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The Role of Road Grades in Drive Cycle Analysis for Electric Vehicle

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The adoption of electric vehicles (EVs) is rapidly increasing globally, with more people recognizing their benefits. Diverse traffic conditions and terrain in different countries present unique challenges for EV performance evaluation, a critical yet often neglected factor in conventional methods. This research examines the impact of road grade on drive cycle analysis. Utilizing the technical specifications of a local EV minibus, simulations were conducted in AVL Cruise M to assess how varying road grades in drive cycles influence energy consumption. The study incorporated three different drive cycles: Japan Mode Urban 1, Urban Driving Cycle (UDC), and Federal Test Procedure (FTP75), each simulated with varying road grades. The findings revealed a substantial increase in energy consumption on graded drive cycles. This underscores the importance of considering road grades in drive cycle assessments. Furthermore, this can be used to ensure that vehicle specifications are realizable in actual route conditions.

1. Introduction

Electric Vehicle (EV) is gaining its momentum in global adoption driven by the consumer's growing awareness of climate change, technological advancements that make the EV more efficient, and government policies and subsidies (Łebkowski, 2024). In 2023, a remarkable market growth of EV market, with nearly 14 million new electric cars registered, represents a 35 % year-on-year increase (IEA, 2024). Consumers are influenced by the environmentally mindset and choose alternative vehicles to reduce carbon footprint and support cleaner transportation alternatives leading to the increasing demand of EV (Wang & Witlox, 2025). Governments and corporations are also supporting net-zero emission targets by promoting EV adoption through incentives and financial support. Additionally, the advancements of the technology make the EV more efficient especially in the battery technology. The increasing numbers of competitors in the EV industry has contributed to cost reductions. Thus, the adoption rate of EV will continue to increase (IEA, 2024).

The growing electrification of transportation or e-mobility in the Association of Southeast Asian Nations (ASEAN) is driven by the commitment of decarbonization in the transportation sector. Indonesia plans to become the manufacturing hub of EV by targeting to export 200,000 EV units by 2025. One of the leading ASEAN countries in the battery market is Thailand, it approves 10 battery manufacturing projects (Ramamurthy et al., 2021). Moreover, the Philippines targets a 50 % EV fleet penetration both in government and private in the year 2025 (DOE, 2023). The ASEAN e-mobility is strongly supported by the government, corporations, and consumers, all who are vital in the adoption of EV. ASEAN region emerged a key hub for battery manufacturing and a major player in the global EV ecosystem (Ramamurthy et al., 2021).

Although the EVs are gaining popularity among consumers, adoption still faces challenges in relation to the energy consumption that can be linked to consumers' perception about range anxiety, long time to recharge and limited availability of charging infrastructure (Modi and Bhattacharya, 2022). Modelling electric bus charger deployment and scheduling can reduced the operational costs (Lim et al., 2022). Integrating the route elevation profiles in energy estimation can help a reliable a modelling and scheduling for EVs.

The energy consumption of the vehicle can be analyzed using drive cycle analysis. It is a standardized procedure that utilizes the vehicle specifications and velocity – time profile in assessing the vehicle's

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performance. It is important that selecting a standardized drive cycle represents the driving conditions of the local traffic conditions (Guo et al., 2024). Assessing the EV energy consumption and operational efficiency can be assessed using the drive cycle analysis. The driving patterns and traffic conditions – such as the acceleration, deceleration and idling, can directly impact the energy consumption and can provide data for range predictions (Sharma et al., 2024). Moreover, integrating the road gradient data can significantly improve the energy consumption models and the vehicle range predictions. Previous study uses the Digital Elevation Model (DEM) and the Global Positioning System (GPS) traditional approach of assessing the energy consumption of vehicles provides slope data calculations and driving patterns correlated to the terrains. The study measured the impact of EV energy efficiency on the road gradient, proving that it can deliver accuracy to 5 % to 8 % in energy use. Additionally, uphill segments can increase the energy consumption exponentially while downhill segments enable regeneration that depends on the braking pressure (Liu et al., 2017).

