

Smart Energy Management System Using IoT and Microcontroller Technology

Amol N. Godase¹, Mayuri N. Bhosale², Anuja A. Ghodake³, Vaishnavi M. Waghmare⁴, Vaibhavi P. Sakhare⁵
^{1,2,3,4,5}Department of Electrical Engineering, SKN Sinhgad College of Engineering,
Korti, Pandharpur, Maharashtra-413304
Correspondence: amolgodase999@gmail.com*

Abstract— Energy management has become essential due to the increasing demand for electricity and the need to reduce energy wastage. Traditional energy monitoring systems do not provide real-time monitoring and efficient control of energy consumption. To address this issue, an IoT-based Energy Management System using a microcontroller is proposed. The system monitors electrical energy consumption and transmits the data through the Internet of Things (IoT) platform for real-time analysis and monitoring.

In this system, a microcontroller is used as the main control unit to collect data from sensors that measure voltage, current, and power consumption. The collected data is processed and sent to a cloud server through an IoT module. Users can access this information through a mobile application or web interface, which allows them to monitor energy usage from any location. The system can also provide alerts when energy consumption exceeds a predefined limit, helping users take necessary actions to reduce power usage.

Keywords: Internet of Things (IoT), Energy Management System, Microcontroller, Smart Energy Monitoring, Power Consumption, Real-Time Monitoring, Energy Efficiency, Smart Grid, Cloud Computing, Sensors.

I. INTRODUCTION

The ongoing increase in industrial activity, city growth, and tech advances has caused a big rise in the world's need for energy. Because of this, it's important to use energy efficiently and save it in both homes and businesses. Old ways of checking energy use are usually done by hand, take a lot of time, and don't work well for saving power. To fix these issues, new research has been focused on using smart control and communication tools in energy systems.

The Internet of Things (IoT) is a big change in technology that allows for real-time tracking, analysis, and control of electrical systems using connected smart devices.

IoT systems can automatically manage energy by collecting data from sensors and controlling appliances through the internet or mobile devices. These systems help improve how energy is used, reduce waste, and lower energy bills.

In this study, an IoT-based energy management system using a microcontroller is created to offer a smart and automatic way to manage power use. The system uses a microcontroller like Arduino Uno or ESP32 as the main control unit. It gathers real-time data on voltage, current, and energy use from sensors. This data is sent over the internet to a cloud platform, allowing users to monitor and adjust connected devices through a website or app.

The main goal of this system is to track energy use in real time and manage electrical loads automatically.

It can spot high energy use, send warnings, and shut off heavy users when needed. Also, IoT helps analyze how energy is used over time, predict future use, and schedule tasks to make energy use more efficient. The system can also connect with renewable energy sources like solar panels, helping make energy management more eco-friendly. This IoT-based system shows how smart energy use can work in homes and businesses. By using such smart tools, people can help reduce overall energy needs and support efforts to protect the environment.

II. RELATED WORKS

In recent years, several research efforts have been made toward developing intelligent and automated systems for monitoring and managing electrical energy using modern communication technologies. Traditional energy management approaches have relied heavily on manual operations and GSM-based control systems, which provide limited real-time functionality and lack scalability. The emergence of Internet of Things (IoT) technologies has significantly transformed the field, enabling cloud connectivity, automation, and data-driven optimization for efficient power management.

A paper titled "IoT-Based Energy Monitoring System for Optimizing Power Consumption", presented at the 8th International Artificial Intelligence and Data Processing Symposium (DAP'24), discusses the design and implementation of an IoT-based energy monitoring system for optimizing power usage in university facilities

[1]. The system employs an ACS712 current sensor and an ESP8266 Wi-Fi module to measure and transmit real-time current and power data to a Firebase cloud database. A web-based graphical user interface (GUI) provides remote control of electrical lines in various rooms, promoting efficient energy utilization and reducing operational costs. The study achieved a current sensing accuracy of $\pm 1.5\%$, demonstrating reliable system performance. However, voltage sensing was not included, which limits the precision of total power measurement. The authors suggest that integrating voltage measurement in future versions could enhance accuracy and scalability. From the literature, it is evident that this study successfully demonstrates real-time cloud-based monitoring, though its application scope remains confined to controlled institutional settings. In a related study, Rakibul Hasan et al. proposed an IoT-based Smart Energy Management System (EMS) for residential applications in their paper "IoT Based Smart Energy Management in Residential Applications", presented at the International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT 2019)



