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Smart Energy Monitoring System and Carbon Emission Dashboard

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Abstract—**The Smart Energy Monitoring System and Carbon Emission Dashboard is an IoT-based project that tracks electricity consumption and estimates carbon emissions from electrical appliances. Its main goal is to cut energy waste, improve power management, and support environmental sustainability. The system constantly measures energy usage and shows real-time data on a digital dashboard. This helps users understand their consumption patterns and take action to save energy. The project features an Arduino Uno with the ATmega328P microcontroller as the main controller, along with an ACS712 Current Sensor for accurate current measurement. An ESP8266/Node MCU module provides Wi-Fi communication and sends data to an online dashboard for remote monitoring. Other components include a Relay Module, LED Bulbs, a Breadboard, Jumper Wires, Resistors, an LCD Display, and a Power Supply Adapter for circuit operation, display, and appliance control. Supporting ICs, such as the ACS712 IC, ESP8266 IC, LM7805 voltage regulator, and ULN2003 Relay Driver IC, enhance the system's performance. The dashboard shows key parameters like current usage, power consumption, energy units, and estimated carbon emissions. This affordable and effective system is suitable for homes, industries, and smart buildings to improve energy management and protect the environment.**

Index Terms—**Internet of Things (IoT), Smart Energy Monitoring, Carbon Emission Tracking, Arduino Uno, Real-time Dashboard**

I. INTRODUCTION

The Smart Energy Monitoring System and Carbon Emission Dashboard is an IoT-based system designed to track electricity use and estimate the carbon emissions from electrical appliances. Rising energy demand and environmental pollution have created a need for better energy management systems. This project allows users to monitor power usage in real time and promotes energy saving. The system features an Arduino Uno with the ATmega328P microcontroller, an ACS712 Current Sensor, and an ESP8266/Node MCU for sensing, processing, and wireless communication. The gathered data is shown on a digital dashboard for straightforward monitoring and analysis.

II. LITERATURE REVIEW

Over the past decade, researchers have completely transformed how we track electricity by showing that highly accurate energy monitoring does not require expensive industrial equipment. On the hardware side, D. D. Tung (2019) proved that an affordable Arduino Uno paired with basic consumer-grade sensors could measure power parameters with less than a 2% error rate. This foundational setup was later upgraded in 2022 by engineers who introduced cheap ESP8266 Wi-Fi chips and a lightweight MQTT protocol to easily stream data to the cloud. Getting that data delivered quickly was solved by R. Govindarajan (2020), whose tests on wireless networks like Bluetooth and Zigbee showed that smart edge units can cut cloud latency down to under 2 seconds for real-time viewing. This speed opens the door for practical home applications; for instance, S. L. Gonzaga (2019) demonstrated that analyzing live consumption streams allows systems to accurately predict monthly household utility bills and push instant smartphone alerts when an appliance begins to fail. Ultimately, giving users immediate access to this data drives massive environmental benefits. A landmark 2025 study in Nature Scientific Reports revealed that automating energy measurements through local edge computing shifted institutional behavior so effectively that it slashed net energy consumption by up to 35% and cut carbon emissions by up to 31%.

III. OBJECTIVES

- To develop a compact, cost-effective device that can log real time voltage and current in a continuous AC circuit.
- To create reliable algorithm on an open-source microcontroller for processing raw data into active power(watts) and energy metrics (kWH).
- To use local grid factor to accurately compute real time carbon footprints.

IV. METHODOLOGY

1. Physical Sensing: Analog sensors capture live AC signals; a voltage module steps down the line voltage, while an ACS712 Hall-effect sensor measures current, feeding both signals into an Arduino Uno.
2. RMS & Power Calculation: The Arduino samples the AC sine waves over 20-ms windows, calculates true Root Mean Square (Vrms) and (Irms) values, and computes active power (W) and cumulative energy consumption (kWh).
3. Carbon Footprint Tracking: The local firmware multiplies the total kWh by the 2026 India Grid Factor (0.736 kg (CO_2) to calculate real-time greenhouse gas emissions down to the gram.
4. Local Visualisation: The processed metrics are displayed on a node-level 16x2 I2C LCD screen, alternating between active power draw and total carbon footprint data for immediate on-site visibility.
5. Cloud Upload & Remote Control: The Arduino transfers the data via serial communication to an ESP8266 Wi-Fi module, which uploads it to a cloud dashboard; users can then send remote commands back to trigger a mechanical relay and cut AC power.

V. EXPERIMENTAL SETUP

1. The Voltage Sensor and ACS712 Current Sensor connect directly to the analog input pins of the Arduino Uno. They feed real-time waveforms into the processor.
2. A 5V Power Supply provides clean, regulated direct current across the shared VCC and Ground rails of the system components.
3. The 16x2 LCD Display links through the I2C serial data (SDA) and serial clock (SCL) lines to show alternating real-time telemetry locally at the node.
4. Digital Pin 7 of the Arduino connects directly to the control terminal of the Relay Module, breaking or establishing the AC connection for the connected load.
5. The ESP8266 Wi-Fi Module connects to the hardware serial transmission pins, creating a bridge to send updated telemetry to the cloud platform.

VI. DISCUSSION

The Smart Energy Monitoring System and Carbon Emission Dashboard successfully demonstrated real-time monitoring of electrical energy consumption and estimation of carbon emissions using IoT technology. The system was able to measure voltage and current values through sensors connected to the Arduino Uno and calculate power consumption accurately for different electrical loads such as bulbs.

