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Sustainable Energy Management using IoT and AI Based Solution

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ABSTRACT: The fusion of Internet of Things (IoT) and Artificial Intelligence (AI) is playing a transformative role in the realm of sustainable energy management. With the deployment of IoT-enabled sensors and devices, it is now possible to track energy consumption in real time, offering valuable insights into how energy is used across different settings. These insights make it easier to manage energy resources more efficiently, aligning supply with actual demand.AI technologies, including both machine learning and deep learning, take this further by examining the large datasets gathered from these devices. They help identify patterns, detect unusual behavior, and forecast energy needs, enabling smarter planning and operational strategies.

This results in more effective energy distribution and a significant reduction in energy loss.In addition, AI-powered IoT systems can automate processes that typically consume high levels of energy, such as air conditioning, lighting, and heating. These systems can adapt to changing conditions like occupancy or environmental changes, which ensures that energy is only used when necessary while maintaining comfort levels. Consumers can also receive tailored advice on energy usage, empowering them to make better decisions and adopt more sustainable habits.By merging AI with IoT in the energy sector, we can move towards a more intelligent and sustainable energy framework. This integration contributes to lowering carbon emissions and supports the broader goal of combating climate change. As global energy requirements rise, embracing such innovative technologies is vital for building greener cities, enhancing infrastructure, and ensuring a healthier environment for the generations to come.

KEYWORDS: IoT-based energy management, Artificial Intelligence, Machine Learning, Smart energy systems, Real-time monitoring, Energy efficiency, Sustainable technologies, Predictive analytics, Energy automation, Carbon footprint reduction, Intelligent infrastructure, HVAC optimization, Smart grid, Environmental sustainability, Energy conservation.

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I. INTRODUCTION

In recent times, the rising demand for energy—driven by urban expansion, industrial advancement, and increased reliance on electronic devices—has placed significant stress on current energy systems. This surge has led to higher levels of energy wastage, environmental harm, and a pressing need for more sustainable energy practices. Traditional approaches to energy management, which depend heavily on manual checks and fixed control settings, are proving inadequate in addressing the complexities of modern energy needs.

The development of advanced digital technologies, especially the Internet of Things (IoT) and Artificial Intelligence (AI), offers promising solutions to these challenges. IoT facilitates communication between interconnected devices like smart meters, sensors, and controllers, which can gather real-time data on factors such as energy consumption, temperature, occupancy, and humidity. This data helps create a detailed picture of how energy is being used across residential, commercial, and industrial spaces.

Artificial Intelligence plays a key role by interpreting the data collected through these IoT systems. Leveraging machine learning and deep learning methods, AI can recognize patterns, anticipate energy requirements, identify irregularities, and either suggest or implement actions to optimize energy usage. For instance, AI can manage heating or cooling systems based on actual usage patterns or schedule equipment operations to avoid high-demand periods, thereby conserving energy. These intelligent tools minimize manual oversight, improve system performance, and support environmentally conscious practices.

This project focuses on building a smart system that integrates AI and IoT to monitor and optimize energy use in real time. The goal is to empower users with the ability to oversee and manage their energy usage effectively, leading to reduced consumption, cost savings, and support for sustainable living. Through the fusion of cutting-edge technologies with energy infrastructure, the initiative aims to advance environmental responsibility and serve as a model for future energy systems.

Connected IoT devices make it possible to observe and manage energy usage, production, and storage in real time, whether at the level of smart grids or individual user appliances. This interconnectivity supports accurate control and flexible adjustment of energy distribution across different systems [1] [5] [6][10].Techniques such as deep learning, reinforcement learning, and predictive modeling are employed by AI systems to anticipate energy needs, streamline power distribution, identify irregularities, and make real-time adjustments to energy consumption[1][2][5][7][8][10].
Block chain is utilized to authenticate energy usage records and transaction details, promoting greater transparency and reliability within decentralized energy networks [1][7].Lower operational expenses and a decrease in greenhouse gas emissions [4].

