Envisioning S.E.M's by Inducting Edge Computing and Predictive Modelling for Achieving Net Zero Goals

Major project report submitted
in partial fulfillment of the requirement for award of the degree of

Bachelor of Technology
in
Computer Science & Engineering

By

SRIPATHI MANIDEEP REDDY (20UECS0809) **(17713)**

Under the guidance of
Dr. G.DHANABALAN M.E.,Ph.D.,
ASSOCIATE PROFESSOR

DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING
SCHOOL OF COMPUTING

VEL TECH RANGARAJAN DR. SAGUNTHALA R&D INSTITUTE OF SCIENCE & TECHNOLOGY

(Deemed to be University Estd u/s 3 of UGC Act, 1956)
Accredited by NAAC with A++ Grade
CHENNAI 600 062, TAMILNADU, INDIA

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CERTIFICATE

It is certified that the work contained in the project report titled ”ENVISIONING S.E.M’S BY INDUCTING EDGE COMPUTING AND PREDICTIVE MODELLING FOR ACHIEVING NET ZERO GOALS” by ”SRIPATHI MANIDEEP REDDY (20UECS0809)” has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

Signature of Supervisor	**Signature of Professor In-charge**
Computer Science & Engineering	**Computer Science & Engineering**
School of Computing	**School of Computing**
Vel Tech Rangarajan Dr. Sagunthala R&D	**Vel Tech Rangarajan Dr. Sagunthala R&D**
Institute of Science & Technology	**Institute of Science & Technology**
May, 2024	**May, 2024**

DECLARATION

We declare that this written submission represents my ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

(Signature)

(SRIPATHI MANIDEEP REDDY)

Date: / /

APPROVAL SHEET

This project report entitled (ENVISIONING S.E.M'S BY INDUCTING EDGE COMPUTING AND PREDICTIVE MODELLING FOR ACHIEVING NET ZERO GOALS) by (SRIPATHI MANIDEEP REDDY (20UECS0809)) is approved for the degree of B.Tech in Computer Science & Engineering.

Examiners **Supervisor**

Dr. G.DHANABALAN M.E.,Ph.D.,
ASSOCIATE PROFESSOR

Date: / /
Place:

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We express our deepest gratitude to our respected **Founder Chancellor and President Col. Prof. Dr. R. RANGARAJAN B.E. (EEE), B.E. (MECH), M.S (AUTO),D.Sc., Foundress President Dr. R. SAGUNTHALA RANGARAJAN M.B.B.S.** Chairperson Managing Trustee and Vice President.

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SRIPATHI MANIDEEP REDDY (20UECS0809)

ABSTRACT

With the abrupt realization of the requirement for sustainability and sustainable processes, there is an acute increase in awareness of how resource generation and consumption are being conducted. In the modern world, new ideas and solutions are heavily dependent on computation, power, and energy. Electrical energy is one of the fundamental and foundational aspects upon which all these innovations are realized. The rising apprehension of applying sustainable practices to action has called for solutions to improve and achieve a set of 'net zero goals'. In response to the growing demand for electricity in the 21st century, a strategic approach is essential for effective energy conservation. This research outlines an implementation of a smart energy meter, built from the ground up, inducted into an edge network, and uses predictive modeling to complete a set of a tripartite eco-system. The design of an individual edge is designed and depicted, along with its performance as a part of an edge node in a multi-nodal network. This initiative aims to utilize modern predictive approaches to map consumption and take precautionary and insightful actions that curb excessive utilization and waste of electricity. The project envisions a future where IoT's real-time monitoring and edge intelligence's rapid data processing contribute to achieving net zero goals.

Keywords: Sustainability, Resource generation, Consumption, Electrical energy, Sustainable practices, Smart energy meter, Edge network, Predictive modeling, IoT (Internet of Things), Net zero goals

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

IoT	Internet of Things
GSM	Global System for Mobile Communications
CNN	Convolutional Neural Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MQTT	Message Queuing Telemetry Transport
HTTP	Hypertext Transfer Protocol
GBM	Gradient Boosting Machines
SARIMA	Seasonal Autoregressive Integrated Moving Average
NSTC	National Science and Technology Council

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Chapter 1

INTRODUCTION

1.1 Introduction

In response to the escalating demand for sustainability and eco-conscious practices, heightened awareness of the intricacies surrounding resource generation and consumption has emerged. The aftermath of the COVID-19 pandemic has spurred numerous innovations, discoveries, and developmental breakthroughs, heavily reliant on computation, power, and energy. Electrical energy stands as a fundamental cornerstone amid these pillars, crucial for groundbreaking advancements. The quest for implementing sustainable practices into action has driven a compelling search for solutions to enhance and actualize 'net zero goals'. This concern encompasses multifaceted factors, with energy generation and consumption at its core. From 2010 to 2019, the average energy production trend exhibited a positive growth rate of 2.5% annually, with global power generation in 2022 increasing by approximately 2.3%. However, despite this growth, only 20.4% of energy is prone to electrification, while the majority still relies on fossil fuels. As of 2021, there are reportedly about 2.3 billion residences worldwide, a number expected to exponentially grow by 2024, underscoring the significant impact potential of proposed energy solutions.

This project introduces a smart energy meter meticulously engineered from the ground up and integrated into an edge network. This innovation employs predictive modeling within a tripartite ecosystem, focusing on the design and performance of individual edges as part of a multi-nodal network. By leveraging modern predictive approaches, we aim to map consumption patterns and proactively curb excessive utilization and waste of electricity. This initiative envisions a future where real-time monitoring through the Internet of Things (IoT) and rapid data processing via edge intelligence collectively contribute to achieving net zero goals. Our work not only addresses current challenges but also envisions a sustainable energy landscape for future generations. In the ever-evolving energy systems landscape, a thorough exploration of technical intricacies surrounding sustainable energy solutions is imperative. Through this interdisciplinary exploration, we aim to provide valuable insights that inform policy decisions, drive societal acceptance, and propel technological advancements, ultimately fostering a future where sustainability is not just a goal but a collective reality.

1.2 Aim of the project

The aim of the project is to implement a smart energy meter within an edge network, leveraging predictive modeling to achieve a tripartite eco-system. The goal is to enable real-time monitoring of electricity consumption, coupled with rapid data processing and insightful actions to mitigate excessive utilization and waste. Ultimately, the project aims to contribute to the realization of 'net zero goals' by integrating modern technologies like IoT and edge intelligence into energy management practices.

1.3 Project Domain

The project domain outlined in the provided text revolves around sustainability and energy management in the context of a post-COVID world. It encompasses a broad spectrum of interconnected issues, including resource generation, consumption patterns, renewable energy adoption, and the pursuit of 'net zero goals' to mitigate climate change. With the COVID-19 pandemic acting as a catalyst for heightened awareness of environmental challenges, there is a pressing need to reevaluate existing energy practices and transition towards more sustainable alternatives. Electrical energy emerges as a central focus due to its foundational role in driving technological innovation and powering societal advancements.

The domain also highlights the imperative of integrating sustainable practices into action, underscoring the importance of holistic solutions that address both technological and socio-political dimensions. This entails leveraging predictive modeling and smart technologies to optimize energy consumption, while also fostering policy reforms and societal engagement to drive systemic change. Additionally, the domain emphasizes the disparities in energy access and consumption patterns globally, signaling the need for inclusive solutions that cater to diverse socio-economic contexts. By exploring the intersection of technological innovation, policy interventions, and societal engagement, the project domain seeks to pave the way for a more sustainable and equitable energy future that aligns with the overarching goal of achieving 'net zero' emissions.

1.4 Scope of the Project

The scope of the project outlined in the provided text is expansive and multifaceted, encompassing various aspects of energy management, sustainability, and technological innovation. Firstly, the project aims to delve into the intricacies surrounding resource generation and consumption, with a particular emphasis on electrical energy. This entails examining existing energy production trends, consumption patterns, and the transition towards renewable sources. By analyzing data from recent years, the project seeks to identify key challenges and opportunities in the energy landscape, laying the groundwork for informed decision-making and strategic interventions.
Moreover, the project endeavors to explore innovative solutions to enhance energy efficiency and promote sustainable practices. This includes the development and implementation of smart energy meters and predictive modeling techniques to optimize energy consumption and reduce waste. Additionally, the project aims to investigate the role of edge networks and IoT technologies in enabling real-time monitoring and data-driven insights for effective energy management. By integrating technological innovation with policy reforms and societal engagement, the project seeks to foster a collaborative ecosystem that drives systemic change towards a more sustainable and resilient energy future. Overall, the scope of the project encompasses a comprehensive approach to address the complex challenges of energy sustainability, with the ultimate goal of contributing to the realization of 'net zero' emissions targets.

Chapter 2

LITERATURE REVIEW

[1] Thummar et al. as developed an IoT-based metering system integrating sensors, Arduino, and Wi-Fi to monitor energy usage, providing real-time consumption insights and enhancing user engagement. Their study significantly contributes to smart energy meters by promoting energy efficiency through data-driven insights and seamless communication of energy data. By leveraging IoT capabilities, the system empowers users to make informed decisions about their energy consumption habits, revolutionizing energy management practices. Thummar et al.'s work underscores the potential of IoT technologies in promoting sustainable and efficient energy usage, highlighting the importance of real-time monitoring for empowering users in energy conservation efforts. Overall, their study offers valuable insights for researchers and practitioners in the development of IoT-based solutions for smart energy management.

