



## Hybrid smart grid with sustainable energy efficient resources for smart cities



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### ABSTRACT

A smart city is a safe and productive metropolitan area that offers its residents a high standard of living through optimized resource planning. The advent of smart cities has allowed consumers to easily and reliably control home resources. In this regard, power control is a challenging activity, involving the optimal scheduling of connected devices to optimize electricity utilization. Therefore, this problem needs to be addressed with considerable attention and dedication. Several solutions are presented for energy optimization in smart cities, but not for real-time energy optimization. This paper introduces a hybrid smart grid that produces electricity from various sources Photovoltaic (PV), hydro and thermal power with a delivery system that satisfies energy optimization of the energy costs in real-time (ECRT) by considering the latency factor (FoL). This research aims to build resources in a smart grid (SG) for efficient control of power operations management. This paper models sustainable energy from all-natural sources and organized the proper energy distribution system at an optimized level for energy efficiency in a smart city. This paper presents various ideas and smart energy solutions that provide more advancement to several disciplines that concentrate on performance enhancement, smart and efficient resource utilization, and sustainable design.

### 1. Introduction

The transformation to clean energies occurs on multiple global scales. Several communities, cities, and regional government bodies have come together to establish plans to turn their area's electricity resources into a potential renewable energy infrastructure [1,35]. In the current power system, energy conversion from generation station to the distribution system or the customer end is rather costly [2]. To prevent costly defects in electrical equipment requiring careful intervention in the use of electrical appliances, it is necessary to properly leverage the energy that can be accomplished by numerous methods such as tracking, regulating, and projecting [3]. It is often recommended to supply the excess electricity to the system, where the user builds renewable energy (RE) projects in their local areas.

Incorporating RE options through the power system gives a big approach to tackling multiple critical energy-related concerns like rising environmental issues and dependence on oil and market demand uncertainty attributable to extremely volatile pricing of fossil energy [4]. RE production can generally be expected to provide the installed device power, output rates, and regional region natural and climatic dynamics. Several monitoring mechanisms and strategies requiring increased costs are used to mitigate the effects of sustainable incorporation [5]. That some of the more widely employed technologies include power storage devices, operating equilibrium methods, and other revolutionary solutions like hydroelectric power and rechargeable vehicles [6]. Fig. 1 shows different types of renewable energy.

The energy technologies sector is making massive changes in the generation, circulation, collection, and methodologies of having to sell

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power in the form of the competition of increasing its flexibility and reducing both prices and service demands [7,26,27]. RE began to be appealing during most of the mid-70s energy revolution while the hazard of conducting out of fossil diesel was grasped, leading to the development of RE and resource extraction sustainability [8]. Renewable and sustainable energy sources, such as wind and solar, can eventually replace increased-emission energy sources. Using these renewable energy technologies, smart cities will provide a substantial portion of electricity needs. Table 1 shows the list of cities that plan to become fully optimized smart cities and that were enacted into legislation or approved as a specific purpose by executive actions.

This paper focuses on optimizing the procedure that facilitates successful management to accommodate the supply volatility from renewable resources and thus enable optimized incorporation of renewable energy into the power network. The key goal is to manage the activities in a way that minimizes the electrical load fluctuations. The paper explores different stages of incorporating renewables into the power grid to show the principle of this method.

This research would investigate the dynamics of sustainable RE in technology in smart cities. The paper stuff was organized in a subsequent manner. Section 2 addresses the extensive review of previous papers on energy efficiency transitions in smart cities. In Section 3, the proposed solution is provided. In Section 4, we discuss RE sources for energy efficiency in smart cities. In Section 5, we discuss our paper's conclusion, and in the last section, we outline the future directions for our research.

## 2. Literature Review

RE supplies are termed clean energy options, and because of their environmentally sustainable existence, they are increasingly significant. Important activities such as structural reform of desolate area and cities are required to be addressed with the establishment of RE, in response to the fulfillment of the commitments to satisfy foreign environmental regulation treaties [9]. There is indeed a worldwide trend to substitute traditional fuels with RE sources to meet the excessive electricity demand [10]. Regardless of the growing increase in electricity use for more safety and comfort globally, there has been a critical need for electricity use in cities.