[2]. The proposed system employs a NodeMCU microcontroller integrated with a Wi-Fi module for data acquisition, transmission, and real-time monitoring. Users can remotely control household appliances, while energy consumption data and corresponding costs are periodically updated to a remote server. The study further introduces the concept of sub-metering for high-power appliances to achieve detailed consumption tracking. The system enhances data transparency and enables efficient load management, encouraging energy conservation. Compared to conventional metering systems, which lacked real-time data communication and user interactivity, this IoT-based design demonstrates greater flexibility, scalability, and automation potential for residential applications. IOT Based Energy Management System Using Microcontroller Department of Electrical Engineering Page 4 Similarly, Suresh Kumar V. developed a Home Energy Management System with Automated Power Scheduling using GSM, published in the International Research Journal of Engineering and Technology (IRJET), Vol. 5, Issue 5, May 2018.

Several researchers have developed IOT-based energy management systems to monitor and control electricity usage in homes, offices, and industries. These systems use sensors to measure voltage and current, sending real time data to cloud platforms like Blynk, Thing Speak, or Arduino Cloud. Many smart home systems integrate energy monitoring with mobile apps, allowing users to control appliances remotely and reduce wastage. In industries, IOT systems track machine power usage and optimize energy efficiency. Some projects combine renewable energy sources like solar panels with IOT monitoring for better utilization. Advanced systems use AI and machine learning to predict energy consumption patterns and suggest optimal schedules.

IOT-enabled smart meters are widely used for real-time billing and detailed consumption reports. Integration with home automation allows automatic switching of devices based on usage. Load controls systems help reduce peak-hour energy consumption. Overall, these studies demonstrate that IOT technology can significantly improve energy efficiency, cost savings, and sustainable energy management. In industrial setups, IOT-based energy management helps monitor machine energy consumption, optimize load distribution, and reduce unnecessary energy use. Some systems also combine renewable energy sources, such as solar panels, to track both energy generation and consumption, improving sustainability. Advanced approaches use AI and machine learning algorithms to predict future energy consumption patterns and recommend efficient usage schedules. The integration of smart meters provides precise, real-time billing and detailed consumption reports, making energy management more accurate. Further, IOT systems are increasingly being integrated with home automation and building management systems to automatically switch off non-essential devices during peak hours or when not in use. Some research focuses on load balancing and demand-side management, ensuring optimal use of electricity in smart grids. Studies have also highlighted the benefits of IOT energy management in reducing electricity costs, improving energy efficiency, and promoting sustainable and green energy practices.

III. PROBLEM STATEMENT

To address the issue of inefficient energy usage and lack of real-time monitoring in conventional systems. To develop

an IoT-based energy management system using a microcontroller (such as Arduino Uno) for continuous monitoring and control.

To reduce energy wastage and improve efficiency through smart, automated, and remote energy management. In today's world, increasing electricity consumption and wastage of energy have become major concerns in homes and industries. Most users are unaware of how much power their appliances consume, leading to higher electricity bills and inefficient energy use. Traditional energy meters only provide total consumption data but do not offer real-time monitoring or remote control of devices. There is a need for a smart system that can continuously monitor, analyze, and control energy usage from anywhere. The IOT-Based Energy Management System aims to solve this problem by using Internet of Things (IOT) technology to provide real-time monitoring, data analysis, and remote control of electrical loads. This system helps users optimize power usage, prevent energy wastage, and promote efficient energy management.

IV. METHODOLOGY

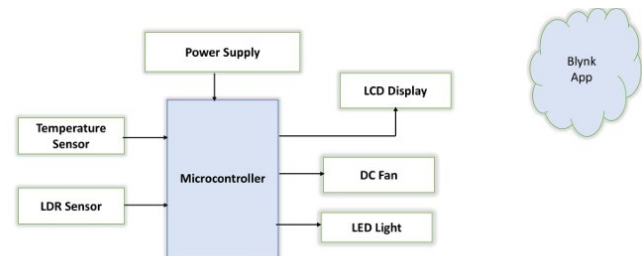


Fig. 1. Proposed System Block Diagram

A. Power Supply: Provides the necessary voltage and current to the entire system. Converts AC mains voltage (230V/110V) to low DC voltage (usually 5V or 12V) suitable for the microcontroller, sensors, and actuators. Ensures stable operation of all components, preventing damage from voltage fluctuations.