Even with the growing interest in electric vehicles energy consumption, there is a gap in understanding the impact of road grade in the EV performance particularly when considering the local terrain and traffic conditions. While some studies have explored the influence of road grade, few have systematically integrated the road grade into drive cycle analysis, especially for local EV. Furthermore, the novelty of this study lies in quantifying the energy gap between standard testing and real-world energy demands in varying terrains through simulation-based assessment. This study aims to address these gaps by focusing on the impact of road grade on energy consumption for a local EV minibus using the drive cycle analysis. Then, the study will assess the energy consumption across different drive cycles in varying road gradients. Lastly, assess the implications of incorporating road grades into drive cycle analysis.

2. Methodology

The study workflow of this research as shown in Figure 1, is based on the evaluation of the impact of road grade on EV energy consumption using drive cycle analysis. The study focused solely on the influenced of road grade and factors such as regenerative braking, thermal conditions and auxiliary power consumption were not modelled in the simulation.

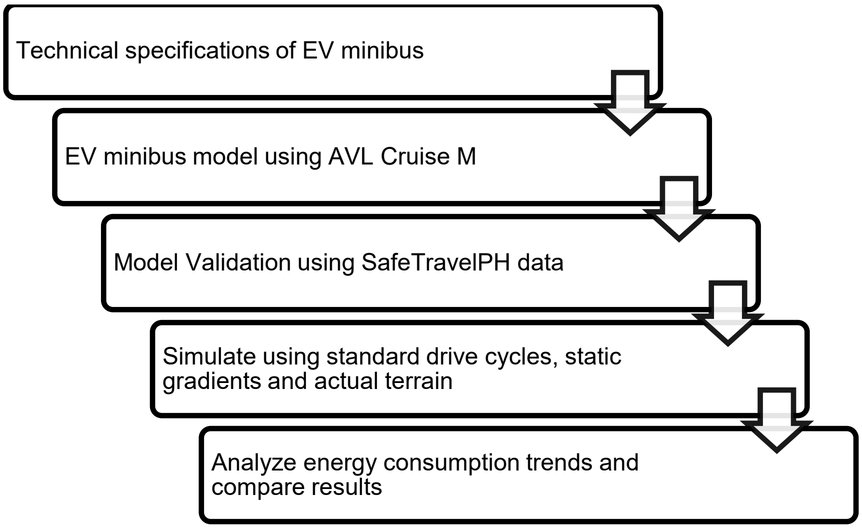

Figure 1: Study workflow

2.1 Technical Specifications of the EV minibus

The Community Optimizing Managed Electric Transport (COMET) EV minibus operating in Baguio City was selected for this study. The selection was based on its relevance to real-world urban transport in varying terrain in Baguio City to analyze the impact of energy consumption. The e-motor has a maximum torque and power of 270 Nm and 120 kW, respectively as shown in Table 1:

Table 1: COMET EV Minibus Technical Specifications (Global Electric Transport, n.d.)

Parameter	Specification	Value
Powertrain	Fully Electric Vehicle	-
Battery	Lithium Iron Phosphate	53 kWh, 350 V Nominal
Electric Motor	Power	120 kW
	Max Torque	270 Nm
Passenger Capacity	Seated	18 occupants
	Standing	12 occupants
	Total	30 occupants
Range	Per Full Charge	100 km
Dimensions	Length	6,200 mm
	Width	2,150 mm
	Height	2,350 mm

2.2 EV minibus model

AVL Cruise M is a vehicle simulation software that assesses the performance, efficiency and emissions of the vehicle. The EV minibus was modelled to evaluate the impact of the different grades in the energy consumption. The model was divided into three core components namely powertrain and drivetrain, battery system and energy management, and control and monitoring systems. The powertrain and drivetrain components are the backbone of the EV's propulsion system in Figure 2. The e-motor serves as the heart of the EV converting the electrical energy from the battery to mechanical energy. The battery and energy management system consists of charger, battery cooling and energy flow analysis where energy flow is optimized. Lastly, the control and monitoring system track the metrics like speed, state of charge (SOC) and energy consumption.