Energy from the sun can be specifically transformed into photovoltaic PV electricity. PV production is a method of transforming radiation from the sun or photoelectric effect into useful electrical energy utilizing

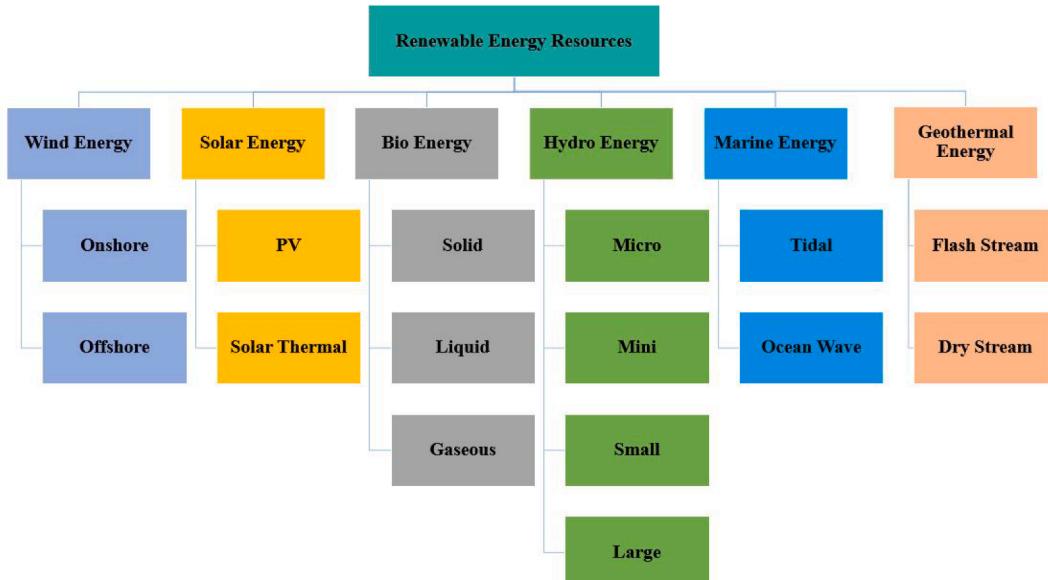
**Table 1**  
Smart Cities Target for 100% Energy Efficiency.

State	Completion Year	Explicit Executive Goal	100% Target Type
Rhode Island	2030	Order	Renewable energy
Washington DC	2032	Law	Renewable energy
New York	2040	Law	Clean energy
Connecticut	2040	Order	Clean energy
California	2045	Law	Clean energy
Hawaii	2045	Law	Renewable energy
New Mexico	2045	Law	Clean energy
Washington	2045	Passed	Clean energy
Virginia	2045	Law	Clean energy
Maine	2050	Law	Renewable energy

a photovoltaic effect-exhibiting solar cell surface [11]. The global energy Organization has classified solar thermal applications into four groups, namely, residential off-grid, non - residential off-grid, remote grid linked, and consolidated power generation systems [12]. A standard PV panel consists of about 36 either 72 series-connected cells, encapsulated in an aluminum frame, depending on the model and the form of technology employed.

Geothermal energy has become a very promising form of clean green technology that exists naturally. Taking advantage of these environmental resources is easy and brings absolutely no detriment to the community [13]. Geothermal doesn't suffer from the intermittent nature of other energy sources. Its performance in production is fairly moderate compared with other alternatives. Geothermal resources may be utilized by the usage of an Organic Rankine Cycle mostly as fuel for power production plants [14]. Geothermal power solutions need substantial initial expenditure and include relatively minimal operational expenses.

RE overtakes oil and coal as the primary form of energy production and becomes the basis for meeting the global energy targets. Bioenergy plays a significant role across growing alternative sources of energy [15]. Recognizing the value of bioenergy, appropriate analysis of the new frameworks and their applications and economic prospects can enable consumers, and stakeholders to understand the trading strategies for growth. Bioenergy relates to any organic substances produced by some natural operation, such as industrial and agricultural processes [17]. Applications of bioenergy may be in gas, fluid, and solid forms. It can be used for various purposes, such as generating power, generating heat, and producing fuel for transport. Significant bioenergy resources



**Fig. 1.** Renewable energy types for energy efficiency.

will be burning instantly in the fireplace, and the heat produced is being used for electricity generation [18].

Wind energy is linked to the transition of atmospheric circulation from high ambient pressure regions to neighboring areas of low pressure, with speeds corresponding to the pressure gradient. The strong winds over the oceans, deeps, and lakes appear calm during daylight relative to the adjacent mass across land regions [19]. For instance, wind power is a robust and well-established technology capable of generating electricity at a comparable rate with coal and renewable energies like nuclear deployed as during the past several years [20]. For certain areas of the world, the sum of wind energy is economically negligible, mankind has long gained from its usage for different purposes. Table 2 shows methodologies for incorporating renewables.

