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Araştırma Makalesi / Research Article

# Performance Comparison of Fuel Cell and Electric Vehicles on Different Road Gradients

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**Abstract**

The importance of green energy is increasing day by day. Hence, research on zero-emission transportation technologies has been advancing rapidly. In this study, the performances of electric and fuel cell vehicles, which are emission-free vehicles, are compared. These vehicles are designed with reference to the actual parameters of fuel cell and electric vehicles of the vehicle manufacturer Toyota. The Worldwide Harmonized Light Vehicles Test Procedure was applied to these vehicles incorporating road gradients of -1.5%, 5%, 10%, and 15% into the driving cycle. The range, battery temperature, battery energy consumption and state of charge values of these vehicles were analyzed. The results show that increasing gradient leads to an increase in energy consumption and battery temperature in both vehicles and a decrease in battery state of charge. However, the electric vehicle shows a decrease in range, especially on steeper gradients, and is more sensitive to significant gradient increases. On the other hand, the fuel cell vehicle-maintained battery stability against increasing gradients and did not experience any range loss despite the increase in battery temperature and consumption. These results emphasize the role of road gradient on vehicle performance and sustainability.

**Keywords:** Fuel cell vehicle, Electric vehicle, Battery, Energy consumption, Road grade.

# Yakıt Hücreli ve Elektrikli Aracın Farklı Yol Eğimlerinde Performans Karşılaştırılması

**Öz**

Yeşil enerjinin önemi her geçen gün giderek artmaktadır. Bu sebeple, sıfır emisyon ulaşım araçlarıyla ilgili çalışmalar hız kazanmaktadır. Bu çalışmada, emisyonsuz araçlardan olan elektrikli ve yakıt hücreli araçların performansları karşılaştırılmıştır. Bu araçlar, araç üreticisi Toyota'nın yakıt hücreli ve elektrikli araçların gerçek parametreleri referans alınarak tasarlanmıştır. Tasarlanan bu araçlara Dünya çapında Uyumlu Hafif Araçlar Test Prosedürü sürüş çevrimine -%1,5, %5, %10 ve %15 eğimler eklenerek uygulanmıştır. Eğimlerin bu araçlarda menzil, batarya sıcaklığı, batarya enerji tüketimi ve şarj durum değerleri incelenmiştir. Bulgular artan eğimin her iki araçta enerji tüketiminin ve batarya sıcaklığının artmasına yol açarken, batarya şarj durumunun azalmasına sebep olmaktadır. Ancak elektrikli araçta özellikle daha dik eğimlerde menzilde azalmaya yol açtığı görülmekte ve belirgin eğim artışlarına daha fazla hassasiyet gösterdiği belirlenmiştir. Buna karşılık, yakıt hücreli araç artan eğimlere karşı batarya kararlılığını korumuş, batarya sıcaklığı ve tüketimi artmasına rağmen menzil kaybı yaşamamıştır. Bu sonuçlar, yol eğimimin araç performansı ve sürdürülebilirliği üzerindeki rolünü vurgulamaktadır.

**Anahtar Kelimeler:** Yakıt hücreli araç, Elektrikli araç, Batarya, Enerji tüketimi, Yol eğimi.

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## 1. Introduction

Today, environmentally friendly technologies are used in the automotive sector to reduce fossil fuel dependency and prevent global warming (IPCC, 2021). Internal combustion engine vehicles emit carbon dioxide with the combustion of the fossil fuels they use. Electric, hybrid and fuel cell vehicles have been introduced as a solution to these vehicles that increase carbon emissions and cause environmental pollution (IEA, 2020). Hybrid vehicles are technologies in which internal combustion engine vehicles and electric motors are used together. Aiming to reduce dependence on fossil fuels, this vehicle is used as a transition technology between today's internal combustion engine vehicles and electric vehicles. In these vehicles, the emission value cannot go below a certain level as the internal combustion engine is activated for long distance driving (Hawkins et al., 2013). Electric vehicle technology is used to achieve zero emissions. These vehicles have zero emission value because they use engines that run entirely on electricity and do not require fossil fuel consumption. Fuel cell vehicles use hydrogen energy sources (Staffell et al., 2019). Hydrogen combines with oxygen during an electrochemical reaction to generate electricity, emitting only water vapor and heat in the process. Since they do not emit any harmful gases, these vehicles are considered zero emission (Schmidt et al., 2017).

In line with environmental sustainability, electric and fuel cell vehicles have gained an important place in the automotive industry due to their zero emission (IEA, 2022). Electric vehicles are used in combination with electric motors and batteries. Using lithium-ion batteries, these vehicles are very popular due to their high energy and power density, high energy efficiency and low operating costs (Li et al.,2024). Thanks to rapid advances in battery technologies, they are becoming widespread with significant improvements in range and charging times. Fuel cell vehicles have the advantages of short refueling and long range by using hydrogen as the energy carrier (Togun et al., 2024). In these vehicles, fuel cells are used in combination with batteries and supercapacitors to provide optimum performance in line with the desire for fast starting and acceleration.

Despite the advantages of fuel cell and electric vehicles, their performance varies depending on various factors such as road and environmental conditions. There are various driving procedures to evaluate the performance of electric and fuel cell vehicles under global conditions. One of these driving cycles, the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), allows the emission values, fuel consumption and range of vehicles to be analyzed with reference to real driving conditions (Yuan et al.,2023). The WLTP driving cycle creates acceleration, deceleration and cruising driving scenarios, taking into account urban, intercity and highway segments. However, since this driving cycle is performed on a flat dynamometer, it does not take road gradient into account. In order to better analyze the driving dynamics of vehicles, the road grade factor should be taken into account.

The variation of parameters in real driving conditions of vehicles with different powertrains has significant effects on range and energy consumption (Jiang et al.,2019; Sayah et al., 2024).

Studies on road gradient in electric and fuel cell vehicles have been addressed in the literature. (Sayah et al.,2024), developed an energy management strategy for fuel cell hybrid vehicles that takes road slope into account. Power sharing and energy efficiency were taken into account by creating different road slope scenarios. In this study in Hong Kong, a real driving cycle with steep gradients was created. The study aims to show the effect of inclination on range and energy consumption in an electric bus (Tong et al.,2023). In the study conducted by Ahn et al. it was observed that the energy consumption of the battery electric vehicle increased by 113% on a 6% slope (Ahn et al.,2020). The study also made a comparison with internal combustion vehicles and found that the electric vehicle consumed more energy. Hebala et al.,2025, investigated the performance of fuel cell, electric and hybrid vehicles with road slope and wind data. With this study, they showed that energy consumption and SOC are directly affected by the slope.