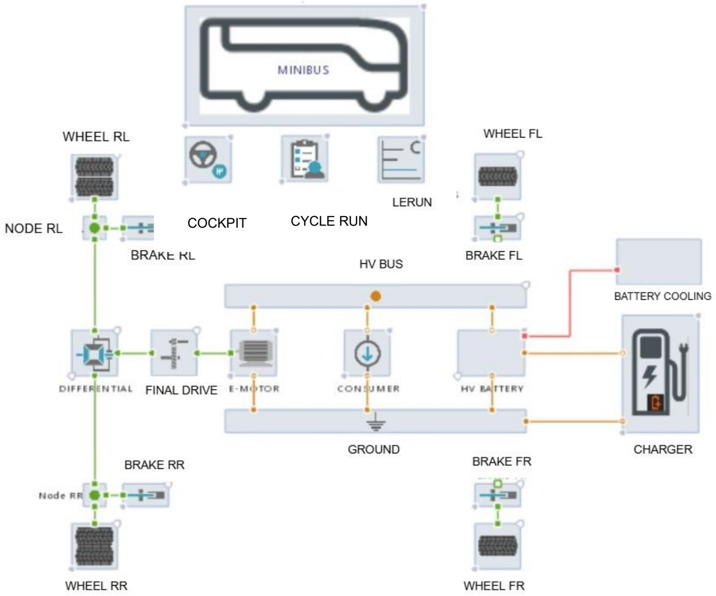

Figure 2: COMET EV minibus model

2.3 Validation of the EV model

The EV model was validated using the real-world data from SafeTravelPH – a platform supported by Asian Development Bank (ADB) supported application that allows commuters to report and view road transport issues. The process of validation integrated the three datasets from SafeTravelPh, such as velocity-time profiles and the elevation data of the Baguio City were incorporated in the validation. Moreover, the battery use assumption for full-day operation will not exceed 80 % to 90 % of the daily discharge balances practicality and the avoiding the deep discharges. The empirical data was compared to the model's outputs to verify its precision and reliability as shown in Table 2. The EV model predicted the average range of 34.05 km closely approximates the observed average from SafeTravelPh 34.47 km, and its estimated operating hours of 9.58 h.

Table 2: EV Model Validation

Parameter	SafeTravelPh	EV Model
Average Range	34.47 km	34.05 km
Time Duration	9.58 h	9.58 h

2.4 Simulation using standard drive cycle, actual terrain and static gradients

The standard drive cycles used in the simulation are FTP75, Japan Mode Urban 1 and UDC. The Federal Test Procedure (FTP75) represents urban driving with frequent stops (idling, low speeds) ideal for minibuses operating in cities like Baguio, where stop-and-go traffic dominates. The Japan Mode Urban 1 simulates the congested urban conditions with low speed and high idle time that mimics minibus routes in a busy area of Baguio. Moreover, Urban Dynamometer Driving Cycle (UDC) focuses on low-speed urban driving with a velocity of less than 50 kph, relevant to public transportation.
The road grades with constant slopes of 0 %, 4 %, 8 % and 12 %. It simplifies the simulation by isolating the impact of grade resistance. Also, it enables direct comparison across slopes. Furthermore, it is the standardized evaluation of Society of Automotive Engineers (SAE) J2807's static gradient testing and assessing vehicles and applicable in testing the energy consumption of EVs (SAE, 2025). Additionally, integrating the actual terrain of Baguio City able us to provide a benchmark for hilly routes in urban areas. Thus, static gradients and actual grade profile of Baguio City helps in assessing energy consumption comparison directly to grade.

3. Results

In this section, it analyzed the impact of the varying grades in energy consumption. The results of the EV minibus model showed a significant variation in energy consumption in different drive cycles and varying road grades.