It anticipates consumption patterns, identifies areas of energy waste, fine-tunes heating, cooling, and lighting systems, and supports responsive energy management based on demand fluctuations [3][9].

II. METHODOLOGY

Proposed Method

The developed solution combines the capabilities of the Internet of Things (IoT) and Artificial Intelligence (AI) to create a smart, automated, and scalable platform for managing energy in a sustainable way. Unlike conventional systems that rely on static controls and manual interventions, this modern approach supports live monitoring, data-driven forecasting, and autonomous regulation of energy consumption across different environments—whether residential, commercial, or industrial.Within this system, a network of IoT-enabled components—such as smart meters, environmental sensors, and control devices—is installed throughout the infrastructure. These devices collect continuous data on factors like power usage, ambient conditions, occupancy levels, and equipment operation. The collected data is transmitted either to a cloud server or processed locally using edge computing, where AI algorithms are applied for further analysis.

Machine learning and deep learning models are used to interpret the incoming data and generate actionable insights. These models can recognize trends in consumption, predict future energy demands, and pinpoint irregularities or inefficiencies. For instance, they can forecast periods of high usage to implement load balancing or demand-side adjustments. Additionally, the system can detect equipment faults that lead to unnecessary energy loss or highlight areas with excessive consumption. Using this information, automated actions can be taken—such as adjusting climate

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control and lighting systems, triggering maintenance alerts, or sending tailored energy-saving suggestions to users.it show in fig 1.

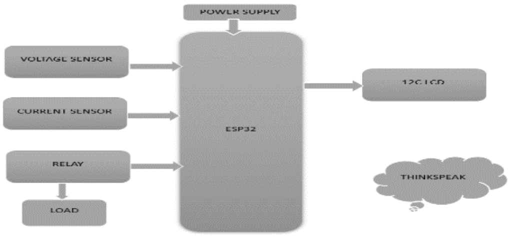

Fig 1. Block Diagram Proposed

In addition, the system is built to be flexible and user-centric. Beyond automating energy-related operations, it delivers personalized insights and conservation suggestions based on each user's behavioral patterns and past consumption data. This approach encourages users to take an active role in reducing energy usage. The platform is also capable of seamlessly incorporating renewable energy sources, such as solar panels or wind turbines, by efficiently regulating their input into the energy network and coordinating with storage units like batteries.

This AI and IoT-integrated strategy enhances energy efficiency, lowers operational costs, and supports long-term environmental goals. It contributes to the development of intelligent energy grids, minimizes carbon output, and lays the foundation for ongoing innovation in eco-friendly technologies.

POWER SUPPLY

A widely used setup in electronic power supplies includes a bridge rectifier, an RC filter, and a 7805 voltage regulator. The bridge rectifier plays a vital role in converting alternating current (AC) into direct current (DC). It is constructed using four diodes—labeled D1, D2, D3, and D4—arranged in a specific bridge layout. This configuration ensures that the output remains unidirectional by converting both halves of the AC waveform into a positive voltage. In operation, diodes D1 and D3 conduct current during the positive half-cycle of the AC signal, while D2 and D4 become active during the negative half-cycle. As a result, the circuit produces a pulsating DC voltage. Since this output still contains fluctuations or ripples due to residual AC content, an RC filter is commonly added to smooth the voltage before further regulation.It show in the fig 2 .