Corresponding evaluations and revisions to current legislation are undertaken in different countries. This suggests that RE enactment is a complicated problem for authorities and needs an ongoing evaluation of social, cultural, technical, and environmental factors [16]. Given the tremendous promise and advantages of supporting sustainable energy, there are challenges which need to be addressed at both global and regional level. Limited expenditure in green energies is one of the obstacles as it requires large upfront operational costs, and the potential gains of these ventures require time to evaporate. Key hazards with wind and solar energy will be addressed subjectively and, where necessary, in terms of cost savings and could have an effect on the system above and beyond the costs involved in the installation and maintenance of the power generation network [33]. Hydropower is typically well incorporated with current activities but has far reduced development capacity. Tide, wind, water, and geothermal resources are presently far more constrained in proportion and production. Energy conservation is often perceived as an energy source, which is not typically paired with RE, which is mentioned below since greater output capacity.

**Table 2**  
Methodologies for incorporating Renewables.

Article	Proposed Solution	Method	Advantages	Disadvantages
[21]	Adaptive Power Supply	Mathematical	Existing solvents and formulations developed.	Computationally costly, precise data and condition.
[22]	Quadratic Framework			
[23]	Linear/nonlinear integer hybrid program			
[24]	Exhaustive power transfer	Numerical	Speedy answer and usability of the system.	Globally optimum not assured and open to adjustment of parameters.
[25]	Alternating current power flow			
[28]	Modified flow of power			
[29]	artificial bee colony	Heuristic	Relatively clear arrangement of issues and flexibility of composition.	Just power device functionality, needs input function model and no position and scale distinction.
[30]	particle swarm open source			
[32]	Genetic Algorithms			
[32]	harmony search			

Environmental change, in the current situation, is affecting the climate and future of humanity. The electricity supply industry of power plants produces about 75 % of the world's gross CO<sub>2</sub> emissions [34]. Many nations have aligned with the goals of sustainable growth by drawing up a framework for the introduction of RE, a path map to meet its goals, and national strategies for the creation of RE. Energy consumption is increasing rapidly, and overall global growth will be more than double by 2030, although power demand will nearly triple where it is today. Technological advances have made it easier to utilize such natural resources more effectively to produce energy.

### 3. Proposed Framework

The core targets of the smart city network are identified. Such goals aim to carry out a common paradigm for evaluating medium-to-long-term approaches for environmental and energy conservation in small to medium-sized communities. Different specifications were developed, including the smart city platform's technological functionalities [37]. Such criteria are defined through a collaborative and dynamic process where cities, modeling experts, computer scientists, and other stakeholders in the city, along with energy market power distribution providers, examine their specific needs and perspectives. A collective understanding between community stakeholders on its functionality will be established, meaning that all feasible criteria are taken into account.

The renewable generation developments were encouraged by solution developers to extend the enabling infrastructure for power generation. Several communities around the world have taken steps and become smart cities, although each situation is unique. Every city administration must change priorities and strengthen initiatives to fulfill its particular needs. This paper addresses integrated technology solutions to increase network performance, resource stability, and rising the scale of energy storage for off-grid applications. Examination of the present situation in modeling, optimization and management systems for the operation of the distribution system.

The infrastructure of growth strategy improves demand and generation convergence at the production phase. Fig. 2 represents the new modern grid that is interconnected with all sources to provide a cleverer, faster, and more efficient approach to satisfying the rising electricity demand. The infrastructures produce major production industries, make rational choices, and take decisive action to build the next decade's workplace and a creative, productive economy. The key emphasis is placed on determining the routing pattern of load within defined limits and expectations optimally. Citizens are also considered to have set the functioning ranges of their loads before scheduling, while the optimization algorithm can pick the ideal optimum solutions without breaching constraints.

Let there are several loads scheduled in time  $t$ , and the energy  $E_t$  is required to meet the energy requirement. Therefore,  $E_{min}$  and  $E_{max}$  and are the lower and upper bound for the required energy.  $T_c$  is the time required for the 24 h cycle, and  $c$  represents one hour cycle.

Time  $T$  refers to the specified time period.  $B_{t_i}$  and  $F_{t_i}$  are the first and final bound. The range of time slots used to run the system is represented by  $i$ .