In this study, two different vehicles were designed by considering the parameters of both electric (bz3 model) and fuel cell (Mirai 2 model) vehicles of Toyota, one of the world vehicle manufacturers. Different gradients (-1.5%, 5%, 10%, 15%) were applied to these vehicles in the WLTP driving cycle. Vehicle performances according to inclined and uninclined driving cycles are compared and analyzed in detail. The temperature, energy consumption and state of charge (SOC) values of the batteries used in fuel cell vehicles and electric vehicles were compared. At the same time, the ranges of vehicles were recorded according to the inclines and a comparative analysis of the two vehicles was made. This study comprehensively investigated not only the energy consumption but also the battery SOC and temperature, range and hydrogen consumption of both electric and fuel cell vehicles modeled with commercial vehicle data in different road gradient scenarios.

According to the results of the study, the battery energy consumption and SOC of electric and fuel cell vehicles decreased depending on the road grade, while the temperatures increased. Accordingly, while the electric vehicle lost range depending on the road grade, the fuel cell vehicle maintained its range. In addition to the real-world driving conditions, this study has determined that it is important to compare electric and fuel cell vehicles with different gradients.

## 2. Materials and Methods

### 2.1. Modelling of Vehicle

The forces acting on the vehicle in the longitudinal dynamics of the fuel cell and electric vehicle are shown in Figure 1.

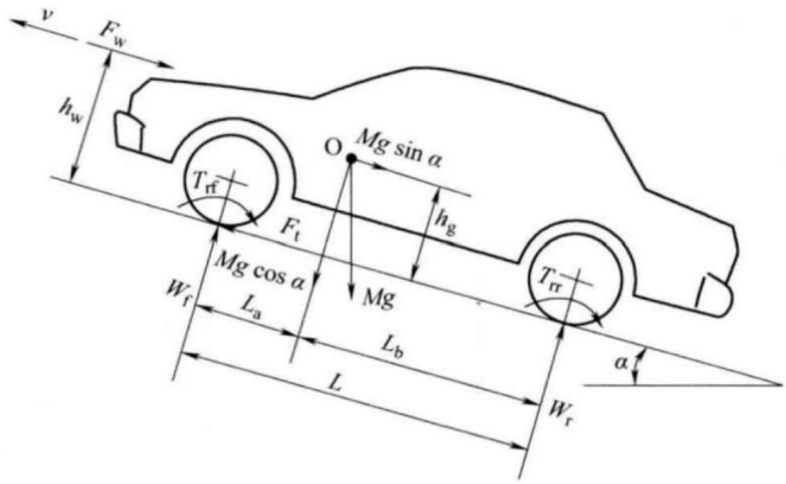


**Figure 1.** Longitudinal dynamics of the vehicle

The force balance of the forces acting on the vehicle is shown in Equation 1.

$$F_t = F_w + F_i + F_j + F_f \quad (1)$$

The vehicle has to overcome four different forces - rolling resistance ($F_f$), road gradient force ($F_i$), acceleration force ($F_j$), aerodynamic force ($F_w$) - to meet the speed signature.

Rolling resistance can be simply expressed as in Equation 2.

$$F_f{=}mgf\,cos_{\alpha} \quad (2)$$

Here, f is the rolling resistance coefficient. f is a coefficient whose value depends on factors such as road conditions, tire conditions (temperature, material, size, construction, inflation pressure). The aerodynamic force of a vehicle is a function of vehicle speed. Equation 3 calculates this function.

$$F_w = {}^1/_2\,\rho C_d A u^2 \quad (3)$$

Where $\rho$ is the air density, $C_d$ is the drag coefficient, $A$ is the frontal area of the vehicle, $u$ is the velocity of the vehicle in m/s relative to the air.

The road grade force is the component of gravity when a vehicle is on a road with an grade angle $\alpha$ and is calculated as shown in Equation 4.

$$F_i = mgsin_{\alpha} \quad (4)$$

The product of mass and acceleration is the force caused by the acceleration that must be overcome. The acceleration force is expressed in Equation 5.

$$F_j = m\frac{du}{dt} \quad (5)$$

## 2.2. Vehicle Parameters

In this study, -1.5%, 5%, 10% and 15% gradients were applied in addition to the WLTP driving cycle designed using real data to compare the performance of fuel cell and electric vehicles. For the fuel cell vehicle, the specifications of the sedan type Toyota Mirai 2 vehicle were used, while for the electric vehicle, the specifications of the sedan type Toyota bz3 vehicle were taken as reference. ADVISOR (Advanced Vehicle Simulator) program of Matlab/Simulink was used for modeling the vehicles and obtaining simulation results. Technical specifications of Toyota Mirai 2 and Toyota bz3 vehicles are given in Table 1.

**Table 1.** Vehicle parameters.

| | **Mirai 2** | **Bz3** |
|---|---|---|
| **Body Type** | Sedan | Sedan |
| **Vehicle weight (kg)** | 1900 | 1835 |
| **Motor Power (kW)** | 134 | 180 |
| **Motor Type** | Permanent Magnet | Permanent Magnet |
| **Battery Type** | Li-ion | Lithium iron |
| **Battery Capacity (kWh)** | 1.2 | 65.28 |
| **Fuel Cell Type** | PEM | - |
| **Fuel Cell Power (kW)** | 128 | |
| **Wheelbase (mm)** | 2920 | 2880 |
| **Drag Coefficient (Cd)** | 0.29 | 0.218 |

WLTP is a test standard developed to measure fuel consumption, $CO_2$ emissions and range of vehicles under more realistic conditions. Compared to the previous test procedure, New European Driving Cycle (NEDC), WLTP better reflects real driving conditions by including a longer distance (around 23 km) and higher average speed (around 47 km/h) The WLTP driving cycle is a standard used worldwide not only in conventional vehicles but also in electric vehicles. This driving cycle is used to determine $CO_2$ emissions and fuel consumption. Formerly known as the NEDC, this driving cycle was developed to address evolving technologies and driving conditions. The updated WLTP provides a better match between measured emissions and fuel consumption data and laboratory and on-road test drives. The WLTP driving cycle consists of four different sections with different maximum speeds: low, medium, high, and extra-high. These four sections are intended to simulate urban, suburban, rural, and highway scenarios, respectively (Mock, 2017).

However, WLTP tests are usually conducted in stationary laboratory environments and on flat surfaces, which means they do not adequately reflect the impact of road gradient on test results. However, especially for electric and fuel cell vehicles, sloping roads have a significant impact on energy consumption and range. As battery temperature rises with increasing gradient, range losses become more pronounced. In fuel cell vehicles, hydrogen consumption can increase significantly. Therefore, incorporating real-world conditions such as road gradient into WLTP tests is of great importance to more accurately assess the performance of electric and fuel cell vehicles. Speed and elevation versus time for WLTP cycle at 15% road grade is shown in Figure 2. Speed and elevation versus time for WLTP cycle at -1.5% road grade is shown in Figure 3.

