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# How do drivers' attitudes to low emission zones change after experiencing it? – A pilot study in Norway

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ABSTRACT

Air quality is a problematic issue in many urban areas in the world, and transport contributes to this. This study investigates attitudes towards a piloted low emission zone (LEZ) and distance-based differentiated road user charging (RUC) system. Both policy instruments are likely to be implemented in combination in Norway, aiming at curbing local environmental issues in the largest cities and cover other external costs of car use. The piloted system uses GNSS to track the vehicles and we focus specifically on plug-in hybrid vehicles (PHEVs). The drivers in the experiment were encouraged to use electricity as much as possible within the LEZs, and the drivers were given a monetary incentive which simulates a distance-based RUC within the zones. Forty participants tested the system for several weeks. The technical data from the vehicles, and the participants' attitudes were measured both before and after testing the system and were analysed together to measure the participants' behavioural change and how this correlated with their attitudes towards the system. The results revealed a significant change in the drivers' attitudes before and after testing the system. The participants who were successful in using the LEZ system as intended (i.e. increased use of the electricity mode within the LEZ) gained a more positive attitude. There was no difference between the successful and the unsuccessful groups in their attitudes towards distance-based RUC. These findings highlight the importance of understanding how innovative transport policies aiming at regulating negative externalities from car use are affecting people's everyday life, as this is the major explanatory variable for user acceptance. Furthermore, the study also shows that using distance-based RUC as an incentive for stimulating to a mode shift to the electric engine in PHEVs is a promising avenue.

## 1. Introduction

Air quality is a significant problem in many urban areas in the world, and the transport sector is responsible for almost 30 % of the total $CO_2$ emission within the European Union, of which over 40 % can be attributed to passenger vehicles (Fevang et al., 2021). During the 1990 s, the Euro emission standards for vehicles was introduced to reduce harmful emissions, such as nitrogen oxides ($NO_x$), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) (RAC, 2023; Oltra et al., 2021; European Commission, 2021). Vehicle emission reductions have improved significantly since the 1990 s, contributing to improved air quality country-wide, but the local concentrations can still be high, particularly in some cities (Winkler et al., 2018). Hence, air quality in urban areas has become a political issue, and cities are forced to act, proposing the implementation of relevant policy instruments for imposing restrictions on traffic (Oltra et al., 2021).

Low emission zones (LEZs) are among the most widely adopted traffic policies in urban areas in Europe aiming at improving urban air quality (Zhai and Wolff, 2021). LEZs are areas within a city where there are restrictions on the operations of polluting vehicles (access restrictions), or where their operations are deterred through economic charging schemes. These policies have been proven to have great impact on local air quality, changing individuals' mobility choices to other transport modes, and making cities more attractive for visitors (Tarriño-Ortiz et al., 2021). An analysis of London's LEZ shows that during the second phase of the London LEZ the concentration of particulate matter was reduced by 5.5% (Zhai and Wolff, 2021). Furthermore, $NO_2$ concentrations were found to have decreased in Madrid after the implementation of LEZ (Lebrusán and Toutouh, 2021), and significant reductions of $PM_{10}$ and $NO_2$ concentrations were found after the implementation of LEZ in Lisbon (Santos et al., 2019). As environmental issues and development of urban areas are gaining increased political interest, pricing of road transportation to cover external costs in city centres has received new interest in the academic community. Different

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varieties of distance-based road use charging (RUC) are particularly gaining attention as Global Navigation Satellite System (GNSS) solutions are increasingly getting more advanced. For instance, Munir et al. (2021) find in their bibliometric review of the literature on road network pricing that there has been a substantial increase in the number of publications from 2018 and onwards. LEZs can be considered as one of several possible implementations of road network pricing, and within these zones it is possible to execute distance-based RUC to cover the external costs of car use.

LEZ can be implemented in a wide variety of ways and will be adjusted to the local or national context where it's implemented. One of the key features that varies is whether all vehicles (or just some types of vehicles) are included in the system. Traditionally, categorisation of vehicles in LEZs has been based on the Euro class requirements, such as in the London LEZ (Zhai and Wolf, 2021). Our study is based on a LEZ system that differentiates between zero-emission vehicles and traditional combustion engine vehicles, and we focus our study specifically on Plug-in Hybrid Electric Vehicles (PHEVs,). PHEVs are vehicles where the powertrain can be managed by the driver by using different driving modes, for instance shifting the propulsion power source between gasoline and electricity, or a hybrid mode where the vehicle itself regulates the composition between the two power sources. Norway has been a frontrunner in the adoption of battery electric vehicles (BEVs, i.e., vehicles that make use of electricity only), much due to policies aimed at favouring BEVs (Fevang et al., 2021). At the same time, PHEVs have become highly popular, since PHEVs also have been included in some of the policies favouring BEVs, such as reduced import fee on new vehicles. This has sparked a discussion on whether PHEVs should have reduced fees in the existing tolling system in Norway because the drivers of PHEVs could make use of their vehicles' functionalities to operate their vehicles like a BEV within a LEZ (Seter et al., 2021). We are therefore focusing on PHEVs in this analysis, where PHEV drivers were given a monetary incentive (see Section 2.1) for driving on electricity within the LEZ, which simulated a distance-based RUC. A human machine interface (HMI) offered information on the location of the zones in a map based on GNSS (i.e., a LEZ), every participant was shown a price for driving on petrol in cost per kilometre driven, and the equipment in the vehicle registered how far the vehicle drove within the zone (i.e., simulating a distance-based RUC). Hence, due to the technical data gathered from the vehicle in this experiment we can measure behavioural change of the participants. In other words, did the participants use more electricity within the LEZ when recommended by the system?

A second key feature that can vary in LEZ implementations is what collection technique is used for the pricing of the transportation. Several different strategies have been tested, such as physical toll booths, electronic charging, or toll stickers (vignette) (Schubert et al., 2022). Collection techniques for tolling technologies have seen a rapid development, where short-range radio transponders, automatic number plate recognition (ANPR) and positioning systems has made road tolling easier, cheaper, and more reliable (Munir et al., 2021; Iseki and Demisch, 2012). In Norway, a concept study from 2022 by the Norwegian Tax Administration and the Norwegian Public Roads Administration concludes that the current road taxation system in Norway is not accurate enough, and a stepwise implementation of a distance-based road pricing using GNSS is recommended (KVU, 2022). Hence, exploring how drivers would respond to a distance-based RUC is interesting for informing a potential future implementation of such policy measures.

### 1.1. Implementation of LEZs in Norwegian cities

Several cities in Norway have been reported to be above the threshold values for air pollutants, and Norway was found liable for not complying to the Air Quality Directive by the European Free Trade Association's (EFTA) Surveillance Authority (ESA) in 2015 (Santos et al., 2020). In 2016 a Norwegian national regulation was passed to enable local implementations of LEZ in Norwegian cities and municipalities (Lovdata, 2022). The city of Oslo started the political process of investigating whether they could implement a LEZ in 2017 after a suggestion from the local Green Party. This process met resistance from many different stakeholders, particularly from the industry and transport companies. There were also many unresolved issues related to the enforcement of such zones, and there were questions concerning technology, which both contributed to the idea of a LEZ in Oslo being abandoned.[1] Hence, so far, no city or municipality in Norway has implemented LEZ.

Simultaneously, several Norwegian cities are starting to include BEVs in their charging schemes. In 2019, BEVs in Oslo became a part of the tolling system, although the fares are considerably lower than for diesel and petrol vehicles.[2] For PHEVs no similar exemption from tolling has been offered, but with the introduction of LEZ it might become a topic of whether the owners of PHEVs should be allowed to enter the LEZ, or pay a lower fee, if they can document that they are driving on electricity, in practice operating the vehicle as a zero-emission vehicle inside the LEZ. Previous studies have shown that the consumers buying PHEVs are more likely to be choosing between a PHEV and a regular combustion engine vehicle than between a PHEV and a BEV (Fevang et al., 2021; Lane et al., 2018). Hence, when allowing PHEVs to enter the LEZ if they can document that they are driving on electricity, one could shift some consumers over from a regular combustion engine vehicle to a PHEV.

Tolling has a long history in Norway and has historically been used for financing road infrastructure such as roads, bridges, and tunnels. Today, however, the purpose of tolling of roads has become more complex and include a multitude of political goals, such as reducing the number of vehicles, stimulating the use of electric vehicles, reducing ques, and reducing emission from vehicles. Tolling is therefore today part of a much larger political framework, and the Norwegian state have made individual agreements with the four largest cities in Norway, called "city growth agreements" where it is stated that future growth of personal transport in these cities should be covered by public transport, cycling or walking.[3] Within this context, the introduction of LEZs has been discussed in Norway as a measure for stimulating to a modal shift, away from private cars to other transport modes.

### 1.2. National policies for RUC

At the same time as cities are working on restraining car use, national policies in Norway favouring zero emission vehicles have made Norway a frontrunner in implementation of BEVs. A powerful policy instrument in Norway for making BEVs more attractive is the current road usage tax, which is paid only on the sales of petrol and diesel. The purpose of the road tax is to price the external costs that the vehicles impose on society. External costs can include accidents, queues, noise, road wear, and environmentally harmful emissions. Hence, the tax is included when buying petrol and gas, which effectively means that BEVs are not paying for the external costs. However, this could be about to change, as the Norwegian state is experiencing reduced income form the road use tax as the share of BEVs is increasing (KVU, 2022).