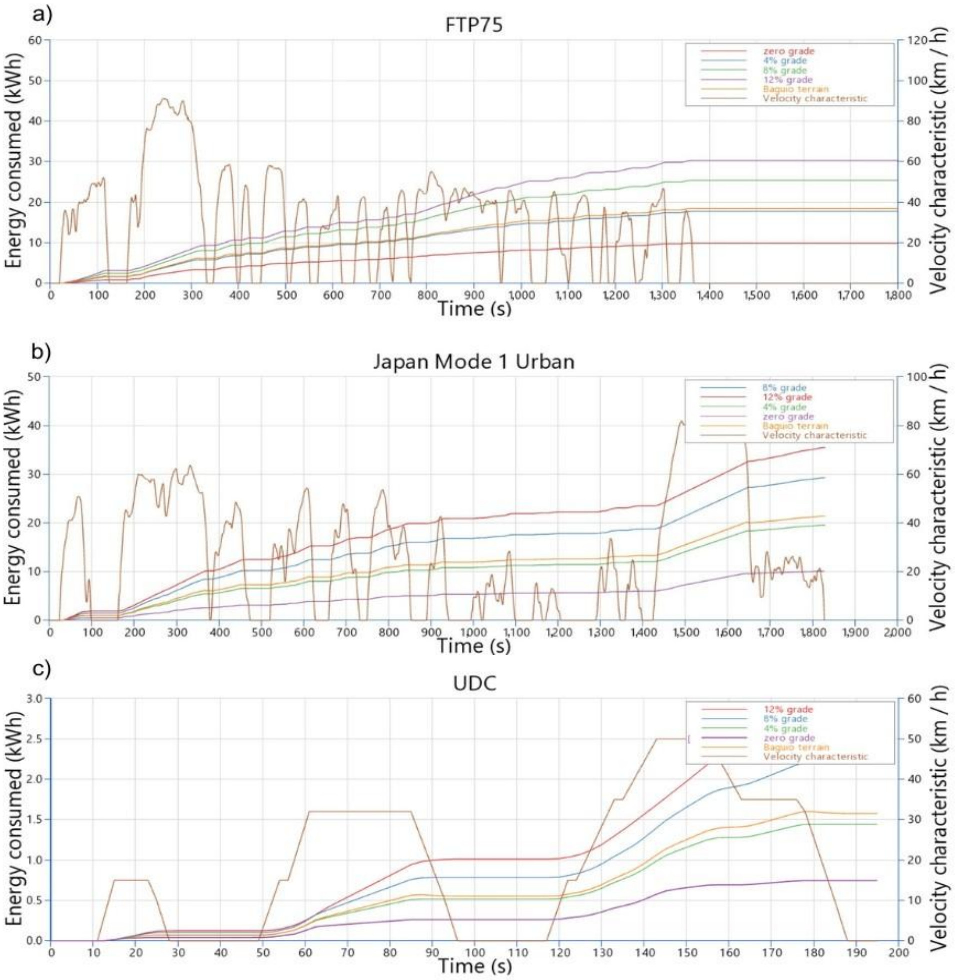

Figure 3: Impact of varying grades in energy consumption in (a) FTP75, (b) Japan Mode 1 Urban, (c) UDC

The graph in Figure 3 illustrates the relationship between the three standard drive cycles, road grades, and energy consumption. Regenerative energy is excluded in the simulation to analyze the energy consumption based on the conservative benchmarking and most of the grade set are static except to the actual Baguio City terrain. The energy consumption in kWh trends as shown in Figure 3 varied significantly across drive cycles.

The FTP75 drive cycle in Figure 3a shows the frequent stops, starts, and velocity fluctuations mimicking the suburban or city traffic with a top speed up to 90 km/h. The frequent accelerations of the EV increase energy demand due to high torque requirements. In the aspect of road grades, the energy consumption increases due to gravitational load. It reflected the interplay of road grades and driving patterns. For the FTP75 driving cycle, there was a spiked increase of energy consumption, from 9.9 kWh at 0 % grade to 30.3 kWh at 12 % grade while the Baguio terrain with mixed grade has an energy consumption of 18.43 kWh. Approximately 7 to 8 kWh of energy consumption increases by 4 % grade increment.

In Figure 3b - Japan Urban 1 Mode, the velocity characteristics simulates like dense urban driving with frequent stop and starts, low average speed of less than 25 kph due to congestion and traffic signals and high idling time because of traffic jams. The energy consumption rose consistently with steeper grades with an average increase of 23.6 kWh of energy consumption while the Baguio terrain has an energy consumption of 21.41 kWh, which is 1.85 kWh higher than the grade 4 %.

Lastly in Figure 3c, the UDC driving cycle has a velocity range of 0 to 50 kph and it has moderate to frequent acceleration throughout the cycle. UDC showed a clear upward trend with grade. An energy used of 0.75 kWh at grade 0 %, increasing to 1.44 kWh at 4 %, 2.22 kWh at grade 8% and lastly 2.86 kWh at grade 12 %, while the Baguio terrain has an energy consumption of 1.58 kWh that matches the 5 % to 10 % grade.

