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Determining the main factors influencing the energy consumption of electric vehicles in the usage phase

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Abstract

Electric vehicles (EV) are often considered as an environmental conscious alternative to conventional vehicles with internal combustion engines (ICEV). In order to quantitatively analyse the environmental benefits, it is essential to explore the energy consumption behaviour of EV during the usage phase. However, this information is neither available in public domain nor commercial database. Theoretically, the energy consumption of driving EV will be influenced by a number of factors, such as road conditions, traffic, etc. Thus, this paper applied Design of Experiment (DoE) method to explore the statistical significance of the selected factors. In order to simulate the real world usage phase, the Nissan LEAF was tested in Sydney metro area, and the energy consumption was collected under various conditions. The screening results define the main factors impacting the energy consumption, as well as measuring the magnitude of those impacts. As a result, a simple binary model is generated to estimate the energy consumption of EV for a specific usage condition.

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Keywords: Electric vehicle; Design of Experiment; Energy consumption

1. Introduction

Private road transportation is a key contributor to the mobility of our global society. Against the background of climate change, the scarcity of resources and a growing population, governments and manufacturer have to look for solutions to reduce the environmental impact of private transport. In European Union (EU) road transport constitutes about one-fifth of the total carbon dioxide emissions. Private vehicles alone are responsible for around 12%, where the emissions are increasing annually [1]. Furthermore, manufacturers are forced to achieve mandatory emission targets for new vehicles [2]. An emission reduction of 60% in the transportation sector is targeted in the EU until 2050 [3]. Electric vehicles (EVs) play an important role to reduce greenhouse gases since they are a possible alternative to internal combustion engine vehicles (ICEV). This development can be seen from the worldwide increasing demand of electric vehicles [4].

Environmental sustainability and the reduction of the carbon footprint are an increasing incentive for customers to purchase an EV [5]. Even though an EV does not have any tailpipe emissions like the ICEV, the environmental impact resulting from energy production and the other life cycle stages have to be taken into account. This is particularly the truth for countries like Australia, where the electricity is mainly generated from black coals. Like other active products with a long life span, the use-phase has a great importance for

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its environmental performance. In other words, it is essential to analyse the behaviour of the energy consumption during the use phase [6].

Life Cycle Assessment (LCA) is a standardized methodology to quantify the environmental impact over the whole life cycle of a product or service. However, the regional diversity is often not considered in the LCA use phase due to a lack of precise information of the regional factors' impacts. Initial studies suggest that the energy consumption of EVs is influenced by a wide range of factors. For instance, the temperature in different climate zones can influence the drivetrain efficiency and can lead to an increasing energy demand as a result using heating and or cooling [7]. Metropolitan areas are responsible for more than 80% of on-road traffic and EVs are especially an alternative for urban traffic. However, the consumption in metropolitan areas differs from the consumption on the highway. Additionally, the traffic as well as the topography can have a significant influence on the energy demand [8-10]. Critically, no empirical model is available to depict these influences and predict the consumption according to the area of use [11]. Therefore, this paper aims to experimentally determine the significance of selected factors influencing on the energy consumption of EVs in the use-phase.

The remaining sections are structured as follow: section 2 reviews all possible factors which may influence on the energy consumption of EVs; section 3 presents the design of experiments (DoE) in order to explore the statistical significance of selected factors; section 4 reveals the main results from experiments and a binary model for predicting consumption; and, section 5 concludes the findings and recommends for future work.

2. Literature survey

There are numerous factors that can influence the energy consumption of an EV. According to the initial study on ICEV, there are more than 16 main urban driving parameters from vehicle technology to driver's behaviours [12]. After reviewing existing models for vehicle consumption, Figure 1 lists all the main influencing factors and categories them into 6 groups:

- *Technology and vehicle factors*:

Battery system is one of the core components of an EV, and its technology has a major impact on the energy consumption. The associated design factors include battery type, number of cells, the stacks, and the battery management system (BMS) design. These factors further determine the battery capacity, energy intensity and the mass [13]. Also, battery ages due to charging cycles, which is measured by the State of Health (SoH). In addition, the regeneration rate has an impact on the overall energy consumption. However, regenerative braking is not working with high State of Charge (SOC) and a high battery temperature [14].

The HVAC system is also considered as a main factor. Due to the absence of combustion engines, either PTC (Positive temperature coefficient) heater or heat pump is needed to generate heat which requires a higher energy than air conditioning in principle. Nevertheless, the actual consumption is highly associated with the local climate and driver's behaviour [15]. Other auxiliary components include lighting of the vehicle, radio, navigation system and optional seat heating and other comfort related devices, which are not related with the vehicle's propulsion. These devices are supplied by a 12 Volt battery which is connected to the traction battery. However, the overall influence on the consumption is low [6].

Other vehicle related factors are the drivetrain and the motor efficiency. They also include the vehicle mass, the size and drag coefficient, and the rolling resistance attributed to tire design and pressure [16].

- *Artificial environment factors*:

Artificial environment include the infrastructure and the environment related to humans such as intersections, traffic and traffic lights, the level of urbanization. [12].

The traffic can be characterized by the amount of congestions, its flow and average speed. The higher the level of congestion, the higher is the overall consumption. The higher the traffic, the more a vehicle has to decelerate and accelerate because of several stops and the variation of speed hence the consumption rises. There are several possibilities to characterize and quantify the traffic factor, i.e. average speed, idle time or stops per kilometre [17-18].

The level of urbanization is characterised by its population density. Urban areas usually feature with high number of intersections, traffic lights and forced stops, low mean speed limit, low average speed during rush hours, etc. In comparison, rural areas and highways show opposite characteristics [17].

Other factors are the road conditions, construction sites, intelligent transportation systems and traffic management systems [12].

- *Natural environment factors*

The natural environmental factors include the topography of a region, the climate zone, the weather and countless more variables. Topography can be characterized by different parameters, i.e. the average slope, the total ascent or descent in meters. In general, the higher the variance of altitude, the higher is the consumption due to the need to overcome the additional vertical force [13, 17].

Both the vehicle's and its components' efficiency and the driver are affected by the climate [19] In particular, the weather has an impact on the driving behaviour, i.e. heavy rain and fog can interfere the driving. The ambient temperature and humidity are correlated to the use of the heater and air conditioning.

Other impact factors can be the characteristics of the seasons, the day hours, air density, weather extremes and the visibility on the road.

- *Driver factors*

The driver can be characterized by his aggressiveness. This is illustrated by the acceleration and deceleration pattern. The more aggressive the driving style, the higher is the variability in acceleration and deceleration and the average speed. This behaviour causes an increased consumption [17-18]. The driving behaviour is attributable to several driver characteristics: age, gender, etc. [12]