This was the background for the concept study carried out by the Norwegian Tax Administration and the Norwegian Public Roads

[1] See https://www.nbf.no/artikler/2018/politikk-kommunikasjon-og-rekruttering/lavutslippssone-i-oslo-skrinlagt/ and https://bilimportorene.no/lavutslippssone-utsatt-inntil-videre/ (only in Norwegian).

[2] See https://www.fjellinjen.no/privat/nyhetsarkiv/slik-blir-takstene-for-elbil-i-bomringen-article1610-966.html for information on the tolling system for BEVs in Oslo (only in Norwegian).

[3] See https://www.regjeringen.no/no/tema/transport-og-kommunikasjon/kollektivtransport/belonningsordningen-bymiljoavtaler-og-byvekstavtaler/id2571977/ (only in Norwegian).

Administration in 2022, and the recommendation from the report was to have a stepwise introduction of distance-based road pricing at the national level. As a step 1, zero-emission vehicles would be charged based on distance travelled. Step 2 includes the heavy vehicles (KVU, 2022).

### 1.3. Combining LEZ and RUC

Hence, in the case of Norway, if LEZs are implemented, they are likely to be combined with distance-based RUC. By combining LEZs with RUC, it is possible to merge the need of the Norwegian state to gain income and cover external costs from road use with the need of the largest Norwegian cities to pose local restrictions on traffic. Similarly, the LEZ in London is combined with congestion charge and an ultra-low emission zone operating 24 h.

While no Norwegian city has implemented a LEZ yet, and distance-based RUC is still being evaluated by the Norwegian Tax Administration and the Norwegian Public Roads Administration, a study focusing on Oslo shows that LEZs could have a large potential for improving air quality: Santos et al. (2020) compares the effect of different measures for decreasing $NO_2$ air concentrations in the Oslo area using modelling predictions and find that LEZ is the most effective measure, while the second most effective measure was increased parking fees. All other permanent measures were found not to be effective. Out of the suggested temporary measures considered, the most effective measure was a ban on diesel vehicles during periods with cold weather. Hence, PHEVs could be allowed to enter the LEZ if they can document that they are using electricity, the introduction of LEZ could be a more accepted political instrument among the population.

Indeed, a major barrier for the implementation of effective policies to curb climate change is the lack of support from the public (Jagers et al., 2019), an argument also found in the literature on the implementation of autonomous vehicles (AVs) (Butler et al., 2021) and of advanced driver assistance systems (ADAS). Individuals, given their role as end-users of products and services, will have a critical role in determining which solutions could be adopted, both in terms of climate policies and the use of AVs in the future. Hence, investigating the level of support for individual policies becomes crucial, especially before the policies are implemented, as this could help to ease the process of implementation, such as in the case of LEZ in Norwegian cities.

### 1.4. Measuring drivers' attitudes to technology

There are many different approaches to how drivers' attitudes towards a technology can be investigated. "Acceptability" refers to the prospective judgement of a policy that will be introduced in the future. This approach means that the target group have not yet experienced the policy (Romero et al., 2020; Jia et al., 2017). Typically, these studies are concerned with intentions to adopt the suggested technology, often referred to as theory of reasoned action, or they use the stated preference method which focuses on a choice experiment (Fevang et al., 2021). A different approach is to look at the "acceptance" of a policy, which is the target group's attitudes after experiencing the effects of a policy (Jia et al., 2017). This can be investigated using many different approaches, including surveys and information on behavioural change. Both approaches are important tools for measuring how drivers will respond to a particular technology or policy. For instance, studies have found changes in users' attitudes when investigating acceptability and acceptance for congestion charging in Sweden (Schuitema et al., 2010; Börjesson and Kristoffersson, 2018), and for license plate restriction policy in China (Jia et al., 2017). In these studies, the results showed increased support for the systems after experiencing them.

Another example of changed attitudes can be found in Fevang et. al. (2021), who investigated the adoption of battery electric vehicles (BEVs, i.e. vehicles that make use of electricity only) in Norway, finding strong evidence that actual purchases of BEVs are much lower than consumers' stated preferences. Their results indicated that the stated preferences for BEVs (acceptability) were rated higher than the actual BEV buying behaviour (acceptance), suggesting that experience with the technology is important for attitudes. Hence, the more psychologically distant a product is when described in surveys, the more unlikely it is that the results of such studies can predict actual future behaviour (Skippon and Garwood, 2011). Thus, studies based on acceptability risk having limited validity when predicting future driver behaviour.

Many different factors have been suggested to shape attitudes towards climate or environmental policy measures such as LEZ. Explanatory variables include socio-demographic characteristics, policy attitudes, and characteristics of the proposed measure itself (Jagers et al., 2019). Socio- demographic variables are found in the literature to have a varying effect on the attitude towards LEZs. Some find the higher age groups to be more positive (Mehdizadeh and Shariat-Mohaymany, 2021), while others find that the higher age groups are more negative towards LEZ (Oltra et al., 2021). Men are found to be more negative of LEZ (Mehdizadeh and Shariat-Mohaymany, 2021; Liu and Zheng, 2013). Higher education is shown to give a more positive attitude towards LEZ (Mehdizadeh and Shariat-Mohaymany, 2021), while Tarriño-Ortiz et al. (2021) find that acceptability of LEZ is only weakly related to socio-economic variables such as gender, and education. However, Sun et al. (2016) find that socio-demographic variables have a low association with the acceptability. As argued in Seter et al. (2021) the participants in such experiments are likely to be "early adopters" (Rogers, 2003). The early adopters are in general highly educated, have high income, and have a positive attitude towards new technology.

Strong environmental awareness has been argued to be an important explanatory variable for support of various environmental policies. Overall, several studies investigating attitudes to LEZ find that environmental values have a positive impact (e.g., Mehdizadeh and Shariat-Mohaymany, 2021; Tarriño-Ortiz et al., 2021; Jain et al., 2021; Loukopoulos et al., 2005) However, some studies also find that individuals with strong environmental values do not necessarily take pro-environmental action in their everyday life (Jagers et al., 2019; Shatanawi et al., 2020). Others find that financial gain is a more important motivation for car buyers than perceived environmental benefit (Alzahrani et al., 2019). Another important explanatory variable for attitudes toward LEZ is travel patterns (Tarriño-Ortiz et al., 2021; Liu and Zheng, 2013). A study from Teheran, Iran, find that those living close to the LEZ are more negative, as well as commuters (Mehdizadeh and Shariat-Mohaymany, 2021). Francke and Kaniok (2013) find that frequent drivers were less flexible in their behavioral change intention following different charging schemes. In other words, it is expected that practical issues could be important for explaining attitudes toward environmental policies within transport.

### 1.5. Objectives

Given the large variety in implementation strategies for LEZ, this study aims to address attitudes to LEZ in a Norwegian context. The long tradition for tolling in Norway, combined with the current discussion on distance-based road pricing, strong economic incentives for zero emission vehicles, and increased focus on sustainable urban areas makes it likely that a future implementation of LEZ in Norway will be combined with distance-based RUC. The LEZ would then attempt to regulate traffic within the largest Norwegian cities, while the distance-based RUC would ensure that the external costs are covered by the drivers using the road.

We use an experimental design where the drivers are using their own vehicles over a longer period, which represents a novel approach which will give useful results as this could be argued to resemble more how drivers would be introduced to this kind of technology in real life. Studies focusing on drivers' attitudes are often based on data from experiments that is limited in terms of period used (a drive test or simulator study) or they do have any experience with the technology (i.e., use a stated preference survey). Previous studies have found that the length

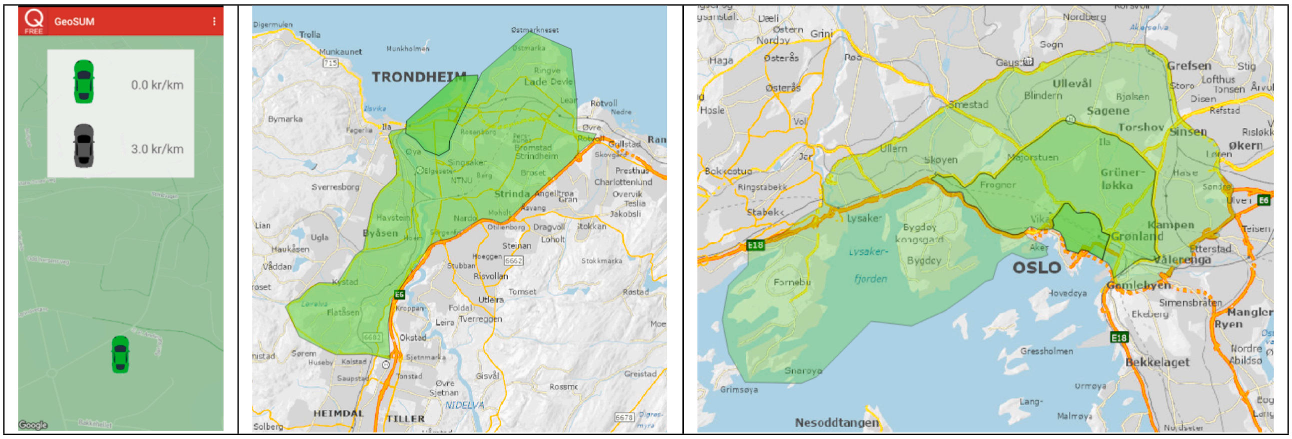


**Fig. 1.** GeoSUM test equipment consists of interface (shown) on smartphone and with OBD2 connector to vehicle (not shown) in left picture. Also shown are the LEZ geofence zones used in the pilot in the city of Trondheim (13 km × 11.0 km shown) and Oslo (11.0 km × 14.0 km shown) in middle and right picture, respectively. A stronger green colour represents a higher price driving on petrol. Both maps are oriented with north upwards. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of the test and the specific test equipment matters for trust in vehicle technology (Lubkowski et al., 2021; Kidd et al., 2017). It can be expected that drivers using their own vehicles will evaluate the equipment differently than those using a test vehicle, or driving a simulator (Lubkowski et al., 2021). This study therefore asks the following question (RQ1) *How do drivers' attitudes towards LEZ change after experiencing the piloted system, and what are the explanatory variables for this change?*

In addition, we also investigate how the drivers would respond to the LEZ being coupled with road user charging (RUC): (RQ2) *What are the drivers' attitudes towards RUC within LEZs?*

To address these questions, this study makes use of an innovative approach, where survey responses from participants in the experiment is combined with technical data from the vehicle measuring the drivers' behavioural change and travel patterns registered through GNSS-derived information. We conducted two surveys, where we measure the participants attitudes toward LEZ before testing the piloted system (acceptability), as well as their attitude towards LEZ after testing the system (acceptance). We measured the participants attitude towards distance-based RUC in the second survey.

