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Development and Comparative Assessment of a Battery-Powered Lawn Mower for Sustainable Landscaping Practices

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ABSTRACT

Conventional lawn mowers powered by gasoline-engines contribute to the global warming and climate change menace. This study presents the development of an eco-friendly lawn mower comprising a 12-Volt, 40 Ampere-hour battery powering a 12-Volt Direct Current (DC) motor attached to a cutting mechanism. Speed and torque requirements for cutting grasses of diverse hardness were achieved using a pulse width modulation (PWM)-based motor controller. A switch mode power supply (SMPS) was implemented as the primary charging unit, while a 60-Watt solar panel and a 40 Ampere charge controller served as an auxiliary charging system. The structural design was developed and simulated using SolidWorks. Performance evaluation yielded average runtime of 2 hours in a sunny condition. The mowing rate varied with factors like operator's skills and nature of grass, but an average of 15-m^2 per hour was recorded for soft grasses. The amount of carbon dioxide (CO_2) emission from an equivalent gasoline-engine lawn mower performing the same task was investigated, and a comparative analysis revealed the economic benefits of adopting this green initiative. Integration of super-capacitor is recommended for further enhancement.

Keywords: Battery-Powered Lawn Mower, Deep-Cycle Absorbent Glass Mat (AGM) battery, DC Motor, Greenhouse Gas Reduction, Solar-assisted Charging System, Sustainable Landscaping Practices.

1. INTRODUCTION

Lawn mower is a grass-cutting machine that uses one or more high-speed revolving blades to trim grasses to a uniform height. It makes grass-cutting faster and easier compared to traditional hand tools. Lawn mowers are commonly used to maintain neat and healthy lawns in residential yards, parks, and gardens. The popularity of sports like golf, cricket and lawn tennis also triggered wider adoption of lawn mowers (Gbasouzor, 2017).

This easy-to-use machine helps homeowners save costs by eliminating the frequent need to hire professional landscapers. Regular lawn mowing prevents the growth of tall grasses that can harbor insects, snakes, and rodents, thereby improving safety and hygiene. The movement of people, animals, and machinery within farms is also made easier and safer through proper mowing (Muhammad, 2021). Lawn mowers are considered as manual, gasoline, or electric, based on power source. The first lawn mower was invented in 1830 by a British engineer, Edwin Budding. His invention, known as the reel mower, consisted of a cylindrical reel of blades mounted on a frame. A user pushes the frame from behind, and the rotating blades create a scissor-like cutting action against a fixed bed knife (Smith, 2018). The operation is quiet, pollution-free, and requires minimal maintenance. However, manual mowers are labour-intensive and best suited for small, flat lawns. (Dutta, 2016).

Consequently, a motorized lawn mower powered by a steam engine was introduced in 1893 by James Sumner of Lancashire, England. The engine was large and heavy, making the mower mainly suitable for commercial use. A more compact domestic lawn mower was achieved in the early 1900s by replacing the steam engine with a small gasoline engine (Khodke, 2018). Gasoline-powered mowers are capable of handling larger lawns, thicker grass, and uneven terrain. They are available in push, self-propelled, and ride-on models. Riding mowers allow users to sit while working, making mowing of large fields less tiring (Yulin, 2019). However, they require more storage space and are difficult to maneuver in tight areas. In addition to noise, gasoline mowers contribute to pollution. Regular maintenance such as oil changes, air-filter cleaning, and spark plug replacement is essential. Moreover, greenhouse gas (GHG) emissions from burning fossil fuel remain a major cause of global warming and climate change (Olalere, 2023).

Electric lawn mowers are lightweight, have fewer parts to maintain, produce no direct GHG emissions, and have a lower carbon footprint compared to gasoline models. They are usually powered via a cord connected to a power outlet, but corded types are restricted by range and often experience cable tangling during operation. Cordless electric mowers powered by rechargeable batteries eliminate this limitation but require recharging for long mowing sessions (Vorel, 2021). When the battery is charged using a photovoltaic (PV) module, the mower becomes solar-powered. (Adubika, 2020).