In addition, we set the range of operation starting time of the operation

$$T_i \in [B_{t_i}, F_{t_i}] \quad (1)$$

The Factor of Latency (FoL) is used to distinguish the frequency of two cases by considering the operation time (OT). In this strategy, we intend to reduce the wait for intelligent systems to improve efficiency [36].

$$FoL_i = \frac{T_i - B_{t_i}}{E_{t_i} - OT - B_{t_i}} \quad (2)$$

The FoL high and low numerical values will be 1 and 0. At the start,

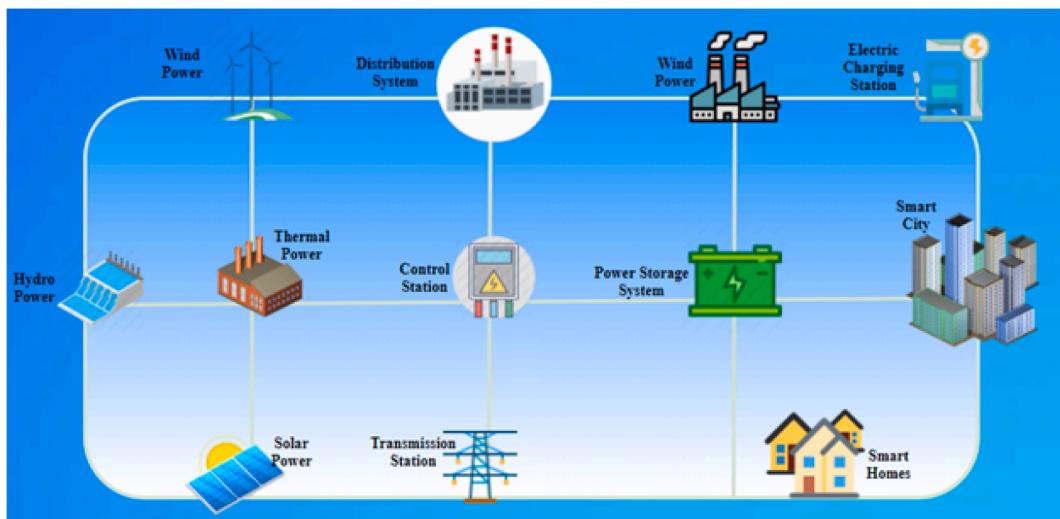


Fig. 2. Smart City and Efficient Design for Integrated Grid.

any appliance time is  $B_i$  then  $FoL$  will be 0. In the start, if the energy level is  $E_i$  the  $FoL$  will be 1. The total of  $FoL$  with the waiting period expense for both components can be calculated as [36].

$$w^{FoL_i} = \frac{(\zeta_i)^{B_i} - C}{P_i^{T_c}} \quad (3)$$

The below model for the waiting constraint for every operating device  $i \in D_i$ . The higher value of  $\zeta_i$  will increase the cost of getting ready.

$$\sum_{t=1}^{T_c} \sum_{i \in D_i} (w_i^{FoL}) (x_i^{(c)}) \quad (4)$$

Here, we need to reduce the energy use rate and reduce the latency factor's cost. By modifying the configuration, the manipulator can control the time and by deciding  $\zeta_i = 1$  for every operation  $i$ , cost of queuing up to reduce the power costs then the scheduling is manipulated as:

$$S_i = \frac{\zeta_i - B_i}{E_{t_i} - B_i} \quad (5)$$

We organize an optimization issue that minimizes the total energy utilization bill while stabilizing the user's convenience with minimal waiting. The goal is to decrease the total energy consumption and find the optimum energy schedules for the increasing device to reduce the bill and decrease  $FoL$ . We take into consideration the planned energy cost in real-time (ECRT) load for one day, in which we aim to limit costs by controlling the use of energy. The hourly expense is defined as:

$$Cost_{total}^T = \sum_{i \in D_i, AL - OL} E_{i, AL} * EUP \quad (6)$$

Where,  $AL$  is the actual load,  $OL$  is the output load and  $EUP$  is the energy unit price. Therefore the objective function is to reduce energy price.

$$Min (Cost_{total}^T) \quad (7)$$

We consider ECRT with the price of electric units is (5.10 to 30.5 KWh). Table 3 shows eight occurrences conceivable. The cost of energy use in the feasible area is considered viable and the optimal level.