The experimental results showed that power consumption increased proportionally with the connected load, and the calculated carbon emission values also increased accordingly. The ESP8266 Node MCU successfully transmitted the data to the cloud dashboard with very low delay, enabling users to monitor energy usage remotely in real time. The relay module also responded effectively to remote ON/OFF commands from the dashboard, proving the feasibility of smart load control. The LCD display provided continuous local monitoring, while the cloud dashboard improved visualization through live readings and status indicators. The system encouraged energy awareness by converting electrical usage into carbon emission values, helping users understand the environmental impact of electricity consumption. Although the prototype achieved reliable performance, slight fluctuations were observed in sensor readings due to electrical noise and sensor calibration limitations. These variations can be reduced in future work by using higher-precision sensors and advanced filtering techniques. Overall, the project demonstrated that integrating Arduino, ESP8266, IoT dashboards, and carbon-emission calculations can create an effective low-cost smart energy management solution suitable for homes, educational institutions, and small industries.

Table 1: Experimental Readings

Sr. No	Load Used	Voltage (V)	Current (A)	Power (W)	Energy (kWh)	Carbon Emission (kg CO_2)	Relay Status
1	20W Bulb	230	0.09	20.7	0.020	0.014	ON
2	40W Bulb	230	0.17	39.1	0.039	0.028	ON
3	60W Bulb	230	0.26	59.8	0.060	0.044	ON
4	100W Bulb	230	0.43	98.9	0.099	0.073	ON
5	Device OFF	0	0	0	0	0	OFF

Table 2: System Performance Analysis

Parameter	Observed Result
Sensor Response Time	< 2 seconds
WiFi Transmission Delay	~1 second
LCD Update Speed	Real-time
Dashboard Accuracy	±2%
Relay Switching Time	< 1 second
Carbon Calculation Method	Energy × 0.736
IoT Connectivity	Successful
Remote Load Control	Successful

Table 3: Carbon Emission Comparison

Appliance	Power Consumption (W)	Estimated CO_2 per Hour (g)
LED Bulb	9W	6.6 g
CFL Bulb	20W	14.7 g
Incandescent Bulb	100W	73.6 g
Fan	75W	55.2 g
Laptop Charger	50W	36.8 g

VII. RESULT

The Smart Energy Monitoring System and Carbon Emission Dashboard was successfully implemented and tested using different electrical loads. The system accurately measured voltage, current, and power consumption using the ACS712 current sensor and Arduino Uno. The calculated energy consumption values were further converted into estimated carbon emissions using the predefined carbon emission factor.

The ESP8266 Node MCU successfully transmitted real-time data to the IoT dashboard through Wi-Fi connectivity. The dashboard displayed live power consumption, energy usage, and carbon emission values without significant delay. The relay module also functioned properly by allowing remote ON/OFF control of the connected load through the dashboard interface.

Experimental observations confirmed that as the power consumption increased, the corresponding carbon emission values also increased proportionally. The system achieved stable real-time monitoring with an approximate accuracy of ±2% under normal operating conditions.

The developed prototype demonstrated:

- Successful real-time energy monitoring
- Accurate power and carbon-emission calculations
- Reliable wireless data transmission
- Effective remote load control through IoT dashboard
- Improved user awareness regarding energy consumption and environmental impact

The overall system proved to be an efficient, low-cost, and practical solution for smart energy management and carbon footprint monitoring.

VIII. METHODOLOGY

1. Voltage Calculation

The system measures AC voltage using a voltage sensor module.

Formula:

$$V_{rms} = \frac{V_{peak}}{1.414}$$

Where:

V_{rms}= RMS Voltage

V_{peak}= Peak Voltage of AC signal

2. Current Calculation

The ACS712 current sensor measures current flowing through the load.

Formula:

$$I = \frac{V_{sensor} - 2.5}{0.185}$$

Where:

I= Current (A)

V_{sensor}= Sensor output voltage

2.5V = Offset voltage of ACS712

0.185 = Sensitivity for ACS712-5A module

3. Power Calculation

Electrical power is calculated using voltage and current values.

$$P = V \times I$$

Where:

P= Power (Watts)

V= Voltage (Volts)

I= Current (Amperes)

4. Energy Consumption Calculation

Energy consumed over time is calculated in kilowatt-hours (kWh).

$$Energy(kWh) = \frac{Power \times Time}{3600000}$$

Where:

Power = Watts

Time = milliseconds

3600000 converts Watt-milliseconds into kWh

5. Carbon Emission Calculation

Carbon emission is estimated from energy consumption using the India grid emission factor.

$$CO_2 = Energy(kWh) \times 0.736$$

Where:

CO_2= Carbon emission (kg)

0.736 = India grid emission factor (kg CO_2/kWh)

IX. CONCLUSION

The Smart Energy Monitoring System and Carbon Emission Dashboard successfully demonstrated an effective integration of IoT technology, real-time energy monitoring, and environmental impact analysis. The system was able to accurately measure voltage, current, power consumption, and energy usage using Arduino-based sensing modules and transmit the collected data wirelessly through the ESP8266 Node MCU.

The developed dashboard provided real-time visualization of electrical parameters and carbon emissions, helping users understand the environmental effects of electricity consumption. The relay module enabled remote control of electrical loads, making the system useful for intelligent energy management and energy-saving applications.

The project proved that converting energy consumption into carbon-emission data can improve user awareness and encourage sustainable energy usage. The system achieved reliable monitoring performance with low cost, simple hardware, and easy implementation, making it suitable for homes, educational institutions, and small-scale industries.

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