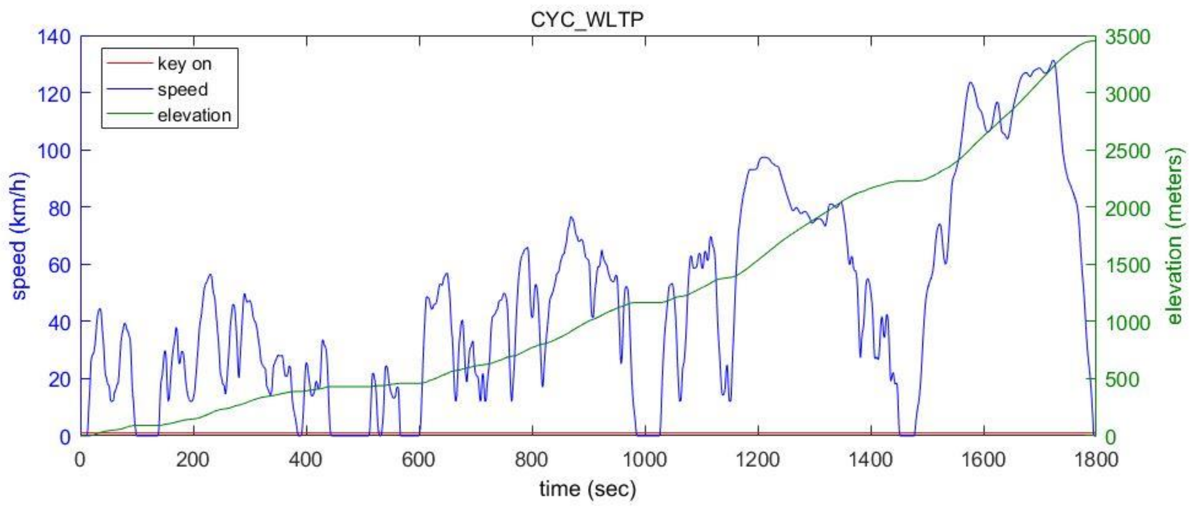


**Figure 2.** Speed and elevation versus time for WLTP driving cycle at 15% road grade

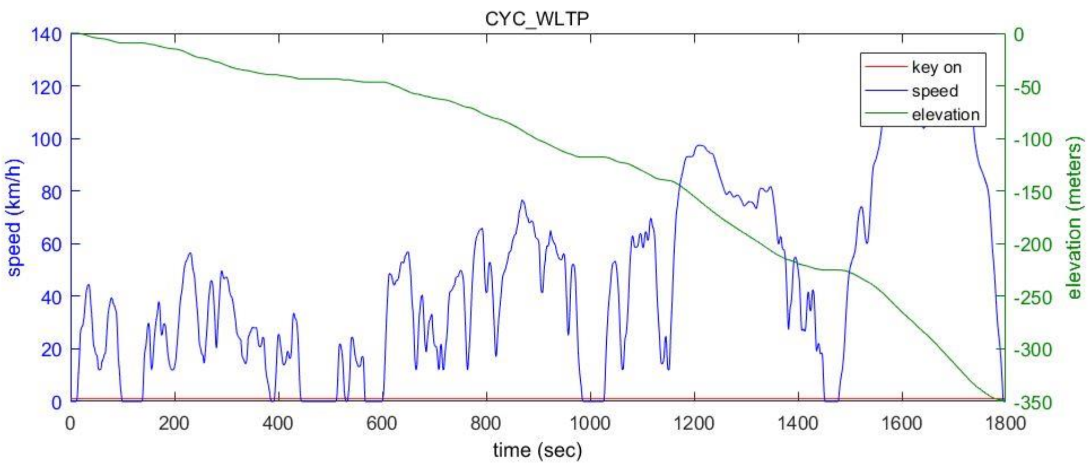


**Figure 3.** Speed and elevation versus time for WLTP driving cycle at 15% road grade

The ADVISOR program was used to create the slope profile integrated into the WLTP in Figure 2 and Figure 3. This profile is defined as an increasing function depending on the driving cycle time. This data was added to the WLTP drive cycle file in the simulation program. This data was calculated as the instantaneous slope and included in the driving resistance calculated by the slope formula in Equation 4.

This study also investigated the temperature of batteries in fuel cell and electric vehicles as a function of slopes. Therefore, it includes a model that accounts for battery thermal behavior. A parallel flow air-cooled system is used in simulations, assuming constant airflow and inlet air temperature for each battery module. This structure is a passive cooling strategy designed to limit battery temperature under thermal load and maintain system thermal stability.

## 3. Findings and Discussion

Toyota Mirai 2 and Toyota bz3 were designed to compare the performance of electric and fuel cell vehicles on different gradients. WLTP driving cycle created with real world data was applied to these designed vehicles. Then, different gradients (5%, 10%, 15%) were applied to this driving cycle and the battery performance and range of the designed vehicles were compared.

### 3.1. Electric Vehicle Results

Figure 4 shows the battery consumption of the designed electric vehicle at different gradients.