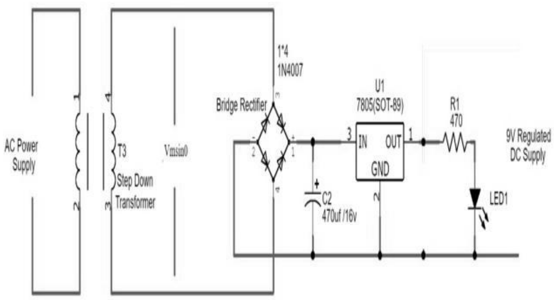

Fig 2. Circuit Diagram of Rectifier

An RC filter, commonly made up of a resistor (R) and a capacitor (C) arranged in parallel, is employed to reduce the voltage ripple in the output of a rectifier circuit. The capacitor charges when the voltage peaks and discharges during the dips, thereby smoothing out the fluctuations. The effectiveness of this filtering process depends on the specific values chosen for the resistor and capacitor, which are selected based on how much smoothing is needed and the characteristics of the load. Even after filtering, minor voltage variations may still be present. To achieve a consistent +5V output, a 7805 voltage regulator is added. This device is a widely used linear regulator known for delivering a steady voltage, regardless of variations in input supply or load demand. It provides a dependable and regulated power source for various electronic components and systems.

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16 X 2 LCD DISPLAY

The 16x2 LCD is a commonly used display module in embedded applications, electronics projects, and digital devices for presenting textual information. It features two rows, each capable of displaying up to 16 characters, allowing for a total of 32 visible characters at any given time. Each character space can show letters, numbers, or custom symbols. This module operates on Liquid Crystal Display (LCD) principles, where liquid crystal elements control light passage to create the desired characters. Many versions come with built-in backlighting to enhance readability under different lighting environments. To use a 16x2 LCD with microcontrollers or digital systems, specific interfacing techniques are applied, often involving parallel or serial communication methods .The 16x2 LCD commonly uses the HD44780 controller, making it easier to communicate with microcontrollers. It typically features 16 pins, including power, contrast, and data/control lines and show in the fig 3.

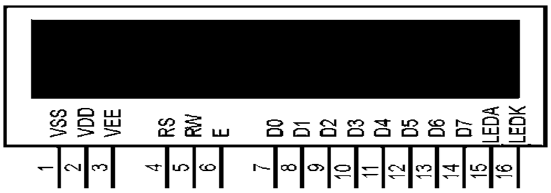

Fig 3. LCD Display Pin Diagram 16 x 2

ESP 32 MICROCONTROLLER

The ESP32 is a compact microcontroller that integrates a dual-core processor, memory, and various programmable input/output interfaces. It is built around the Xtensa LX6 processor, supporting efficient multitasking through its two cores. This chip includes native Wi-Fi and Bluetooth capabilities, supporting multiple Wi-Fi modes such as Station, Access Point, and simultaneous SoftAP operation. Bluetooth features include both Classic Bluetooth and Bluetooth Low Energy (BLE). The ESP32 offers a variety of interfaces, including GPIO pins, SPI, I2C, UART, and PWM, allowing it to connect easily with sensors, motors, and other peripherals. It contains onboard flash memory for storing programs and SRAM for handling data during operation. The memory sizes can vary depending on the module or development board. Developers commonly program the ESP32 using the Arduino IDE, which offers flexible, low-level hardware control. Programming languages like C and C++ are widely used for developing applications on this platform. The ESP32's rich feature set makes it a popular choice for IoT, automation, and Sustainable Energy Management Using Iot And Ai Based Solution and show in the fig 4.

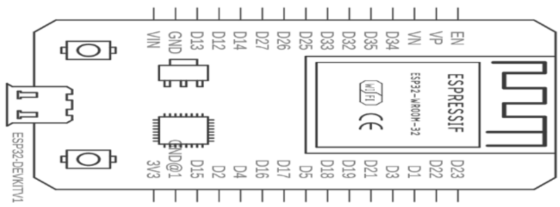

Fig 4.Pin Diagram of ESP 32 Microcontroller

CURRENT SENSOR

The ACS712 sensor provides accurate current measurement, making it ideal for smart energy meters to track real-time power usage. When used in IoT-based energy systems, it enables continuous monitoring of electrical consumption for various devices. This helps users gain insights into their energy habits and make better decisions to reduce waste. The sensor supports instant data updates, which are essential for efficient energy management. Additionally, it can be integrated into home automation setups to automatically adjust energy use based on user-defined conditions and show in the fig 5.