Another promising innovation is the fuel-cell-powered lawn mower, though its widespread adoption depends on advancement in fuel-cell technology as well as hydrogen infrastructure development. (Jiang, 2013). The ageing of electric motors, batteries, charge-controllers, PV modules, and other components reduces the overall effectiveness of electric mowers over time (Dutta, 2016). Recent technological advancements have led to the development of IoT-based and robotic lawn mowers, allowing minimal human intervention during operation, thereby saving energy and time (Tayyab, 2022). These modern mowers are integrated with smart features like GPS, sensors, and programmable settings that enable precise mowing and efficient energy use. They are often equipped with automatic shut-offs, safety locks, and protective shields to minimize accidents. However, robotic mowers are expensive and require expertise for setup, maintenance, or software updates. They are best suited for smaller lawns and may struggle with uneven terrain or thick grass (Daniyan, 2020).

The choice of a lawn mower depends on factors such as terrain, lawn size, user preference, and affordability. Consumers who do not consider lifecycle costs may avoid electric mowers due to their higher initial purchase price compared to gasoline-powered alternatives of the same category. (Mohatkar, 2022). A study by Saidani (2021) revealed the environmental and economic trade-offs between gasoline and electric-powered lawn mowers in the United States. Using life cycle assessment (LCA) and life cycle costing (LCC) methodologies, the study showed that switching to electric mowers reduces CO_2 emissions by 49.9% for push models and 32.3% for ride-on types over their lifecycles. Though electric mowers have a slightly higher total cost of ownership (4.7–10.6%), they offer significantly lower operating costs (Saidani, 2021).

The demand for lawn mowers that combine efficiency, ease of use, affordability, and environmental friendliness remains a rising challenge despite the wide range of available options. This study aims to explore recent innovations, compare the performance of different types of lawn mowers, and evaluate their suitability based on evolving user needs and sustainability considerations. The objective is to provide insights that will guide consumers, manufacturers, and policymakers toward more sustainable lawn care solutions.

2. MATERIALS AND METHODS

The eco-friendly lawn mower was designed as a lightweight, battery powered grass cutting machine incorporating a brushless direct current (BLDC) motor as its main drive. Speed of this motor is regulated with a pulse width modulation (PWM)-based motor controller. The speed control reduces energy consumption and enables the motor develop the right torque for grass cutting. The cutting mechanism is an assembly of four pieces of nylon trimmer lines, securely fixed into a trimmer head designed to withstand the centrifugal force. The trimmer head was firmly attached to the motor shaft using a high-strength coupling to minimize vibration and ensure efficient torque transfer.

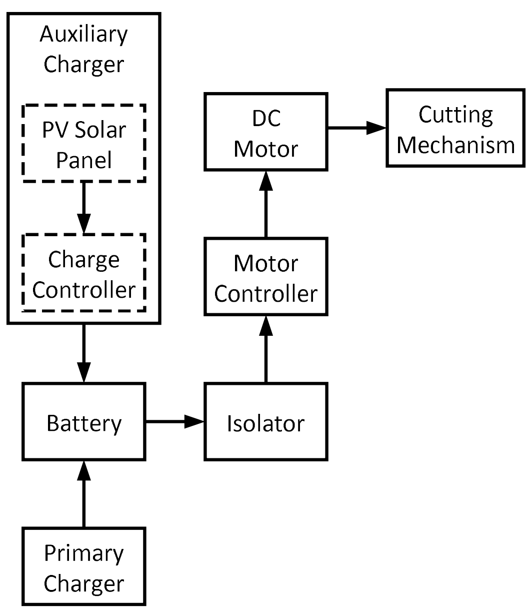

Figure 1: Block Diagram of the Lawn Mower

Battery charging was via two independent sources. The primary charger is a switch-mode power supply (SMPS) designed for fast and efficient battery charging. The auxiliary charging system, comprising a photovoltaic (PV) solar panel connected to a charge controller, was integrated to extend mowing time during operation under sunlight. The charge controller ensures proper voltage regulation, battery protection, and efficient power management between the solar panel and the battery. The isolator is a DC switch for disconnecting the electrical system during maintenance. Table 1 contains information about each of the major components used.