[2] Karpagam et al. was introduced a smart energy meter that utilizes Arduino and ESP8266 technology, specifically designed to detect instances of power theft. This innovative approach not only addresses the critical issue of energy conservation but also underscores the growing importance of modern IoT applications in efficient energy management. By leveraging advanced sensor capabilities and communication protocols, the proposed system offers a proactive solution to mitigate losses due to unauthorized energy usage. Karpagam's work represents a significant advancement in the field of smart energy meters, providing a practical tool for utilities and consumers alike to monitor and safeguard their energy resources. The integration of Arduino and ESP8266 technology enhances the meter's functionality, enabling real-time detection and response to potential theft incidents. Overall, this research contributes valuable insights towards building more resilient and sustainable energy infrastructure.

[3] Midul et al. is developed an IoT smart energy meter equipped with GSM and WiFi capabilities, emphasizing its role in detecting energy theft and facilitating pre-

paid billing systems. This innovative approach contributes to promoting efficient energy usage in households by empowering users with real-time monitoring and control over their energy consumption. By integrating GSM and WiFi functionalities, the meter enables seamless communication and data exchange, enhancing user engagement and enabling proactive measures against unauthorized energy usage. Midul's work represents a significant step towards enhancing energy management practices, providing a practical solution to address issues of theft and billing transparency in the household energy sector. The implementation of IoT technology in the meter's design offers scalability and adaptability to evolving consumer needs, positioning it as a valuable tool for utilities and consumers alike in promoting sustainable energy usage. Overall, this research contributes to advancing the field of smart energy meters and fostering a more efficient and transparent energy ecosystem in households.

[3] Pengwah et al. presented an innovative approach for estimating non-technical losses in power networks by harnessing smart meter data to detect instances of electricity theft. Their method highlights the transformative potential of data-driven solutions in optimizing power distribution systems. By leveraging advanced analytics and machine learning techniques, the proposed approach offers a proactive means of identifying and mitigating losses due to unauthorized energy usage. Pengwah et al.'s research underscores the importance of leveraging data analytics to enhance the efficiency and reliability of power networks. By utilizing smart meter data, their method provides utilities with valuable insights into potential vulnerabilities and enables targeted interventions to safeguard against losses. Overall, this study contributes to advancing the field of power distribution management, showcasing the efficacy of data-driven solutions in addressing complex challenges within the energy sector.

[4] Testasecca et al. explored the optimization of smart energy networks, with a focus on leveraging data-driven techniques to enhance efficiency and sustainability in energy management. Their discussion underscores the importance of incorporating machine learning algorithms and scientific models to analyze and interpret complex energy data. By harnessing advanced analytics, the proposed approach enables utilities and stakeholders to make informed decisions and optimize energy usage in real-time. Testasecca et al.'s research highlights the transformative potential of data-driven techniques in shaping the future of energy management, offering a pathway towards more resilient and sustainable energy infrastructure. By integrating machine

learning and scientific models into smart energy networks, their work contributes to advancing the field and fostering innovation in the energy sector. Overall, this study provides valuable insights into the role of data-driven approaches in optimizing smart energy networks for efficient and sustainable energy management.

[5] Ashokkumar et al. introduced a system designed to deliver real-time energy data to users, with the goal of promoting efficient energy usage and conservation in residential settings. Their system aims to enhance sustainable energy management by empowering users with timely information about their energy consumption patterns. This approach contributes to fostering a culture of awareness and responsibility among consumers, encouraging them to adopt more sustainable energy practices. In the broader context of smart grid security and efficient energy management, numerous studies have emerged, offering innovative solutions to address the evolving challenges in the energy sector. These studies encompass a range of approaches, including advanced data analytics, machine learning algorithms, and novel technologies, all aimed at optimizing energy usage and ensuring the security and resilience of smart grid systems. Collectively, these efforts represent a concerted push towards building a more sustainable and efficient energy infrastructure capable of meeting the demands of a rapidly evolving world.

[6] Selvarathi et al. was introduced Eliot, a smart prepaid energy meter designed to offer real-time electricity usage data to users. The primary objective of Eliot is to reduce energy consumption and promote transparency in energy usage. By providing users with immediate access to their energy usage data, Eliot empowers them to make informed decisions about their consumption habits, leading to greater efficiency and conservation. This innovative approach contributes to advancing sustainable energy management practices in residential and commercial settings. Through its emphasis on prepaid functionality and real-time data monitoring, Eliot represents a significant step towards building a more sustainable and transparent energy ecosystem. Selvarathi et al.'s work underscores the importance of technological innovation in driving positive change in energy management, highlighting the potential of smart meters to revolutionize how we consume and conserve energy. Overall, Eliot holds promise as a practical solution for promoting energy efficiency and transparency, ultimately contributing to a more sustainable future.

[7] Badr et al. as introduced a privacy-preserving energy prediction scheme utilizing federated learning for smart grids. This innovative approach addresses two critical challenges: communication efficiency and data privacy. By leveraging federated learning techniques, the proposed scheme enables smart grids to perform energy prediction tasks while ensuring the privacy of user data. This is achieved by keeping data decentralized and performing model training locally on user devices, thereby minimizing the need for data sharing and preserving user privacy. Badr et al.'s work represents a significant advancement in the field of smart grid security and data privacy, offering a practical solution for addressing privacy concerns while maintaining the efficiency of energy prediction algorithms. This research contributes to fostering trust and confidence in smart grid systems, paving the way for more widespread adoption and deployment of advanced energy management technologies. Overall, the proposed privacy-preserving energy prediction scheme holds promise for enhancing the security and privacy of smart grid systems while supporting efficient energy management practices.

[8] Kumar et al. was conducted a study on the resilience of smart electric meters against cyber security attacks, emphasizing the critical importance of robust cybersecurity measures in the energy sector. Their investigation underscores the vulnerability of smart meters to cyber threats and the imperative for implementing effective security protocols to safeguard energy infrastructure. As the Internet of Things (IoT) continues to revolutionize energy management, numerous studies have emerged focusing on enhancing both efficiency and security. These studies encompass a range of approaches, including encryption protocols, intrusion detection systems, and anomaly detection algorithms, all aimed at fortifying IoT-based energy management systems against potential cyber attacks. Collectively, these efforts underscore the need for a comprehensive approach to cybersecurity in the energy sector, ensuring the resilience and integrity of critical infrastructure in the face of evolving threats.

[9] Harini et al. is introduced a system for automated energy monitoring, billing, and control, highlighting the pivotal role of the Internet of Things (IoT) in residential energy management. Their system leverages IoT technologies to enable real-time monitoring of energy usage, automated billing processes, and remote control functionalities. By integrating IoT devices and sensors, Harini et al.'s system offers

homeowners greater visibility and control over their energy consumption, leading to improved efficiency and cost savings. This research represents a significant advancement in the field of residential energy management, providing a practical solution for leveraging IoT to optimize energy usage and promote sustainability. By emphasizing the importance of automated monitoring and control systems, Harini et al. contribute to shaping a more efficient and responsive energy ecosystem in residential settings. Overall, their work underscores the transformative potential of IoT in revolutionizing how we manage and consume energy in our homes.

[10] Jamuna et al. detailed an IoT-based metering system featuring a microcontroller and GSM modem, specifically designed to tackle challenges related to manual electrical maintenance and theft detection. Their system leverages IoT technology to enable remote monitoring and control of electrical systems, enhancing efficiency and security. By integrating a microcontroller and GSM modem, the system facilitates real-time data transmission and communication, allowing for timely detection of potential theft incidents. Jamuna et al.'s research represents a significant contribution to the field of smart metering, offering a practical solution for addressing the complexities of electrical maintenance and theft prevention. This work underscores the importance of IoT in modernizing traditional energy infrastructure and promoting more sustainable and secure energy management practices. Overall, their IoT-based metering system holds promise for improving operational efficiency and enhancing security in electrical systems.

[11] Manikandan et al. was introduced a system designed for automated power usage calculation, billing, and payment processes, harnessing the capabilities of the Internet of Things (IoT) to enhance efficiency in energy management. Their system streamlines energy consumption tracking and billing procedures, leveraging IoT technologies to automate processes and improve accuracy. By integrating IoT devices and sensors, Manikandan et al.'s system enables real-time monitoring of power usage, facilitating more transparent and efficient billing practices. This research represents a significant step forward in modernizing energy management practices, offering a practical solution for optimizing processes and reducing administrative overhead. Additionally, recent studies have explored innovative approaches in smart grid security and energy monitoring, reflecting a broader trend towards leveraging technology to address evolving challenges in the energy sector. These efforts underscore

the importance of continuous innovation in enhancing the resilience and efficiency of energy infrastructure. Overall, Manikandan et al.'s work and recent studies highlight the transformative potential of IoT and other advanced technologies in shaping the future of energy management.

[12] Maule et al. concentrated on an IoT-based electricity monitoring system that integrates the Web of Things (WoT) to facilitate effective energy management. Their research emphasizes the utilization of IoT technology to enable real-time monitoring and control of electricity consumption, enhancing efficiency and promoting sustainability. By incorporating WoT principles, the system provides interoperability and seamless integration with existing web technologies, thereby enhancing accessibility and user experience. Maule et al.'s work represents a significant advancement in the field of energy management, offering a practical solution for leveraging IoT and web technologies to optimize energy usage. This research contributes to shaping a more connected and responsive energy ecosystem, empowering users with greater control over their electricity consumption. Overall, their focus on integrating IoT and WoT underscores the importance of interoperability and accessibility in driving innovation and efficiency in energy management systems.

