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Synergizing Smart Energy and Core Electrical Networks for Sustainable Power

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Abstract
In order for power systems to be safe and efficient, smart energy technologies must be connected to the main electricity networks. If you want to improve stability, resilience, and sustainability, this paper looks at how smart energy solutions and standard electricity lines can work together. To keep track of and change how much energy is used and made, we talk about important technologies like smart meters, improved monitors, and Internet of Things (IoT) devices. Using less fossil fuels and releasing less carbon dioxide is easier when smart energy systems make it easier to add green energy sources like solar and wind to the grid. Modern tracking and control systems in smart grids make them more stable by letting flaws or outages be found and fixed quickly. To make energy use more efficient, smart grids allow programs called demand response, which let customers change how much energy they use based on real-time prices or grid conditions. The paper also looks at how data analytics and machine learning can help improve grid operations and energy management. Forecasting repair of grid equipment is made possible by these technologies. This makes the grid more reliable and cuts down on downtime. It is also easier to make advanced energy predicting models with their help, which makes it easier for grid workers to balance supply and demand. The combining smart energy technologies with basic electricity networks in a way that makes them work better together looks like a good way to make power systems that last and work well in all situations. We can improve energy economy, protect the environment, and make sure that future generations will always have access to power by using smart grids and other new technologies.

I. INTRODUCTION

Adding smart energy technologies to main power grids seems like a key step toward a more environmentally friendly future. As the need for energy around the world continues to grow, standard power lines are having trouble staying reliable, being efficient, and having a positive effect on the environment. Smart energy solutions are a big step forward that could change how we make, share, and use power. It goes into great detail about how to connect smart energy to main electricity networks. It talks about the reasons behind this, the latest technology advances, and the possible benefits of this game-changing project. The needs of today can't be met by traditional power lines, which usually have centralized production and one-way power flow [1]. There are many problems with these grids, such as old equipment, limited insight into how the grid works, and the chance of problems happening. Furthermore, using fossil fuels to make electricity damages the earth and

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speeds up climate change. Instead, smart energy technologies use new ideas and computers to build a stronger and more reliable energy system that can handle these problems in a more complete way. The idea of a "smart grid" an updated power grid that uses cutting-edge communication, tracking, and control technologies is at the heart of the smart energy revolution [2]. Smart grids allow power to move in both directions, which makes it possible for distributed energy resources (DERs) like solar panels, wind turbines, and energy storage systems to work with the grid without any problems. Smart grids make the grid more flexible, lower transport losses, and encourage the use of green energy by spreading out power production and giving pronsumers (consumers who also make electricity) more power.