Table 1: Component Specifications

S/N	Component	Specification
1	Brushless DC Motor MY1016 Z	12V, 300W, 0.5Nm 6000-8000 RPM (No-load) 8mm Shaft Diameter
2	PWM-Based Motor Controller	12V, Rated Current: 40A PWM Frequency: 20 kHz
3	Battery	12V, 40Ah, AGM Deep-Cycle
4	Battery Charger	12V, 50A, SMPS
5	Solar Panel	60W, 18V Mono-crystalline
6	Solar Charge Controller	40A, 12/24V, MPPT
7	Trimmer Head	5-inch, Universal head with line slots
8	Trimmer Line	STIHL 2.4mm round mowing nylon line. Four pieces, 10 inches long each.
9	DC Cable	4.0mm^2, Single-Core
10	DC Isolator Switch	12-48 VDC, 63A, IP66, Waterproof

2.1 Design Considerations

Several factors collectively contributed to implementation of the lightweight, robust, and environmentally friendly lawn mower.

Energy Efficiency

The motor was selected for its high efficiency, low noise, and longer operational lifespan compared to a brushed DC motors. The use of a PWM-based motor controller allows precise control of motor speed, reducing unnecessary energy consumption.

Power Supply Reliability

The battery was chosen for its ability to deliver consistent power over long periods. It tolerates deep discharge cycles without significant degradation. Integration of a solar charging system extends the battery runtime during operation under sunlight.

Cutting System Efficiency

Size and material of the trimmer lines ensured safe and effective grass cutting while minimizing mechanical load on the motor. Industry-reported torque range of 0.35 to 0.5 Nm, for battery-powered lawn mowers utilizing lightweight nylon trimmer lines, was considered in the motor selection. "This torque level is suitable for cutting light to medium-density grasses, especially when the mower operates at high speeds within 6000 to 8000 RPM" (remodelorrmove.com).

Mechanical Strength and Corrosion Resistance

Mild steel sheets and galvanized pipes were used for the frame to achieve a balance between strength and weight. Paint was applied to protect against rust and ensure long-term outdoor durability.

Ease of Assembly and Maintenance

The mower was designed with modularity in mind, allowing easy replacement of critical components such as the motor, battery, and trimmer head. Electrical connections were made with high-quality DC cables and organized neatly to simplify troubleshooting and maintenance tasks.

User Safety

All current paths were properly insulated, and cable routing was designed to prevent accidental damage or exposure.

2.2 Design Calculations

Components selection was based on data obtained from the design calculations, with little adjustments according to market availability in some cases.

I. Battery Sizing

$$\text{Energy Required} = \text{Motor Power x Operation Time}$$

$$E_{required} = P_{motor}\ x\ t_{operation} \tag{1}$$

$$= 300\ W x\ 1h\ = 300\ Wh$$

This is energy consumed for 1 hour operation.

$$\text{Battery Capacity (Ah)} = \frac{\text{Energy Required}}{Battery\ Voltage} \tag{2}$$

$$= \frac{300\ Wh}{12\ V} = 25\ \text{Ah}$$

With 70% depth of discharge (DoD);

$$Adjusted\ Battery\ Capacity = \frac{25\ Ah}{0.7} \approx 36\ Ah$$

Thus, a 40 Ah, 12 V, AGM battery is suitable.

II. Runtime of the Lawn Mower

$$\text{Runtime} = \frac{\text{Battery Capacity}}{\text{Current Drawn}} \quad (3)$$

$$\text{Current Drawn} = \frac{\text{Motor Power Consumption}}{\textit{Motor Rated Volatage}} \quad (4)$$

$$= \frac{300\text{ W}}{12\ V} = 25\ A$$

This is the current drawn from the battery by the motor.

$$\text{From Equation (1): Runtime} = \frac{40\text{ Ah}}{25\text{ A}} = 96\text{ min.}$$

III. Effect of Solar Charging on Runtime

$$\text{Current from Solar System} = \frac{\text{Module Wattage}}{\text{System Voltage}} \quad (5)$$

$$= \frac{60\text{ W}}{12\ V} = 5\text{ A}$$

$\therefore$ Current Drawn with Solar Support;

$$= (25 - 5)\text{ A} = 20\text{ A}$$

The solar system offsets 5A out of the 25 A which the motor draws from the battery.