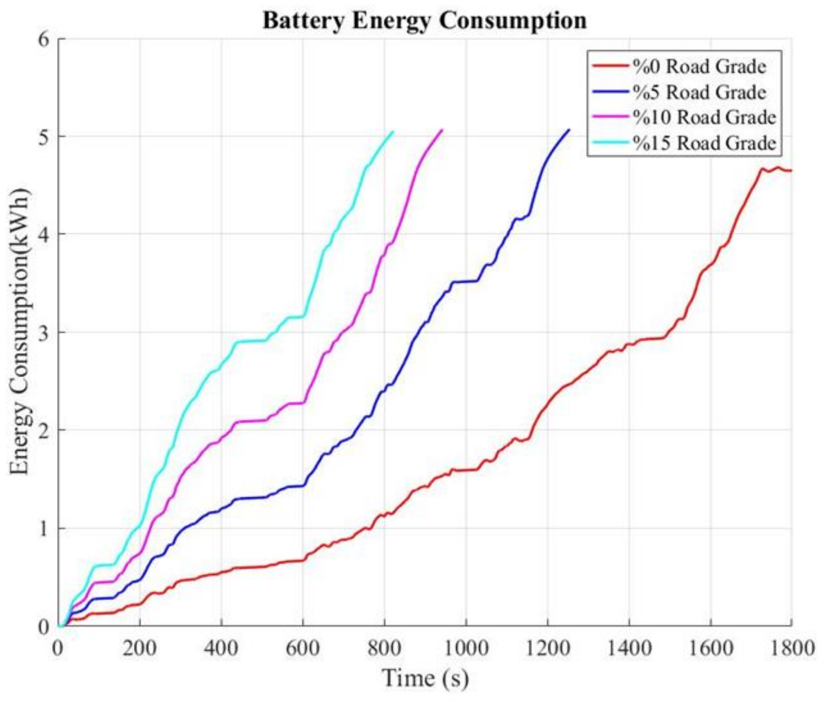


**Figure 4.** Battery energy consumption of electric vehicle at different road gradients in the WLTP driving cycle

The designed electric vehicle was tested at 0%, 5%, 10% and 15% road gradients in the WLTP driving cycle. It is observed that cumulative battery energy consumption increases significantly with increasing road gradient. However, it is also observed that the range decreases with increasing road gradient. In the WLTP driving cycle, while the driving cycle was completed in 1800 seconds at 0% gradient, it took 800 seconds at 15% gradient and could not complete the driving cycle. On a 0% gradient road, the battery consumes approximately 4.7 kWh of energy at the end of 1800 seconds of driving. On a 15% gradient road, this consumption reaches 5.0 kWh at 800 seconds. According to these results, energy consumption is 6.4% higher at 15% gradient compared to 0% gradient, but this increase is realized in 55.6% less time. At the same time, the average power consumption at 15% slope is about 2.4 times higher than at 0% slope. This shows that the battery system is subjected to higher instantaneous power demands as the slope increases. As the grade increases, energy consumption also increases gradually as the engine demands more power (Jiang et al.,2019; Hüner, 2024). Therefore, as the grade increases, the power demand from the battery increases due to the increase in the power demand of the engine. This shows that energy consumption can change significantly in sloping terrain conditions.

Figure 5 shows the battery SOC of the designed electric vehicle at different road grades.

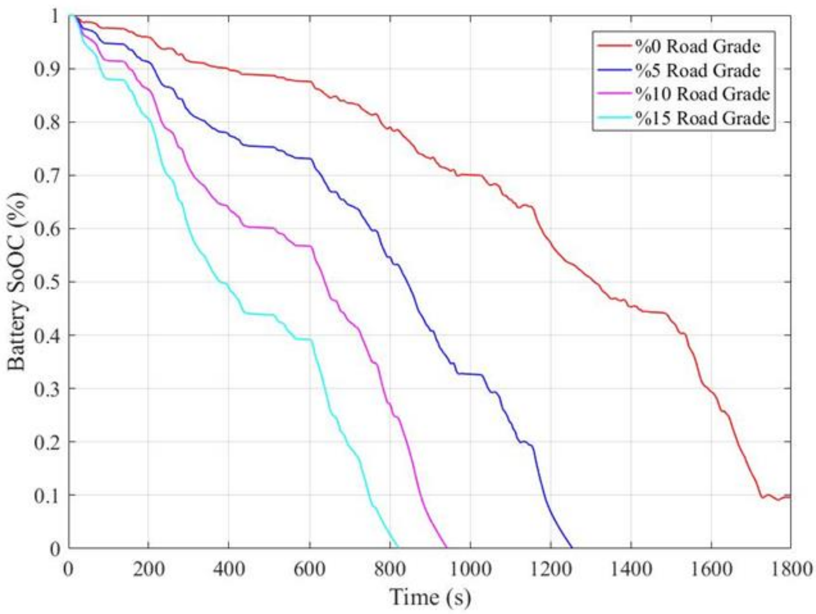


**Figure 5.** SOC value of the electric vehicle at different road gradients

Figure 5 shows the battery SOC change at different road gradients in the WLTP driving cycle of the electric vehicle. The results clearly show that the SOC value of the battery decreases rapidly as the grade increases. On high gradient roads, the power demand of the engine increases the amount of energy required from the battery. When evaluated together with the battery energy consumption in Figure 4, the increase in battery energy consumption directly affects the battery SOC. It is seen that as the gradient increases, the range that the battery can travel decreases, and it cannot complete the WLTP driving cycle. On a 0% gradient road, the battery is fully discharged in approximately 1780 seconds, while it is discharged in 1250 seconds at 5% gradient, 960 seconds at 10% gradient and 790 seconds at 15% gradient. This means that the battery consumes energy in 29.8%, 46.1% and 55.6%

shorter time as the slope increases. This data reveals that as the road gradient increases, the battery is depleted in a much shorter time, placing more intense loads on the energy system.

The battery SOC performance of the electric vehicle on a downhill slope of 1.5% is given in Figure 6.

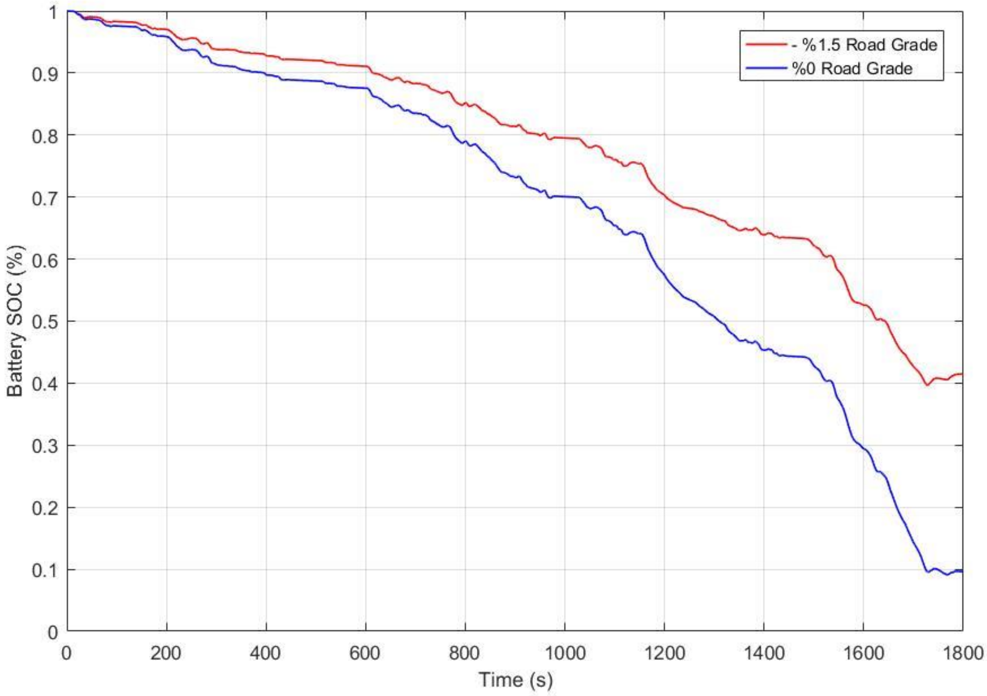


**Figure 6.** The battery SOC performance of the electric vehicle on a downhill slope of 1.5%

In Figure 6, the vehicle started driving on a -1.5% slope with approximately 99.3% SOC, and after 1800 seconds, the SOC value dropped to 42.1%. In contrast, on the flat road, the initial SOC value remained the same, remaining only at 1.0% at the end of the drive. This result demonstrates that the battery loses less energy during downhill driving thanks to regenerative braking, and the vehicle achieves significant energy recovery. While the battery's total SOC loss on the -1.5% slope was 57.2%, this loss reached 98.3% on the flat road. This reveals that battery consumption in the downhill scenario is 41.8% lower than on the flat road. The findings demonstrate the contribution of regenerative braking to energy efficiency on slopes. Figure 7 shows the battery temperature of the electric vehicle.