By combining the GNSS-derived travel patterns with results from surveys, it is possible to combine objective data from the vehicle concerning changed travel behaviour with subjective data on the attitudes of the drivers. The experimental setup represents a novel approach within the literature, where the participants in the experiment had the equipment installed in their privately owned vehicles for eight weeks, providing the drivers valuable hands-on experiences over a long time period. This experiment provided us with a unique dataset of technical data from the vehicles.

## 2. Method and procedure

### *2.1. Description of pilot and data collection*

In total 75 participants driving PEHVs in the cities of Oslo and Trondheim were equipped with a test on-board unit (OBU) developed by Q-Free. Q-Free (Q-Free, 2022) is a Norwegian technology company for intelligent transport system solutions, mostly known for their tolling solution. The OBU consisted of the on-board diagnostic 2 (OBD2) connector communicating via Bluetooth with a smartphone where an application was used as human machine interface (HMI). The OBU logged data from both the vehicle and the smartphone (see left picture in Fig. 1). This equipment was kept in the vehicles for eight weeks with the two first weeks acting as a black mode period, meaning that no information was given to the drivers, i.e., only a black screen was shown during driving, although data was still logged. In the last six weeks of the pilot, referred to as the live mode period, the participants were shown their vehicle position on a map and the presence of geofenced LEZ in green (see middle and right picture in Fig. 1), and given an incentive to drive on electricity inside the LEZs. The purpose of the black and live mode periods was to help identify a causal link between the equipment and the behaviour of the test drivers. By tracking the test drivers in the black mode period, a before-treatment measurement of driving behaviour could be established and compared with the behaviour of the participants after being exposed to the treatment in the live mode period.

When driving into a LEZ the driver got information that he/she had entered a LEZ and that it was recommended to drive on electricity. Every participant was shown a price for driving on petrol in cost per kilometre driven, and the price simulates a distance-based RUC (see Arnesen et al., 2021 for more information). Driving on electricity was always free of charge inside the LEZ. In the experiment, driving outside the zones was free of charge independent on using petrol or electricity. At the beginning of the pilot, the participants were given the promised of price money of 1,000 Norwegian Kroner (NOK) after the pilot (approximately 100€). They were also informed that the cost of driving on petrol within the LEZ would be deducted from this maximal possible sum (1,000 NOK) to simulate actual payment. As we are interested in RUC, which is a payment, we chose this approach to get closer to a real implementation as an alternative to rewarding the drivers more directly, e.g. giving rewards for behavioural change.

Different zones were defined for both Trondheim and Oslo to differentiate the cost per kilometres. While Trondheim presented two zones (inner and outer), Oslo presented three zones (inner, middle and outer), see Fig. 1: lighter green represents outer zone and stronger green represents inner zone. The inner zones represented a higher price for driving on petrol. The cost per kilometre was set to 3 NOK/km and 6 NOK/km in the outer and inner zone of Trondheim, respectively, and 2 NOK/km, 4 NOK/km and 6 NOK/km for the outer, middle and inner zones of Oslo, respectively. Once a week, the participants were informed of the remaining sum on their price money, and at the end of the pilot the participants were paid the remaining price money. The pilot experiment was conducted from mid-September to mid-November 2020. The geofences and their assigned prices were stored in the National Road Data Base in Norway (NVDB, 2022) and read by the OBU. The LEZs in each city roughly followed the current tolling boarders, with Trondheim given one extra inner zone. The location of the current tolling stations in these two cities can be found in the a ppendix. The zones defined for this pilot was decided by the Norwegian Public Roads Administration and represents a first iteration on how future LEZs could

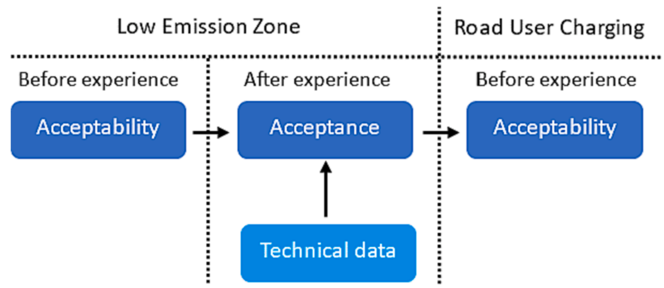


**Fig. 2.** Overview of evaluation approach when measuring acceptability/acceptance and acceptability for LEZ and RUC, respectively, using the pilot setup and its data collection.

be set up for these two cities. The political focus in Norway is typically to replace or add to the current tolling borders, with the aim to reduce traffic and pollution within the cities, which also was supported in the recent concept study by the Norwegian Tax Administration and the Norwegian Public Roads Administration (KVU, 2022), discussed in more detail in Section 4.2 in this paper. The prices for driving within the LEZs were estimated using the current prices at the tolling stations, average trip length from local travel surveys and balanced up against the length of the live mode period of the pilot (six weeks). More details on the test set up and the construction of the LEZs can be found in Arnesen et al. (2020).

Variables from three data sets are used in the analysis of this paper, two surveys (before and after using the system to evaluate acceptability and acceptance of LEZ, respectively), and the technical data log generated from the OBU test equipment to collect possible behavioural changes. In addition, the test provided an interesting backdrop for the drivers to evaluate their acceptability towards a RUC system for LEZs. An overview of the evaluation approach is shown in Fig. 2.

### 2.2. Questionnaires

The overview of all included questions in both questionnaires are presented in Table 1. For all variables excluding the socioeconomic variables and the two explanatory variables related to electricity usage habits, for which the scales are given in the caption of the table, a numeric scale from 1 to 5 was used to represent the answers on one of two scales: from “Strongly Disagree” (1) to “Strongly Agree” (5), and from “No degree” (1) to “Large Degree” (5). Although the scales used for these questions are not identical for acceptability and acceptance in terms of the phrasing used, the results are still comparable as they are all scales ranging from 1 to 5, where the middle category, 3, represents a “neutral” category in both scales. In addition, we asked an open-ended question to gain more qualitative insights into how the equipment and the experiment was perceived by the participants, this was important to gain more in-depth knowledge.

The explanatory variables are derived from previous research, presented in section 1.4, and are divided into groups. We have the following groups of variables: socio-demographic (SD), importance of car (IC), technology optimism (TO), and environmental awareness (EA), as well as more practical-oriented variables related to electricity (EL) and attitudes related to PHEVs (PA).

### 2.3. Technical data: Behavioural change documented through GNSS-derived travel patterns

The technical data contained GNSS-derived travel pattens that were used for measuring travel behaviour and behavioural change. The application logged technical data including GNSS position, heading, and presence within zones, while vehicle data from OBD2 port included parameters like speed and rpm (rounds per minute) at a frequency of approximately 1 Hz. These parameters also revealed electricity and

**Table 1**
Concepts targeted by the pre- and post-questionnaire. For sociodemographic variables the numbering are given as follows: Gender as “Female” (1) or “Male” (2), Age as integer numbers, Education as “No more than junior high school” (1), “high school” (2), “college/university 3 years or less” (3), “college/university 4 years or more” (4) or “PhD study and more” (5), and Years with license as integer numbers. For the explanatory variables related to electricity usage the following is used: How often do you charge? as “Less than once a week” (1), “Approximately once a week” (2),“ Several times a week” (3), “Daily” (4), “Several times a day” (5), and How far can car drive on pure electricity? as “Less than 10 km” (1), Between 10 and 20 km“ (2), ”Between 20 and 30 km“ (3) and ”Above 30 km“ (4).