$$\therefore \text{ Runtime with solar support} = \frac{40\text{ Ah}}{20\text{ A}} = 120\text{ min.}$$

$$\text{Runtime extension due to solar support} = (120 - 96)\text{ minutes}$$
$$= 24\text{ minutes or } 25\%$$

IV. Solar Influence on Discharge Rate

- Without Solar Support:

$$\text{Battery Discharge Rate} = \frac{100\%}{Runtime\ (min)} \quad (6)$$

$$= \frac{100\%}{96\ min} \approx 1\%\ per\ min$$

❖ With Solar Support:

Battery Discharge Rate = $\frac{100\%}{Runtime\ (min)}$

$$= \frac{100\%}{120\ min} \approx 0.8\%\ per\ min$$

As a result of solar charging, discharging of the battery is expected to decrease by approximately 12% for an hour operation.

2.3 Implementation

Structural work of the mower was designed and simulated using SolidWorks 3D CAD software to verify mechanical strength, balance, and component layout. The frame dimensions were optimized for average adult ergonomics to reduce operator fatigue. Mild steel sheet (2mm thickness) and galvanized steel pipes (Ø20mm x 2mm) were selected as the frame materials due to their high strength-to-weight ratio and corrosion resistance.

Two plastic wheels, 8 inches in diameter, were chosen for ease of mobility and ground clearance, suitable for various grass types and terrain conditions. Fabrication operations included marking-out, cutting, bending, welding, grinding, drilling, and painting. Extra attention was given to welding quality and structural balance to ensure long-term durability. After fabrication, the frame was coated with weather-resistant paint to prevent corrosion and enhance aesthetics. The fabricated frame accommodated all major components, ensuring compactness and accessibility for maintenance.

Figure 2: 3D Model of the Lawn Mower

Field tests were conducted to evaluate the operational performance of the developed mower. Testing involved clearing designated areas of land characterized by different grass types and hardness levels. The battery was fully charged prior to each trial operation. Performance data relating to cutting efficiency, battery discharge rates, solar panel support, and operational endurance were collected for detailed evaluation. Operator's handling-skill, grass type, and terrain were noted as variables potentially affecting the results. The recorded data were analyzed to determine the average mowing capacity per hour and total runtime per full battery cycle.

Environmental benefits of the solar-assisted battery-powered lawn mower was assessed using an equivalent gasoline-engine lawn mower to perform the same task. Fuel consumptions were measured and the corresponding CO_2 emissions were weighed based on the intergovernmental panel on climate change (IPCC) emission factor. This approach enabled estimation of carbon foot print attributable to the conventional mowing method.

3. RESULTS AND DISCUSSION

3.1 Mowing Rate

The developed prototype was tests across four different grass types commonly found in Lagos, Nigeria and the mowing rates were calculated based on average area mowed divided by time taken under typical mowing condition as given by Equation (7). The highest mowing rate was exhibited on soft grasses, but as the grass texture became thicker and tougher, the mowing rate decreased progressively. Table 2 summarizes the results, while Figure 3 presents the corresponding graphical comparison. These results validate suitability of the mower for typical domestic and institutional lawns.

$$\text{Mowing Rate} = \frac{Area\ Mowed\ m^2}{Time\ (min)} \tag{7}$$

Table 2: Mowing Rate

Grass Type	Texture	Average Area Mowed (m^2)	Average Time Taken (min.)	Mowing Rate (m^2/hour)
Carpet Grass	Soft	15	60	15
Bermuda Grass	Medium	13	65	12
Bahia Grass	Hard	11	68	9.7
Elephant Grass	Very Hard	9	72	7.5