B. Temperature Sensor (e.g., LM35, DHT11, DHT22):- Measures the ambient temperature in the environment or near a device. Sends temperature data to the microcontroller for processing.

C. LDR Sensor (Light Dependent Resistor): Detects the intensity of ambient light. Outputs an analog signal to the microcontroller proportional to the light level.

D. LCD Display (16x2 or 20x4): Provides a local visual display of system data such as: Voltage, current, and power consumption of devices. Temperature readings from the sensor. Status of appliances (ON/OFF). Helps users monitor energy usage without using the mobile app. can display real-time alerts for abnormal conditions.

E. DC Fan: Acts as a controllable load in the system for testing energy consumption. Can be turned ON/OFF automatically based on temperature readings or user commands from the IOT app. Demonstrates load control and automation features of the system.

F. LED Light: Serves as another controllable load. Can be switched automatically based on LDR sensor readings (ambient light) or manually via the app. Helps reduce

electricity consumption by turning lights OFF when not needed.

G. Microcontroller (Node MCU): Acts as the brain of the system. Collects data from sensors (temperature sensor, LDR, voltage/current sensors). Processes the data to calculate power consumption, detect thresholds, and control loads. Sends real-time data to the IOT platform (Blynk app) using built-in Wi-Fi. Receives commands from the app to switch devices ON/OFF remotely.

H. Blynk App (IOT Platform): Cloud-based application for monitoring and controlling devices. Receives data from the microcontroller and displays it on smartphones. Allows users to: o Monitor voltage, current, power, temperature, and light levels. Turn appliances like fans or lights ON/OFF remotely.

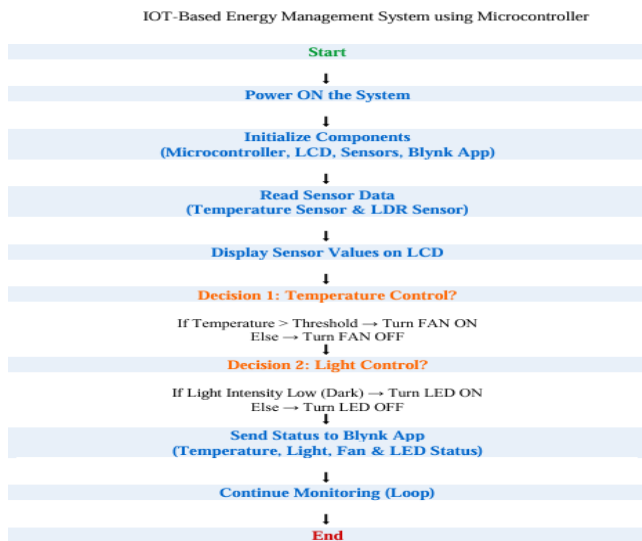


Fig. 2. Flow Chart of Methodology

V. PROGRAMMING CODE

```

#define BLYNK_TEMPLATE_ID "TMPL3VVeF97I8"
#define BLYNK_TEMPLATE_NAME "IoT Based Energy Management System"
#define BLYNK_AUTH_TOKEN "fsdzXdZ8Nkd1HWLyqsCjCeO5Gxjsu7Ue"
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <DHT.h>
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#define DHTPIN D4
#define DHTTYPE DHT11
#define FAN_PIN D5
#define LDR_PIN A0
#define LED_PIN D6
LiquidCrystal_I2C lcd(0x27,16,2);
DHT dht(DHTPIN, DHTTYPE);
char auth[] = BLYNK_AUTH_TOKEN;

```

```

char ssid[] = "Ra-one";
char pass[] = "Galaxy123";
int currentSpeed = 0;
bool manualMode = false;
BlynkTimer timer;
BLYNK_WRITE(V3)
{
    manualMode = param.asInt();
}
void setup() {
    Serial.begin(115200);
    dht.begin();
    lcd.init();
    lcd.backlight();
    pinMode(FAN_PIN, OUTPUT);
    pinMode(LED_PIN, OUTPUT);
    analogWriteRange(1023);
    Blynk.begin(auth, ssid, pass);
    Serial.println("Connecting to Blynk...");
    timer.setInterval(2000L, sendData);
    lcd.setCursor(0,0);
    lcd.print(" Welcome ");
    lcd.setCursor(0,1);
    lcd.print("Connecting...");
    delay(2000);
}
void loop() {
    Blynk.run();
    timer.run();
    float temp = dht.readTemperature();
    int ldrValue = analogRead(LDR_PIN);
    if (isnan(temp)) return;
    // 🚪 Fan Control Logic
    int targetSpeed = 0;
    if (!manualMode) {
        if (temp < 25) targetSpeed = 0;
        else if (temp < 28) targetSpeed = 400;
        else if (temp < 31) targetSpeed = 700;
        else targetSpeed = 1023;
    } else {
        targetSpeed = 1023;
    }
}