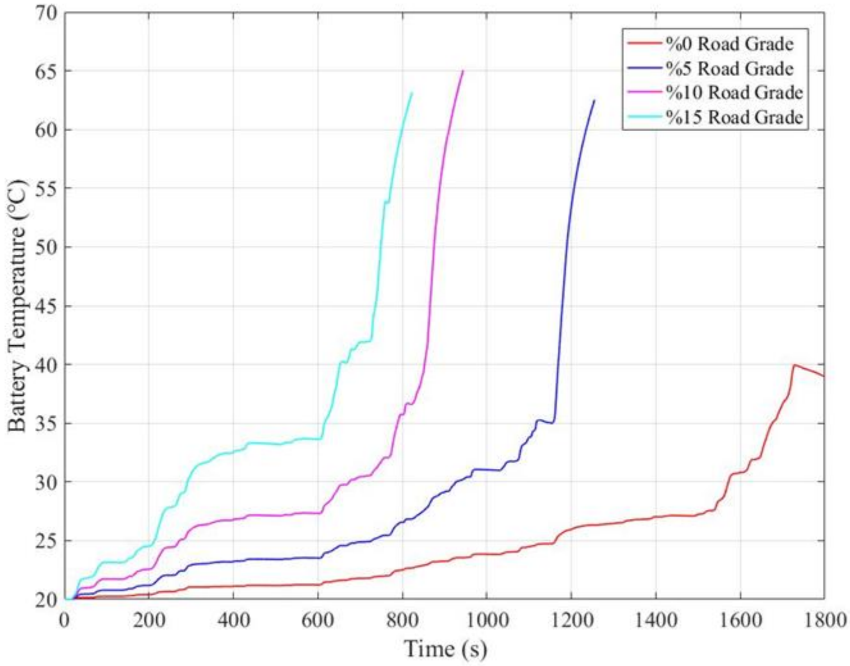


**Figure 7.** Battery temperature at different gradients in the WLTP driving cycle of the electric vehicle

According to the battery temperature graph for different road grade given in Figure 7, while the battery temperature remained at normal levels at 0% road grade, the battery temperature reached the highest levels at 15% road grade. Especially on roads with 10% and 15% gradients, sudden increases in battery temperature are observed. While the battery stays at 40°C in 1800 seconds on the flat road, it reaches up to 60°C in only 800 seconds on the 15% gradient road. On the 5% gradient road, the battery temperature reached approximately 62 °C after 1200 seconds. The temperature increase was 110% higher than at 0% gradient and occurred in 33% less time. At 10% gradient, the battery temperature reached 65 °C in 900 seconds. The temperature increase was 125% higher than at 0% gradient and occurred in 50% less time. At 15% gradient, the battery temperature reached 63 °C in only 750 seconds, ending the test at the thermal limit. In this case, the temperature increase was 43 °C. As the inclination rate increases, the thermal stress to which the battery is exposed increases significantly. The fact that the temperature rises in a much shorter time, especially at 10% and 15% gradients, shows that battery systems need a more advanced thermal management strategy for high gradient driving.

This is explained by the sudden increase in the energy consumption of the battery and the sudden decrease in the battery SOC value on the 15% gradient road when evaluated with the results in Figure 4 and Figure 5. As the battery rapidly consumes energy to meet the engine power demand at this grade, the temperature inside the cell increases.

### 3.2. Fuel cell vehicle results

Figure 6 shows the battery energy consumption of the fuel cell vehicle at different gradients.