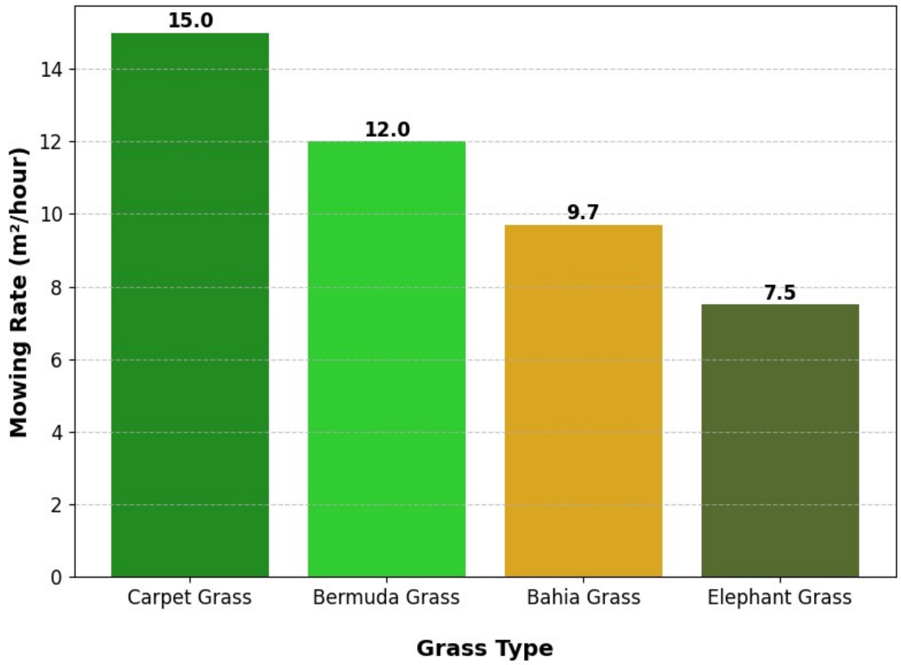

Figure 3: Mowing Rate for Different Grasses

3.2 Operational Endurance

To assess the energy consumption pattern and operational endurance of the developed prototype, a voltage profile analysis was conducted for the different grasses. Each mowing session began with a fully charged battery at 12.85 V. Voltage readings were taken at 20-minute intervals over a 2-hour period. The operation ends once terminal voltage of the battery drops below 10.5 V as recommended by the manufacturer to prevent deep discharge. Figure 4 highlights the discharge trends and the influence of grass texture on battery performance. It was observed that the mower's runtime is directly proportional to toughness of the grass.

Carpet grass maintained relatively high voltages over the full mowing duration, allowing for extended operation. Whereas, elephant grass caused a rapid voltage drop, triggering shutdown in less than 80 minutes. Bermuda and Bahia grasses followed intermediate patterns. Obviously, mowing duration can be extended by tailoring the exercise towards grass type and sunlight availability.

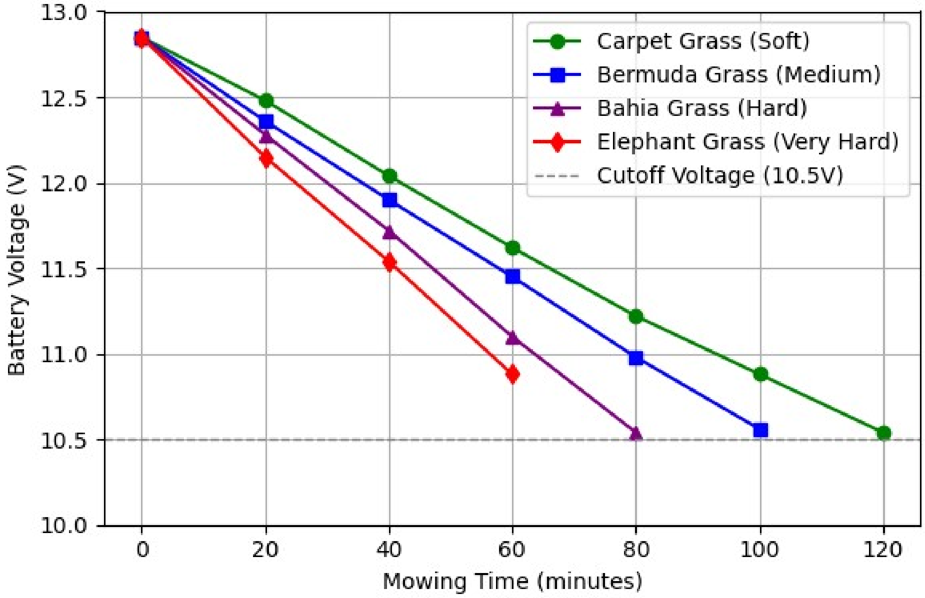

Figure 4: Effect of Grass Texture on Runtime

3.3 Comparative Assessment

The comparison is majorly on environmental implications and costs in order to establish the economic and environmental trade-offs of transitioning from the conventional fossil fuel-based mowers to renewable energy alternatives for sustainable landscaping practices. Real-world market prices and experimental results were used to keep the findings realistic and useful.