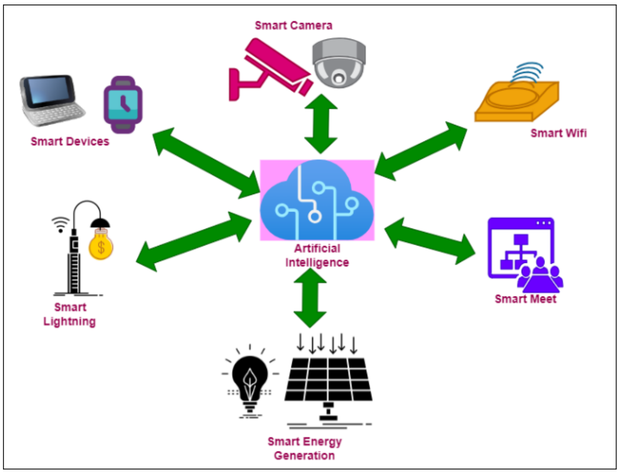

Figure 1: Next Generation technology in sustainable power

Smart meters, sensors, and automation systems are important parts of smart grids because they give real-time information on how much energy is being used, how well the grid is working, and the health of assets. With [3] this amount of detail, utilities can improve grid operations, find problems, and quickly fix grid issues. Also, smart grids make demand response programs possible, which encourages people to change how much energy they use in response to price signs or changes in the grid. Demand-side control helps ease the stress of high demand, lowers the cost of energy, and makes the grid work better generally. Along with making the grid work better, smart energy technologies allow the use of advanced data and machine learning methods for repair and improvement that can be planned ahead of time. Utility companies can predict when equipment will break down, plan repairs ahead of time, and improve asset performance by studying huge amounts of data received from sensors and smart devices. Also, machine learning techniques can make energy forecasts more accurate, which lets grid workers predict changes in supply and demand and make the best use of resources based on those changes. Smart energy that is connected to core electricity networks has a lot of potential to make power systems last for a long time. Smart energy technologies offer a way to a more fair, efficient, and environmentally friendly energy future by encouraging the use of green energy, making the grid more resilient, and giving users more power [20]. But in order to make this idea come true, many scientific, legal, and economic problems must be solved. Smart energy solutions must be easily integrated and widely used, but there are some problems that need to be fixed, like hacking, interoperability, and legal frameworks. The coming together of smart energy and core electrical networks will completely change how we make, share, and use power. We can make the energy system more reliable, long-lasting, and fair by using technology, automation, and green energy. The goal of this study is to look at the many aspects of this synergy, including the new technologies, economic effects, and social benefits of integrating smart energy. We can reach the full promise of smart energy and build a better, healthier future if we all work together and make smart investments.

II. RELATED WORK

Adding smart energy technologies to main power grids is a new area of study and development that is growing quickly. It uses ideas from engineering, computer science, economics, and policy studies, among others. A thorough look at linked work shows a lot of different study projects that are trying to figure out the difficulties, chances, and effects of this big project. Another important area of connected study is the technical progress that is making smart energy systems better and allowing them to connect to regular power lines. A lot of research has been done on how smart meters, sensors, and information networks can help track, control, and improve energy flows in real time. For instance, [4] study shows how important advanced metering infrastructure (AMI) is for making the grid more visible and allowing demand response systems to work. In the same way, [5], [6] look into how smart monitors and IoT devices can be used in electricity grids to find faults, diagnose them, and plan for future maintenance. Researchers have also looked at how smart energy systems affect the stability and robustness of the grid. Smart grids can lower the risk of failures that affect other parts of the grid, handle power outages better, and make the grid more stable by using distributed energy resources (DERs) and autonomous

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control methods. On the other hand, [7] show how spread control methods can make microgrids more resistant to cyber-physical threats and natural disasters. In the same way, [8] look into how advanced control methods and optimization techniques can be used to make the grid more resilient and flexible.

Along with technical progress, linked study has looked into the social and economic effects of integrating smart energy. Researchers have looked into how cost-effective investments in smart grids are, how legal rules affect market dynamics, and how government benefits can help people use green energy. One study by [9] looks at the cost-benefit analysis of smart grid projects and stresses how important it is to think about both economic and social benefits. In the same way, [10] look at how governmental policies affect the use of smart energy tools and encourage new ideas in the energy industry. Researchers have also looked into the social effects of integrating smart energy, such as how it affects fair access to energy, the long-term health of the environment, and social support. Smart energy solutions could help lower energy poverty, make it easier for people to get clean energy, and even out environmental differences by making energy more accessible to everyone. [11] look at how people feel about smart meters and demand response programs. They show how important it is to educate and involve the public in order to build trust and acceptance. Also, research by [12], [13] look at how community involvement and shared decision-making can affect the change to smart energy systems. The research related to smart energy and core electricity networks covers a lot of ground. This includes new technologies, making the grid more reliable, the effects on the economy and policy, and the effects on society. Researchers have added useful knowledge and insights to the development and use of smart energy systems by combining ideas from different fields and study methods. But [14] problems like connectivity, hacking, and legal roadblocks are still big problems that need more work and care from everyone involved. Systems that make energy are made to change main energy sources, like heat, electricity, and cold, into secondary or alternative energy types. Renewable energy sources are usually more important than fossil fuels in a normal intelligent energy system. However, fossil fuels are used as an extra energy source to make sure that the plant stays running all year. Wind machines, water dams, and multigenerational power plants are all common ways to make green energy.