```

```

if (currentSpeed < targetSpeed) currentSpeed += 10;
else if (currentSpeed > targetSpeed) currentSpeed -= 10;
analogWrite(FAN_PIN, currentSpeed);
// LED Brightness Control
int ledBrightness = map(ldrValue, 0, 1023, 1023, 0);
analogWrite(LED_PIN, ledBrightness);
// LCD Update
lcd.setCursor(0,0);
lcd.print("T:"); lcd.print(temp,1); lcd.print("C ");
// Friendly LDR Level
String lightCond;
if (ldrValue < 300) lightCond = "Dark";
else if (ldrValue < 700) lightCond = "Med";
else lightCond = "Bri";
lcd.print("L:"); lcd.print(lightCond); lcd.print(" ");
lcd.setCursor(0,1);
lcd.print("Fan:");
if (currentSpeed == 0) lcd.print("OFF ");
else if (currentSpeed < 500) lcd.print("LOW ");
else if (currentSpeed < 800) lcd.print("MED ");
else lcd.print("HIGH ");
lcd.print("LED:");
if (ledBrightness < 350) lcd.print("LOW ");
else if (ledBrightness < 700) lcd.print("MED ");
else lcd.print("HIGH ");
delay(200);
}
// Blynk Data Update
void sendData() {
float temp = dht.readTemperature();
int ldrValue = analogRead(LDR_PIN);
int ledBrightness = map(ldrValue, 0, 1023, 1023, 0);
Blynk.virtualWrite(V0, temp); // Temperature
Blynk.virtualWrite(V1, ldrValue); // LDR raw value
Blynk.virtualWrite(V2, currentSpeed); // Fan Speed
Blynk.virtualWrite(V3, ledBrightness); // LED
Brightness
Blynk.virtualWrite(V4, manualMode ? 1 : 0); //
Auto/Manual status
}

```

VI. RESULT ANALYSIS

The performance of the “IoT Based Energy Management System using Microcontroller” is evaluated

based on its ability to monitor, control, and optimize electrical energy consumption in real time. The

system was tested under different operating conditions to analyze its accuracy, reliability, and response.

During normal operation, the system continuously measures electrical parameters such as voltage, current,

and power using sensors. These values are processed by the microcontroller and displayed on the LCD as

well as transmitted to the IoT platform. The system provides stable and accurate readings, ensuring

effective monitoring of energy consumption.

1. Real time monitoring of Electrical Parameters Testing at a High Temperature

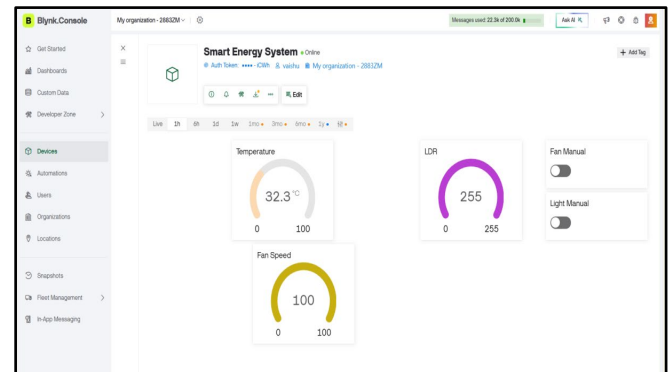


Fig. 3. Testing at a High Temperature

The dashboard of a smart energy management system on the Blynk Console. It is used to monitor and control electrical devices in real time through an IoT platform. The system is currently online, indicating that the device is connected and actively sending data. The dashboard displays important parameters such as temperature, which is 32.3°C, the LDR value of 255 indicating high light intensity, and the fan speed set at 100%. It also includes manual control switches for turning the fan and light on or off. Overall, this interface helps users efficiently monitor environmental conditions and manage energy usage remotely.