I. Battery Recharge Costs

Costs of recharging the battery from Nigerian grid were estimated as follows.

- *Energy per Full Charge (E)*

$$E = V \ x \ Ah \tag{8}$$
$$= 12 \ V \ x \ 40 \ Ah = 480 \ Wh = 0.48 \ kWh$$

- *Input Energy* (E_{input})

Considering losses in SMPS and AGM chemistry, a 90% round-trip efficiency is assumed for the charger.

$$E_{input} = \frac{Energy \ per \ Full \ Charge}{Charger \ Efficiency} \tag{9}$$
$$= \frac{0.48 \ kWh}{0.90} \approx 0.53 \ kWh$$

- *Electricity Tariff (Lagos, NGN)*

Current residential tariff ≈ ₦ 325 per kWh.

- *Cost per Full Charge:*

$= 0.53\ kWh\ x\ ₦\ 325\ per\ kWh \approx ₦\ 173$

But one full charge supports 1.6 h runtime, mowing $1.6\ h\ x\ 15\ m^2/h \approx 24\ m^2$

- $\boldsymbol{Cost\ per\ 15\ m^2\ Run} = \frac{15}{24}\ x\ ₦\ 173$

$\approx ₦\ 108$

- *Annual Recharge Cost (20 runs)*

$20\ x\ ₦\ 108 = ₦\ 2\ 160$

II. Carbon Dioxide Emitted and Fuel Costs

A field experiment was conducted using Honda UMK425 petrol-powered trimmer to mow the same 15 m² area of lawn for each grass type earlier tested. Fuel consumptions were recorded and the resulting CO_2 emissions were derived using the intergovernmental panel on climate change (IPCC) default emission factor of 2.31 kg CO_2per litre of petrol combusted. This value was increased by 40 % to accommodate lower efficiency and incomplete combustion typical of small engines such as those used in gasoline mowers (Li, 2019; (USEPA), 2023). As given in Table 3, the increment resulted in estimated 3.2 kg of CO_2 from one litre of petrol which averagely costs nine hundred and fifty naira. (GlobalPetrolPrices, 2024).

Table 3: Fuel Cost and CO_2 Emission

Grass Type	Approx. Fuel Used (L)	CO_2 Emitted (kg)	Fuel Cost (₦)
Carpet Grass	1.00	3.20	950
Bermuda Grass	1.20	3.84	1,140
Bahia Grass	1.30	4.16	1,235
Elephant Grass	1.60	5.12	1,520

A correlation between grass toughness and carbon emission was seen from the stacked bar chart in Figure 5. Carpet grass mowing produced 3.2 kg of CO_2, while elephant grass exhibited the highest at 5.1 kg. Bermuda and Bahia released 3.8 kg and 4.2 kg respectively. These differences align with volume of fuel consumed and cutting load associated with each grass type.