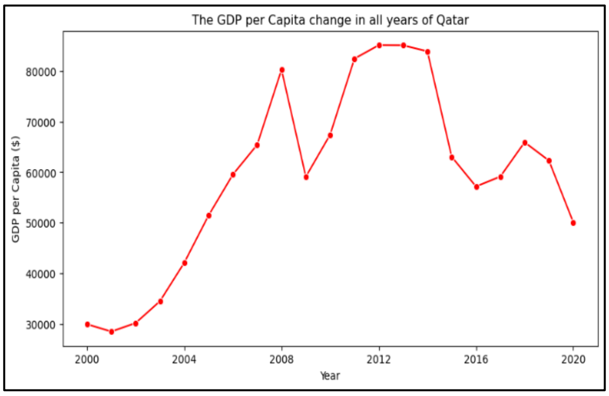

Figure 2: Sustainable energy and GDP per capita over the year

Monitoring and keeping records are very important for making sure that the people who live in the house and the management plan can work together easily. To make sure that home security is good, management systems use different alerts linked to known risks. Homeowners can use Smart Home Energy Management Systems (SHEMS), cell phones, or their hands to control their home's appliances in any way they want. The Internet of Things (IoT) has many big benefits over other information networks, as shown by many research studies [15]. The IoT is becoming more popular because it is easy to use and works with many different connection methods. Adding new digital home appliances to the power grid makes problems like too many harmonics, uneven loads, and unpredictable short-circuit currents worse. But the people in charge of the power grid don't charge homeowners extra because of how their homes affect the quality of the power. So, all of the suggested energy management systems are based on the idea that lowering electricity use or sending power to utility networks will make money. Building Energy Management Systems (BEMS) are being used in business, private, industry, and government buildings. For BEMS to work well and be stable, it needs to combine intermittent green energy sources with the right energy storage systems that are built into buildings. It is important to use as little energy as possible from nonrenewable sources and lower energy needs with technology that saves energy and is good for the environment. Electrochromic devices (ECDs) can control the flow of energy during the day and create fake light at night, so you don't have to have different systems for lighting and cooling. Sensors are used to find out what is going on in a certain area of a building. Depending on how the building is built and how sensors are integrated, a zone could be a single room, a floor, or the whole building [16]. Sensors also measure CO2 levels, temperature, humidity, and the

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number of people inside to keep an eye on comfort. Sensors can also pick up on things like fires, storms, and intrusions. Even though different management methods based on occupancy information are being used to try and cut down on energy waste in buildings, it is still hard to make buildings smarter by giving them more accurate occupancy models that show how much energy they use. Researchers have looked at all the different ways that occupancy-related factors that affect a building's total energy use can be collected and used [17]. They came up with a plan for how to deal with these problems, with a focus on improving the chances for the ICT and building industries.

III. METHOD FOR PREDICTING ENERGY CONSUMPTION IN SMART CITIES

For smart towns to have good energy management and resource sharing, they need to be able to predict how much energy they will use. To correctly estimate how much energy will be used, many different methods and techniques can be used. We'll talk about a way to predict how much energy smart cities will use that uses past data analysis, machine learning algorithms, and Internet of Things (IoT) technologies.

- Gathering Data: Gathering important data is the first step in making predictions about how much energy will be used. This includes past data on how much energy was used, weather data, demographic data, and data from Internet of Things (IoT) devices like monitors and smart meters.
- Data Preprocessing: Once the data is gathered, it needs to be cleaned up, dealt with missing values, and made more consistent so that the model can work better.
- Features Selection: The next step is to pick the features that will be most useful for the forecast model. You can use statistics or your understanding of the subject to do this.
- Model Selection: Linear regression, decision trees, random forests, and neural networks are some of the machine learning methods that can be used to guess how much energy a device will use. Which model to use depends on how hard the problem is and how much data is available.

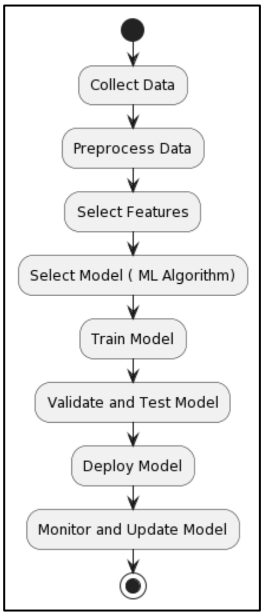

Figure 3: Process flow for predicting energy consumption

- Training the Model: The chosen model is taught with data from the past. To make estimates, the model learns from the data to find trends and links.
- Testing and Validation: Once the model has been trained, it is tested and confirmed using a different dataset to make sure it works correctly and accurately. Then, real-time data is used to test how well it can predict how much energy will be used.
- Deployment: The model can be used to predict energy use in a smart city after it has been taught and tested. Predictions can be used to improve the way energy is distributed, plan for future energy needs, and cut down on waste.
- Monitoring and Updating All the Time: To make the model more accurate over time, it is important to keep an eye on how it's doing and add new data to it all the time.