| **Concept** | **Operationalization** | **Statistics (n = 40)** | | | |
|---|---|---|---|---|---|
| **Pre-questionnaire** | | **Mean** | **Std** | **Min** | **Max** |
| Acceptability LEZ | I expect that the technology will make me more aware of the local emissions from my vehicle. | 4.0 | 0.75 | 1 | 5 |
| Socio-demographic (SD) | **SD1**: Gender | 1.33 | 0.47 | 1 | 2 |
| | **SD2**: Age | 48 | 10.09 | 31 | 63 |
| | **SD3**: Education | 3.6 | 0.83 | 1 | 5 |
| | **SD4**: Years with license | 28.1 | 10.52 | 2 | 45 |
| Electricity (EL) | **EL1:** How often do you charge? | 3.9 | 0.86 | 1 | 5 |
| | **EL2:** How far can car drive on pure electricity? | 3.5 | 0.64 | 2 | 4 |
| Importance of car (IC) | **IC1:** To me, the car is only a practical matter of transportation. | 3.5 | 1.3 | 1 | 5 |
| PHEV attitudes (PA) | **PA1:** I would rather choose to buy a pure battery electric vehicle if the available models, range, and price would fit better to my demands. | 4.4 | 0.87 | 1 | 5 |
| | **PA2:** I choose to save electricity to specific parts of my trip while driving. | 2.4 | 1.48 | 1 | 5 |
| | **PA3:** I choose actively to drive on petrol to achieve higher vehicle speed, acceleration, etc. | 1.9 | 1.07 | 1 | 4 |
| | **PA4:** I try to use the information provided by the vehicle to drive as much as possible on electricity. | 4.2 | 0.74 | 2 | 5 |
| | **PA5:** I am consciously aware of where and when the vehicle is using electricity. | 3.9 | 0.9 | 1 | 5 |
| Technology optimism (TO) | **TO1:** I think it is important to test new technology. | 4.1 | 1.24 | 1 | 5 |
| | **TO2:** I think it is important to drive a car with the most recent technology. | 3.5 | 1.06 | 1 | 5 |
| Environmental awareness (EA) | **EA1:** Human made climate change is the most important challenge in society today. | 4.3 | 0.92 | 2 | 5 |
| | **EA2:** Local emissions are a large problem in my city | 3.4 | 0.98 | 2 | 5 |
| **Post-questionnaire** | | | | | |
| Acceptance LEZ | To what degree did the technology help you drive more environmentally friendly inside the LEZs? | 4.0 | 1.16 | 1 | 5 |
| Acceptability RUC | **RUC1:** I, as a driver of PHEV, am positive towards differentiated charging within geofenced LEZ. | 4.5 | 0.79 | 1 | 5 |
| | **RUC2**: I, as a driver of PHEV, would drive more on electric power than usual now if differentiated | 3.7 | 1.45 | 1 | 5 |

(continued on next page)

**Table 1** (*continued*)

| Concept | Operationalization | Statistics (n = 40) | | | |
|---|---|---|---|---|---|
| **Pre-questionnaire** | | **Mean** | **Std** | **Min** | **Max** |
| Acceptability LEZ | I expect that the technology will make me more aware of the local emissions from my vehicle. | 4.0 | 0.75 | 1 | 5 |
| | charges was implemented within geofenced LEZ | | | | |
| | **RUC3:** When taking your experiences in this pilot study into account, to what degree would you consider it likely that you would switch to electricity within LEZ if this resulted in lower charging rates? | 4.6 | 0.60 | 3 | 5 |
| | **RUC4:** When taking your experiences as a pilot into account, to what degree do you think it is more fair to pay charges based on distance driven within a LEZ, when compared to the tolling system of today? | 4.53 | 0.65 | 3 | 5 |

petrol usage, as in Dahl et al. (2020) and Arnesen et al. (2021) it was shown that on average the participants reduced their driving on petrol within the LEZs in the live mode period as compared to the black mode period. The technical parameters measured in this pilot, e.g., GNSS position, fuel usage and speed, are all parameters that could be necessary to log in an actual implementation of distance-based RUC, including the high frequency of data (1 Hz in the pilot).

### 2.4. Description of the sample

Out of the 75 participants included in the pilot, 40 participants drove within the zones both in the black mode and the live mode period and answered both questionnaires. These represent the included participants in this study, driving in total 9102 km within the LEZ in the black mode and the live mode period combined, or 233 km each on average. Field experiments, as performed in this study, may provide the most reliable results in terms of describing how drivers actually use the technology, but these experiments are in general consuming in terms of both time and budget, which limit the sample size (Harms et al., 2020). Within the area of studying advanced driver assistance systems (ADAS), our sample (n = 40) is regarded as a sufficient sample size. See Bosurgi et al., 2023, Carney et al., 2022, Son et al., 2015 for examples of similar sample sizes in experiments on the effects of ADAS systems on users.

The sample consisted of 27 male and 13 female participants (see Fig. 3), between 30 and 65 years old. One possible reason why there were no participants below 30 is probably because these vehicles are relatively new, being in the upper part of the price segment. Fevang et al. (2020) used a representative sample of car owners in Norway and found that the average age for PHEV owners is 50.8 years, compared to 48.0 years in our data set, supporting that PHEV owners are likely to be in the higher income levels. Their sample also included more males than females. This suggests that the sample in this study could be representative for the PHEV owner population at large in Norway.

The participants were recruited through media and announcements on social media. The recruitment criteria were *i.* to be over 18 years old, and *ii.* people who drive a plug-in hybrid car of the type of Volvo, Toyota or Mitsubishi, as these were the three most sold plug-in cars in Norway at this point in time. As these cars at the time of the pilot had only existed

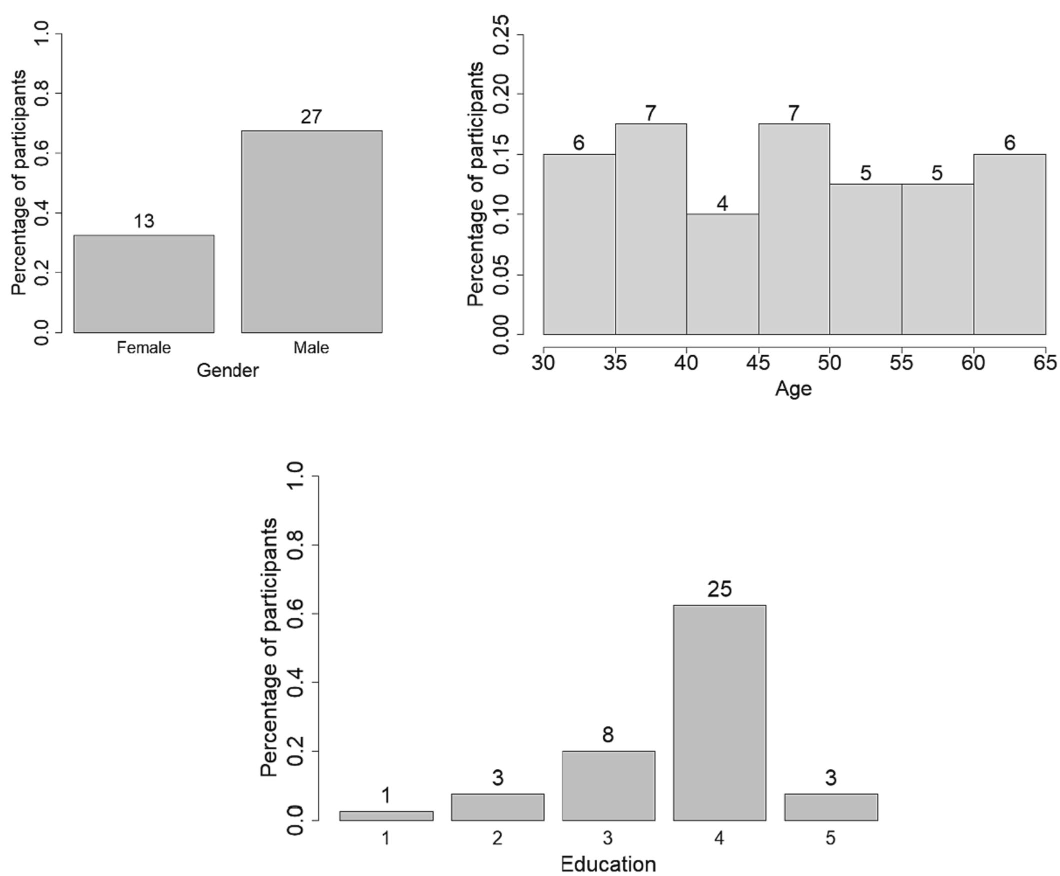


**Fig. 3.** Distribution of gender, age, and education of the 40 participants included in this study. For education, the following coding apply: No more than junior high school = 1, high school = 2, college/university 3 years or less = 3, college/university 4 years or more = 4, PhD study and more = 5. Sample size n = 40 for all three plots.