Readings:

Temperature (T) = 32.3 °C

LDR Value = 255

Fan Speed = 100%

Calculations:

1. Temperature-Based Fan Speed Control

Formula: Fan Speed (%) = $[(T - T_{min}) / (T_{max} - T_{min})] \times 100$
 $= (32.3 - 20 / 50 - 20) * 100 = 41\%$

2. LDR-Based Light Intensity

Formula: Light Intensity (%) = $(LDR / 255) \times 100$
 $= (255 / 255) \times 100 = 100\%$

3. Power Consumption

Assume Fan Power = 75W

Formula: Power = Rated Power \times (Speed / 100)

$$= 75 \times (100/100) = 75W$$

4. Energy Consumption

For 5 hours:

$$\begin{aligned} \text{Energy} &= \text{Power} \times \text{Time} \\ &= 75 \times 5 / 1000 = 0.375 \text{ kWh} \end{aligned}$$

2. Real time monitoring of Electrical Parameters Testing at a Medium Temperature

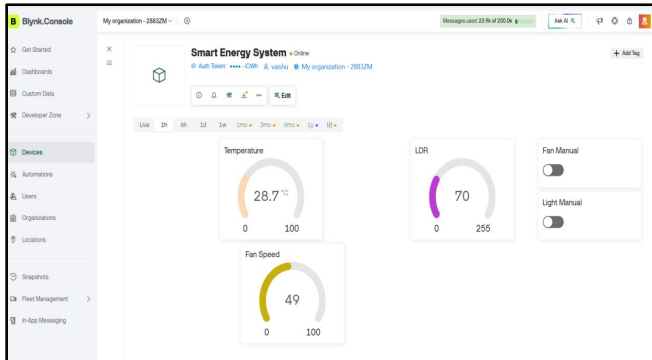


Fig. 4. Testing at Medium Temperature

The Fig4 shows This image shows a Blynk Console dashboard for a project named "Smart Energy System".

The dashboard displays real-time IoT data and controls:

- Temperature Gauge: Shows the current temperature as 28.7°C (scale 0–100).
- LDR (Light Dependent Resistor) Gauge: Indicates light intensity at 70 (scale 0–255).
- Fan Speed Gauge: Displays the fan speed at 49% (scale 0–100).
- Manual Controls: Two toggle switches allow manual operation of the fan and light.

The system is online and actively monitoring environmental conditions while allowing remote control.

Readings:

$$\text{Temperature (T)} = 28.7 \text{ }^\circ\text{C}$$

$$\text{LDR Value} = 70$$

$$\text{Fan Speed} = 49\%$$

Calculations:

1. Temperature-Based Fan Speed Control

$$\begin{aligned} \text{Fan Speed (\%)} &= [(T - T_{\min}) / (T_{\max} - T_{\min})] \times 100 \\ &= [(28.7 - 20) / (50 - 20)] \times 100 \\ &= 29\% \end{aligned}$$

2. LDR-Based Light Intensity

$$\begin{aligned} \text{Light Intensity (\%)} &= (\text{LDR} / 255) \times 100 \\ &= (70 / 255) \times 100 \\ &= 27\% \end{aligned}$$

3. Power Consumption

$$\text{Assume Fan Power} = 75W$$

$$\text{Power} = \text{Rated Power} \times (\text{Speed} / 100)$$

$$= 75 \times (49 / 100)$$

$$= 36.75W$$

4. Energy Consumption

For 5 hours:

$$\text{Energy} = \text{Power} \times \text{Time}$$

$$= 36.75 \times 5 / 1000$$

$$= 0.184 \text{ kWh}$$

Based on the given readings, the system measures a temperature of 28.7°C, which falls under the medium temperature range, resulting in a fan speed of 49% for efficient cooling. The LDR value of 70 indicates low light intensity (27%), suggesting that artificial lighting may be required. The calculated power consumption of the fan is 36.75W, and for 5 hours of operation, the total energy consumed is Approximately 0.184 kWh.

VII. CONCLUSION

The IoT-based energy management system using a microcontroller offers an efficient and smart way to monitor and control how energy is used. It helps reduce power waste by providing real-time data on energy use, allowing users to make better decisions. This system supports energy saving, lowers costs, and helps create smart homes and industries. Overall, it is a reliable, affordable, and sustainable solution for modern energy management.