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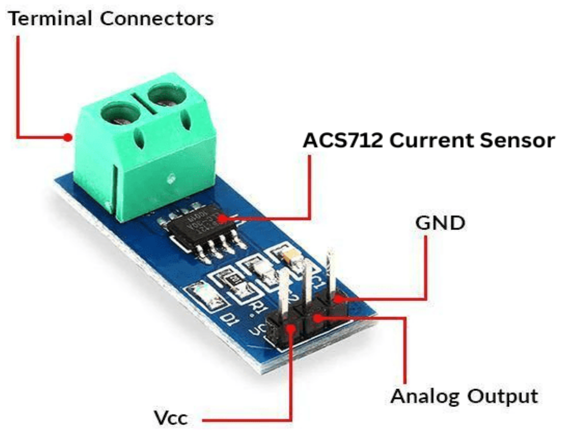

Fig 5.Current Sensor Pin Configuration

VOLTAGE SENSOR

The voltage sensor module is essential for IoT smart energy meters, enabling the measurement of higher voltages by scaling them down to a level safe for microcontrollers. It uses a resistive voltage divider to reduce the input voltage by a factor of five, allowing devices like Arduino to accurately read voltages beyond their normal range. This module supports measuring voltages up to 25V for a 5V input range and up to 16.5V for 3.3V systems. It features screw terminals for secure and easy wire connections. This design ensures reliable voltage monitoring in energy management applications and show in the fig 6 Pin Configuration.

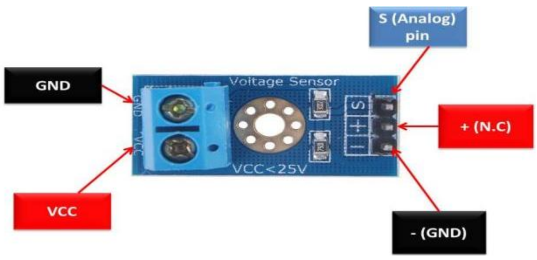

Fig 6.Voltage Sensor Pin Configuration

RELAY

A relay is an electrically operated switch that uses a magnetic field to open or close contacts, enabling control of high-power circuits with low-power signals. When current flows through its coil, the generated magnetic field moves the armature, switching the contacts. Once the coil is de-energized, the armature returns to its original position, breaking the circuit and using for Sustainable Energy Management Using Iot And Ai Based Solution and show in the fig 7.

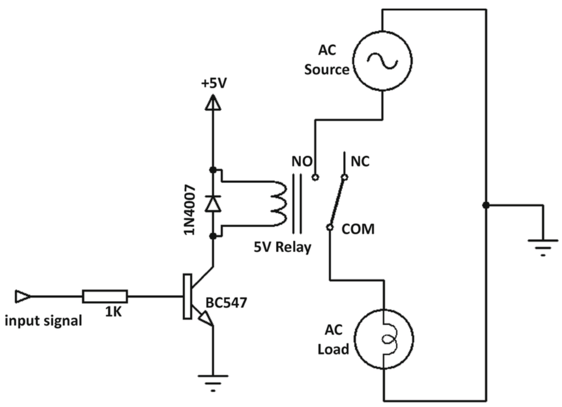

Figure 7. Relay Circuit Diagram

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THINGSPEAK

ThingSpeak is an open-source IoT platform used for collecting, analyzing, and visualizing sensor data in real-time. It allows users to send data from devices to the cloud and create customizable dashboards. The platform supports IOT for advanced data processing and analysis. ThingSpeak is widely used in smart applications for monitoring environmental conditions, energy usage, and more. Its ease of integration with microcontrollers makes it popular among developers and hobbyists and using for Sustainable Energy Management Using Iot And Ai Based Solution.

III. RESULT AND DISCUSSION

The deployment of an IoT and AI-powered energy management system led to encouraging outcomes in reducing power consumption and enhancing efficiency. By gathering live data from smart devices such as energy meters, temperature sensors, occupancy detectors, and light sensors, the system sent this information to a central server. There, AI models processed the data to uncover usage trends, predict demand, and offer suggestions for better control. This enabled timely interventions, like adjusting lighting or HVAC systems, to minimize unnecessary power use.