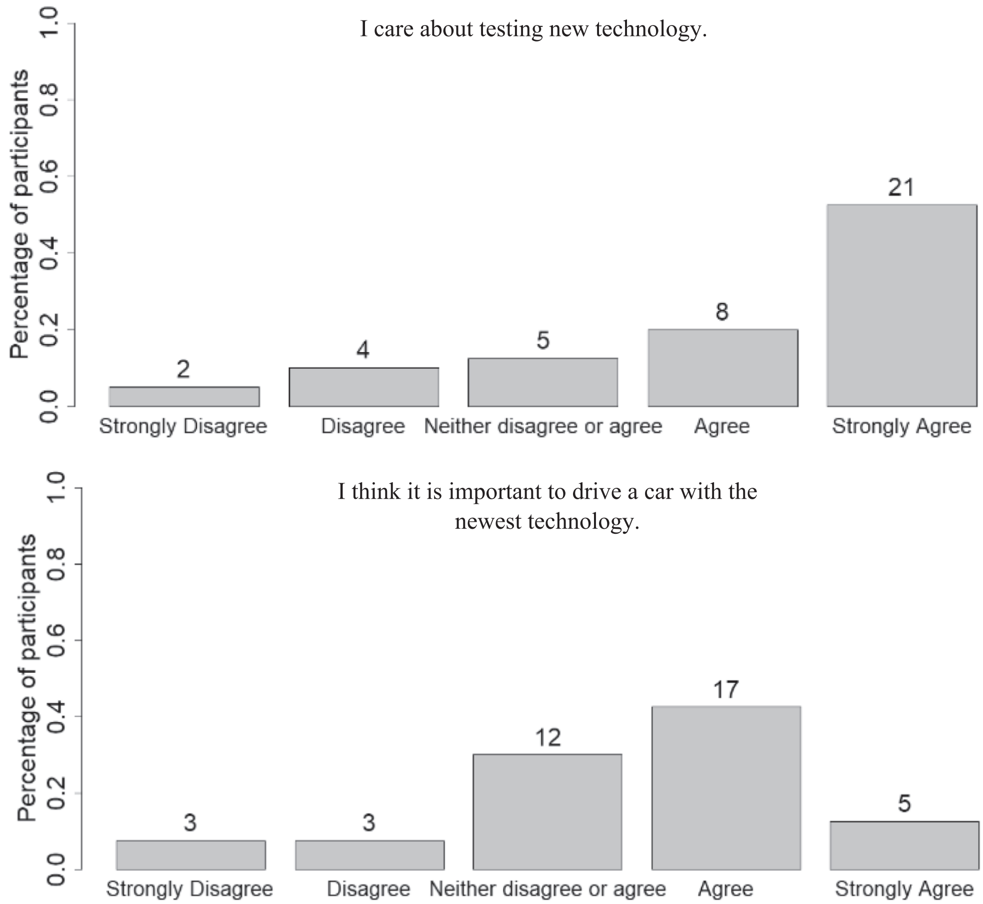


**Fig. 4.** Questions measuring the participants attitude towards using new technology (n = 40).

in the marked for a limited time, all cars were less than 3–5 years old, so it was decided not to collect further details about the model year for each car. Other studies have found that the energy use and GHG emissions are significantly influenced by the drive mode used by PHEVs (Karanam et al., 2022), but this was not the main focus of our study as we were interested in the behavioural change of the drivers.

The responses to the two questions from the pre-questionnaire (see Fig. 4) on technology supports that the sample is characterised by having a high level of technology optimism. The Diffusion of Innovations Theory could also be useful for explaining the descriptive characteristics of the participants in this study. Generalisability is always an issue for studies that have a non-representative sample, but for the purpose of this study and the technology presented here, the early adopters is a particularly interesting sub-group in the population from which experiences can be documented. This group is essential for wide-scale adoption because they are more willing to try new technologies and are therefore likely to be the first buyers.

## 3. Results

### 3.1. Analysis strategy

The initial results of the study showed that the participants in general have a positive attitude towards the LEZ system, both before and after experiencing it (see Fig. 5).

After a visual inspection of the distribution of the responses to both questions, a shift was observed among the participants, with some having a more positive attitude towards the systems, whereas others had a more negative attitude. Based on those initial results, a question arose: *what variables can explain why the system appears more useful to some participants and less to others, when compared to their expectations?* For further exploration, the sample size was split based on the behavioural change measured by the technical logging data. This split was used as basis for the analysis of the acceptance/acceptability questions.

Indeed, the technical data collected allowed to investigate the behavioural change for each participant. The reduction (or increase) of petrol driving within the LEZ was plotted for each participant, with a significant average of 7.5 percentage points change ($p$-value of = 0.0208 using a two-sided $t$-test). All participants above zero drove more on electricity in the live mode period as compared to the black mode period, and the participants below zero drove less on electricity in the live mode period (see Fig. 6). These findings indicate that only some of the participants were successful in increasing their use of electricity driving within the LEZ.

Based on these calculations, the participants were separated into two groups, one consisting of 27 participants that had a measured positive effect of LEZ (Change in electric driving $>$ 0 percentage points), called the “Success”-group, and one group of 13 participants that did not have a positive effect (Change in electric driving $\leq$ 0 percentage points), called the “No Success”-group. Why the system appears more useful to some participants and less to others will be discussed in the following sections.

Aiming to respond the research questions, the following sub-sections present first the results for acceptability and acceptance of LEZ, followed by the results of acceptability of RUC. The last sub-section shows the results of in-depth statistical analyses performed to explore the variables that might explain both the acceptability and/or acceptance of both studied systems.

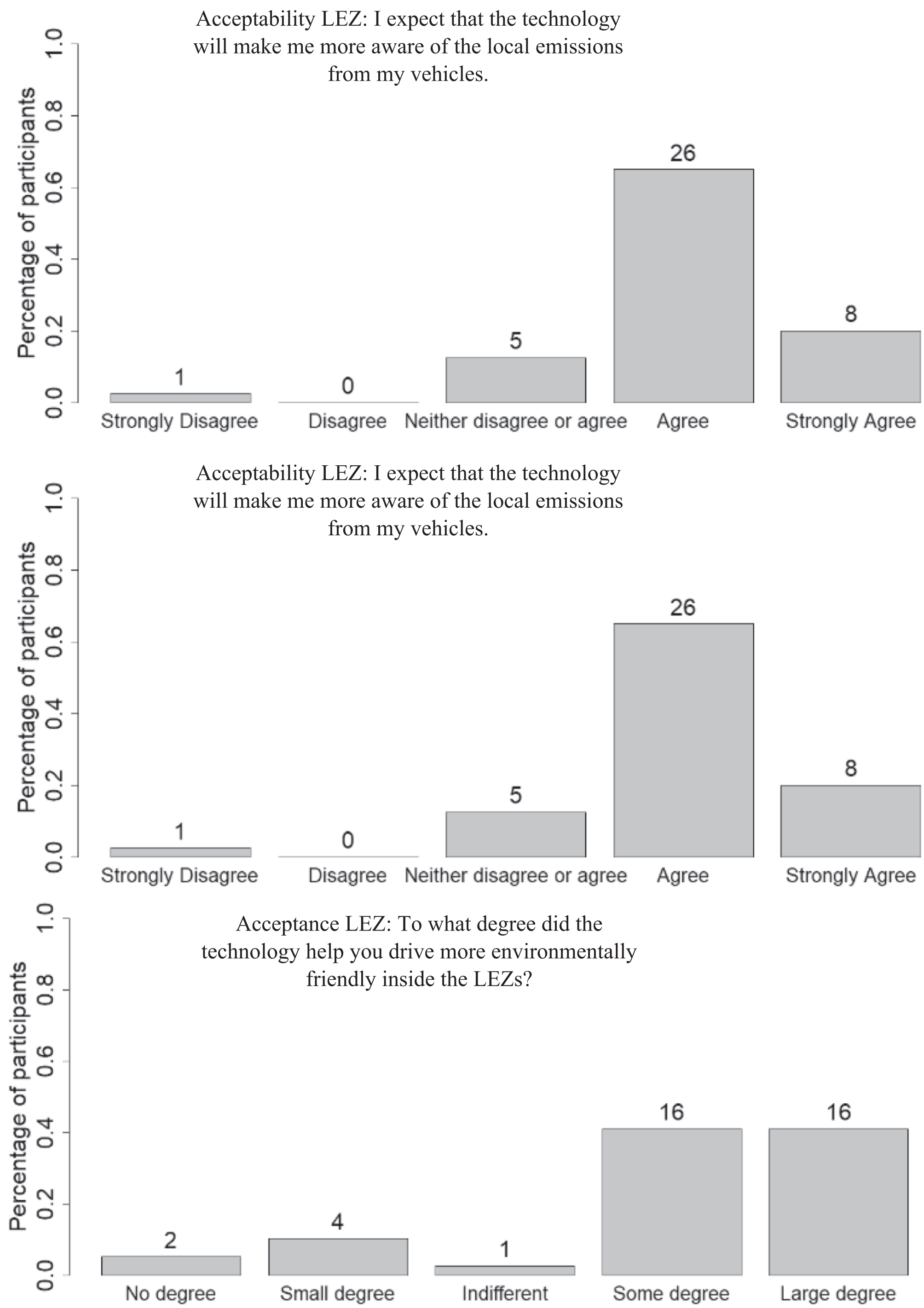


**Fig. 5.** Questions in the pre- and post- questionnaire regarding the acceptability and acceptance of the piloted system for LEZ (n = 40).

### 3.2. Acceptability and acceptance of LEZ

Fig. 7 shows the calculated average answers to both acceptability and acceptance of LEZ, divided by the success and no success group.

For acceptability we can see that the averages of the two groups are quite similar with averages of 3.96 (success) and 4.07 (no success). The yellow colour indicates that the two groups are not found to be statistically significant different. Moving on to the acceptance question for LEZ, we find an average of 4.26 for the success group and 3.50 for the no success group. With a one-sided *t*-test with unequal variances testing for difference in the means we get a *p*-value of 0.03, which we consider a strong indication that there is indeed a difference between the two groups in terms of their acceptance of LEZ. A similar result is given if a Wilcoxon rank sum test is performed to test the difference between the two groups ($p = 0.02$). These results are highlighted in the table with green for the success group, and red for the no success group.

Given the lack of significant difference between the success and no success groups, we suggest that a plausible explanation is that practical matters concerning how the technology fits with your everyday life, such as battery level on longer trips, is an important explanation for the acceptance of LEZ.

