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DIGITAL TWIN PERFORMANCE ASSESSMENT ON AN ELECTRIC VEHICLE AND COMPARATIVE COST ANALYSIS WITH GASOLINE VEHICLE

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ABSTRACT

The paper evaluates the performance of a digital twin on an electric vehicle and compares its operation costs with a gasoline vehicle of equivalent energy usage. This study uses a digital twin technique in the automotive industry to assess performance and compare the cost of electric vehicles to gasoline cars. The twin system measures output data from a converted gasoline Toyota starlet car, comparing its energy usage with gasoline cars. The technology includes internet of thing (IoT), artificial intelligence (AI), machine learning (ML), predictive analysis, simulation tools, virtual sensors and 5G. The outcome reveals that as time increases, speed increases, and battery level depreciates, leading to decreased fuel levels in conventional vehicles, with higher battery consumption voltage in low-speed tests. Low-speed driving consumes more energy than high-speed driving, causing momentum to increase and initial decrease. An electric vehicle was 50.9% less expensive to operate than a gasoline powered vehicle for the same distance, and over a five-year period, maintenance costs were predicted to be 50.6% lower. The operation cost of internal combustion engine (ICE) vehicles doubled that of novel electric vehicles (EVs), and with increasing petroleum prices, the cost increased over 400%. The use of digital twin technology in studied electric-powered vehicle is economical, environmentally friendly and maximizes resources use in favour of global circular economy vision.

Keywords: Digital twin, electric vehicle, internal combustion engine, operation cost.

INTRODUCTION

Digital Twin technology is increasingly used in electric vehicles (EVs) to simulate real-time physical objects, enhancing performance and safety. As environmental consciousness grows and gasoline prices fluctuate, the implementation of digital twins is crucial for EVs (Sunarto, *et al.,* 2015). The 21st century's focus on environmental protection and energy conservation has accelerated the development of electric vehicle technology, offering zero emissions, economic growth, and efficient transportation systems. (Satyendra and Shuoad, 2019; Mahmod *et al.,* 2022).

By 2030, the extinction of internal combustion engines (ICE) will begin due to a growing electric vehicle fleet, causing significant damage to gasoline demand and crude oil prices. Reasons for this include declining technology costs, increased investment in charging infrastructure in major markets like China and the US, and lower operating costs compared to traditional vehicles (Jardel and Jair, 2019). Electric vehicles are economically viable due to reduced costs and increased research and investment by automobile companies, offering lower operating costs even at current oil prices. Electric cars are greener than conventional ones, generating fewer emissions and being more efficient. They have fewer movable parts, resulting in lower maintenance costs and a higher efficiency rate (Bambang *et al.,* 2011; Basselink *et al.,* 2010; Nabi *et al.,* 2019).

Mahmoud *et al.,* (2023), compare model-based and data-driven Digital Twin platforms in EV applications, highlighting data-driven DTs' superiority in handling complex systems. Wasim *et al.*, (2023), analyzed digital twin technology for intelligent Transportation Systems, focusing on electric and autonomous vehicles, and its integration with Internet of Thing (IoT), Artificial Intelligence (AI), Machine Learning (ML), and 5G. Naseri *et al.,* (2023) explores digital twin applications, including cloud-enabled battery management systems and digitalization of battery testing, covering use cases, technologies, hardware/software requirements, electrical modeling, software architectures, and digital platforms for implementation (Seth and Bob, 2013).

Ali and Edward (2011), conducted a study on a 1992 Chevy S-10 Pickup, comparing the costs of electric and gasoline cars, finding that electric cars are nearly twice as expensive. Abhisek *et al.,* (2019), study on an electric Suzuki 800 in Bengaluru, India, found that the conversion performed well in road tests, depending on the required speed and driving range. This research aimed at providing guidance on electric vehicle conversion while restricting scope to electric and gasoline vehicle due to its experimental nature. The study stated how electric vehicles can reduce reliance on gasoline; lower operating costs, and improve energy efficiency.

METHODOLOGY

This research uses digital twin method for electric vehicle (EV) performance assessment, calculates energy usage costs, and compares the novel EV with similar studies, focusing on time, distance, speed, and battery level.