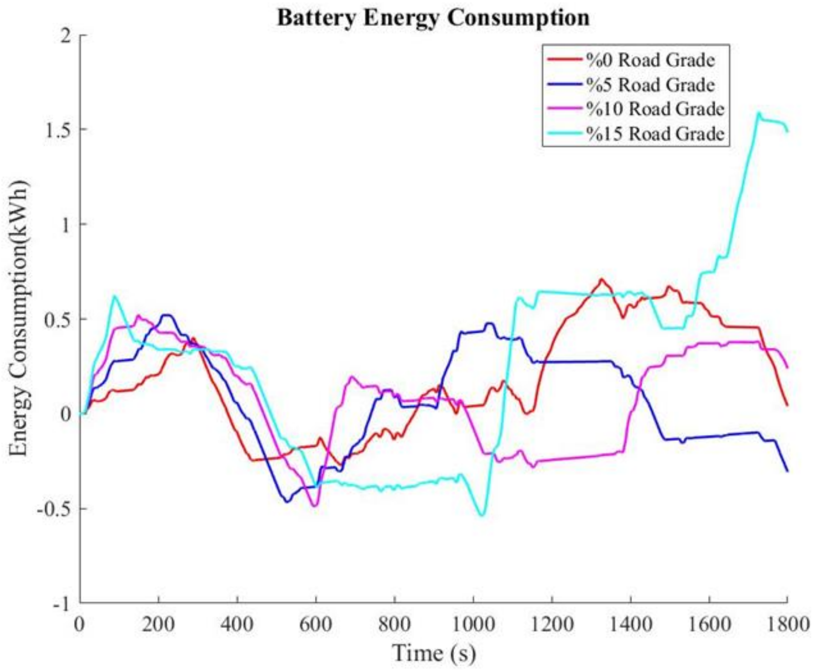


**Figure 8.** Battery energy consumption of the fuel cell vehicle at different gradients in the WLTP driving cycle

Figure 8 shows the cumulative battery energy consumption of the fuel cell vehicle at 0%, 5%, 10% and 15% road gradients in the WLTP driving cycle. According to this graph, the fuel cell vehicle completed a driving cycle of 1800 seconds despite the changing road gradients. While it is observed that the fluctuations in battery consumption increase as the road grade increases, it is seen that the battery has difficulty in meeting the energy requirement at 15% road gradient. At lower gradients, relatively less fluctuations are observed than at higher gradients, while at some points of the driving cycle, the battery energy consumption is negative. On the 0% gradient road, the battery consumption reached approximately +0.85 kWh after 1800 seconds. On the 5% gradient road, the battery consumption was approximately +0.70 kWh, but the energy consumption dropped to -0.4 kWh at certain intervals. This indicates that the excess power of the fuel cell is directed to the battery within the energy requirement of the battery. Similarly, at a 10% slope, the battery consumption was approximately +0.60 kWh and the energy value decreased to -0.5 kWh in the period of 200-600 seconds. At a 15% slope, the battery consumption increased significantly and reached +1.5 kWh. This is approximately 76.5% more energy consumption than at 0% slope and 150% more than at 10% slope. At this gradient, both the fuel cell and the battery directly power the propulsion system. As with the electric vehicle, as the gradient increases in the fuel cell vehicle, energy consumption increases according to the power demand of the engine (Jiang et al.,2019; Hüner, 2024). This graph shows that the fuel cell vehicle utilizes the battery as a secondary energy source and receives support from the battery when the fuel cell is insufficient to meet the demanded power. Figure 9 shows the battery SOC value at different gradient.

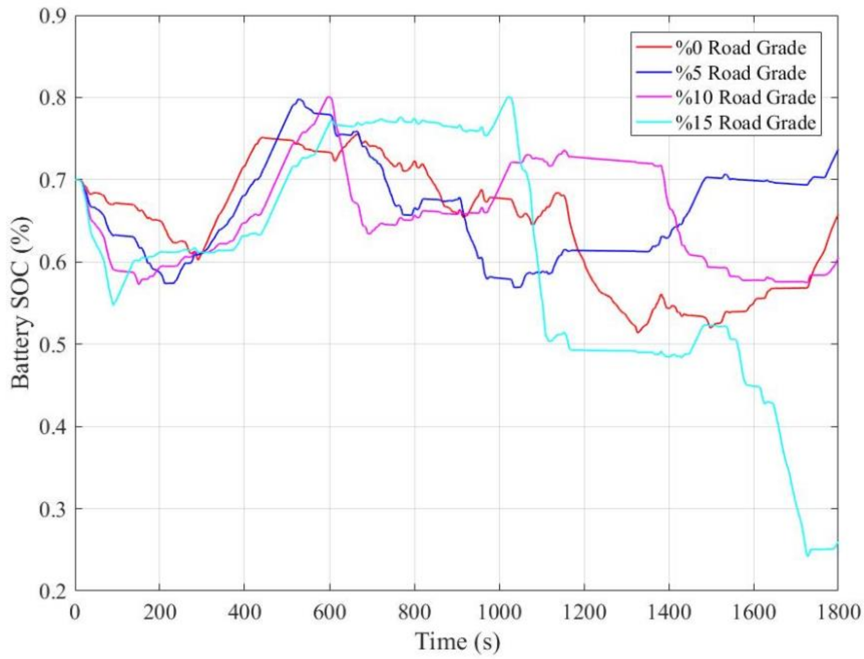


**Figure 9.** Battery SOC value at different gradients in the WLTP driving cycle of the fuel cell vehicle

The diagram illustrates the effect of different road inclinations (0%, 5%, 10%, 15%) over time on the SOC of the battery. The initial SOC value is approximately 70% on all gradients. This indicates that the system is generally balanced between battery energy production and consumption on a flat road with 0% gradient. On a 5% gradient, the SOC rises to 78% by 600 seconds, stabilizing at 74% at the end of the test. This shows that the fuel cell is supporting the battery at the same time. On the road with a 10% gradient, the SOC level initially rises to 80% and stabilizes at 60% at the end of the test. At this gradient, although the fuel cell initially charged the battery, the battery quickly discharged due to the high-power demand. On the steepest gradient, 15% road condition, the SOC reached 80% in the first 600 seconds but dropped to 28% at the end of the test. This indicates that the battery was heavily utilized. This situation is a significant energy consumption in high-sloping road conditions, and it adversely affects the battery life and range. The findings show the need for optimized energy managements strategies for inclines and represent a critical piece of evidence in the performance analysis of fuel cell vehicles.

The battery SOC performance of the fuel cell vehicle on a downhill slope of 1.5% is given in Figure 10.

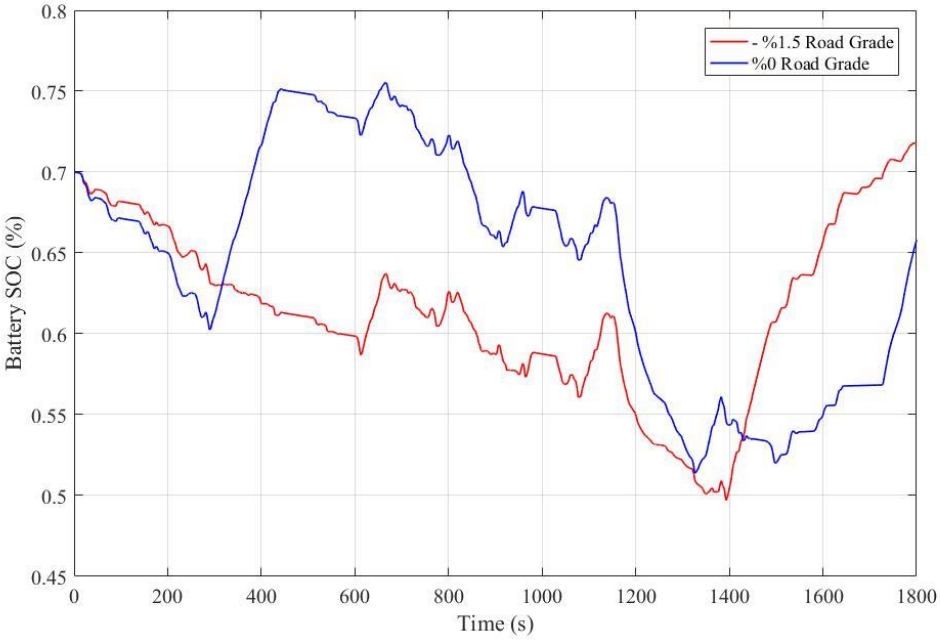


**Figure 10.** The battery SOC performance of the fuel cell vehicle on a downhill slope of 1.5%

In Figure 10, the vehicle entered a significant regenerative braking phase starting at approximately 1400 seconds on a -1.5% slope, and during this period, the battery SOC increased from approximately 51% to 71.5%. During the same time period, the SOC increase on the flat road (0% slope) only increased from 52.5% to 65.5%. This demonstrates that downhill driving increases the efficiency of regenerative braking, enabling the conversion of more kinetic energy into electrical energy. The approximately 20.5% SOC increase achieved on the downhill side is 57.7% greater than the 13% increase on the flat road. These data demonstrate the contribution of regenerative braking to battery energy management on slopes.