A key achievement of the system was a noticeable drop in energy consumption, especially during high-demand periods, thanks to smart scheduling and device automation. The predictive capabilities of the AI allowed the system to respond proactively without disrupting comfort or productivity. Faulty or underperforming equipment could also be flagged early through built-in anomaly detection, helping avoid long-term inefficiencies.Users benefitted from detailed usage insights and tailored advice, encouraging them to change daily habits. These reports led to greater energy awareness and voluntary adoption of conservation practices. The system also supported integration with solar panels and other renewable sources, helping to balance traditional and green energy inputs effectively.

Scalability was another strong point—the system worked just as well in small homes as in large industrial settings. Compared to manual methods, this solution delivered faster responses, better accuracy, and in some instances, energy savings of up to 25%.In summary, combining IoT infrastructure with AI analytics proved to be a reliable approach to real-time energy optimization, supporting sustainability while giving users smarter control and improved flexibility.

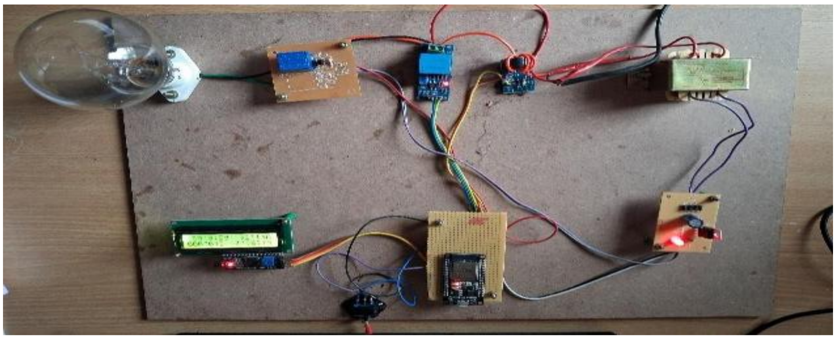

Fig 8.Hardware kit without load

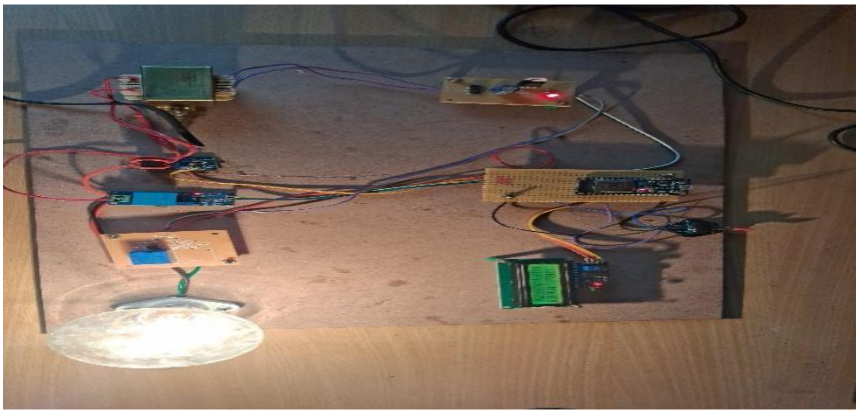

Fig 9. Hardware kit with load

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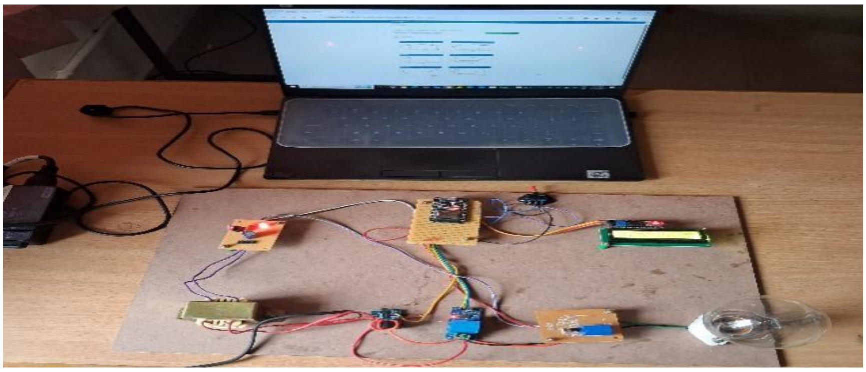