[13] Zhu et al. investigated deep active learning techniques for electricity theft detection, employing convolutional neural networks (CNN) and Bayesian active query methods to minimize data labeling costs. Their research represents a significant advancement in the field of energy security, offering an innovative approach to detecting fraudulent activities in power networks. By leveraging deep learning algorithms and active learning strategies, Zhu et al.'s work enables utilities to identify potential instances of theft more efficiently and accurately. This approach not only enhances the effectiveness of theft detection systems but also reduces the resource requirements associated with manual data labeling. Overall, their exploration of deep active learning techniques highlights the potential of artificial intelligence in improving the resilience and security of energy infrastructure.

[14] Diaz et al. was introduced Vampire, a smart energy meter tailored for synchronous monitoring in computer systems. The meter integrates a range of IoT technologies to ensure accurate recording of energy consumption. This innovative approach enables real-time monitoring of energy usage in computer systems, facilitat-

ing better understanding and optimization of power consumption patterns. By leveraging IoT capabilities, Vampire offers a comprehensive solution for energy management in computing environments, providing insights that can inform decision-making and improve energy efficiency. Diaz et al.'s work represents a significant contribution to the field of energy monitoring and management, offering a practical tool for enhancing sustainability and reducing energy costs in computer systems. Overall, Vampire demonstrates the potential of IoT technologies in revolutionizing energy monitoring practices and promoting more efficient use of resources.

Chapter 3

PROJECT DESCRIPTION

3.1 Existing System

The existing system for energy monitoring and management often relies on traditional meters that lack the capabilities for real-time monitoring and remote control. These meters typically require manual readings and offer limited insights into energy consumption patterns, leading to inefficiencies and potential inaccuracies in billing. Moreover, the lack of advanced communication technologies in traditional meters hinders the ability to detect and respond to anomalies promptly, such as power theft or equipment malfunctions. Additionally, the reliance on manual processes for data collection and analysis increases the likelihood of human errors and delays in identifying issues, resulting in suboptimal energy management practices.

Furthermore, the existing system may lack scalability and flexibility to adapt to evolving energy needs and technological advancements. Traditional meters often have limited functionalities and cannot easily integrate with modern IoT technologies or smart grid systems. This limitation restricts the implementation of innovative energy management solutions and hampers efforts to optimize energy usage and promote sustainability. Additionally, the absence of robust cybersecurity measures in traditional meters poses significant risks, as they are susceptible to cyber attacks and unauthorized access. Overall, the disadvantages of the existing system highlight the urgent need for modernization and the adoption of advanced energy monitoring technologies to overcome these challenges and improve efficiency and reliability in energy management.

3.2 Proposed System

The proposed system aims to address the limitations of the existing energy monitoring and management infrastructure by leveraging advanced IoT technologies and smart metering solutions. One of the key advantages of the proposed system is its capability for real-time monitoring and remote control of energy usage. By integrating IoT devices and sensors, the system enables continuous monitoring of energy consumption patterns, allowing users to access real-time data and insights via web or mobile interfaces. This enhances transparency and accountability in energy usage, empowering consumers to make informed decisions and optimize their energy consumption habits.

Moreover, the proposed system offers enhanced flexibility and scalability compared to traditional metering systems. With support for seamless integration with smart grid technologies, the system can adapt to evolving energy needs and accommodate future expansions or upgrades. Additionally, the implementation of robust cybersecurity measures ensures the integrity and security of data transmitted and stored within the system, mitigating risks associated with cyber attacks or unauthorized access. Overall, the proposed system offers a comprehensive solution for modernizing energy monitoring and management practices, providing benefits such as improved efficiency, accuracy, and reliability in energy consumption tracking and billing processes.

3.3 Feasibility Study

The feasibility study for the proposed energy monitoring and management system involves assessing various aspects related to the project's viability and practicality. This includes evaluating technical feasibility, which involves determining whether the proposed system can be developed using existing technologies and resources. Additionally, economic feasibility analysis is crucial to assess the financial viability of the project, including estimating the costs associated with hardware, software, installation, and maintenance. Furthermore, operational feasibility considers whether the proposed system aligns with the operational requirements and objectives of the stakeholders involved. This includes assessing factors such as ease of use, compatibility with existing infrastructure, and potential disruptions to daily operations. Finally, the feasibility study also examines the environmental and social impacts of the proposed system, considering factors such as energy efficiency, sustainability, and user acceptance. By conducting a comprehensive feasibility study, stakeholders can make informed decisions about the implementation of the energy monitoring and management system, ensuring its successful development and deployment.

3.3.1 Economic Feasibility

In terms of economic feasibility, the proposed energy monitoring and management system presents several factors to consider. The initial investment required for hardware, software, and installation may represent a significant upfront cost. However, this investment is offset by the potential long-term savings resulting from improved energy efficiency and reduced operational costs. Additionally, the system offers opportunities for revenue generation through value-added services such as energy optimization consultations or premium features for users. Moreover, the scalability of the system allows for gradual implementation and expansion, minimizing financial risks and enabling stakeholders to realize returns on investment incrementally. Furthermore, the economic feasibility of the project is bolstered by the potential for regulatory incentives or subsidies for adopting energy-efficient technologies. Overall, while the initial investment may be substantial, the long-term economic benefits and potential for revenue generation make the proposed energy monitoring and management system economically feasible for stakeholders.

3.3.2 Technical Feasibility

From a technical perspective, the proposed energy monitoring and management system appears to be feasible given the current state of technology. The availability of IoT devices, sensors, and communication protocols provides the necessary infrastructure for real-time monitoring and data collection. Additionally, advancements in data analytics and cloud computing offer robust platforms for processing and analyzing large volumes of energy data efficiently. Moreover, the system's integration with existing smart grid technologies enhances its interoperability and compatibility with utility infrastructure. However, challenges may arise in ensuring seamless integration with legacy systems and addressing potential interoperability issues. Furthermore, considerations must be given to data security and privacy measures to protect sensitive information collected by the system. Overall, while certain technical challenges may need to be addressed, the project appears to be technically feasible with the appropriate expertise and resources.

3.3.3 Social Feasibility

In terms of social feasibility, the proposed energy monitoring and management system holds promise for fostering positive societal impacts. By providing consumers with greater visibility and control over their energy consumption, the system promotes awareness and accountability in energy usage. This can lead to behavioral changes among users, encouraging them to adopt more sustainable and efficient energy practices. Additionally, the system's emphasis on transparency and real-time monitoring enhances trust between consumers and energy providers, fostering stronger relationships and collaboration towards shared sustainability goals. Moreover, the implementation of the system may create opportunities for community engagement and education initiatives around energy conservation and environmental stewardship. However, considerations must be given to ensuring inclusivity and accessibility, particularly for vulnerable or marginalized populations who may face barriers to adopting new technologies. Overall, the social feasibility of the project hinges on its ability to empower and engage users in driving positive change towards a more sustainable energy future.

3.4 System Specification

- Real-time energy monitoring capabilities
- Integration with IoT devices and sensors
- Compatibility with smart grid technologies
- Cloud-based data storage and analytics
- Remote control functionalities
- Mobile and web interfaces for user accessibility
- Advanced data encryption and security measures
- Scalability for future expansions
- Interoperability with existing infrastructure
- Compliance with industry standards and regulations

3.4.1 Hardware Specification

- IoT devices with low-power microcontrollers (e.g., Arduino, Raspberry Pi)
- Sensors for measuring electricity usage (e.g., current sensors, voltage sensors)
- GSM and Wi-Fi modules for communication
- Secure hardware elements for data encryption and authentication
- Power-efficient processors to minimize energy consumption
- Memory modules for data storage and caching
- Display modules for user interface (e.g., LCD displays, LED indicators)
- Power supplies (e.g., batteries, AC adapters) with energy-efficient ratings
- Robust casing or enclosures for protection against environmental factors and tampering
- Compliance with relevant industry standards for hardware safety and performance

3.4.2 Software Specification

- Operating system: Linux-based distribution (e.g., Ubuntu, Raspbian)
- Programming languages: Python for backend development, JavaScript for frontend development
- Database management system: MySQL or PostgreSQL for data storage and retrieval
- Communication protocols: MQTT for IoT device communication, HTTP(S) for web-based interactions
- Visualization tools: Matplotlib, Plotly for data visualization
- Development tools: Git for version control, Docker for containerization, Continuous Integration/Continuous Deployment (CI/CD) pipelines for automated testing and deployment

3.4.3 Standards and Policies

Sample attached

Raspberry Pi Raspberry Pi is a series of small single-board computers developed by the Raspberry Pi Foundation. It is widely used in various projects, including IoT applications, due to its affordability and versatility. Raspberry Pi supports various programming languages and can be used for tasks such as data logging, sensor interfacing, and web server hosting.

Standard Used: ISO/IEC 14443

ESP32 ESP32 is a low-cost, low-power microcontroller chip with integrated Wi-Fi and Bluetooth capabilities. It is commonly used in IoT projects for wireless communication and sensor interfacing. ESP32 provides a convenient platform for developing IoT applications due to its compact size, low power consumption, and extensive peripheral support.

Standard Used: ISO/IEC 20922

Voltage Sensor Voltage sensors are electronic devices used to measure voltage levels in electrical circuits. They convert the voltage signal into a proportional analog or digital output, making it easier to monitor and control electrical systems. Voltage sensors play a crucial role in energy monitoring and management systems, providing real-time data on voltage levels for analysis and optimization.

Standard Used: ISO/IEC 29182

Current Sensor Current sensors, also known as current transducers or current transformers, are devices used to measure electric current flowing through a conductor. They convert the current signal into a proportional analog or digital output, allowing for accurate monitoring and control of electrical systems. Current sensors are essential components in energy monitoring and management systems, enabling precise measurement and analysis of power consumption.