A. Storage of Energy

It is a well-known fact that batteries can turn chemical energy into electrical energy. This technology has many uses. To make batteries, you can use different types of electrochemical cells, like lead-acid (Pb-acid), sodium-sulfur, sodium-nickel chloride, and lithium-ion batteries. However, this technology has some problems, such as being expensive, bad for the environment, having a short life span, and having power and current limits. In spite of these problems, battery prices are predicted to go down in the future, making them easier to get and more common. Supercapacitors, flywheels,

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and superconducting magnetic energy storage (SMES) can all be used in situations that need to respond quickly and release a lot of energy quickly. SMES stores electricity by using superconducting coils to make magnetic fields that change orientation. To charge and release double-layer capacitors, supercapacitors use large currents. Even though these technologies aren't usually used to store energy, they can make the grid more stable and the power better. Moving things make flywheels hold energy, but they cost more than batteries and can only provide power for short amounts of time. A lot of countries use hydroelectric storage, also called hydro-pump storage, to make and send electricity. Using this method, water is pumped from one pool to another so that it can be used to make power later. But it's hard to use these methods on a small scale because the units are so big and the temperature and terrain make them limited. In fuel cells, stoves, and engines, hydrogen can be used as a source of energy. When oxygen is used for burning, pure water vapor is released. To make clean fuel that doesn't contain carbon, pre-combustion CO_2 capture methods can be used to make other molecules, like water or fossil fuels. Also, compressed air can be used to store a lot of energy.

Energy storage is a key part of making sure that towns with smart sustainable growth have a dependable and efficient energy source. Energy storage systems can help you deal with the unpredictable nature of green energy sources, lower peak demand, and make sure you have power when the power goes out. Batteries, supercapacitors, flywheels, and pumped water storage are just some of the tools that smart towns use to store energy. These technologies each have their own benefits, and smart cities often use more than one to meet all of their energy storage needs. Adding these energy storage systems to the energy infrastructure that is already in place is one of the hardest parts of making smart towns smarter. To make sure that energy storage systems work with the grid and are easy to control and monitor, this needs to be carefully planned and coordinated. Another important issue is still the price of energy storage, though technological progress and economies of scale are helping to lower prices and make energy storage easier to get. Energy storage in smart, sustainable cities isn't just a way to store energy; it's also a way to make the best use of it. Advanced metering and demand response systems are two examples of smart grid technologies that can help better handle energy storage systems. This way, energy is saved and used only when it is needed. Cities can save money, use less energy, and be more resilient to energy problems by adding energy storage to their smart grids. The energy storage is an important part of smart, sustainable towns because it helps make sure that the energy source is stable, efficient, and long-lasting. As technology keeps getting better and cheaper, energy storage is likely to become a bigger part of how energy is used in smart towns in the future.

IV. MACHINE LEARNING METHODS

A. ARIMA

AutoRegressive Integrated Moving Average, or ARIMA, is a common way to predict time series that can be used to guess how much energy smart towns with sustainable growth will use. ARIMA models are great for looking at and making predictions about time series data, which makes them perfect for figuring out how people will use energy over time. To use ARIMA on the subject of energy storage in smart towns, you can gather past data on how much energy is used, how much green energy is produced, and other factors that are important. Then, this information can be used to teach an ARIMA model. This model will look at past patterns and trends to guess how much energy will be used in the future. One of the best things about ARIMA is that it can see both short-term changes and long-term trends in the data. This makes it a useful tool for guessing how much energy will be used in smart cities, where demand can change a lot depending on things like the weather, the time of day, and how people use the city. Smart towns can better plan and control their energy resources by using ARIMA to predict how much energy people will use. This makes sure that residents and businesses have a stable and long-lasting energy supply.

1. AutoRegressive (AR) Component (p):

The AR component represents the regression of the current value of the series against its past values, also known as lagged values. It can be expressed as:

$$X_t = c + \sum_{\{i=1\}}^{\{p\}} \phi\_i \, X\_\{t-i\} + \varepsilon\_t$$

where:

- X_t is the value of the time series at time t,
- c is a constant term,
- ϕ_i are the parameters of the model,
- p is the order of the AR component (the number of lagged values included in the model),
- ε_t is the error term at time t.

