Heterogeneous Driver Behaviour and Energy Consumption

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Contributor: Sedar Olmez , Jason Thompson , Ellie Marfleet , Keiran Suchak , Alison Heppenstall , Ed Manley , Annabel Whipp , Rajith Vidanaarachchi

By 2020, over 100 countries had expanded electric and plug-in hybrid electric vehicle (EV/PHEV) technologies, with global sales surpassing 7 million units. Governments are adopting cleaner vehicle technologies due to the proven environmental and health implications of internal combustion engine vehicles (ICEVs), as evidenced by the recent COP26 meeting.

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1. Introduction

According to [1], by 2050, 70% of the world's population will live in urban areas, accounting for roughly 6.3 billion people. Battery-powered electric vehicle sales increased from 5.3 million sales in 2019 and are projected to reach over 39.9 million units by 2030 [2]. Given that the majority of people live in urban areas and infrastructure development is targeted at these areas [3], it could be assumed that the majority of electric vehicles (EVs) will be driven in these areas. An environmental benefit that EVs present is the ability to consume energy from renewable energy sources (e.g., wind turbines and solar). Furthermore, the total energy use among EVs is 3.4 times lower than ICEVs that rely on petroleum, diesel or gas, which emit CO_2 that is harmful for the environment. During a well-to-wheel (WTW) analysis of ICEV and EV efficiency, Ref. [4] found that EVs, when using renewable energy, can reach an efficiency level of 40 to 70% depending on the location and environmental factors. In contrast, gasoline- and diesel-powered ICEVs had an WTW energy efficiency of 11–27% and 25–37%, respectively. Almost all vehicle manufacturing companies have started building and testing EV/PHEVs for the commercial market [5][6]. Governments are facilitating benefits to persuade people to replace ICEVs with EVs through economic incentives or legislation. However, not all countries have renewable technology to power these vehicles; some countries, such as China, still depend on coal to power the majority of their electric grid infrastructure [7][8]. In Australia, only 24% of electricity is generated from renewable sources [9]. In their review of EVs and their impact on the climate, Ref. [10] found that vehicles using electricity from sources with lower global warming potentials (GWP) [11] are better than ICEVs. In contrast, Ref. [12] found it was counterproductive to promote EV uptake in countries where electricity is produced from fossil fuels. The statistics mentioned above reaffirm the need to explore the impact these technologies have on future cities.

This study demonstrates how agent-based modelling (ABM) can be harnessed to quantify energy demand in cities from electric-powered vehicles at various spatio-temporal resolutions. To test the model, two variables are configured across multiple test scenarios to demonstrate the subtle differences in outcomes. These variables are the speeding behaviour (known as adherence to speed limits) and the number of vehicles on the street network (density of vehicles).

Firstly, an agent-based method for quantifying energy demand from vehicle behaviour at the individual level is presented. Secondly, heterogeneity among driver behaviour and road characteristics is included, directly impacting the energy required, which is the case in the real world. Finally, the proposed model enables practitioners to quantify the potential energy costs these vehicles incur and compare scenarios such as high traffic to low traffic densities. For clarity, driver behaviour is defined as the interactions of the human driver and the impact those interactions have on the vehicle being driven. This includes, for example, the driver's foot dynamics and its impact on acceleration [13]. This is represented as the speed limit adherence and non-speed limit adherence behaviours, enhancing heterogeneity.

2. Heterogeneous Driver Behaviour and Energy Consumption

A traffic system is characterised by multiple individual actors (e.g., drivers) and a street network made up of individual rules characterised by (for example) traffic lights and posted speed limits. Given this system's individual-level components, it is amenable to being studied using individual-based modelling methods. According to [14], individual-based modelling refers to simulation models that treat individual entities as unique and discrete elements with at least one property (e.g., age, height, speed), and these properties change during the life cycle of the entities. Therefore, in this study, vehicles can be thought of as individual heterogeneous entities with their properties and rules, while the urban street network is the environment within which these vehicle entities are observed.

Agent-based modelling (ABM) is an individual-based modelling method. It provides the means to plan, design and experiment with micro-heterogeneous agents in an artificial, computational environment. ABMs have been utilised in various domains to explain complex phenomena such as those that occur in crime [15][16], ecology [17][18][19], economics [20][21], sociology [22][23], geography [24][25] and transportation [26][27]. One advantage of using ABMs is that they are able to represent a richer and more detailed set of individual actors leading to potential policy alternatives and outcomes compared to the alternative, statistical models [28].

Several agent-based models have focused on electric vehicle research. Ref. [29] developed an agent-based model that measured consumer needs and decision strategies by policymakers to shift from ICEVs to EVs. They found that effective policy requires a long-lasting implementation of a combination of monetary, structural and informational measures. Similarly, Ref. [30] developed a spatially explicit agent-based vehicle consumer choice model to identify the various influences that can affect the uptake of PHEVs. The study found that providing consumers with ready estimates of expected lifetime fuel costs associated with other vehicle types, including the rise of petrol costs, can generate preferences for purchasing EV/PHEVs over ICEVs.

Several studies have also explored the total cost of ownership between EVs and ICEVs from a consumer perspective to quantify the economic differences in ownership between vehicle types. Findings differ geographically due to international differences in the price of petrol, diesel, and electricity. In a study focused on New Zealand, Ref. [31] estimated that the per-kilometre cost of ownership (PCO) for a used EV was twelve percent lower than that of a used petrol-powered car over twelve years (25.5 NZ cents and 31.5 NZ cents for petrol vehicles). Although this study primarily focused on the differences in fuel costs, others have included additional factors such as insurance, vehicle depreciation and maintenance. Ref. [32] analysed these factors between 1995 and 2015 and found that in the UK, USA and Japan, owners of both mid-size battery EVs (BEVs) and hybrid EVs (HEVs) incurred lower costs than owners of ICEVs during the same period.

Fuel and electricity prices need to be estimated beyond the current year to provide insight into the future costs in ownership between EVs and ICEVs. This is difficult given the inherent fluctuation in oil and electricity markets. However, when investigating the relationship between oil and electricity prices, Ref. [33] found that the Engle–Granger co-integration method identified a short-term relationship between these fuel types. Ref. [31], on the other hand, assumed that changes in fuel prices would follow the past decade trends, which exhibit a 1.4% per year increase for petrol and a 1.1% increase for electricity. Their findings for New Zealand, therefore, cannot be easily transferred to an international context because user-end electricity costs differ drastically between countries, with higher household electricity costs in Germany, Denmark and Italy and lower costs in Mexico, Korea, and Turkey [34]. Such discrepancies in findings are reflected in international studies [35], which found that without subsidies, limited models of BEVs and HEVs incurred lower running costs than ICEVs at the time.

As the discussion above indicates, EV modelling is a relatively new area of research. Prior studies also focused on a narrow set of issues such as market penetration and charging infrastructure, which may ultimately be driven by price considerations made by individual prospective owners. We, therefore, contend that planning and developing forecasts of electric energy consumption alongside pricing in urban street networks is of critical importance because electricity demand and pricing will influence uptake.

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