The IoT-Based Energy Management System Using Microcontroller is an efficient, smart, and scalable solution for real-time monitoring and control of electricity use.

By combining IoT technology, sensors, and a microcontroller, the system can measure, analyze, and optimize power usage across many devices and places. It sends real-time data to an IoT cloud platform and allows users to access it remotely via mobile or web apps, which encourages people to be more mindful of their energy use.

The results from experiments show that the system works well, with reliable communication between the microcontroller and the cloud server.

This ensures that current, voltage, and power levels are monitored continuously and accurately. The system's automation, which turns appliances on or off based on set conditions or usage patterns, helps reduce energy waste, lower costs, and avoid overloads. Its ability to log data in real time and display it visually supports in-depth analysis of energy use patterns, which can help with predicting equipment issues and planning energy needs.

REFERENCES

- [1] IOT-Based Energy Monitoring System for Optimizing Power Consumption Years 8th International Artificial Intelligence and Data Processing Symposium (DAP'24), Siege 21-22, 2024, Malatya, Türkiye.
- [2] IOT Based Smart Energy Management in Residential Applications, Rakibul Hasan in International Conference on Advances in Science, Engineering and Robotics Technology 2019 (ICASERT 2019).
- [3] Home Energy Management System with Automated Power Scheduling using GSM, Suresh Kumar. V in International Research Journal of Engineering and Technology (IRJET), Vol.5 Issue 05. May 2018, -ISSN: 2395-0056

- [4] ENERGY MANAGEMENT SYSTEM WITH PROGRAMMABLE NUMBER USING GSM, Dr. Shubhas International Journal of Novel Research & Development. Vol 2. Issue 4. April 2017 ISSN: 2456-4184
- [5] S. N. Han, I. Khan, G. Myoung, N. Crespi, and R. H. Glitho, "Computer Standards & Interfaces Service composition for IP smart object using Realtime Web protocols: Concept and research challenges," *Comput .Stand. Interfaces*, vol. 43, pp. 79–90, 2016.
- [6] M. Swan, "Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0," *J. Sens. Actuator Networks*, vol. 1, pp. 217–253, 2012.
- [7] G. Bedi, G. K. Venayagamoorthy, R. Singh, R. R Brooks, and K. C. Wang, "Review of Internet of Things (IoT) in Electric Power and Energy Systems," *IEEE Internet of Things Journal*, vol. 5, pp. 847-870, 2018.
- [8] L. Li, H. Xiaoguang, C. Ke and H. Ketai, "The applications of WiFi-Based Wireless Sensor Network in Internet of Things and Smart Grid," 6th IEEE Conference on Industrial Electronics and Applications, pp. 789-793, 2011
- [9] Miao Yun and Bu Yuxin, "Research on the architecture and key Technology of Internet of Things (IoT) applied on smart Grid," *International Conference on Advances in Energy Engineering*, pp. 69-72, 2010.
- [10] Q. Ou, Y. Zhen, X. Li, Y. Zhang, and L. Zeng, "Application of internet Of things in smart grid power transmission," *FTRA International Conference on Mobile, Ubiquitous, and Intelligent Computing*, pp. 96- 100, 2012.
- [11] F. Englert, P. Lieser, A. Alhamoud, D. Boehnstedt and R. Steinmetz, "Electricity-Metering in a Connected World: Virtual Sensors for Estimating the Electricity Consumption of IoT Appliances," 3rd International Conference on Future Internet of Things and Cloud, pp. 317-324, 2015.
- [12] Matyushok, V., Vera Krasavina, V., Berezin, A., & Sendra García, J. (2021). The global economy in technological transformation Conditions: A review of modern trends. *Economic Research-Ekonomiska Istraživanja*, 34(1), 1471-1497.
- [13] Matyushok, V., Vera Krasavina, V., Berezin, A., & Sendra García, J. (2021). The global economy in technological transformation Conditions: A review of modern trends. *Economic Research-Ekonomiska Istraživanja*, 34(1), 1471-1497.
- [14] Cantarero, M. M. V. (2020). Of renewable energy, energy democracy, And sustainable development: A roadmap to accelerate the energy Transition in developing countries. *Energy Research & Social Science*, 70, 101716.
- [15] S. K. Singh, "IoT-Based Home Automation and Energy Monitoring Using ESP8266," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)*, Vol. 11, Issue 4, 2023.