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2. Integrated (I) Component (d):

The I component represents the differencing of the series to make it stationary. It can be expressed as:

$$Y_t = \nabla^d X_t$$

where:

- Y_t is the differenced series at time t,
- d is the order of differencing.

3. Moving Average (MA) Component (q):

The MA component represents the regression of the current value of the series against the past forecast errors. It can be expressed as:

$$X_t = \mu + \varepsilon_t + \sum_{\{i=1\}}^{\{q\}} \theta\_i \, \varepsilon\_\{t-i\}$$

where:

- μ is the mean of the series,
- θ_i are the parameters of the model,
- q is the order of the MA component (the number of past forecast errors included in the model),
- ε_t is the error term at time t.

4. Combining AR, I, and MA:

The ARIMA model combines the AR, I, and MA components into a single model. It can be expressed as:

$$Y_t = c + \sum_{\{i=1\}}^{\{p\}} \phi\_i \, Y\_\{t-i\} + \sum_{\{i=1\}}^{\{q\}} \theta_i \varepsilon_{\{t-i\}} + \varepsilon_t$$

B. LSTM

Long Short-Term Memory (LSTM) networks can be used to guess how much energy smart towns with sustainable growth will use. LSTM networks are a type of recurrent neural network (RNN) that can learn long-term relationships, which makes them great for working with time series data.

1. Forget Gate:

The forget gate layer determines what information from the previous cell state Ct−1 should be forgotten or retained. It is calculated as follows:

$$ft = \sigma(Wf \cdot [ht-1, xt] + bf)$$

2. Input Gate:

The input gate layer determines what new information should be stored in the cell state. It is calculated as follows:

$$it = \sigma(Wi \cdot [ht-1, xt] + bi)$$

3. Candidate Cell State:

The candidate cell state C~t is calculated as follows:

$$C{\sim}t = tanh(Wc \cdot [ht-1, xt] + bc)$$

4. Cell State Update:

The cell state Ct is updated using the forget gate, input gate, and candidate cell state:

$$Ct = ft \odot Ct-1 + it \odot C{\sim}t$$

5. Output Gate:

The output gate layer determines the output hidden state ht based on the updated cell state:

$$ot = \sigma(Wo \cdot [ht-1, xt] + bo)$$

$$ht = ot \odot tanh(Ct)$$

V. ENERGY MANAGEMENT AND SUSTAINABLE DEVELOPMENT

Sustainable growth and energy management are two important ideas that work together to help solve world problems like climate change, energy security, and environmental damage. To reach the sustainable development goals, which are meant to meet the needs of the present without making it harder for future generations to do the same, we need to make sure that we handle energy well.

- Energy Efficiency: One of the most important parts of managing energy is making it use less energy. This means using energy more effectively to cut down on waste and use as little energy as possible. Industries, houses, and transportation can use less energy and put out less greenhouse gas by using energy-efficient tools and methods.
- Energy Management: Encouraging the use of clean energy sources like solar, wind, and water is another important part of energy management. These sources won't run out and are better for the earth than fossil fuels. Using less fossil fuels and slowing down climate change can both be helped by adding green energy to the energy mix.
- Smart Grids: Technologies for smart grids are very important in current methods for managing energy. They make sure that power is delivered quickly and reliably, help people use energy more efficiently, and connect green energy sources to the grid. Smart grids also give people better control over how much energy they use by watching and tracking in real time.

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- Storage of Energy: Technologies that store energy are necessary to keep the energy system's supply and demand in balance. They make it possible for irregular green energy sources to be connected to the grid and provide backup power when the main power goes out. Batteries, pumped water storage, and thermal storage are some of the energy storage options that are becoming more and more important for sustainable energy management.
- Policy and Regulations: Policies and rules that support energy management are needed for it to work well. Setting standards for energy economy, encouraging the use of green energy, and giving people incentives to do things that are good for the environment are all very important jobs that governments and lawmakers do. Deals and teamwork between countries are also important for solving the world's energy problems.

