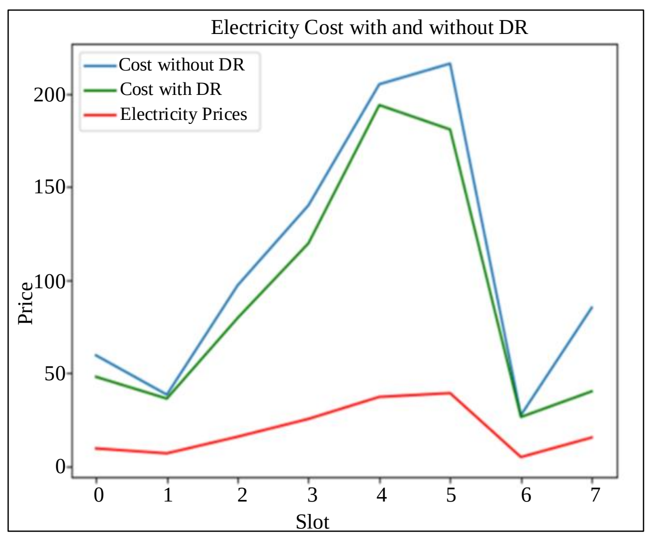

Fig. 9 Electricity cost with/without DR

The chart reveals that electricity costs, when not managed by the IoT system, follow the electricity price trends closely, peaking sharply in the middle slots where electricity prices are at their highest. This demonstrates a typical scenario where appliances consume energy in alignment with user habits, regardless of energy price fluctuations, resulting in higher costs during peak price periods. In contrast, the green line depicting the cost with DR shows significantly reduced costs throughout the same periods. This indicates that the IoT system effectively shifts the operation of high-energy-consuming appliances to times when electricity prices are lower. It optimizes their energy usage in real-time according to dynamic pricing, which significantly lowers the overall energy expenditure.

This strategic shift not only results in direct cost savings for the household but also demonstrates the system's capability to alleviate stress on the electrical grid during peak times. By reducing demand during these critical periods, the system not only conserves financial resources but also supports broader environmental goals by potentially reducing the need for high-polluting peak power plants.

The figure underscores the value of integrating IoT with machine learning into home energy management, showing that intelligent systems can significantly impact energy conservation and cost management. This aligns with the growing need for sustainable energy solutions in residential areas, where energy consumption is often high and inefficient.

5. Conclusion

This study has successfully demonstrated the implementation of optimizing home energy management in Somalia with IoT, incorporating machine learning to manage home energy usage efficiently. The methodology was robust, involving real-time analytics to determine the optimal utilization of various energy sources and control appliance operations effectively.

The system's ability to recommend which appliances should be turned off and when to utilize specific energy sources, based on predictive analytics of price fluctuations and green energy availability, marks a significant advancement in home energy management. Notably, the results underscore the potential for considerable energy savings and enhanced sustainability through intelligent IoT applications. This is particularly relevant for Somalia, where improving energy efficiency can lead to substantial economic and environmental benefits.

Future research should focus on expanding the capabilities of the IoT-based energy management system to enhance its applicability and efficiency. Further development could include integrating a wider variety of renewable energy sources and more advanced machine learning algorithms to predict energy patterns with greater accuracy. Additionally, exploring the scalability of this system to other regions and its adaptability to different environmental conditions would be valuable.

Studies assessing the long-term economic impacts of widespread system adoption could support the case for national policy changes and attract investment. Enhancing user interfaces and incorporating feedback mechanisms would also improve user engagement and system performance, tailoring the energy management solutions to meet individual and community needs better.

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