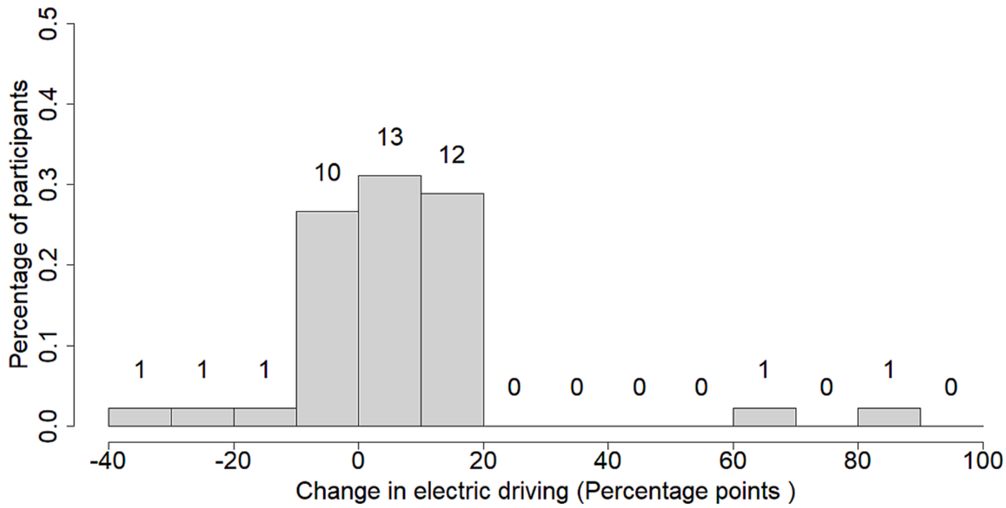


**Fig. 6.** Each participant's effect of the piloted system (n = 40).

| | Success | No Success |
|---|---|---|
| Acceptability LEZ | 3.96 | 4.07 |
| Acceptance LEZ | 4.26 | 3.50 |

**Fig. 7.** Difference between acceptability and acceptance for LEZ for the two groups having success and no success.

**Table 2**
The correlation between the four RUC parameters using Pearson's correlation coefficient.

| | RUC1 | RUC2 | RUC3 | RUC4 |
|---|---|---|---|---|
| RUC1 | 1 | 0.343 | 0.249 | 0.388 |
| RUC2 | | 1 | 0.329 | 0.127 |
| RUC3 | | | 1 | 0.346 |
| RUC3 | | | | 1 |

### 3.3. *Acceptability of RUC*

Four questions were developed to get feedback on the acceptability of RUC (see Table 1). Although none of these questions are measured to be significantly different between the success and no success group (all $p$-values above 0.10), the mean values of the success group were slightly higher compared to the no success group. Moreover, when the data was analysed jointly (i.e. both groups together), the results showed average values above 3.69, suggesting that the majority of the participants were positive towards this type of payment, regardless of the success using the LEZ.

A potential explanation for the lack of significant difference in acceptability of RUC is that the participants did not fully experience the RUC in their everyday life as they experienced LEZ, as only price money was used to simulate RUC.

### 3.4. *Explanatory variables to acceptability and acceptance*

Trying to understand the underlying cause of why some of the participants did not experience increased acceptance after experiencing the system, a significant difference was found between the length driven between the two groups, both inside the LEZs and in total, during the live period. Specifically, an average distance of 137.3 km was driven for the success group increasing their electric driving and 262.6 km on average for the no success group not benefitting from the system inside the zones. Likewise, 401.2 km were driven on average and 535.8 km on average for the two groups in total. The length driven is to some degree a variable out of control for the participants and would in practice set limitations to how much electric driving within the zones the participants can do, given the limited battery capacity of PEHV vehicles.

To check for explanatory variables affecting the participants attitudes towards the piloted LEZ system, the significance of the differences between means of the two identified groups were tested using a two-sided $t$-test with calculated $p$-value. The results showed little to no difference between the two groups, as none of the correlations were found to be significant (all $p$-values above 0.05). Very similar result was found if utilizing Wilcoxon sum of rank tests instead of the parametric $t$-test.

Furthermore, to investigate the presence of correlation between explanatory variables on the one side, and acceptance and acceptability, respectively, on the other side, a simple bi-variable correlation analysis between all combinations of acceptance/acceptability and explanatory variables using to calculate the p-value was performed, see Table A included in the a ppendix. The results in Table A show some few significant relations. To control for multi-dependencies, each of the acceptance/acceptability variables were treated as dependent variables, and the explanatory variables were treated as independent variables in a linear regression model. In addition, we estimate a regression model for the acceptability of RUC by averaging over the four acceptability RUC variables, which is correlated according to Table 2. The correlation between the four RUC variables all show low to moderate correlation.

Moreover, to account for the low number of observations, dependence between the explanatory variables, and optimize fit, a stepwise bi-directional linear regression procedure was implemented to include/exclude independent variables based on the AIC (Akaike Information Criterion). This is done using the packages "stepwise" function within the "StepReg"-package (Li, 2022) in R (R Core Team, 2022). The results, with excluded explanatory variables shown as blank and estimated regression coefficients as numbers, are shown in Table 3, and corresponds well with the significant parameters shown for the Pearson test in Table A in the a ppendix. Below the table we also list the estimated models in equation form.

The estimated models, and especially the included explanatory variables and R-square values can now be compared across models and analysed. The explanatory variables EA1: "*Human made climate change is the most important challenge in society today*" and TO2: "*I think it is important to drive a car with the newest technology*" are found to be best included in the regression model for the acceptance of LEZ (per AIC) and were close to significant in terms of Pearson's test (on a 10 % level). Also, the coefficient for the variable EA1: "*Human made climate change is the most important challenge in society today*" is significantly reduced in comparison to that of Acceptability of LEZ, supporting the hypothesis

**Table 3**
Estimated linear regression models, estimated using a stepwise bi-directional procedure using AIC as selection criteria. Included independent variables are shown with coefficient estimates and estimated standard deviation (sd) and p-values (*, **, and *** and indicate 10%, 5%, and 1% significance, respectively), while excluded variables for some dependent variables is shown with blank cells and excluded variables for all dependent variables are taken out altogether (not shown). Variable denotation is given in the second column. Estimated R-squared values are given in the bottom row for each estimated model.

| | Acceptability LEZ | Acceptance LEZ | Acceptability RUC1 | Acceptability RUC2 | Acceptability RUC3 | Acceptability RUC4 | Acceptability RUC (RUC1:RUC4) |
|---|---|---|---|---|---|---|---|
| Intercept | 1.233 (0.924) | 4.643*** (0.810) | 4.471*** (0.142) | 2.241** (0.904) | 3.049*** (0.564) | 3.648*** (0.737) | 4.142*** (0.565) |
| **SD1:** Gender | | | | | | | −0.343* (0.18) |
| **SD2:** Age | | −0.020* (0.011) | | | | −0.034** (0.017) | |
| **SD4:** Years with license | | | | | | 0.057*** (0.016) | |
| **IC1:** To me, the car is only a practical matter of transportation | | | | | 0.089 (0.065) | | |
| **PA1:** I rather chosen to buy a pure battery electric vehicle if the available models, range and price would fit better to my demands | | | | | 0.133 (0.095) | 0.218** (0.105) | 0.207** (0.097) |
| **PA2:** I choose to save electricity to specific parts of my trip while driving | 0.340** (0.132) | | | | −0.163** (0.065) | | −0.090** (0.061) |
| **TO1:** I care about testing new technology | | | | | 0.255*** (0.082) | | |
| **TO2:** I think it is important to drive a car with the newest technology | | −0.149 (0.108) | | | | | |
| **EA1:** Human made climate change is the most important challenge in society today | 0.447** (0.196) | 0.188** (0.124) | | | | | |
| **EA2:** Local emissions is a large problem in my city | | | | 0.422** (0.251) | | | |
| R^2 | 0.277 | 0.181 | NA | 0.081 | 0.359 | 0.431 | 0.285 |

**Table A1**
Pearson's product moment correlation with two-sided t-distribution to calculate the p-value between all explanatory variables and acceptance/acceptability variables, * indicating significance on a 10 % level, ** indicating significance on a 5 % level. The function "cor.test" is used within the standard "stats"- R package (R Core Team, 2022) for these calculations.

| | Acceptability LEZ | Acceptance LEZ | Acceptability RUC1 | Acceptability RUC2 | Acceptability RUC3 | Acceptability RUC4 | Acceptability RUC (RUC1:RUC4) |
|---|---|---|---|---|---|---|---|
| Gender | −0.033 | 0.144 | −0.049 | −0.105 | −0.261 | **−0.437**** | **−0.357**** |
| Age | −0.176 | **−0.288*** | −0.050 | −0.275 | 0.007 | 0.195 | −0.107 |
| Education | 0.019 | 0.041 | 0.201 | 0.011 | 0.280 | **0.358**** | **0.303*** |
| Years with license | −0.012 | −0.185 | 0.011 | −0.233 | 0.107 | **0.477**** | 0.051 |
| How often do you charge? | −0.231 | −0.040 | 0.120 | −0.171 | 0.117 | 0.216 | 0.028 |
| How long can car drive on pure electricity? | 0.021 | −0.107 | 0.211 | 0.043 | −0.083 | 0.014 | 0.017 |
| To me, the car is only a practical matter of transportation | 0.047 | 0.052 | 0.123 | 0.103 | 0.094 | 0.156 | 0.086 |
| I would rather choose to buy a pure battery electric vehicle if the available models, range and price would fit better to my demands | 0.124 | −0.078 | 0.121 | 0.171 | 0.281 | **0.331*** | **0.394**** |
| I choose to save electricity to specific parts of my trip while driving | **0.394**** | 0.092 | 0.178 | −0.128 | −0.210 | −0.051 | −0.174 |
| I choose actively to drive on petrol to achieve higher vehicle speed, acceleration, etc. | 0.165 | 0.064 | −0.149 | −0.136 | 0.013 | 0.038 | −0.033 |
| I am consciously aware of where and when the vehicle is using electricity | −0.156 | −0.225 | 0.033 | −0.130 | 0.117 | 0.132 | 0.097 |
| I try to use information provided by the vehicle to drive as much as possible on electricity | 0.117 | 0.093 | −0.995 | −0.191 | 0.082 | 0.090 | −0.012 |
| Human made climate change is the most important challenge in society today | **0.350**** | 0.223 | −0.025 | −0.054 | 0.020 | 0.245 | 0.095 |
| Local emissions are a large problem in my city | 0.262 | 0.244 | 0.017 | 0.285 | −0.039 | −0.174 | 0.097 |
| I care about testing new technology | 0.107 | −0.028 | 0.033 | 0.098 | **0.351**** | 0.137 | 0.283 |
| I think it is important to drive a car with the newest technology | 0.128 | −0.247 | 0.155 | 0.101 | 0.272 | **0.439**** | **0.383**** |

that practical matters become more important when testing technologies.