The mathematical representations of the respective loads were developed with their respective limits and constraints. It is obvious that the developed system can handle the domestic load from numerical simulations while retaining consumer comfort. The results are

**Table 3**  
Methodologies for incorporating Renewables

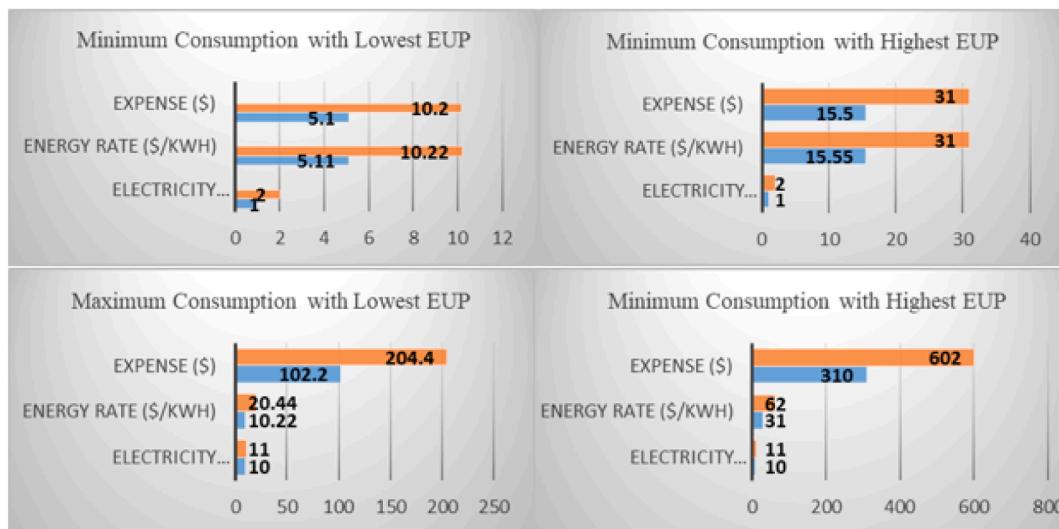
Consumption Level	Energy Unit Price	Electricity Consumption (Kwh)	Energy Rate (\$/Kwh)	Expense (\$)
Minimum	Lowest	1	5.11	5.1
Minimum	Lowest	2	10.22	10.2
Minimum	Highest	1	15.55	15.5
Minimum	Highest	2	31	31.0
Maximum	Lowest	10	10.22	102.2
Maximum	Lowest	11	20.44	204.4
Maximum	Highest	10	31	310.0
Maximum	Highest	11	62.0	602.0

represented graphically in Fig. 3.

Data from the analysis suggest a substantial decrease in electricity costs coupled, it demonstrates that when the minimum EUP with high usage stimulates low prices and the cost would be high when the maximum utilization with high EUP. The moderate state is when the high consumption with the lowest EUP. As relates to the efficiency of the proposed system, we have identified and classified different loads on the basis of different requirements by maintaining both system reliability in terms of decreased peaks and maximum efficiency.

With the gradual growth of the human population, the use of electricity is increasing. Conventional power supplies are not adequate to satisfy the existing demand for energy. The idea of the smart grid (SG) is implemented to meet this need. Currently, several relevant works have been reported analyzing the mechanism of commodity markets and the associated demand. Those works can generally be classified into two main channels. The first type of research focused on researching utility users optimum energy usage plans in reaction to retail market demand. In general, the potential SG is expected to be a hybrid infrastructure in which electricity users are not only linked to suppliers but also certain local utility infrastructure. Inexpensively and productively, local energy platforms promote local energy exchanges between energy users and distributed energy vendors, which are intended to support all respondents.

A common model of these metropolitan areas is the micro-grid where residential homes and companies are provided with on-site electricity supplies and centralized resources like electric vehicles. The common goals of power management in SG include minimizing electricity costs, reducing the peak to optimal ratio, maximizing user comfort, minimizing consolidated energy consumption, and integrating RE. The residential area absorbs a large deal of energy, and its use is increasing



**Fig. 3.** Illustration of cost outcomes with different utilization.

rapidly. This reality leads investigators towards smart city infrastructure [31]. The operational challenge is to balance an operating power station power cost, which connects a renewable energy source with a storage unit attached to the main grid. The setting in order framework provides control over the storage device.