4. Discussions

The results revealed an important gap in EV energy estimation, particularly in the mixed grade such as Baguio City. The flat terrain averages 6.92 kWh across all drive cycles while the actual energy demand using Baguio City terrain doubles to 13.81 kWh and on static 12 % inclination nearly quadrupled to 22.89 kWh. This discrepancy resulted from frequent acceleration and high torque demands during elevated terrains. The unaccounted energy spikes can significantly undermine range reliability leading to user anxiety and mistrust in EV performance.

The urban drive cycle such as Japan Mode 1 Urban and UDC, which has a stop-and-go traffic, amplified the energy consumption. Steep inclines like in Baguio City or a 12 % grade in Japan Mode 1 Urban consumed a remarkable 251 % increase in energy compared to flat terrain. Thus, inability to account for the energy consumption from actual inclination and diverse driving environments can lead to inefficient adaptation of EV design, vulnerability to energy wastage and diminishing performance.

It shows that road grades matter in doing assessments and analysis in the energy consumption of EV. Many regions have mixed terrains and assuming flat grades in the analysis leads to underestimate the energy needs resulting in unreliable range claims and inadequate vehicle designs. EVs tested in flat terrain may fail in hill areas due to insufficient battery capacity, motor power and thermal management. Moreover, significant hilly terrains require denser charging infrastructure to address the heightened energy consumption. Thus, the integration of road grades affects the EV adoption and reception of the stakeholders to the EV system.

5. Conclusions

This study modelled a local EV minibus using AVL Cruise M and simulated it using varying road grades into established standard drive cycles (Japan Mode Urban 1, UDC, FTP75). It demonstrates that road grades significantly increase EV energy consumption during drive cycle simulations. The research highlights a critical limitation of conventional evaluations of EV that neglect terrain in the assessing the performance. In the Philippine setting, ignoring the terrain in the assessment can cause a systemic failure in the deployment of the EV. The energy consumption goes from an average of 6.92 kWh on the flat terrain to 13.81 kWh in the hilly terrain of Baguio City, and it spiked to 22.89 kWh on a steady 12 % grade. The additional energy demand is mainly due to frequent acceleration and higher torque required for the steeper slopes. Thus, the significant rise in energy consumption in the results shows how important it is to include the road grade information when studying driving patterns.

The significant increase in energy consumption from 6.92 kWh (flat terrain) to 13.81 kWh (Baguio terrain) demonstrates the critical need for terrain-adjusted battery sizing to ensure EV's maintain reliable range under real-world terrain. To improve energy consumption estimation accuracy, manufacturers must embed terrain-specific capacity buffers in vehicle design, rigorously validated against regional elevation profiles.

Furthermore, region-specific drive cycles integrating elevation data must be developed. Manufacturers' range claims should be validated using localized cycles and mandates for slope-resilient components such as torqueenhanced motors. The Local Government Units (LGU) must lead and enforce the verification of EV manufacturers' range claim before deployment. A localized LGU-led terrain integration must be developed to standardize the manufacturer testing and this prevents costly mismatches. The process of standardization will prevent misleading performance claims and secure a consumer trust in mixed terrain roads. Thus, alignment between testing standards and real-world conditions will boost consumer confidence in EV performance.

Incorporating road grades into drive cycle assessments is important in sustaining EVs growth that meet the real-world demands. It provides realistic energy estimates for mixed terrain regions and enhances accuracy in designing the electric vehicle including battery and motor sizing, and thermal management. Furthermore, the integration of terrain-adjusted metrics in the EV design helps EV adoption. Lastly, it supports stakeholders, especially the government in establishing policies that supports EV growth. Thus, prioritizing the grade inclusive assessments can ensure stakeholders positive EVs delivery that foster trust and sustainability.

In the Philippines, where road conditions in most regions are like Baguio city that has varying steep slopes, the research findings have significant impact on the EV adoption. A reliable EV performance integrating road grades and informed consumers can boost consumer confidence and encourage stakeholders to invest in EV. The realistic and terrain-including assessments will help pave way for wider EV acceptance that leads to sustainable growth in the country’s transportation sector.

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