Fig 8. Hardware Used in Thingspeak Without Load

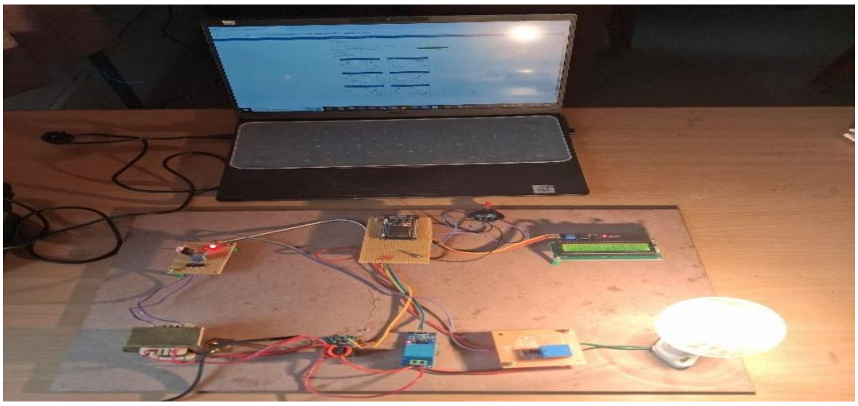

Fig 9. Hardware used in Thingspeak with load

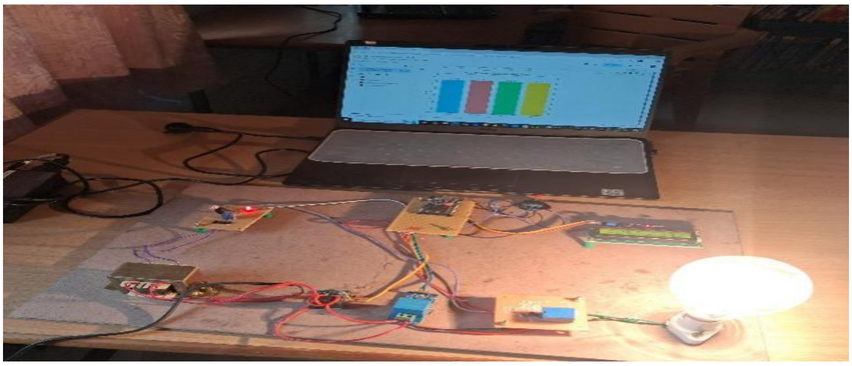

Fig 10. AI Power Management System

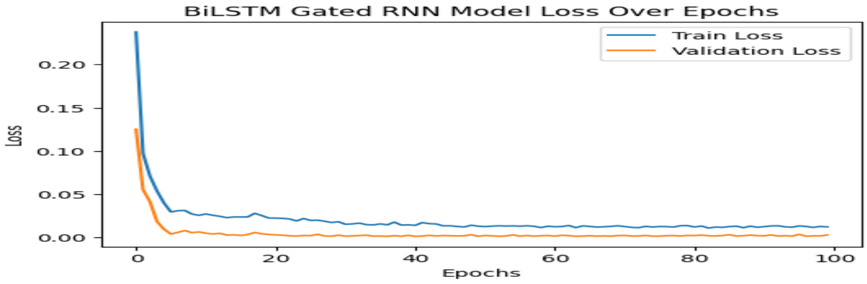

Fig 11. RNN Model Loss Over Epochs

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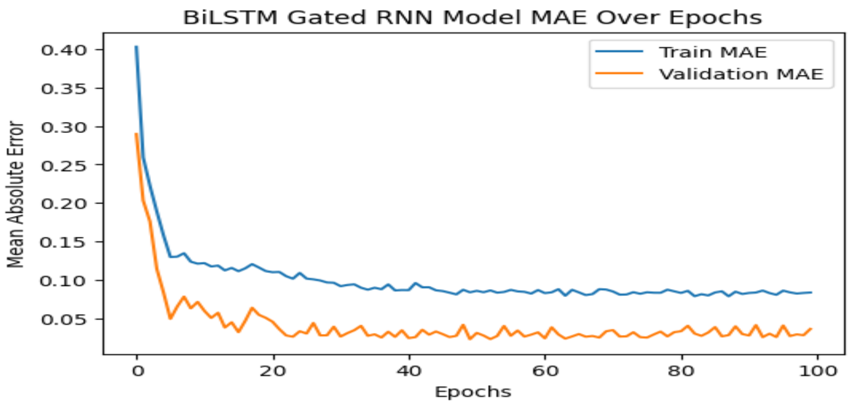

Fig 12. Gated RNN Model MAE Over Epochs

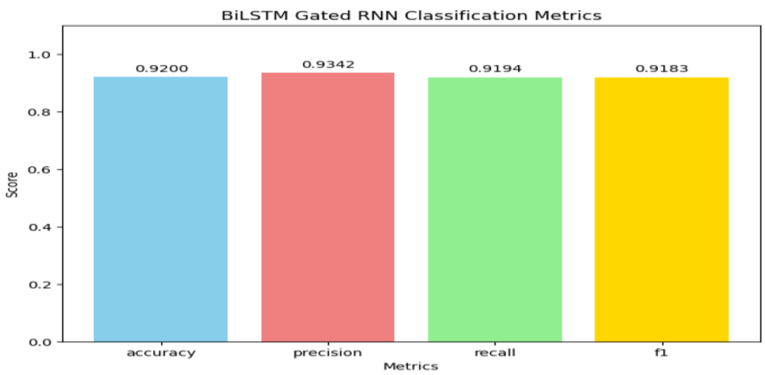

Fig 13. Gated RNN Classification Metrics

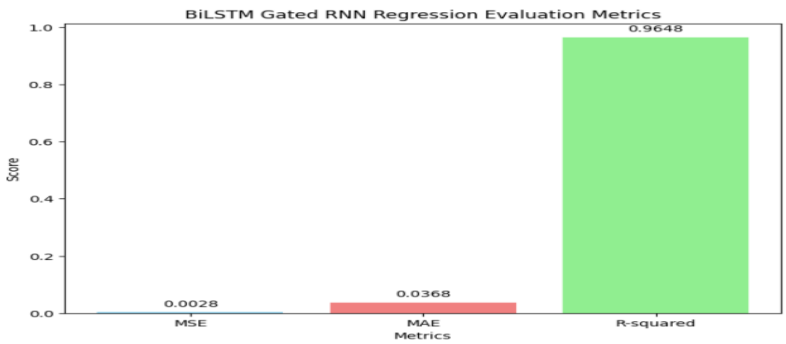

Fig 12. Gated RNN Regression Evluation Metrics

IV. CONCLUSIONS

Combining the capabilities of IoT and AI provides an innovative and effective pathway for managing energy in a more sustainable manner. This project has shown that by using IoT devices to gather real-time information and applying AI for analysis, energy use can be better predicted, controlled, and optimized. As a result, unnecessary energy consumption is reduced, operational efficiency is improved, and environmental impact is minimized.The system made use of smart control strategies, predictive modeling, and automatic load management to respond to changing energy needs and user behavior. It also incorporated renewable power sources and real-time fault detection, adding further value in terms of energy reliability and system performance.In addition to the technical benefits, the approach offered users helpful insights into how they use energy, encouraging conscious efforts to reduce waste. Its flexibility and ability to scale make it ideal for use in both home environments and larger industrial settings.Ultimately, this integration of

IoT and AI represents more than just a tech upgrade—it marks a positive shift toward eco-friendly, intelligent energy use. Embracing this kind of system helps cut emissions, protect natural resources, and advance toward long-term energy sustainability targets.

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