Description of the electric vehicle

The construction of a DC series wound electric motor began with a manual third-generation Toyota Starlet Car, which was chosen for its lightweight design and easy adaptation to an electric motor. The car's gasoline engine, gas tank, exhaust pipe, muffler, clutch assembly, and radiator were removed, left with the manual transmission. A 5mm carbon steel adapter plate was attached to the transmission bell housing, measuring gear box shaft and coupler diameter, and tracing the bell house for DC series wound electric motor bolting (Figures 1, 2, 3 and 4).

Figure. 1: ICE removed from the Toyota Starlet Car

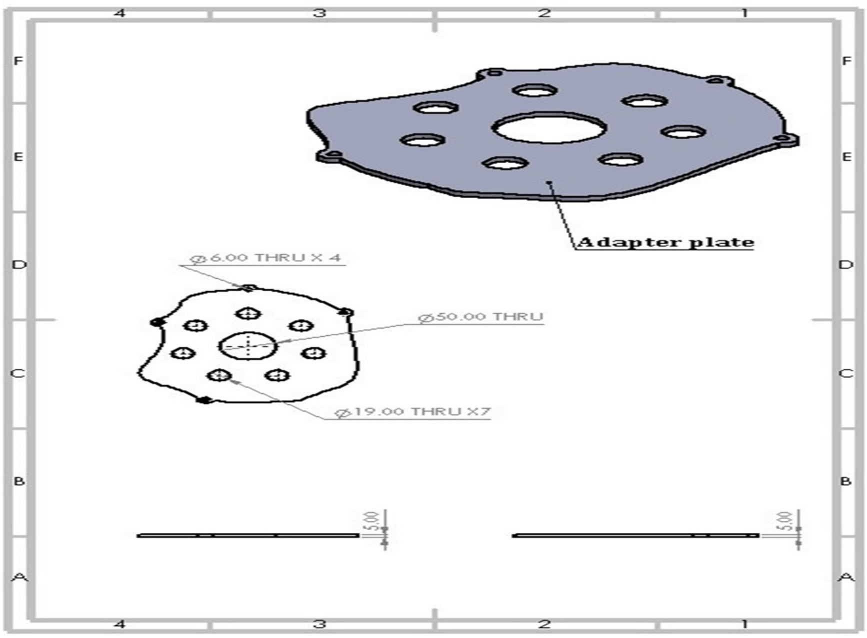

Figure 2: Design of Adapter Plate

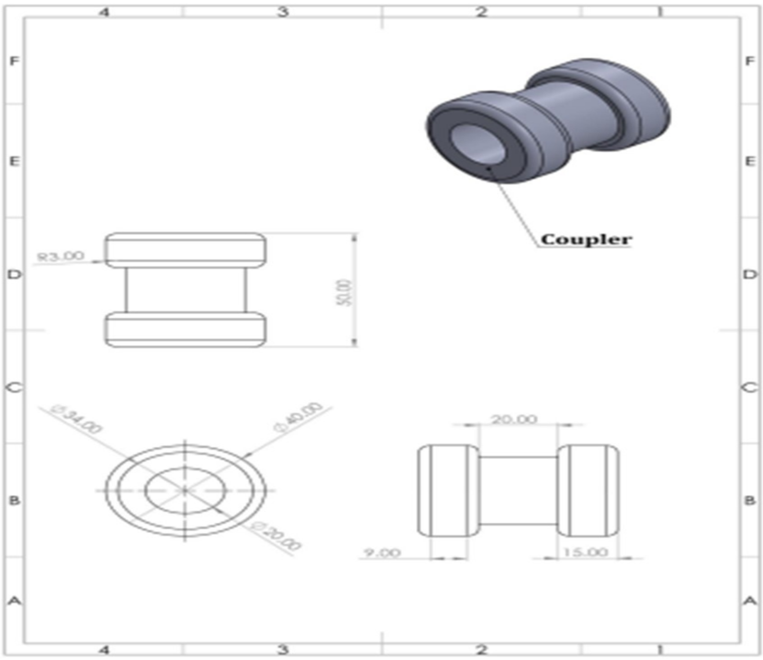

Fig. 3 Design of coupler

Figure 4: Coupling of DC Motor and Adapter Plate with the transmission of the donor car

An electric controller controls the DC motor, receiving signals from batteries and delivering power. The controller replaces the manual pedal, and two battery-racks are installed at the front and rear of the car. The system uses 12 AGM lead acid batteries connected in series for 48V and 600Ah, an on-charger for charging, a brake assist system with a booster vacuum pump, and other components for proper functioning.