Standard Used: ISO/IEC 18038

Firebase Firebase is a mobile and web application development platform acquired by Google. It provides various services such as real-time database, authentication, hosting, and analytics, making it easy to develop and deploy cloud-based applications. Firebase can be integrated into IoT projects for data storage, user authentication, and real-time communication, enhancing the functionality and scalability of the system.

Standard Used: ISO/IEC 27001:2022

Chapter 4

METHODOLOGY

4.1 General Architecture

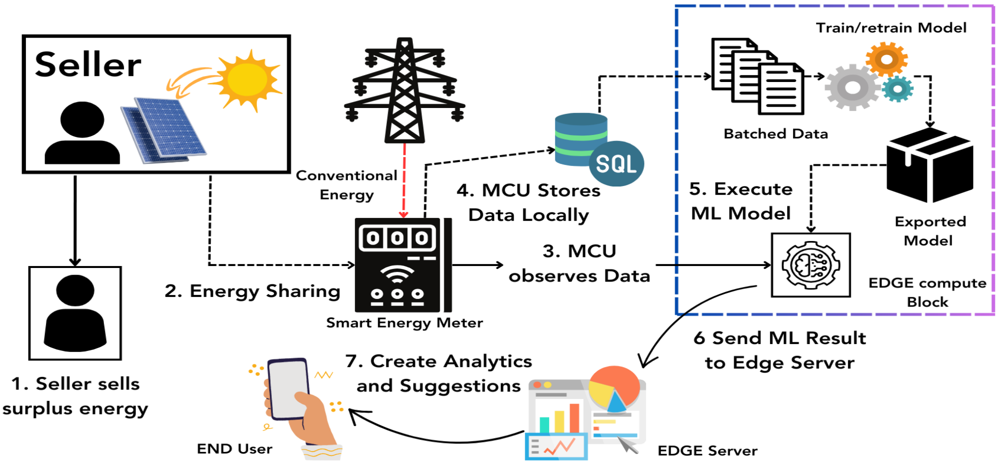

Figure 4.1: **Architecture Diagram**

Description :

The architecture begins with a comprehensive data processing stage, where historical electricity usage data is collected and refined through feature engineering and normalization. This stage is crucial for preparing the data in a format that is conducive to effective analysis and modeling. Following preprocessing, the model employs a trio of predictive algorithms in the Component Models stage. This includes SARIMA , an excellent choice for capturing seasonal trends and patterns in electricity consumption, Random Forest, known for its robustness and ability to handle complex, non-linear relationships, and Gradient Boosting Machines (GBM), which sequentially improves predictions by learning from previous errors.

4.2 Design Phase

4.2.1 Data Flow Diagram

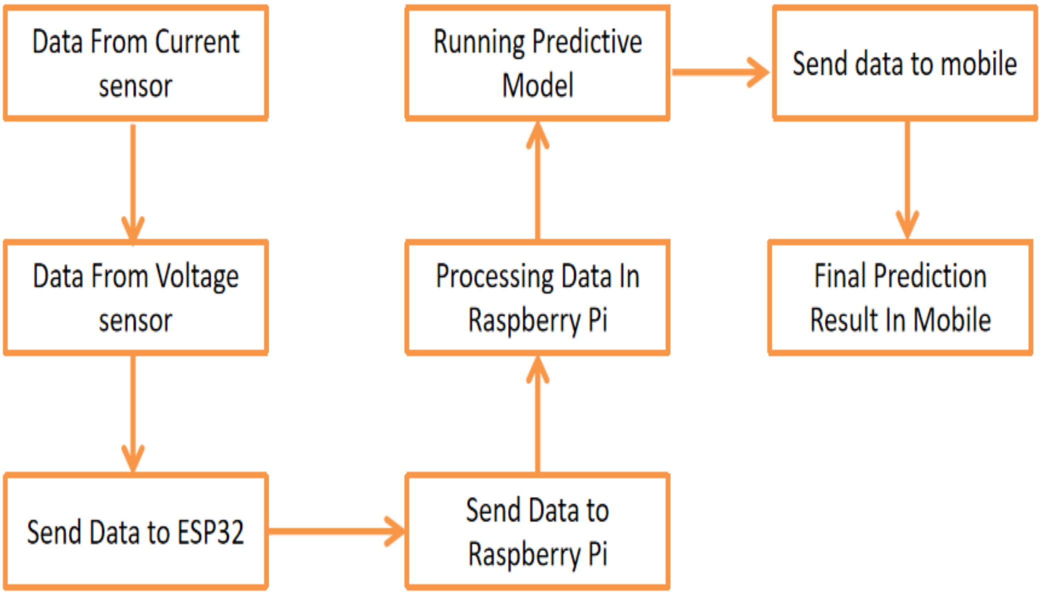

Figure 4.2: **Data Flow Diagram**

Description :

The data flow diagram shows the process of sending data from two sensors: a current sensor and a voltage sensor. The data from these sensors is then processed by the Raspberry Pi. After processing, the Raspberry Pi sends the data to two destinations: a mobile device and an ESP32 microcontroller (another small computer). It's unclear from the diagram whether the ESP32 sends any data back to the Raspberry Pi.

4.2.2 Class Diagram

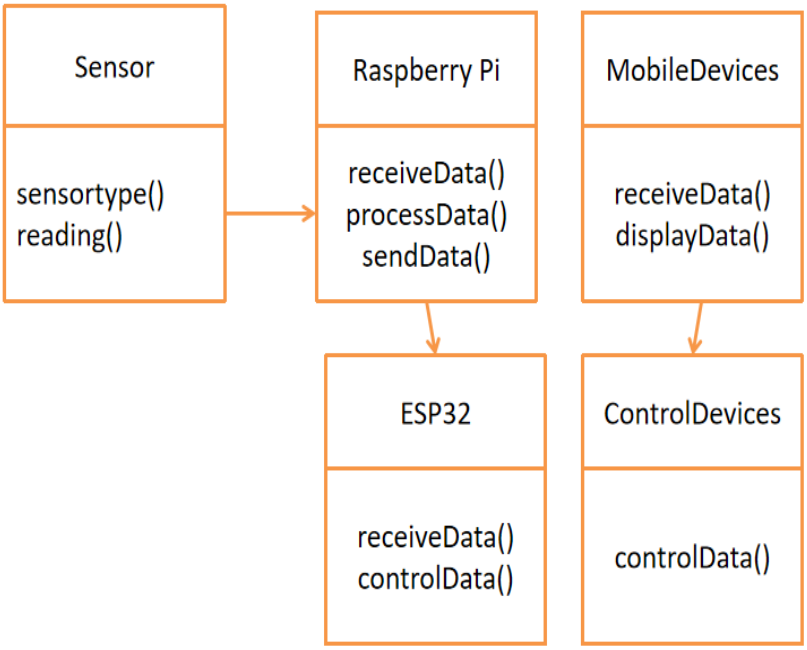

Figure 4.3: **Class Diagram**

Description :

The diagram depicts classes representing sensors, Raspberry Pi, mobile devices, and ESP32 microcontrollers. Sensors send their data (reading) to the Raspberry Pi. The Raspberry Pi processes the sensor data and can send it to mobile devices for display. Additionally, the Raspberry Pi can send data to ESP32 microcontrollers, which can then control external devices. The arrows represent data flow between the classes.

4.2.3 Entity-Relation Diagram

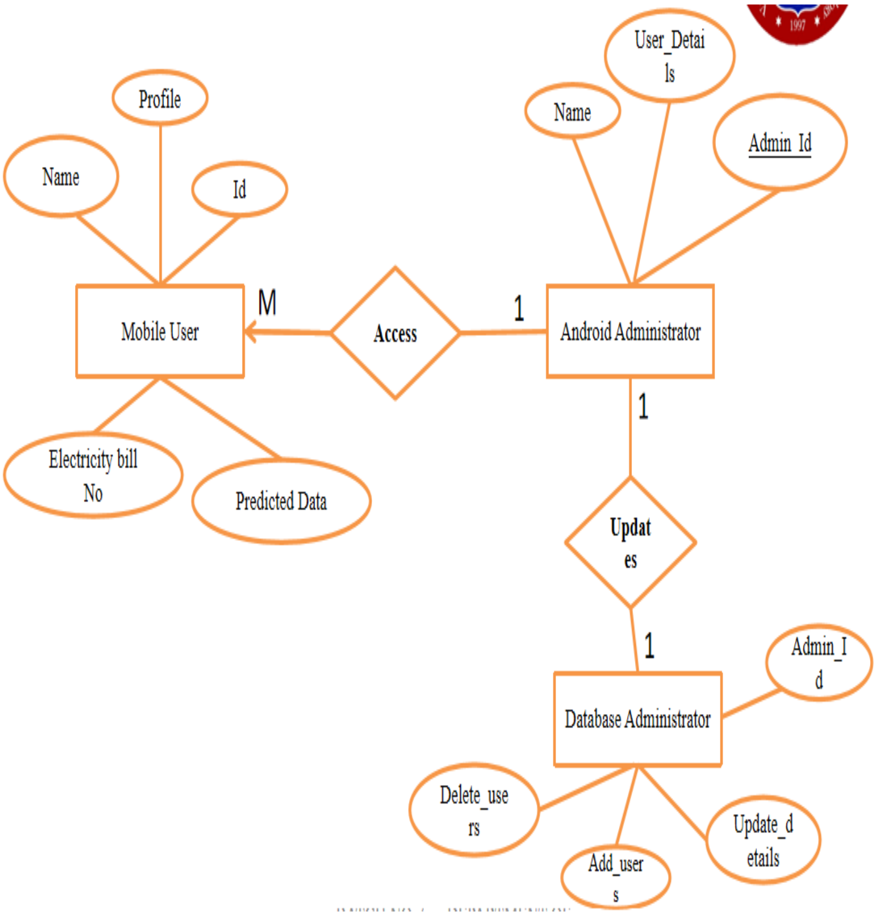

Figure 4.4: **Entity Relationship Diagram**

Description :

There are two main entities: Mobile User and Database Administrator. Each mobile user has attributes like Name and ID. The mobile user connects to the database administrator through an Access relationship. This likely signifies the mobile user's ability to access the database (possibly through an app). The database administrator can perform actions like adding, updating, and deleting user information. There's also a connection between the mobile user and another entity, possibly named Electricity Bill. This suggests that mobile users might be able to view or manage their electricity bill information through the system.