As for Acceptability RUC1 no significant coefficient was found in the correlation calculation, and only EA2:"*Local emissions are a large problem in my city*" was found for Acceptability RUC2, corresponding well with the large correlation coefficient also in the Pearson's tests. For Acceptability RUC3 four estimated coefficients were found to be significant in the regression model. All these variables measure in some sense proven choices in terms of technology and how to use it, which corresponds well with the fact that Acceptability RUC3 measures the likeliness of taking the piloted system into use in their everyday life. The most notable change from the Pearson's test results in Table A in the a ppendix is in the result for Acceptability RUC4. Here the previously significant correlation between Acceptability RUC4 and TO2: "*I think it is important to drive a car with the newest technology*" is not included. In addition, SD2: "*Age*" is included as opposed to SD1: "*Gender*" and SD3: "*Education*"


**Fig. A1.** Current tolling stations in Trondheim, to be compared to the piloted LEZs in Fig. 1. Source: https://vegkart.atlas.vegvesen.no/#kartlag:geodata/@249465,6899594,4/hva:!(id ~ 45)~.

being significant in the correlation test. As tests show that none of these explanatory variables are particularly co-dependent, is reasonable to believe that in this case the stepwise regression model succeeds in modelling some dependence not captured by the simple bi-variable test. Only for the model averaging over the four questions on acceptability for RUC is SD1: "*Dender*" found to be significant. This can indicate that some dependence on gender was picked up by averaging over more questions, however, in general we did not see more explanatory variables being significant for this average model compared to the models for the individual questions, in addition to the R squared value neither being increased. This leads to the conclusion that no additional information about the dependencies for the acceptability of RUC can be drawn when averaging over the individual questions.

However, for the model averaging over the four RUC acceptability questions, the two explanatory variables PA1: "*I rather chosen to buy a pure battery electric vehicle if the available models, range and price would fit better to my demands*" and PA2: "*I choose to save electricity to specific parts of my trip while driving*" are deemed significant, which does fit with well with previous research. The explanatory variable PA1 indicates that the group giving high score here is willing to buy an electric vehicle, and probably will in near future, and are likely from a RUC standpoint to see that it could provide some economic benefit for them. For the explanatory variable PA2, we have an indication that the group giving high score, tends to be more negative in their acceptability of RUC. Being that this still is regarded as an acceptability study for RUC, this might come from the experience that practical matter would be a main driver for how much one would have to pay with a RUC system. That is, they perceived control of where to drive on electricity today would not necessarily give them any benefits for their PEHV vehicle in the future.

It is also notable that the R-square value in the modelling of

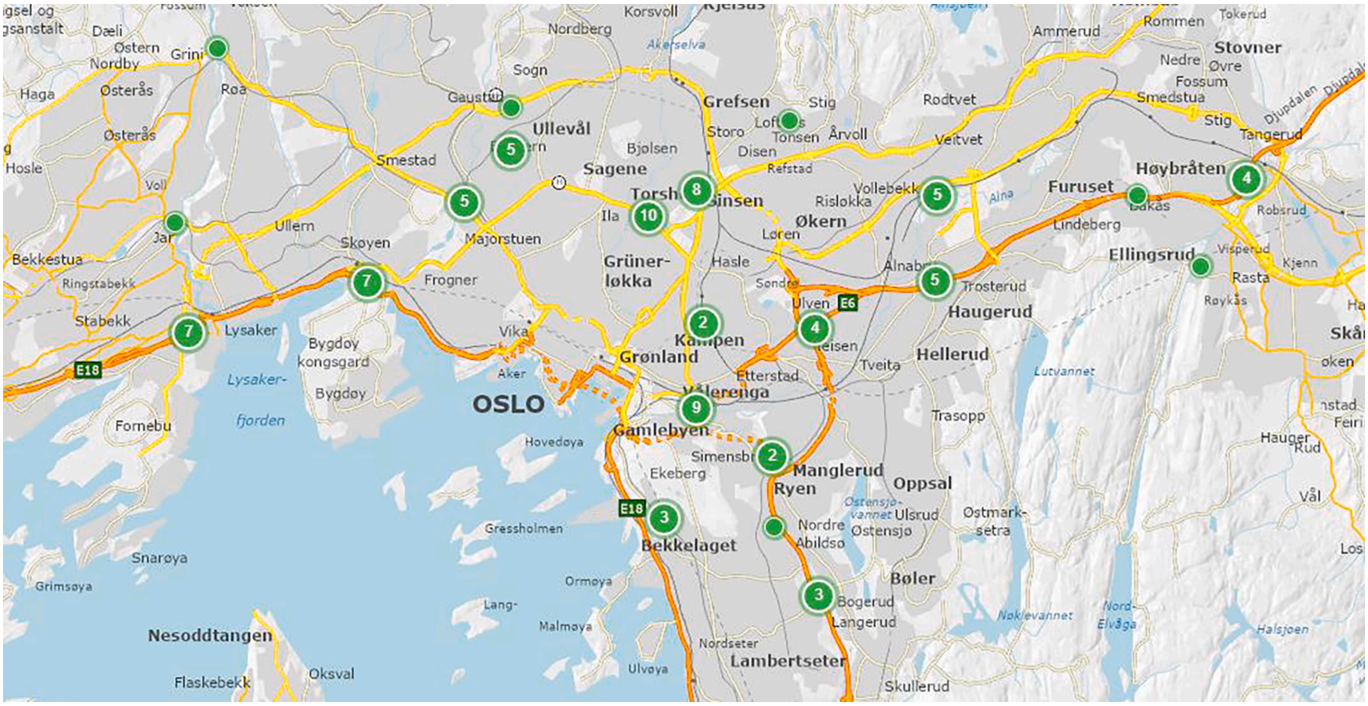


**Fig. A2.** Current tolling stations in Oslo, to be compared to the piloted LEZs in Fig. 1. Source: https://vegkart.atlas.vegvesen.no/#kartlag:geodata/@249465,6899594,4/hva:!(id ~ 45)~.

Acceptability RUC4 is the highest case. Acceptability RUC4 measures the deemed fairness of such as system, while the second largest R-square is for Acceptability of RUC3, which is about using a system that would give a personal economic benefit. We argue that both RUC3 and RUC4 are stronger formulated compared to RUC1 and RUC2 and is therefore more sensitive to potential significant explanatory variables driving the attitude of the respondents.

## 4. Discussion

Limitations and further research.

This study addresses the people's stated preferences and lived experiences of LEZ, contrasting both acceptability and acceptance of such transport policy measures in the everyday life of drivers. In addition, the acceptability of RUC within LEZ was also investigated as this is a likely combination of policy measures in Norway. As such, this work uses an innovative research approach and brings unique insights as few studies about LEZ and RUC are based on evaluating the hands-on experience of drivers of both policies. Nevertheless, the limitations of this study should be acknowledged, together with recommendations for future research.

Although the project team strove to recruit 75 participants to include in the pilot study, only 40 participants drove within the zones both in the black mode and the live mode period and answered both questionnaires. This is a principal limitation of the present study, as this might be considered a small sample size, thus affecting the significance values of the carried statistical tests. However, although the presence of significant results is low, there were observed changes in correlations for specific variables between acceptability and acceptance of LEZ, suggesting a change of attitude among the tested drivers. Being that attitude change is a main focus of this paper, these results suppose an interesting finding warranting further discussion and research. Furthermore, when doing these many statistical tests it is to be expected that some would indicate results to be significant or close to significant, even though they might not be, especially when the number of participants is as low as in this study. However, being a Pilot study, the results are still relevant to discuss, not only for showing reasonable explanations, but also because they are based on a quite unique data set. Other studies with a lower number of participants but with actual experience of new technology as in Skippon and Garwood (2011) and Viktorová and Šucha, (2019) have also shown valuable insights.

Another possible limitation is that this study is based on participants located in two Norwegian cities, which means that the results must be interpreted within the Norwegian context, and not generalised to other demographic groups. Indeed, an important finding in the literature is the large differences between cities, which may indicate that acceptance levels of such policies are influenced by a large variety of factors (including values, customs and traditions as cultural products) and highlights the importance of regional context (Jia et al., 2017). Other possible factors that could influence the results can be related to driving behaviour, for example the usual driving distance between home and workplace locations, and whether the driving trips are of an essential (e.g. to and from work) or non-essential nature (e.g. recreational events). Further studies should study deeper these factors.

For the purpose of this study, in which the change in attitude is examined, these results are particularly interesting as data on actual experience and behaviour on new technology is considered valuable for defining and investigating new research paths within this topic. Additional studies on this topic, including a larger sample size and in different geographical contexts, are thus encouraged.