There are some problems with energy management and sustainable growth that need to be fixed in order to make the energy system more efficient and last longer. Here are a few of the biggest problems:

- Balancing Supply and Demand: One of the hardest things about managing energy is making sure that the quantity and demand of energy are equal. Since irregular green energy sources are being used more and more, it is important to manage the changes in supply. To make sure there is a steady flow of energy, smart grid systems and energy storage options need to be developed.
- Energy Efficiency: It is very hard to make things use less energy, especially in areas like houses, transportation, and industry. Even though technology has improved, many systems and processes that use a lot of energy are still not working as well as they could. To solve this problem, we need to use tools, habits, and laws that save energy.
- Infrastructure Development: Another problem is building the infrastructure needed for long-term energy output and transport. This includes building places to make renewable energy, growing the grid to include renewable energy sources, and making transportation systems that use renewable fuels efficiently.
- Financial and Economic Limits: Making the switch to renewable energy systems often needs big investments in new equipment and technologies. Progress in this area can be slowed down by money problems, such as not having easy access to funds and high start-up costs. To make this shift easier, governments and banking companies need to offer rewards and ways to get money.
- Policy and Regulatory Framework: Making and following good energy rules and policies is necessary for encouraging long-term energy growth. However, growth can be slowed down by inconsistent policies, unclear rules, and political obstacles. To get people to invest in clean energy options, governments need to make policies that back those investments.
- Behavioral Change: One of the biggest problems is getting people to change how they use energy and how they feel about it. People and companies need to be educated, made more aware of energy-saving tools and practices, and given incentives to do so.
- Global Cooperation: To solve problems in energy management and healthy growth, people from all over the world need to work together. Global problems like climate change and energy security can't be fixed by one country at a time. This shows how important it is for countries to work together and find answers.

VI. DISCUSSION

The statistics give a full picture of the world's energy situation by focusing on the number of terawatt hours (TWh) created by different energy sources, with a focus on green energy. When you compare green and nonrenewable sources, you can learn a lot about how to use energy in a way that is better for the environment. The Renewables Power Generation collection shows the growth of the main types of renewable energy from 1997 to 2023. It includes Hydro, Wind, Biofuel, Solar PV, and Geothermal. With this graph, you can look at how these green energy sources have grown and changed over time, revealing patterns and trends. Also, the information on the Top 20 Countries Power Generation gives a full description of the country statistics for each type of green energy. This knowledge is very important for knowing how green energy is produced around the world and what each country does to promote sustainable energy practices. The last two files give a full picture of the world's energy production because they include the global TWh produced from green and nonrenewable sources. It lets us see how much green and nonrenewable energy sources add to the world's energy mix. This shows how far we've come in making the energy system more safe and eco-friendly. Overall, these records give us useful information about the move toward green energy

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sources around the world. They show how far important areas like hydropower, wind power, biofuels, solar photovoltaics, and geothermal energy have come. In doing so, they stress how important it is to use clean energy to fight climate change and protect the earth.

Table 1:ML Method Energy Prediction result

Model	Accuracy	Precision	Recall	F1 Score	AUC	MSE	RMSE
ARIMA	89.63	92.35	89.63	90.23	92.11	35.23	18.66
LSTM	94.25	95.12	94.55	93.45	95.63	15.45	13.47

In the table 1, It shown as how well ARIMA and LSTM, two machine learning models, predict energy use. It was decided how good the models were by looking at their F1 score, AUC, mean squared error (MSE), and root mean squared error (RMSE). The ARIMA model was right about 89.63% of the time, which means it forecast the amounts of energy use in the dataset almost 90% of the time. The accuracy of 92.35% means that 92.35% of the time, the ARIMA model was right when it said that energy use would go up or down. The recall of 89.63% means that the ARIMA model was able to correctly identify 89.63% of the real times when energy use went up or down. The F1 score, which is the harmonic mean of accuracy and memory, is 90.23%, which means that accuracy and recall were both well done.