It is widely agreed that deterministic techniques are insufficient to work adequately with the diverse and unpredictable complexities of renewable energy resources [38]. In the area of real-time grid synchronization, the action being taken at that time slot has an effect on the subsequent states and possible measures to be taken, making it especially difficult to investigate the performance [39]. In high definition optimization, the irrefutable study aimed at the dimensionality of the iterative algorithm, expelling classical deep learning algorithms from feasible architectures [40,41].

A new roadmap for 2035 was recently put into action by the Egyptian government. It intends to harness the country's RE capacity and include more investments in the transmission system's infrastructure. This is intended to ensure the safety and stability of the kingdom's power generation. It would also reduce reliance on fossil fuel-fired energy plants and satisfy the ever-increasing power requirements on a sustainable basis. In this context, the country's goal is to generate about 20% of power from RE capitals by 2022 and pursue a larger proportion of RESs by 42% by 2035 [43].

A fictional rural community village containing 100 homes (400 dwellers) as well as a few small industrial buildings and industries in the North-West of Western Australia. Its semi-residential simulation model with a regular AC load of 2 MWh has indeed been suggested. Residents receive their fuel supply from fuel tanker vehicles, which brings an added expense to the power turbines' fuel prices. A stand-alone 100% RE hybrid grid was proposed, which involves possibilities for solar PV farming and renewable energy storage technologies to efficiently meet energy requirements [44].

The key problems related to them based on renewable energies, which rely on both climate and geographical, thereby impacting the scale of hybrid systems' components. The existence of sustainable sources allows both architects and practitioners to identify the different influences and factors associated with the design of the hybrid model [45]. In this particular circumstance, the scale of a hybrid system relating to a green environment that results in an optimization process where a performance index can be optimized [42]. The scientific study aimed at optimizing the system's overall costs, including the parameters and limitations of the process, was determined [46].

Hybrid grid networks are typically a combination of REs. The hybrid systems provide electricity consistently, without any interruption, as the

batteries connected to them maintain the power. In comparison with conventional power plants that use fuels as fuel, the cost of maintenance of hybrid grid systems is low. Hybrid grid systems operate more effectively than the conventional plants. Hybrid grid system works effectively in all sorts of circumstances despite wasting resources. Conventional turbines, which supply high power as they are switched on, hybrid grids manage power appropriately [47]. A hybrid grid may have equipment that adjusts the power generation of the devices to that which is associated.

Based on the study carried out by the researchers, it was indicated that most studies actually followed sustainable procurement approaches to improve the architecture of hybrid grid in power generation system. The service, interaction and synchronization of various energy sources must be monitored and will become challenging. Batteries attached to the device may have a shorter lifetime because they're often subjected to external elements such as fire, rain, etc. The range of devices that can be attached to a hybrid grid energy system varies from architecture to architecture and is constrained [48]. In order to overcome the problem of electricity production, the increasing research development in hybrid grids has been seen as an inevitable and critical solution.

#### 4. Conclusion and Future Work

To maintain maximum energy efficiency in a very dynamic environment like a smart city. The development of the power flow regulator improves the performance of the hybrid energy transfer. The emergence of smart cities has made it easier to regulate residential capital conveniently and efficiently. Energy management is a demanding task in this respect, requiring the efficient arrangement of linked systems to maximize energy usage. This paper proposes a hybrid smart grid that generates electricity from different sources of photovoltaic (PV), hydro and thermal power with a distribution network that, through considering the latency factor (FoL), achieves energy optimization through the energy costs in real-time (ECRT). This research aims to develop the efficient control of power operations management to meet the energy optimization for energy efficiency in the smart cities.

We intend to develop the predictive model in the future. In fact, instead of providing unalterable data access probabilities with each event, the program will consider the occupant's actions and create probabilities models that represent reality more closely. The paper brings numerous concepts and advanced renewable energies that deliver greater innovation to a wide range of issues directed at improving efficiency, managing intelligent renewable capital, and resource efficiency for smart cities.

## CRediT authorship contribution statement

**Muhammad Ibrahim Khalil:** Conceptualization, Methodology, Formal analysis, Writing - original draft. **N.Z. Jhanjhi:** Methodology, Visualization, Supervision, Writing - review & editing. **Mamoona Humayun:** Methodology, Visualization, Supervision, Writing - review & editing. **SivaKumar Sivanesan:** Methodology, Visualization, Supervision, Writing - review & editing. **Mehedi Masud:** Conceptualization, Formal analysis, Investigation, Writing - original draft. **M. Shamim Hossain:** Investigation, Software, Validation, Writing - review & editing, Funding acquisition.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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