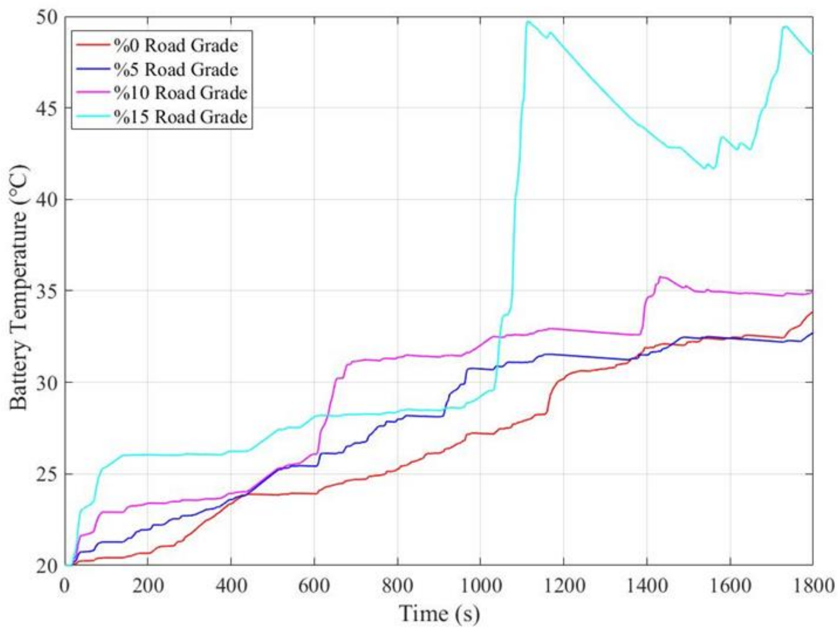


**Figure 11.** Battery temperature of the fuel cell vehicle at different gradients in the WLTP driving cycle

Figure 11 shows the battery temperature of the fuel cell vehicle at different gradients. When the effects of different road gradients on the battery charge rate (SOC) and battery temperature are considered together, it is seen that the battery is depleted faster, and the temperature rises significantly with increasing gradient. Especially at 0% and 5% road grade, battery consumption is more balanced, and temperature increase is more controlled. However, at 10% and especially 15% gradients, the battery is discharged faster, and the temperature rises sharply. It shows that at 15% gradient the temperature increase is 136% higher than at 0% gradient. This indicates the need for a more effective thermal management strategy on high gradient roads. Especially at 15% gradient, the temperature reaches 50°C, indicating that the battery is more strained on such roads and the heating problem can reach serious dimensions.

In fuel cell vehicles, the amount of hydrogen consumed during the driving cycle is important. The amount of hydrogen consumed during the WLTP driving cycle for different road gradients is given in Figure 12.

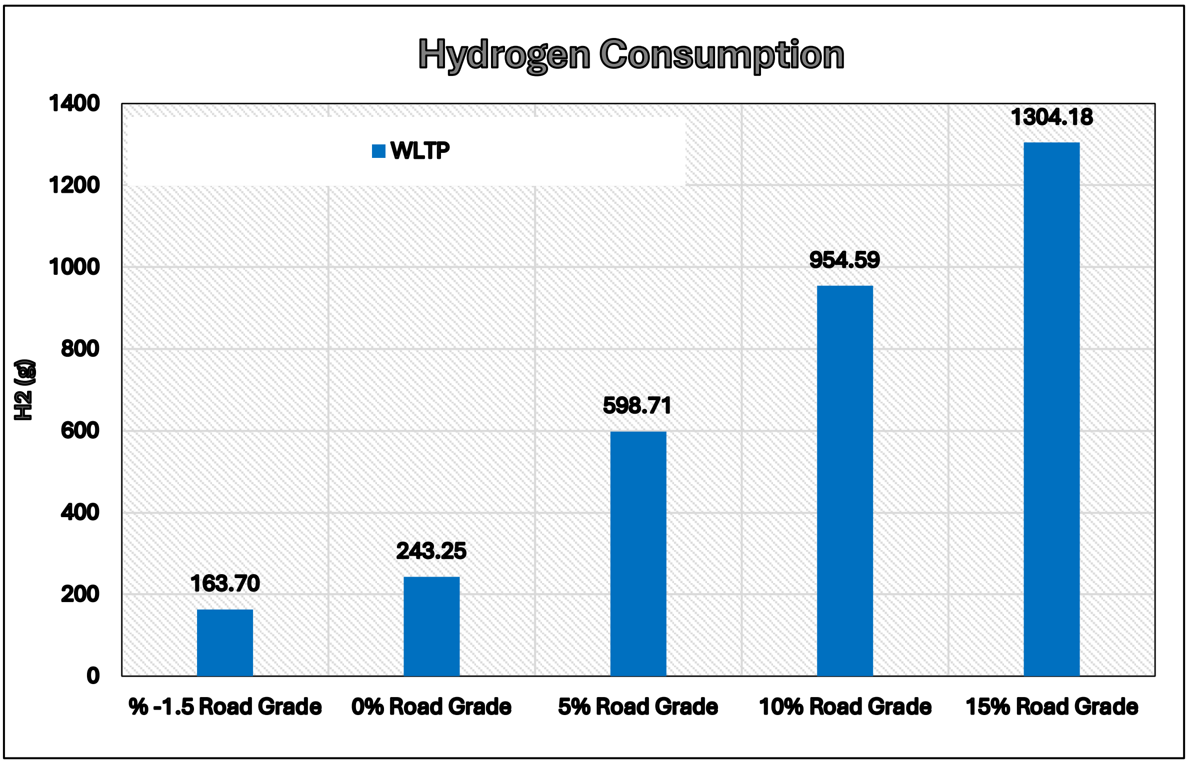


**Figure 12.** Hydrogen consumption of the fuel cell vehicle at different gradients in the WLTP driving cycle

The total hydrogen consumed by the WLTP driving cycle with 0% road gradient is 58.1 l/100 km. Since the total distance of the driving cycle is 23.26 km, a total of 13.51 l of hydrogen is consumed. The density of the fuel used is 18 g/l. Thus; the total hydrogen consumed in the WLTP driving cycle is 243.25 g.