4.3 Algorithm & Pseudo Code

4.3.1 Algorithm

Due to NSTC(Nactional Science and Technology Council), I can't disclose the details of Algorithm.

4.3.2 Pseudo Code

Due to NSTC(Nactional Science and Technology Council), I can't disclose the details of Pseudo code.

4.4 Module Description

4.4.1 Module1

Node Device Establishment :

The Node Device is the cornerstone of the proposed smart energy meter system. Though it is simple in the sense of a single unit, when it is joined with many such nodes, it groups into a very big and complex network that provides an exceptional outcome. It encompasses the following key components:
Microcontroller : A microcontroller forms the brain of the Node Device. It orchestrates the interaction between sensors, data processing, and communication with the Edge Network. Parametric values, namely, voltage and current data from sensors, are efficiently gathered using an ESP32 microcontroller. This data, crucial for understanding electricity consumption, is transmitted to a Raspberry Pi in the edge network. ESP32 is particularly applied in this case as the master of the circuit. The ESP32's real-time capabilities enhance responsiveness. A Raspberry Pi model 4B is used as a slave for computing and preparing the payload response based on the data provided by the Master ESP32.
Voltage Sensor : The inclusion of a voltage sensor is essential for accurately measuring the voltage in the electrical system. This sensor, often based on Hall Effect technology, provides real-time voltage data to the microcontroller. The high precision ensures reliable energy consumption calculations .
Current Sensor :A current sensor is integrated to measure the flow of electrical current in the system. It is proven that an accurate sense of current can be obtained by

employing Hall Effect sensor or Electromagnetic Induction principles . While there are many alternatives to detect current, using the above-said method, the current sensor delivers precise current readings to the microcontroller. This data is crucial for comprehensive energy usage analysis.

LCD Sensor : To enhance user interaction and provide real-time feedback, an LCD sensor is incorporated. This sensor serves as the display interface, showing users their current energy consumption, historical data, and other relevant information. It facilitates user awareness and engagement in energy conservation. Additionally, the LCD provides a handy validation to the electrician or any other electrical operator to verify its performance and operation.

4.4.2 Module2

Intelligent Edge Network Supported by Node Data

The main purpose of this research is to utilize the implementation of an edge network to reduce data overload while maximizing the relevance of monitoring data . This would allow the user to organize and utilize energy in a way that promotes net zero goals.

Raspberry Pi 4 Model B Controller: The above collected data is transmitted to a Raspberry Pi, serving as the slave component of the node device edge of the network. On the Raspberry Pi, a SARIMA model processes the received data, predicting energy consumption costs for the next month.

Predictive Modelling : Once the data is successfully stored in the local database within the Raspberry Pi 4 model B, a live script takes in the data or updates the data to produce or change the prediction accordingly. This makes the standard node of a network intelligent. Thus, the name Intelligent Edge Node. The intelligence algorithm includes the employment of a customized ML model. The proposed predictive modeling approach includes an ensemble machine learning model designed for the sophisticated task of predicting electricity consumption on a specific future billing day. At its core, the model integrates advanced time series forecasting and ensemble learning techniques to provide accurate and reliable predictions

4.4.3 Module3

User Interface for Edge Control

To complement the intelligent edge network, a user-friendly mobile app is developed, offering real-time energy consumption monitoring. Integrated with the ESP32 and Raspberry Pi infrastructure, the app provides users with immediate insights into their current energy usage patterns, fostering awareness and informed decision-making. Leveraging AI capabilities, the app delivers personalized tips for energy conservation derived from the SARIMA model's analysis of historical data. Additionally, the app forecasts next month's energy consumption , empowering users with anticipated costs to plan and adjust their usage patterns and With a user-centric design, the app ensures seamless navigation through real-time data, conservation tips, and future predictions, enhancing the overall user experience. This methodology combines hardware integration, advanced analytics, and a user-friendly mobile interface to create a comprehensive energy consumption management system.

The app emphasizes data security with user authentication, encryption, and access controls. It boosts user engagement with energy-saving challenges and notifications. Available on multiple platforms, the app is regularly updated to incorporate user feedback and new technologies, ensuring its effectiveness and adaptability in energy management.

4.5 Steps to execute/run/implement the project

This work was supported, in part, by the National Science and Technology Council, Taiwan, grant number NSTC 112-2221-E-197-015. So Due to Privacy & Terms, I can't able to share the implementation details of the project.

4.6 Input and Output

4.6.1 Input Design

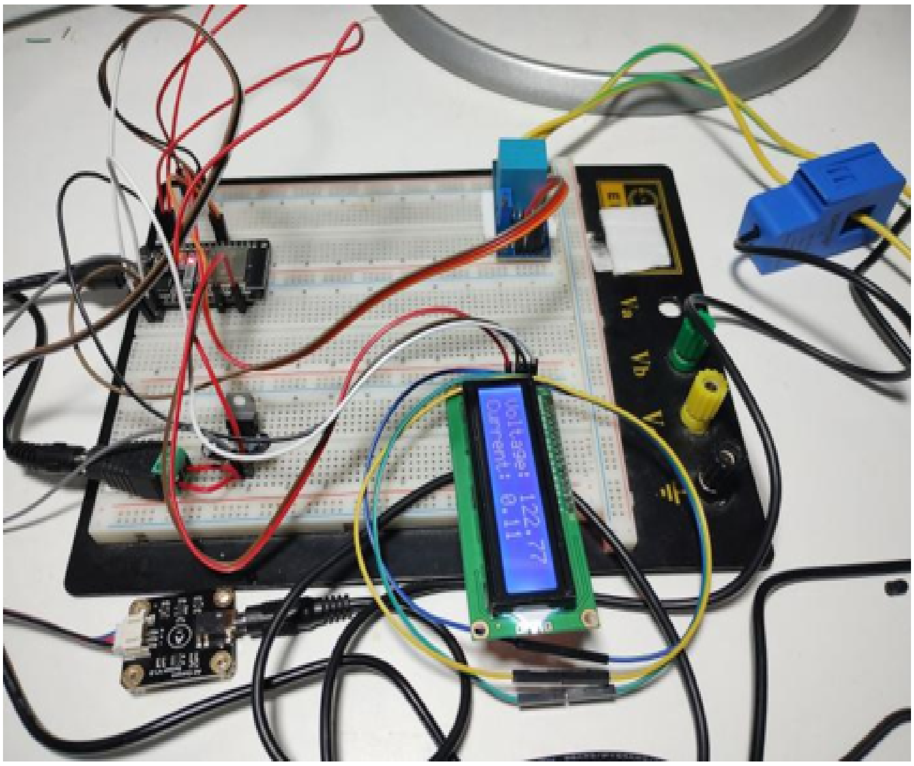

Figure 4.5: **Sensors Circuit**

4.6.2 Output Design

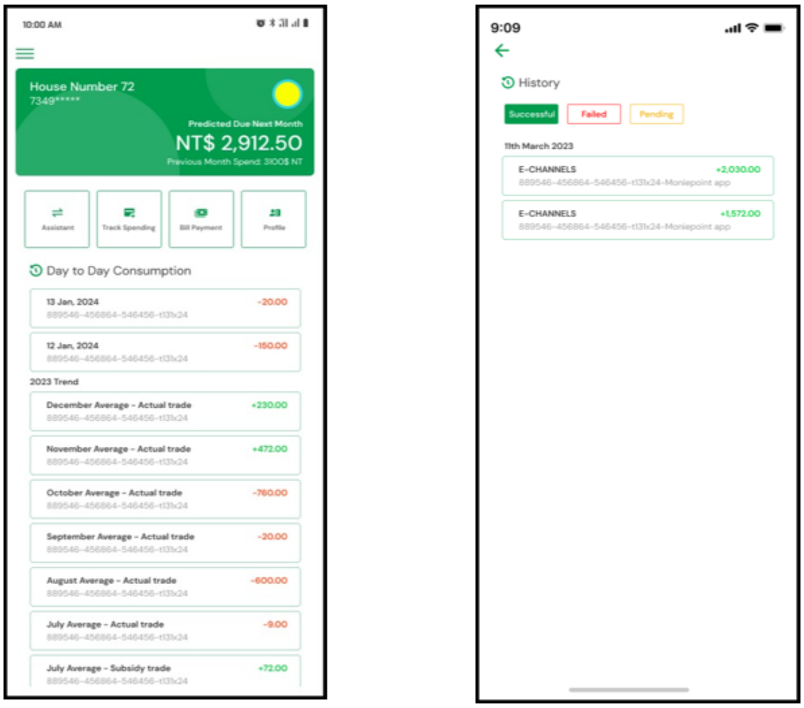

Figure 4.6: **User Interfacel**

4.7 Testing

4.8 Types of Testing

4.8.1 Unit testing

Testing for the smart energy meter project involves rigorous unit testing to ensure the accuracy and reliability of individual components. This includes verifying sensor readings, data processing algorithms, and predictive modeling accuracy. Communication between the energy meter and edge network undergoes testing for reliability and error handling, while edge intelligence is scrutinized to validate its decision-making logic. Integration testing assesses the cohesive operation of components, while boundary condition and error handling tests ensure robustness and resilience. Performance testing measures system responsiveness and resource utilization, and security testing validates data encryption and access control mechanisms.