## 5. Discussion of the findings and policy implications

The results of this study show that there is a difference between the measured acceptability and the measured acceptance towards LEZs. Based on the results, this study suggests that practical matters concerning how the technology fits with your everyday life could be an important explanation for acceptance of innovative transport technologies. Indeed, when measuring acceptance of the LEZ system the results suggest that the practical matters, such as battery level restrictions, are more important for explaining the acceptance levels among the participants than other explanatory variables.

As a part of the questionnaire used in this study, we also got feedback from the participants' responses in open-ended questions. One participant stated that "*I did not change my behaviour during the test. The battery* *has enough capacity for all my driving*", supporting that the practical matters are important explanatory variables for acceptance of the LEZ system. This was also supported by another participant stating that "*I normally use the battery in the city*". These comments suggest that these PHEV drivers primarily use the battery in their everyday driving, and it could then be assumed that it is easier for these drivers to use and succeed with the LEZ system tested in this pilot. The finding that practical issues is an important explanatory variable for PHEV owners behaviour is also supported by other studies, such as Chakraborty et al. (2020) who find that practical issues such as electricity prices, driving range, and electric motor power are important to explain PHEV owners' charging behaviour.

While the participants' expectations towards the technology were quite similar among different drivers before experiencing it (i.e., the level of acceptability), a statistically significant difference was found among the participants after experiencing the technology (i.e., the level of acceptance). This is an interesting finding on attitudes towards technology because it demonstrates how attitudes change over time and with experience. An important reason why attitudes change with experience is that people then can see how the new policies affect their lives, i.e., how they need to change their behaviour, and whether the policy fits with their lives, i.e., there is no need for changed behaviour. These findings are also supported by other research explaining attitudes towards LEZ, which has identified travel patterns, which also is a practical issue, as a key variable for explaining the attitude towards LEZ (e.g., Mehdizadeh and Shariat-Mohaymany, 2021; Tarriño-Ortiz et al., 2021).

The findings of this study are also in line with research findings on attitudes towards ADAS and AVs (e.g., Lubkowski et al., 2021; Hartwich et al., 2019) suggesting that there is a learning effect when experiencing the technology over time. Begattio et al. (2015) suggest that a learning process is a non-linear function with a rapid increase during the first few sessions, and then remains high. However, as seen in this study, not all participants were successful, despite having a longer period with experiencing the technology. According to the findings of Lubkowski et al. (2021), people who experienced ADAS to act unexpectedly, rated their trust in the system significantly lower over time. The participants in this study who did not succeed in making the shift to electricity could be left with a feeling that they, or the system, were unsuccessful despite making their best efforts. This seems to influence the drivers' acceptance of the system. Furthermore, when such systems are developed, it needs to consider the current fleet of vehicles and the level of maturity of the technology. If drivers have expectations about their vehicle and the LEZ system performing at a certain level, and these expectations are not met, the acceptance of the policy itself may become lower.

Regarding the implications of our results for transport policy, the findings of this study highlight the importance of understanding how environmental and climate policies within the transport sector affect the everyday life of people. Since support among the population is critical for succeeding in implementing policies for mitigating climate change and environmental issues (Jagers et al., 2019), ensuring a high level of support for policies is crucial. Successful policies are dependent not just on the *attitudes* of the public, but also on the *actions* of the public, for instance to change the modal choice from passenger traffic to public transport and active modes (Tarriño-Ortiz et al., 2021). To avoid massive resistance from the local population and industry, it is important to use experiences from acceptability studies as well as measurements of acceptance from large-scale, realistic pilots. For instance, the results from such studies could be used in information campaigns to prepare the drivers of for instance the barriers against implementing the technology. PHEV drivers are found to not use their vehicles' drive mode as intended by the car manufacturer (see Karanam et al., 2022), and information campaigns on how to use the drive mode might be important and give PHEV drivers an incentive to maximise the positive effects of their vehicles.

In a Norwegian context, RUC and LEZ are part of a larger political framework. Norway has a long history of tolling, which historically have been used as a political tool for financing building of local road infrastructure such as roads, bridges, and tunnels, according to the beneficiary pays principle. While this principle is still used for freestanding tolling stations built to finance new infrastructure, the system around road use charging is today part of a much larger political framework, where some policies are decided and implemented at the local city level, while others are national policies.

At the local policy level, the goal of road use charging includes a multitude of political goals, such as reducing or limiting the number of vehicles in the city, stimulating the use of electric vehicles, reducing ques and noise, and reducing emission from vehicles. It is not a given that the public will support a local-level road use charging regime. For instance, Börjesson and Kristoffersson (2018) highlight that local decisionmakers have not been able to build long-term support for the congestion charging in Gothenburg. Explanations brought forward in the Gothenburg case are considerable small congestion problems, large marked shares for cars, and low marked shares for public transport. This example supports the argument that experiencing positive effects is important for supporting local level policies, such as the implementation of LEZs. Other studies also point to experiencing positive effects from the policy as an important predictor of acceptance: Jia et al. (2017) studied license late restriction policy in Tianjin, China, and found that although drivers may have low acceptability, the same drivers have a higher degree of acceptance after implementation as the drivers experienced the positive effects of the policy.

For local effects for reducing pollution, LEZ for PHEVs is a quite successful combination of removing local emissions from within the LEZ to outside the LEZ (Arnesen et al., 2021). Other studies have also confirmed that active use of the drive modes in a PHEV can significantly impact vehicle emissions (Sugihara et al, 2021). Studies have shown that consumers buying PHEVs are more likely to be choosing between a PHEV and a regular combustion engine vehicle than between a PHEV and a BEV (Fevang et al., 2021; Lane et al., 2018), meaning that securing incentives for driving on electricity for PHEVs in cities may be important for stimulation of a gradual shift toward zero-emission vehicles. Furthermore, PHEVs are continuously being equipped with larger batteries, making it possible to drive longer on electricity. This could make it easier for commuters living outside the LEZ to run the engine more on electricity when driving inside the LEZ.

This study also gave insights to the acceptability of distance-based RUC. The participants experienced a simulation of distance-based RUC, but as this was a secondary application and only price money was involved with rates specially adjusted for the pilot period, this is not considered as more than a showcase introduction and constructed pilot incentive enabling the participants to answer acceptability questions. However, it gives important insights into acceptability of distance-based road use charging. In Norway, the concept study for road user charging and tolling developed by the Norwegian Tax Administration and the Norwegian Public Roads Administration in 2022 highlights that understanding the attitudes towards pricing of road use is important (KVU, 2022). The quality review of the concept study executed by an external consultation firm came to the same conclusion as the concept study itself; a stepwise implementation of distance-based road pricing is recommended (Menon, 2023).

While no conclusion is offered yet, it is expected that road use charging will become a more prominent political topic at the national level in Norway in the near future, particularly due to the increasing share of BEVs which causes challenges for the current tax system for road use charging. As the share of BEVs continue to increase, also in the heavy vehicle segment, there is a strong need for new mechanisms to ensure that BEVs also cover external costs. In 2022 a total of 83 percent of new cars registered in Norway were BEVs, and BEVs represent 21 percent of the passenger car fleet in Norway.[4] It is expected that this policy challenge will also be relevant to other countries with similar tax systems for road use charging as the share of BEVs are increasing.

## 6. Conclusion

Air quality is a major challenge in many areas in the world, and policymakers are therefore investigating which policies can help reducing local emissions in these areas. LEZs could be an important tool in this regard and measuring the drivers' attitudes towards such systems is important because the lack of support is among the main barriers for implementing effective policies aiming at reducing emissions. This study compared the acceptability and acceptance of a piloted LEZ system in Norway and investigated the acceptability towards a distance-based RUC system within these zones. There was found a difference in the attitude towards the piloted LEZ system when measuring both acceptability and acceptance, and those participants who gained a more positive attitude were the ones that was successful in using the LEZ system as intended (i.e. increased use of the electricity mode within the LEZ). Hence, the most important explanatory variables were practical matters such as available travel distance. These findings highlight the importance of understanding how innovative transport policies aiming at regulating negative externalities from car use are affecting people's everyday life. Even though not difference were found in the acceptance levels for the RUC measures, we argue that using distance-based RUC as an incentive for stimulating to a mode shift to the electric engine in PHEVs is a promising avenue.

The implementation of LEZs is considered as a possible measure in Norway, for instance in combination with distance-based RUC. Further investigations using a realistic large-scale test of distance-based RUC is recommended not only from an acceptability point of view. As the share of BEVs and PEHVs increases internationally, new solutions for road charging should aim at a more just solution than payments at fixed points, and solutions should be implemented to optimize the populations acceptance. As new technological solutions are developed, an important argument for using such innovations is that the implementation of digital infrastructure does not require large investments in physical infrastructure. Using digital infrastructure is also likely to be increasingly important as more advanced vehicles are entering the roads. By using geofencing, LEZs can be implemented technologically either by updating the software in the vehicle making the process automatic, or by using retrofitted equipment in the vehicle where a screen can communicate to the driver that a LEZ is approaching, and that the driver of the vehicle should switch the engine over to electricity.

### CRediT authorship contribution statement

**Hanne Seter:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Petter Arnesen:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Claudia Moscoso:** Writing – review & editing.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[4] Statistics Norway, https://www.ssb.no/transport-og-reiseliv/landtransport/statistikk/bilparken/artikler/fire-av-fem-nye-biler-i-2022-var-elbiler.

### Data availability

The authors do not have permission to share data.

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### Appendix

Table A1
Fig. A1
Fig. A2

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