The brake assist system comprises a vacuum pump, cylinder, hose, contactors, battery gauge and fuses (250Amps and 500Amps) to enhance braking efficiency (Figure 5).

Fig. 5: Connection of electronics device with the donor car

Digital twin, digital twin hardware, hall motor speed sensor, real-time clock and battery level sensor

Digital twin technology was used as real-world data to create simulations for predicting product or process performance. It integrates IoT, AI, and software analytics to enhance output, studying parameters for better future behavior prediction. C++ was used for programming the digital twin due to its higher control over memory and system resources, while Java was used for programming the android applications. ESP32 is a low-cost, low-power system microcontroller with integrated Wi-Fi and Bluetooth, used to access the internet and reading and writing digital signals. The speed sensor is a linear magnetic hall sensor that measures the polarity and strength of a magnetic field, and counts engine rpm digitally. The DS1307 is a low-cost, precise clock with an inbuilt TXO, AM/PM indication, 24-hour or 12-hour mode, two programmable time-of-day alarms, and an I2C bidirectional bus employed for serial data transport. Batteries were the module resistors used as voltage dividers and communicators with an analog output pin for real-time battery level monitoring.

Digital twin working principle

The esp32 microcontroller, equipped with a Wi-Fi client, was used for wireless transactions between the system and user. The hardware includes an RTC, hall motor speed sensor, and battery level sensor, with an Android application for data capture. The esp32 module captures signals from the android application, initiating RTC, hall motor speed sensor, and battery level sensors. The system sends data to a cloud server every minute, including RPM, speed, voltage, and time stamp, which can be used for prediction purposes.

Electric vehicle and internal combustion engine vehicle operation costs of the same energy equivalent

The empirical evaluation of the operating costs of electric vehicles and gasoline-powered vehicles of the same energy equivalent is as follows:

A litre of gasoline contains 8.9 kWhr of energy, requiring a utility cost multiplied by 8.9. Automotive internal combustion engines are only 18% efficient, requiring 20% of the total energy. A vehicle with 20% efficiency requires 17.0litre/100km with an average cost of a litre of petrol fuel in Nigeria at #165. Therefore, an electric vehicle with discharge efficiency of 80% with the grid electricity in Nigeria at #36.6 per kWhr equates #1,386.2k per 100km. Battery replacement costs for electric vehicles are high, with lead acid batteries lasting about five years. The cost of replacing the entire battery pack was #380,000, which adds to the electricity cost of #1,073,100. In case of ICE vehicle regular maintenance, plugs, coils, oil coolant, oil change and labour amount to #13,000. Operating a gasoline vehicle for 10,000km per year without ICE engine replacement costs of #104,000 per year and #520,000 for five years would be #1,922, 500.

The operating cost of ICE vehicle of the same equivalent energy usage with electric vehicle is almost double. However, it is important note that the average life-span of an ICE ranges between four to seven years before replacement. There is possibility of replacing the ICE at the end of five years. So, the cost this engine used in Nigeria is about #250,000. This amount added to the previous operating cost calculated would be #2,172,500. This is more than the double cost of operating electric vehicle of same capacity under the same circumstance. The operating cost of an ICE vehicle in Nigeria is almost double that of an electric vehicle, with an average life of four to seven years before replacement.

RESULTS AND DISCUSSION

The electric car, powered by a 48V DC motor and 28.8kwhr capacity absorbent glass mat lead acid batteries, underwent on-road testing at Ikole-Ekiti Campus of FUOYE. The distance covered, the speed (km/hr), battery level in voltage and time stamp (minutes) were observed (Tables 1 and 2). As distance and speed increased, the battery level depreciated (Table 1). Since the battery level determined the longevity of the system, the digital twin system helped to monitor the battery level while running to keep the record of the voltage drop in relation to the speed of the system. This data was used to optimize the battery capacity.