Through meticulous testing, the project aims to achieve real-time monitoring of electricity consumption and contribute to 'net zero goals'. By integrating IoT and edge intelligence, the system can effectively mitigate waste and promote sustainable energy management practices.

Input

```
"Due to NSTC Guidelines I can't diclouse the testing details."
```

Test result

4.8.2 Integration testing

Integration testing for the smart energy meter project is essential to validate the seamless operation of its interconnected components. This phase brings together individual modules to assess their collective functionality within the system. Integration tests ensure that data flows smoothly between components, communication protocols are correctly implemented, and interfaces are properly integrated.

Moreover, integration testing evaluates the interaction between the energy meter and edge network components, validating their interoperability and synchronization. It ensures that data processing algorithms receive accurate inputs from sensors, predictive models utilize updated data for analysis, and edge intelligence makes informed decisions based on real-time information. By conducting thorough integration testing, the project can ensure the holistic functionality of the smart energy meter system, facilitating reliable monitoring and mitigation of electricity consumption towards the realization of 'net zero goals'.

Input

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"Due to NSTC Guidelines I can't diclouse the testing details."
```

Test result

4.8.3 Functional testing

Functional testing for the smart energy meter project focuses on validating its features and functionalities to ensure they meet the specified requirements. This testing phase involves assessing the system's ability to perform essential tasks such as real-time monitoring of electricity consumption, data processing, and predictive modeling. Functional tests verify that the energy meter accurately collects data from sensors, processes it efficiently, and generates insights to facilitate informed decision-making.

Additionally, functional testing evaluates the responsiveness and usability of the system's interface, ensuring that users can interact seamlessly with the smart energy meter. It encompasses scenarios such as simulating various energy consumption patterns, testing the system's ability to detect anomalies, and verifying the effectiveness of mitigation actions. By conducting comprehensive functional testing, the project can guarantee the reliability and effectiveness of the smart energy meter in contributing to sustainable energy management practices and achieving 'net zero goals'.

Input

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"Due to NSTC Guidelines I can't diclouse the testing details."
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4.8.4 Test Result

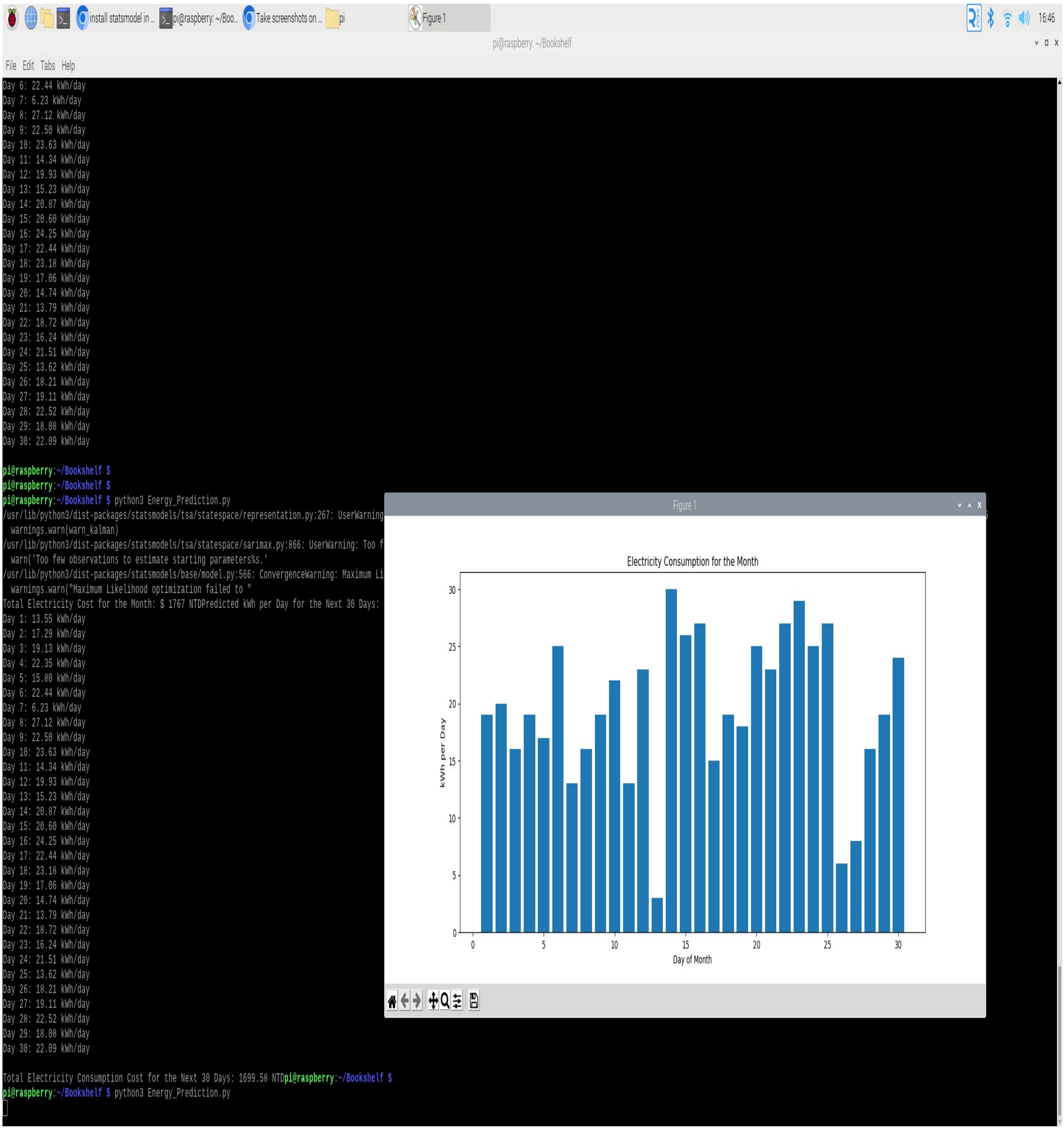

Figure 4.7: **Pediciton of the Model**

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Efficiency of the Proposed System

The proposed system offers several advantages that contribute to its overall efficiency. Firstly, by leveraging IoT technologies and real-time monitoring capabilities, the system enables continuous monitoring of energy consumption patterns, allowing for proactive identification of inefficiencies and optimization opportunities. This real-time visibility empowers users to make data-driven decisions to reduce energy wastage and improve overall efficiency. Additionally, the integration of smart meters and sensors allows for automated data collection and analysis, reducing the need for manual intervention and streamlining energy management processes. Moreover, the scalability and flexibility of the proposed system enhance its efficiency in adapting to changing energy demands and infrastructure requirements. The modular architecture of the system allows for easy integration of additional sensors, devices, and functionalities as needed, ensuring that it remains adaptable to evolving needs and technologies. Furthermore, the use of cloud-based storage and analytics facilitates efficient data management and processing, enabling timely insights and actionable intelligence. Overall, the proposed system's combination of real-time monitoring, automation, scalability, and cloud-based analytics contributes to its efficiency in optimizing energy usage and promoting sustainability.

5.2 Comparison of Existing and Proposed System

Existing system:
The existing system of smart energy meters typically relies on basic monitoring capabilities, providing users with limited real-time data on energy consumption. These meters may offer simple features such as remote reading and basic analytics, but they often lack advanced functionalities for detailed analysis and optimization. Users may face challenges in identifying energy inefficiencies and optimizing usage patterns

due to the limited insights provided by these meters. Additionally, integration with other smart devices and systems may be limited, limiting the overall efficiency and effectiveness of energy management. The existing system uses a prediction model based on linear regression, which may not capture the complex patterns and seasonality present in energy consumption data.

Proposed system:

The proposed system of smart energy meters introduces advanced features and capabilities aimed at improving energy monitoring and management. Leveraging IoT technologies and advanced analytics, the proposed system offers real-time monitoring of energy consumption patterns with detailed insights and customizable analytics. Users can access comprehensive data on energy usage, identify inefficiencies, and optimize consumption patterns for increased efficiency and cost savings. Integration with other smart devices and systems enables seamless communication and interoperability, enhancing the overall efficiency and effectiveness of energy management efforts. The proposed system utilizes a SARIMA (Seasonal Autoregressive Integrated Moving Average) model for energy consumption prediction, which accounts for seasonal patterns and temporal dependencies, providing more accurate forecasts compared to linear regression. Overall, the proposed system represents a significant advancement in smart energy meter technology, offering enhanced capabilities for optimized energy usage and sustainability.

5.3 Sample Code