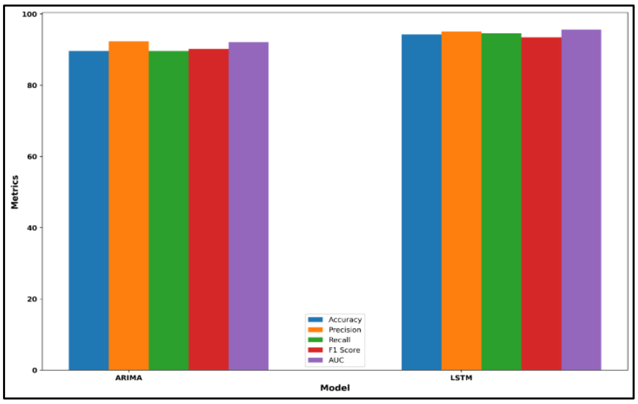

Figure 4: Representation of ML Method Energy Prediction

In every way, though, the LSTM model did better than the ARIMA model. The LSTM model did a better job of predicting energy use, with an accuracy of 94.25%, a precision of 95.12%, a recall of 94.55%, and an F1 score of 93.45%. The AUC of 95.63% is more proof that the LSTM model is very good at making predictions. In addition, the LSTM model had a lower MSE of 15.45 and a lower RMSE of 13.47 than the ARIMA model, which means that its forecasts were more accurate.

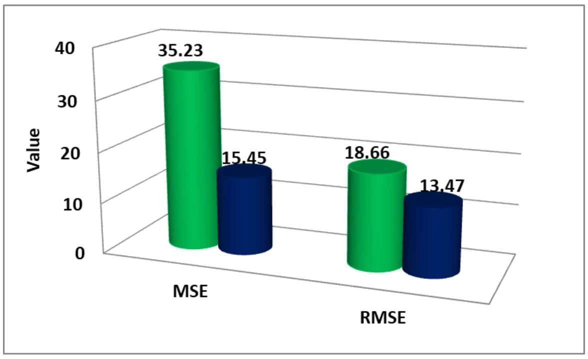

Figure 5: Comparison of M model with MSE and RMSE

The LSTM model did a better job than the ARIMA model at predicting how much energy would be used. It had higher accuracy, precision, recall, F1 score, AUC, and MSE and RMSE. The LSTM model seems to be better at predicting energy use trends based on these results, leading to more accurate and reliable predictions.

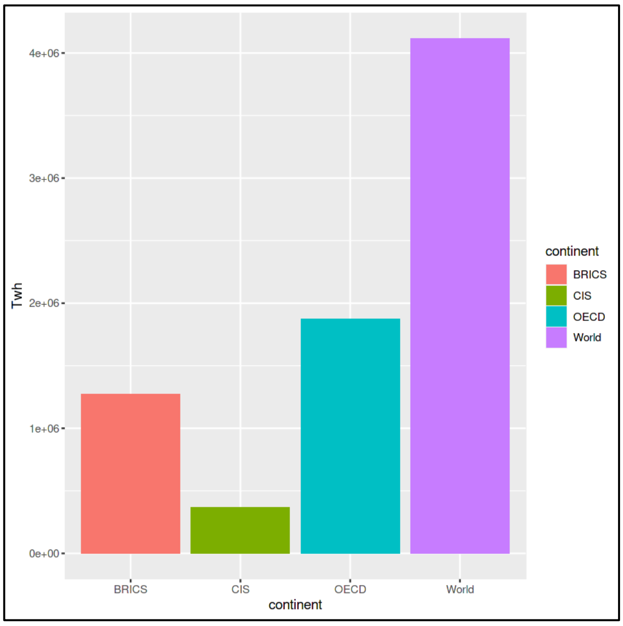

Figure 6: Comparison of Energy consumption for different continent

VII. CONCLUSION

The combination of smart energy technologies with main power networks has a huge amount of promise for

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making power systems last for a long time. Smart energy systems can improve the production, transfer, and use of energy by using cutting edge technologies like IoT, AI, and data analytics. This makes them more efficient, reliable, and environmentally friendly. One big benefit of this synergy is that it makes it easier to connect green energy sources to the grid. Smart energy systems use IoT devices and AI algorithms to predict how much green energy will be produced, figure out the best way to connect it to the grid, and control how much it changes and stops working. This not only cuts down on the use of fossil fuels, but it also helps lower greenhouse gas pollution and slow down climate change. The general efficiency of the power grid can also be improved by adding smart energy systems. Smart grids can cut down on waste and make the grid more reliable by keeping an eye on how much energy is being used in real time and changing the supply to match. All of these things can help people and energy companies save money and make blackouts and other problems less likely. Another big benefit of smart energy systems is that they give people the power to take an active role in managing their energy. Smart meters and energy management systems let people keep an eye on how much energy they use, change how they use it, and even make their own power from solar panels on their roofs or other green sources. This not only lowers energy costs but also helps make the energy system more sustainable and spread out.

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