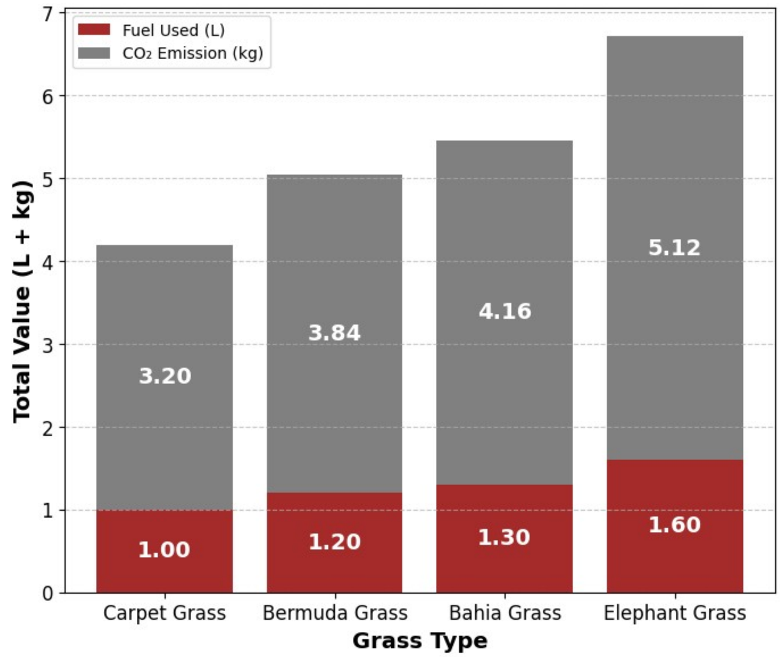

Figure 5: Fuel Used and CO_2 Emitted per 15m^2

III. Life Cycle Cost

Production of our prototype incurred an upfront cost of approximately ₦ 211,000 while the market price for Honda UMK425 petrol trimmer is just ₦ 135,000. Despite the higher initial investment, total operating cost for the solar-assisted mower over a five-year lifespan, remains significantly lower - due to zero fuel costs and reduced maintenance (no oil changes or spark plug replacements). Table 4 summarizes the life-cycle costs for quick comparison.

Table 4: Life Cycle Cost (LCC) Comparison

Aspect	Solar-Assisted Battery Mover	Honda UMK425 Petrol Trimmer
Initial Cost	₦ 211,000	₦ 135,000
Fuel per 15 m^2	0 L	1.6 L
Fuel Cost per 15 m^2	₦ 0	₦ 1,520 @ ₦ 950/litre
Annual Fuel Cost (20 runs)	₦ 0	₦ 30,400
Annual Battery Recharge Cost (20 runs)	₦ 2,160	₦ 0
CO_2 Emissions (per run)	0 kg	5.12 kg
Seasonal Emissions (20 runs)	0 kg	102 kg
5-yr Life-Cycle Cost	₦ 221,800 (upkeep is negligible)	₦ 373,100 (plus 30 % maintenance)

The recharge cost of ₦ 108 per 15 m^2 is quite negligible compared to petrol cost of ₦ 1,520 to mow the same 15 m^2 area of lawn. Over a season of 20 runs, the solar-assisted mower incurs ₦ 2,160 on electricity – approximately 93 % less than fuel cost for gasoline mower which amounts to ₦ 30,400. Recurring fuel purchases and periodic engine servicing elevated life-cycle cost of the gasoline-powered lawn mower.

4. CONCLUSION

Gasoline lawn mowers and farm machineries emit thirty million tons of greenhouse gases annual in the USA - responsible for one-fourth of all non-road fuel emissions (Saidani, 2021). In this study, an eco-friendly lawn mower has been designed, fabricated, and compared with its gasoline equivalent. Unlike previous electric mower designs, our prototype couples on-board solar harvesting that ensures uninterrupted operation of up to two hours under direct sunlight without grid dependency. This novel combination of energy sources and real-time solar support represents a significant advance in off-grid landscaping equipment. Comparative evaluation against the Honda UMK425 gasoline trimmer under identical field conditions further emphasizes the prototype's environmental benefits.

While the gasoline model emitted 5.12 kg of CO_2 for mowing 15 m^2 area of lawn, our mower performed the same task with zero direct emissions. Moreover, the solar-assisted system reduced net energy costs and minimized maintenance requirements, demonstrating over a 25 % extension in runtime and a complete elimination of fuel-related emissions. These findings confirm not only the technical feasibility but also the practical superiority of solar-augmented battery mowers for sustainable landscaping in tropical urban environments.

Overall, the mower achieved satisfactory mowing efficiency, low battery discharge rate, and manageable energy consumption. Thus, it is a sustainable alternative to conventional gasoline-powered mowers, as it offers a clean, efficient, and cost-effective solution for residential lawn maintenance. Future work may focus on integration of super-capacitors, which could provide rapid discharge capabilities during peak load conditions such as cutting dense or wet grass patches. This enhancement is recommended to further stabilize voltage drops and extend effective runtime.

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