Table 1: Observations from drive test I

S/N	Distance (m)	Rpm	Speed (km/h)	Battery level (v)	Time (min)
1	0	0	0	53.45	1
2	262.8	1858	8.76	53. 17	2
3	620	2631	12.40	52.72	3
4	962	3065	14.44	52.31	4
5	1250	3185	15.00	51.95	5
6	1472	3124	14.72	51.58	6
7	1750	3201	15.08	51.16	7
8	2003	3189	15.02	50.68	8
9	2134.5	3021	14.23	50.25	9
10	0	0	0	50.06	10

Table 2: Observations from drive test II

S/N	Distance (m)	Rpm	Speed (km/h)	Battery level(v)	Time (min)
1	0	0	0	53.43	1
2	401	2558	12.05	53. 12	2
3	1091	4631	21.82	52.86	3
4	1748	5565	26.22	52.61	4
5	2430	6189	29.16	51.39	5
6	2933	6224	29.33	51.15	6
7	3519	6401	30.16	50.90	7
8	3913	6229	29.35	50.75	8
9	4145	5865	27.63	50.53	9
10	0	0	0	50.39	10

It was observed that an increase in speed led to a decrease in distance covered (Figure 6). It indicated an increase in battery consumption, as the car spent more time in motion. An increase in distance covered led to reduction in battery level while an increase in speed implied more battery consumption (Figure 6).

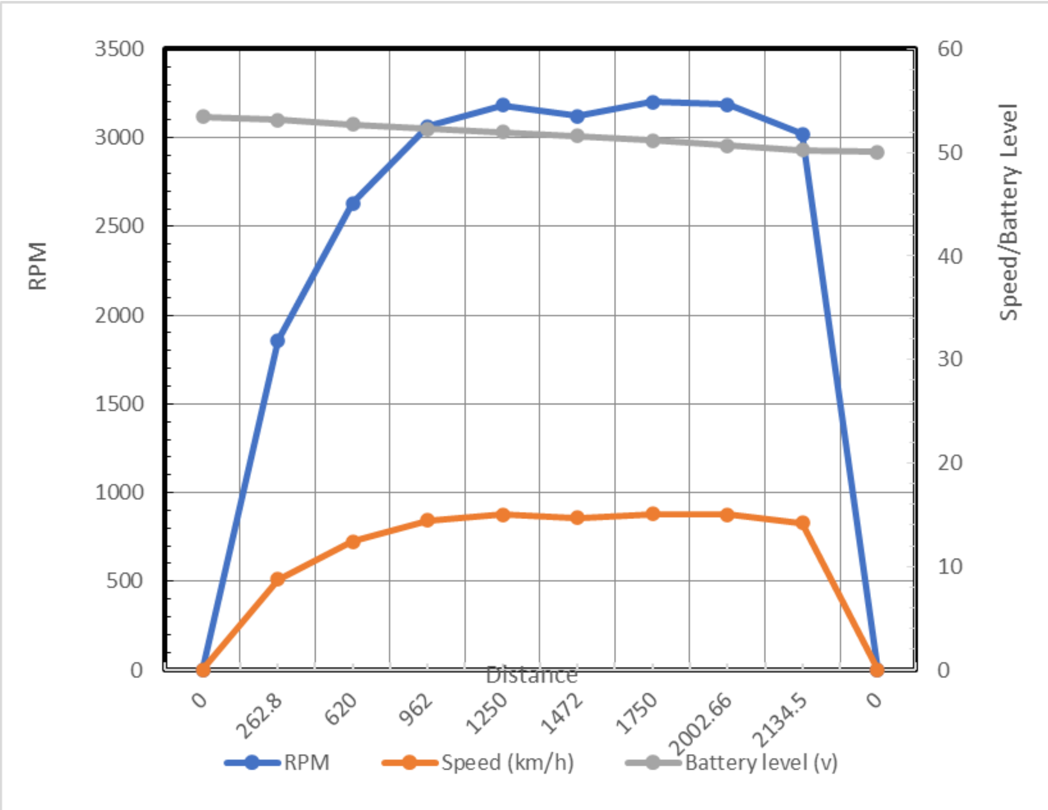

Fig. 6: Distance against Speed and Battery level (Drive test I)

High-speed car behavior, illustrating momentum increased and inertial decreases, resulting in constant speed and reduced battery consumption (Figure 7). It showed that as the speed increased, the distance increased, while the battery consumption remained consistent in constant motion. Time consumption directly correlated with battery level, as more time spent on a car's motion resulted in increased battery usage (Figure 7). There were variations in battery consumption based on the road conditions and the distance covered by the car. This implies decrease in battery level as speed increases. The cost of mileage (fuel price and electricity), and maintenance of gasoline vehicle was greater than electric powered vehicle over 5 years at distance of 1000 km (Table 3). Carbon dioxide emission produced by the gasoline vehicle was predicted 157g/km while that of electric powered vehicle was negligible indicating its acceptability for use in reducing greenhouse effect (Table 3).