```
"Due to NSTC Privacy $ Terms I can't diclouse the testing details."
```

Output

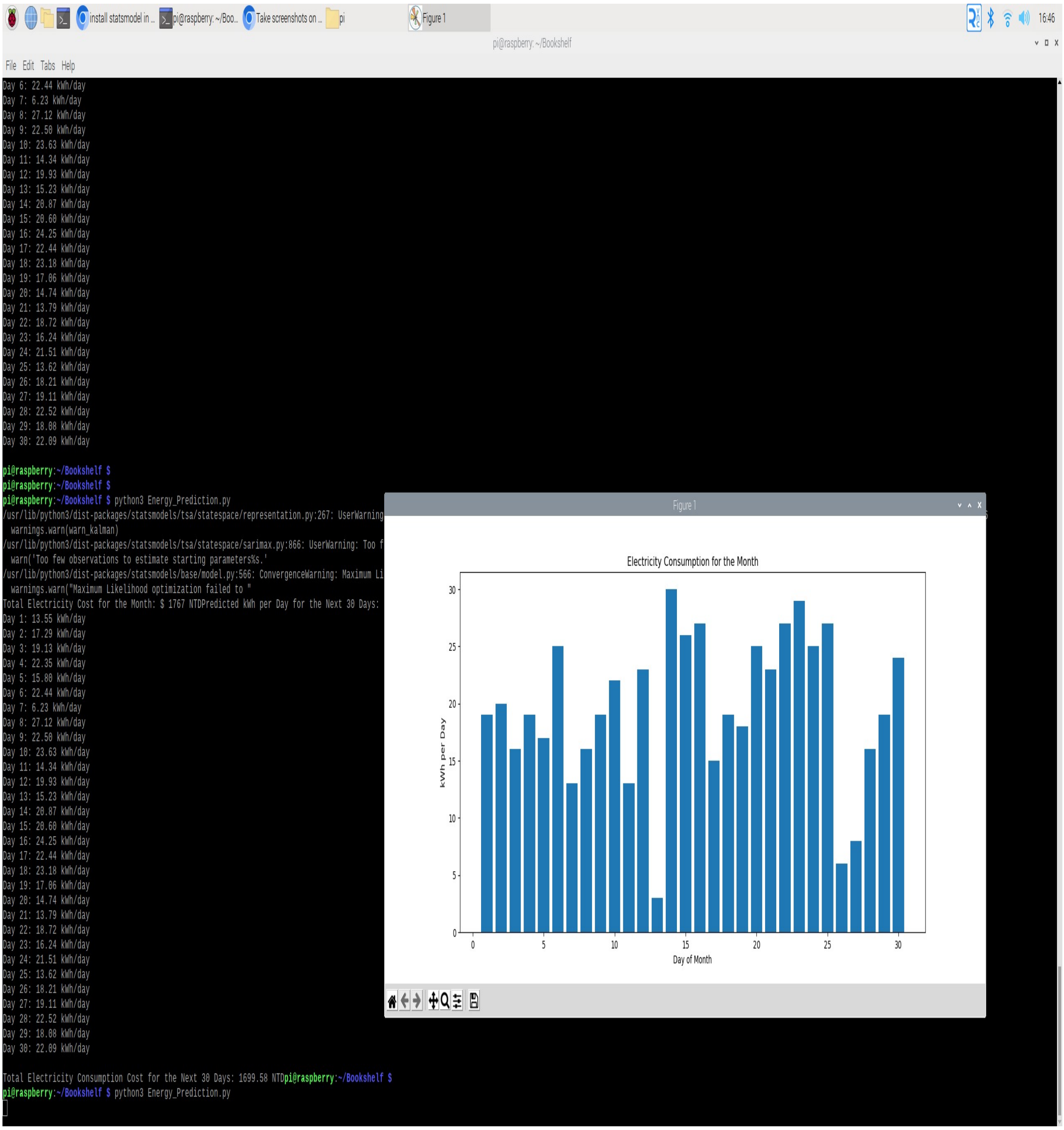

Figure 5.1: **Predicted Energy Consumption**

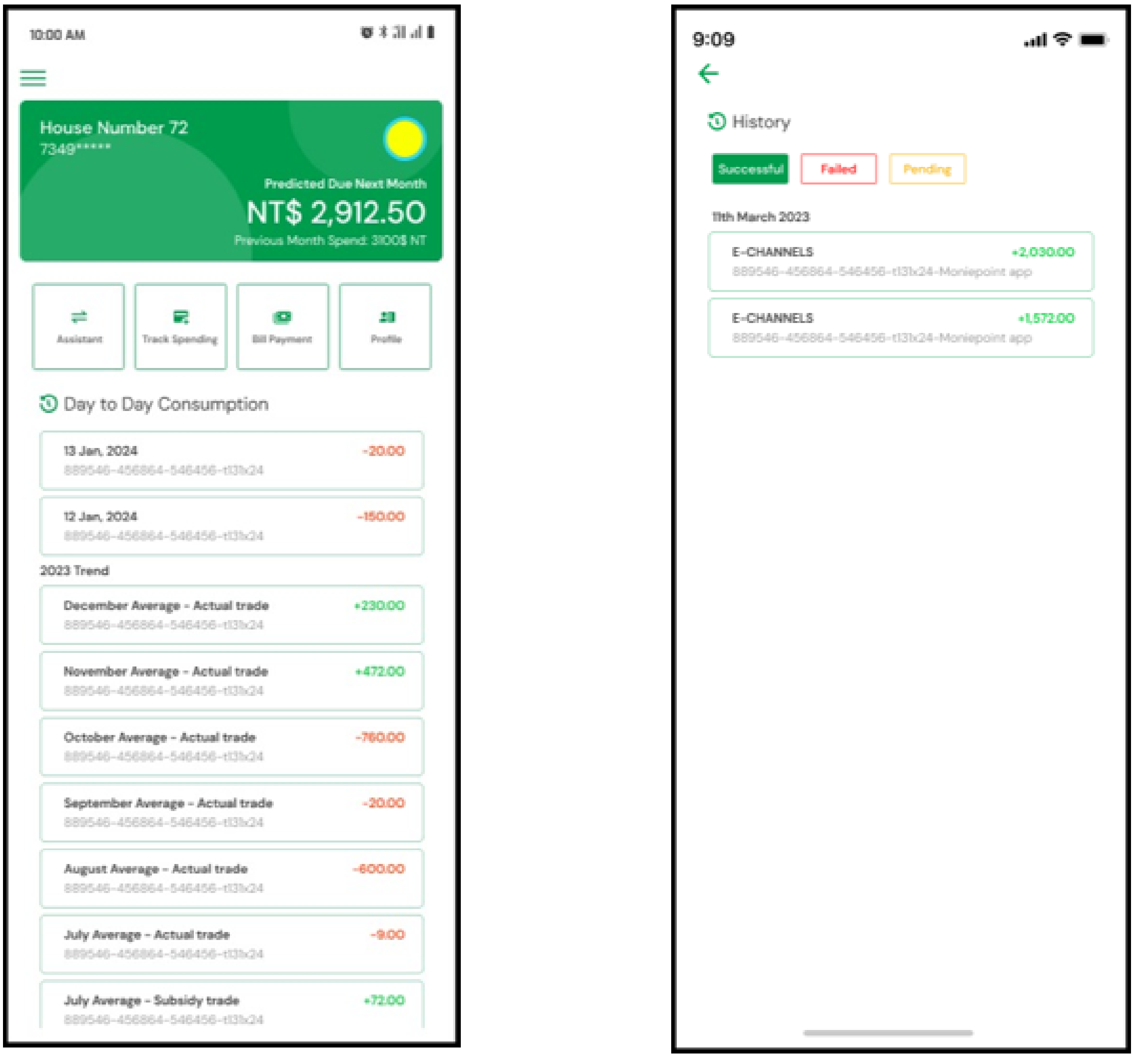

Figure 5.2: **User Application Interface**

Chapter 6

CONCLUSION AND FUTURE ENHANCEMENTS

6.1 Conclusion

The successful integration of an intelligent edge network with a sophisticated ensemble machine learning model marks a significant milestone in the pursuit of sustainable energy management. By meeting its predefined objectives, particularly in striving towards net-zero goals, this research underscores the pivotal role of cutting-edge technologies in addressing contemporary energy challenges. The seamless coordination between the Node Device, empowered by ESP32 microcontroller and various sensors, has laid a resilient groundwork for precise energy consumption analysis. This efficient data management system not only ensures accuracy but also promotes resource optimization, a crucial aspect in the journey towards sustainable energy practices.

Moreover, the utilization of advanced predictive analytics, harnessing the combined power of SARIMA, Random Forest, and GBM algorithms within the Raspberry Pi 4 Model B, has yielded commendable results. Achieving an 83.5% accuracy rate in forecasting electricity consumption reflects the efficacy of this approach in empowering stakeholders with actionable insights. These insights enable informed decision-making, empowering users to adopt more sustainable energy consumption patterns. Additionally, the implementation of a user-friendly mobile application enhances engagement and awareness among consumers, further catalyzing the transition towards greener energy practices. Furthermore, the edge server's capability to provide accurate action recommendations based on a predefined resource pool underscores the system's adaptability and responsiveness to dynamic energy demands. Rigorous testing and validation processes have solidified the system's reliability, safety, and overall effectiveness, instilling confidence in its potential for broader applications in smart energy management. As such, this study not only contributes to the academic discourse but also lays a robust foundation for the widespread adoption of edge technologies in advancing energy conservation efforts and realizing ambitious net-zero objectives.

6.2 Future Enhancements

Looking ahead, several avenues exist for enhancing the capabilities and impact of the integrated intelligent edge network and machine learning model in smart energy management. One potential avenue for improvement lies in the refinement and expansion of the predictive analytics framework. By incorporating additional machine learning algorithms or refining existing ones, such as integrating deep learning techniques like neural networks, the accuracy and granularity of energy consumption forecasts could be further enhanced. Additionally, leveraging real-time data streams and incorporating feedback mechanisms into the predictive model could enable more adaptive and responsive energy management strategies, ensuring continuous optimization and improvement.

Furthermore, enhancing the interoperability and scalability of the system could significantly broaden its applicability and impact. Integrating standardized communication protocols and open interfaces would facilitate seamless integration with existing infrastructure and enable interoperability across different smart energy systems and devices. Moreover, designing the system with modular architecture and cloud-based services would enhance scalability, allowing for easy expansion and adaptation to varying deployment scenarios and evolving user needs. By fostering a more interconnected and adaptable ecosystem, future enhancements could unlock the full potential of edge technologies in revolutionizing energy management and advancing towards sustainable, net-zero energy goals on a global scale.

Chapter 7

INDUSTRY DETAILS

7.1 Industry name : National Ilan University

7.1.1 Duration of Internship : 23/09/2023 - 22/01/2024

7.1.2 Duration of Internship in months : 4 Months

7.1.3 Industry Address : No. 1, Section 1, Shennong Rd, Yilan City, Yilan County, Taiwan 260

7.2 Internship offer letter

國立宜蘭大學
National Ilan University NIU

Nov 9, 2023

Mr. Manideep Reddy Sripathi

Passport No: X6191709

Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology

India

Letter of Acceptance

Dear Mr. Manideep Reddy Sripathi,

On behalf of National Ilan University, we are pleased to inform you that you have been granted admission as a Visiting Student of TEEP@AsiaPlus Program at Department of Electronic Engineering during the visiting period from September 24, 2023 to January 22, 2024.

We would like to extend our warmest welcome and look forward to seeing you at NIU in the near future. We wish you all the best.

Po-Ching-Wu

President Po-Ching Wu
National Ilan University

Figure 7.1: **Internship offer letter**

7.3 Internship Completion certificate

國立宜蘭大學
National Ilan University NIU

Certificate of Completion

This is to certify that Manideep Reddy Sripathi has participated in TEEP@AsiaPlus "Department of Electronic Engineering", hosted by National Ilan University in Taiwan, from September 24, 2023 to January 21, 2024, and completed all the requirements.

National Ilan University
Office for International Affairs

Office of International Affairs
National Ilan University
January 21, 2024

Figure 7.2: **Internship Completion certificate**

Chapter 8

PLAGIARISM REPORT

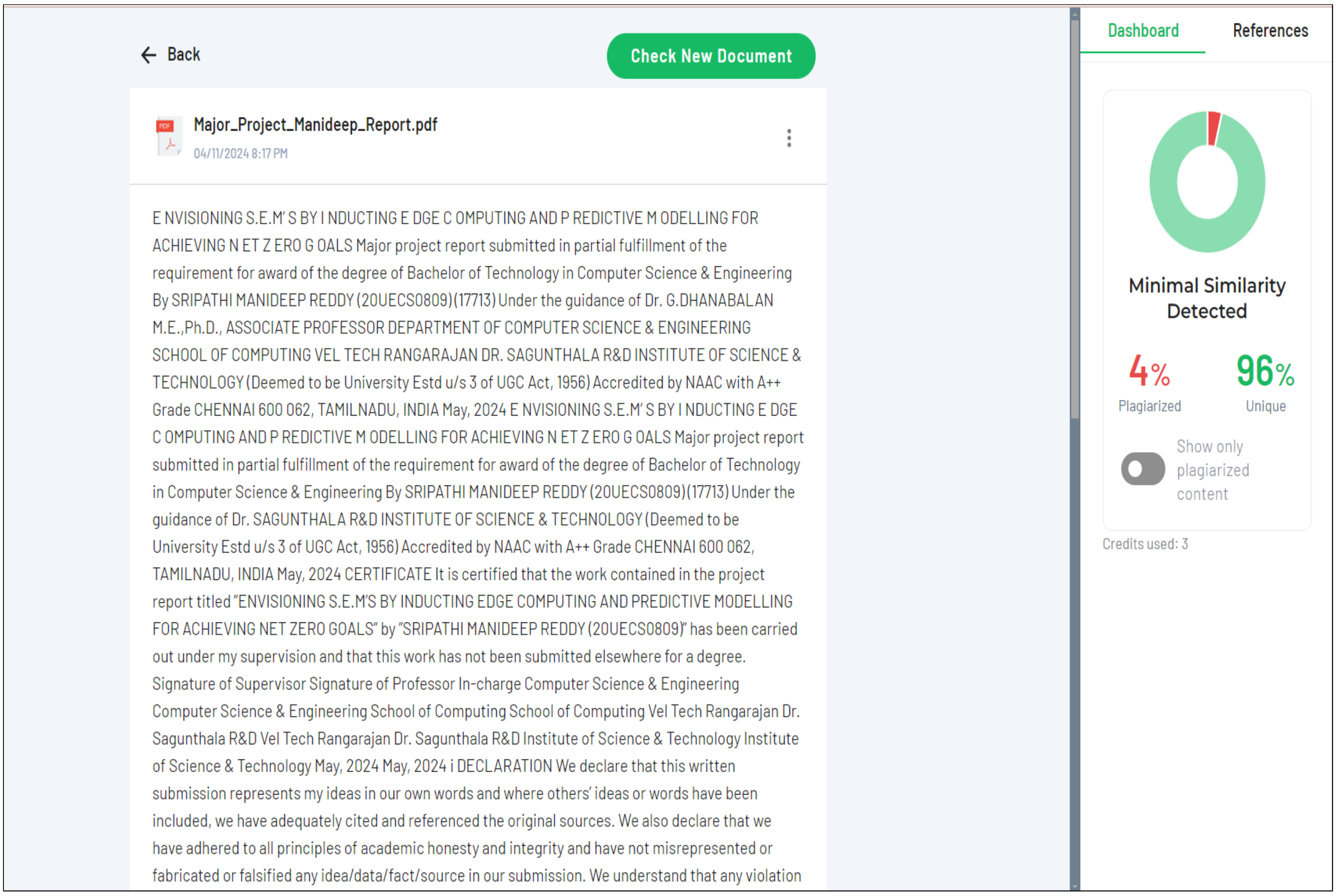

Figure 8.1: **Plagiarism Report**

Chapter 9

SOURCE CODE & POSTER PRESENTATION

9.1 Source Code