As the inclination of the fuel cell vehicle increases, the hydrogen consumption of the fuel cell increases as the power demanded by the engine increases. While it was 243.25 g on the road without inclination, 598.71 g hydrogen consumption occurred on the road with 5% inclination. At the end of the WLTP cycle, the hydrogen consumption was 954.59 g on the 10% inclined road and 1304.18 g on the 15% inclined road. However, fuel consumption has also decreased because the energy lost on the downhill road is recovered thanks to regenerative braking. 163.70 g of hydrogen was consumed at the end of the WLTP driving cycle on a -1.5% slope.

### 3.3. Comparison of results for electric and fuel cell vehicles

The designed fuel cell vehicle and the electric vehicle were compared by integrating different gradients into the WLTP driving cycle containing real world data. For this comparison, the parameters of the two vehicles were taken from the same vehicle manufacturer, and the body type was selected as Sedan.

The comparison of the ranges of electric and fuel cell vehicles in the same driving cycle but at different gradients is given in Table 2.

**Table 2.** Comparison of range of electric and fuel cell vehicles

| Road Grade | Toyota Mirai 2 range | Toyota bz3 range |
|---|---|---|
| -%1.5 | 23.3 km | 23.3 km |
| 0% | 23.3 km | 23.3 km |
| 5% | 23.3 km | 11.4 km |
| 10% | 23.3 km | 7.1 km |
| 15% | 23.3 km | 5 km |

In the comparison of electric and fuel cell vehicles according to gradients, the electric vehicle gradually decreases its range against the gradient, while the fuel cell vehicle maintains its range according to the gradient. In the electric vehicle, the rapid decrease in SOC as the gradient increases and the rapid increase in energy consumption have significantly reduced the range. In the fuel cell vehicle, on the other hand, the fact that the fuel cell is the primary energy source keeps the battery's SOC and energy consumption more balanced as the battery supports sudden power and demands. This is also reflected in the range, ensuring that the range remains constant as the road grade increases. However, when a downhill slope is applied, there is no loss of range in the vehicles thanks to the more balanced use of the SOC of the battery with the effect of regenerative braking in electric and fuel cell vehicles.

While electric and fuel cell vehicles have different ranges, fuel consumption, and battery charge levels, one common characteristic of these two vehicles is their zero emissions when used. At the end of the WLTP driving cycle, both vehicles have zero emissions. Figure 13 shows the emission values.

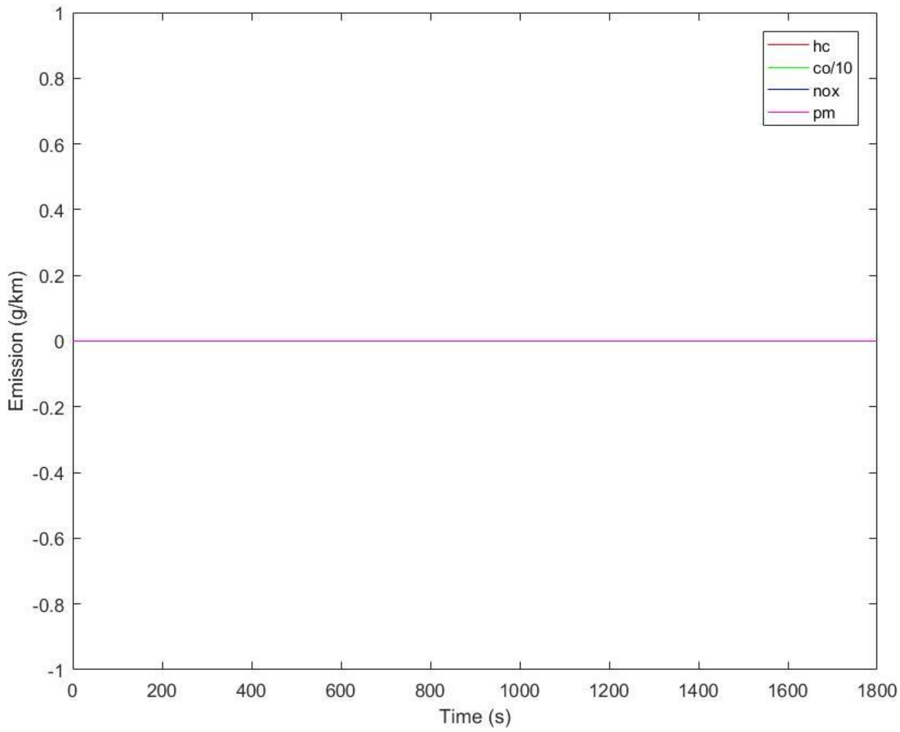


**Figure 13.** Emission values of electric and fuel cell vehicles

Figure 13 shows that at the end of the WLTP driving cycle, the hydrocarbon (hc), carbon monoxide (co), nitrogen oxide (nox) and particulate matter (pm) values of both vehicles are zero.

Hebala et al. compared the performance of fuel cell and electric vehicles in extreme cases in 2025. The electric vehicle exhibits high depletion performance with a large decrease in battery SOC, while the fuel cell vehicle exhibits a moderate decrease (Hebala et al.,2025).

The same study categorized road gradients as low, normal, medium and high. When they evaluated the energy consumption of both vehicles according to these road gradients, they observed that the electric vehicle consumed more than the fuel cell vehicle at every road gradient (Hebala et al.,2025).

According to these results, this study is consistent with other studies.

## 4. Conclusions and Recommendations

In this study, the performance of battery electric vehicles and fuel cell vehicles at different gradients in WLTP driving cycles is compared. For the electric vehicle, the parameters of the Toyota bz3 vehicle are taken as reference, while for the fuel cell vehicle, the Toyota Mirai 2 is taken as reference. For the vehicle performances, 5%, 10% and 15% gradients were applied to the WLTP driving cycle. The range, battery SOC, temperature and energy consumption of these vehicles were analyzed against different gradients. While the fuel cell vehicle did not experience any loss in range over different gradients, the range of the electric vehicle lost range as the gradient increased. In the fuel cell vehicle, the battery SOC suffered a loss in sudden power demands, while it managed to stabilize the SOC with the support of the fuel cell. In the electric vehicle, on the other hand, the battery SOC decreased rapidly as the gradient increased and ran out of charge before completing its range. While the battery temperature in the fuel cell vehicle showed average performance, it was observed that the battery temperature increased as the road grade increased. In the electric vehicle, the battery temperature is higher than the fuel cell vehicle and the battery temperature increases as the road grade increases. In the fuel cell vehicle, energy consumption is lower and balanced because the battery is the secondary energy source, and the fuel cell uses the battery when it needs additional energy. In the electric vehicle, energy consumption is higher as the battery is the only energy source and increases rapidly as the gradient increases. With this analysis, it is emphasized that road grades should be considered as an effective factor in vehicle performance evaluation.

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**Competing of Interest**

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**Statement of Research and Publication Ethics**

The author declares that this study complies with Research and Publication Ethics.

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