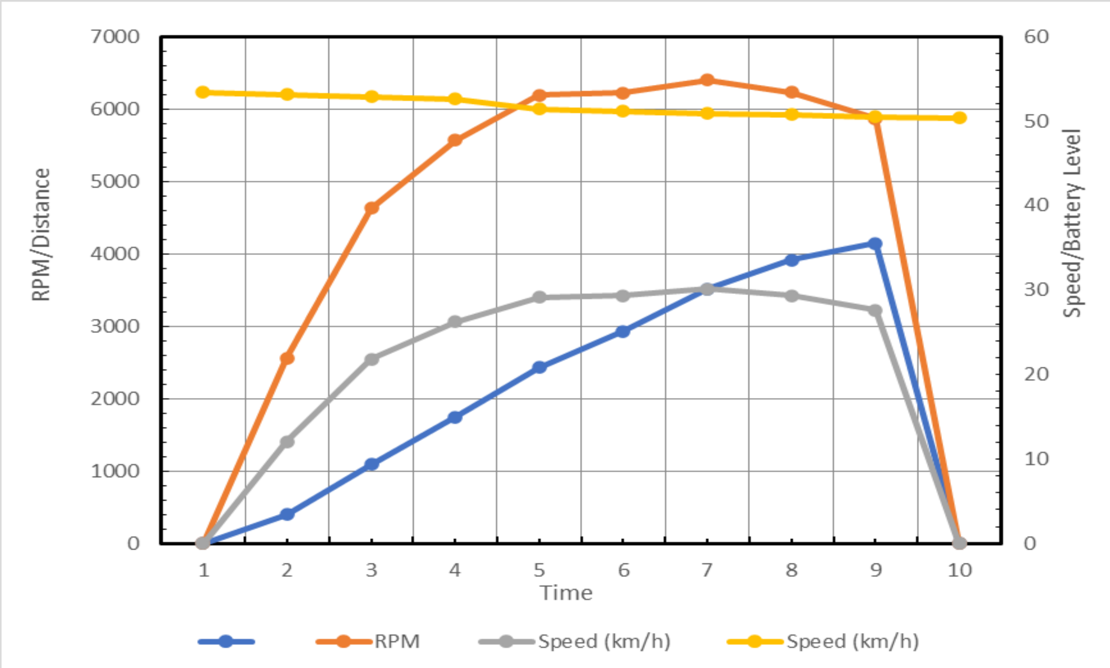

Figure 7: Time against speed (km/h, rpm) and battery level (Drive test II)

Table 3: Costs of operation of the EV and ICE

S/n	Parameter	Gasoline powered Vehicle	Electric powered Vehicle
1.	Carbon dioxide emission	157g/km	Negligible
2.	Cost of mileage (Fuel price & electricity at #165 & #36.6/kwhr)	#2,805 per100km	#1,386 per100km
3.	Cost of maintenance over 5 year and distance of 10000km	#2.,172,500	#1,073,100
4.	Total distance cover for full charge	Tank capacity	36.4km
5.	Charging time	volume (litres)	6 hrs,

The comparison of the built EV showed a better performance than other similar researched works as reported (Figure 8). Distance cover for full charge developed FUOYE-EV was 36.4km at 56-65km/hr having a 28.8kwhr capacity of battery. Unlike similar EV with highest 22km/hr speed mileage at full charge of 27km with battery power of 28kw/h that under-performed (Figure 8). The comparison of the newly built EV and other similar research works had a longer distance except that of EV built in Nopember Indonesia. However, the speed of the EV at Indonesia is the lowest among others. The EV built at FUOYE Nigeria had the longest distance covered.