```
"This work was supported, in part, by the National Science and Technology Council, Taiwan, grant number NSTC 112-2221-E-197-015. So Due to Privacy & Terms, I cannot able to share the Source code of the project."
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9.2 Poster Presentation

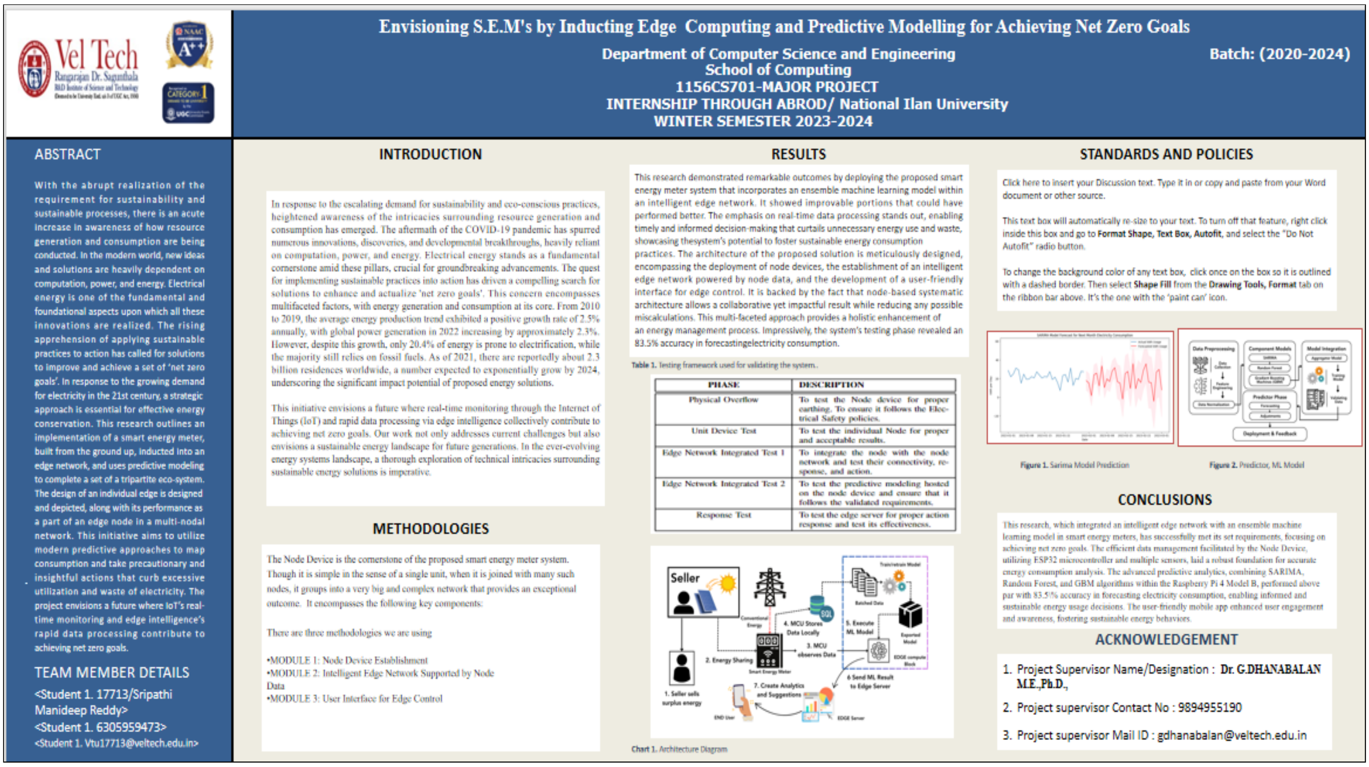

Figure 9.1: **Poster Presentation**

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