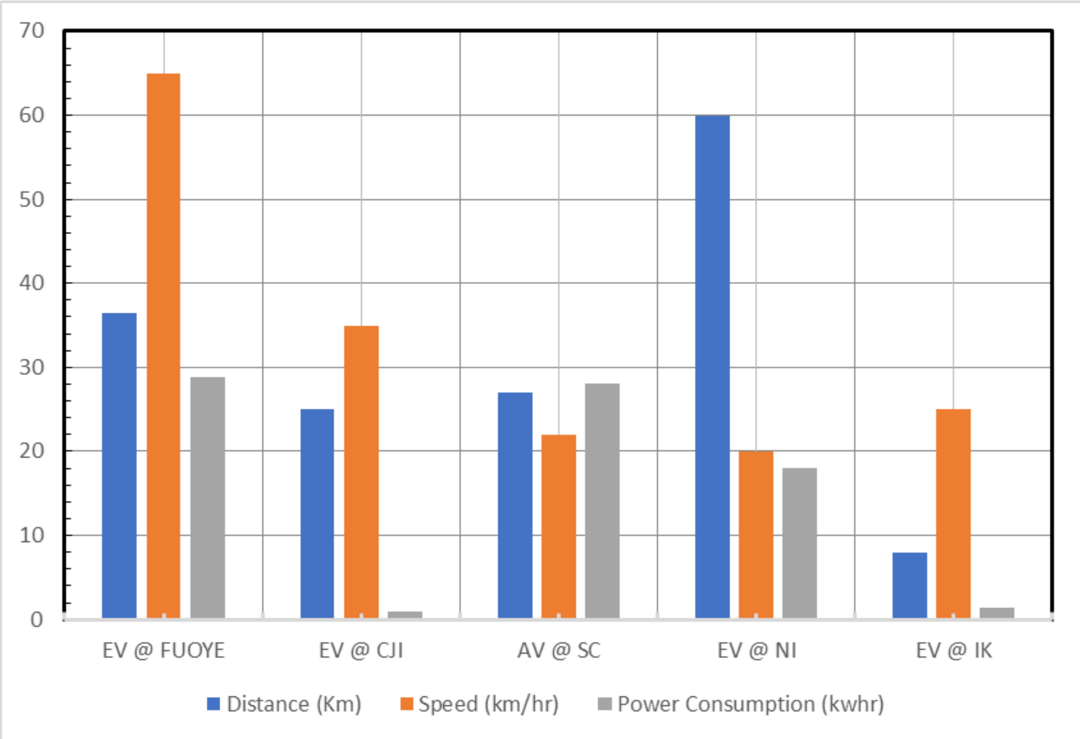

Figure 8: Comparison of novel EV with similar research work (Sunarto et al., 2015)

EV: Electric vehicle at Federal University Oye Ekiti Nigeria (FUOYE); CJI: Chaennair Jamilnadu India ; SC: Shenzhen Chaina; NI: Nopember Indonesia; Ik: India Karnatalca.

Road testing at Ikole-Ekiti Campus of FUOYE involved digital twin system measurements for distance covered, speed, battery level, and time stamp (Tables 1 and 2). As the speed in revolution per minute (rpm) increased so also the speed in kilometer per hour (km/h) increased. The voltage of battery consumption in test I was high (Table 1). This implied that when the car runs at low speed, more energy is consumed than at high speed. This justifies the fact that, as the vehicle travelled some appreciable speed, the momentum increased and the inertial decreased, resulting to less power to keep the vehicle's speed in constant motion (Table 2). Carbon dioxide emission of gasoline engine of equivalent energy with the newly built EV was 157 g/km at average 16.8 litres/100km (Table 3).

Tests I and II showed that as time and speed increased; battery level depreciated. This explaines the relationship among times, speed, and distance covered in a conventional vehicle. As speed increases, so does km/h time. Battery voltage consumption was higher at low speeds, resulting in increased momentum and less power (Tables 1 and 2). The newly built EV has a negligible carbon dioxide as contrary 157g/km emission by a gasoline engine, while using an average of 16.8 litres/100km (Table 3). The operation cost of ICE almost doubled that of a newly-built EV, even at #165.00k petrol price, with exponentially increasing petroleum product prices causing a 400% increase (Table 3). The new EV covered longer distances with the lowest speed.

CONCLUSION

The study highlights the significant cost savings and environmental benefits of using electric energy as fuel for vehicles, stating its advantages over traditional combustion engine vehicles. Electric vehicles are cleaner, more efficient, and environmentally- friendly, potentially saving ICE vehicles from extinction or scrap when oil reserves deplete. It prevents toxic emissions and global warming. The study highlights how electric vehicles can reduce reliance on gasoline; lower operating costs, and improves energy efficiency. It also suggests the application of digital twin technology for real-time energy consumption measurement. Electric vehicle technology is rapidly growing and becoming a viable alternative to internal combustion engines. To charge EVs, connect to solar electric stations, use chargers with higher ampere ratings or smart algorithms, replace batteries with lighter ones, develop AI and machine learning software for charging and battery lifetime prediction, and modify donor vehicles with aluminum body parts and thinner glass.

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