***Word count: 9824***

The impact of widespread adoption of electric vehicles on air quality in Dublin

Transport sector is one of the most carbon-intensive sectors of the world economy and it deserves particular attention. It was the second largest source of greenhouse gas emissions in Ireland accounting 17,7% of the total emissions. Emissions from transport grew by 6,1% in 2021 compared to 2020 (Environmental Protection Agency, no date). Governments need to find solution to handle harmful emissions and tackle climate change effects in long run and renewable energy and more specifically electric vehicles (EV) could become game changer. Electric vehicles have been growing in popularity in recent years, and this is expected to continue, with a ban on the sale of new petrol and diesel cars coming into force in 2030. Only in Ireland licensed EV has increased by 81% from 8.554 in 2021 to 15.642 in 2022. The Climate Action Plan 2021 which was accepted by the Government of Ireland provided a detailed plan for taking decisive action to achieve a 51% reduction in overall greenhouse gas emissions by 2030 and setting us on a path to reach net-zero emissions by no later than 2050, as committed to in the Programme for Government and set out in the Climate Act 2021 (*Vehicles licensed for the first time December and Year 2022 - CSO - Central Statistics Office*, 2023). Adoption of EVs is a good approach to achieve zero emission goal but there are several drawbacks as well in regards of EVs such as infrastructure, electricity usage, costly battery replacement.

In this study I would like to observe if this endeavour is demonstrably the way that could significantly change the transport sector harmful emission through the adoption of EVs and estimate how much does this effect to reach the goal that was undertaken in Climate Action Plan.

## **Objectives**

1. Environmental effects of internal combustion engine vehicles among industrial and residential users
2. Quantify the potential reduction of greenhouse gas emissions and air pollutants from road transport by switching to electric vehicles in Dublin.
3. Assessing the impact of government incentives on the market expansion of electric vehicles in the present day and its long-term implications
4. Challenges hindering the proliferation of electric mobility in Dublin: Infrastructure, financial, and energy-related perspectives.

**Literature review**

Increasing transport volumes cause more negative impacts on the environment. One of these impacts is the air pollution problem caused by many anthropological activities like industrial and transport activities (Knez *et al.*, 2014). The European Union had a plan to reduce the amount of greenhouse gases (GHG) emissions by 20% (*2020 climate & energy package*, no date). As part of the [European Green Deal](https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en), the Commission [proposed](https://climate.ec.europa.eu/eu-action/european-green-deal/2030-climate-target-plan_en) in September 2020 to raise the 2030 greenhouse gas emission reduction target, including emissions and removals, to at least 55% compared to 1990 (*2030 climate & energy framework*, no date). To reduce emissions and diversify energy sources, alternative fuels have been promoted and suggested by several methodologies at the EU. Electromobility came along as a serious alternative to conventional mobility systems is gaining ground across the EU (Milojević *et al.*, 2018). A study provides valuable insights into the impact of car emissions on public health in a regional centre with a developed industry and a significant transport load. The study found that there is an excess of the maximum permissible concentrations (MPC) of several pollutants, including nitrogen dioxide, formaldehyde, hydrocarbons, and soot. The level of carcinogenic danger for adults and children is rated as average. These findings can be important for making effective management decisions in the field of environmental protection and public health (Mislyuk *et al.*, 2023). Analysed the correlation between automobile exhaust, PM2.5, and air pollution to explore the rate of contribution of automobile exhaust to PM2.5 pollution and the effect of government regulation on automobile exhaust gas, a study found that car exhaust is the main cause of PM2.5 pollution and divided the governance strategy into two methods: reducing the number of motor vehicles and reducing the emissions capacity of motor vehicles. The results of the study show that restriction measures can effectively relieve road pressure (Qin and Gao, 2022).

The growing demand for electric vehicles can be observed in the vehicle markets. Various factors influence potential buyers when purchasing a vehicle. Some are driven purely by curiosity to explore the new technology, while others consider environmental consciousness and choose to switch from an internal combustion engine vehicle to a purely electric or hybrid vehicle. There are also those who make the switch in hopes of achieving cheaper sustainability. A study empirically investigates the factors influencing a consumer’s intention to adopt an electric vehicle (EV) through a review of 211 peer-reviewed research articles published between 2009 and 2019. The study categorizes influential factors into four main types: demographic, situational, contextual, and psychological. A comprehensive overview of the theoretical perspectives was also developed to understand adoption behaviour and a consumer’s intentions towards EVs. A simple meta-analysis shows that the trend of studies on the influencing factors for adopting EVs has increased significantly over the past decade (Singh, Singh and Vaibhav, 2020).

Using machine learning to identify the electric vehicle mainstream market” by Gerardo Zarazua de Rubens explores the EV consumer market across Denmark, Finland, Iceland, Norway and Sweden. The study uses machine learning on a 5067-respondent dataset finding 6 consumer clusters. The study finds that ∼68% (3 clusters) of the current consumer market is primed for EV adoption. Price is the main determinant in the short term for EV mass adoption. (Zarazua De Rubens, 2019). An empirical study in Germany forecasts the market potential of electric vehicles by looking at 14 categories of vehicle. The study found that in general, conventional car buyers evaluated convenience and performance attributes of the car more important than battery electric car buyers. All groups, however, generally held positive attitude and a high level of perceived behavioural control over buying fuel-efficient cars(Lieven *et al.*, 2011). Another study examined that which factors are the most important to make purchase decisions when somebody buys a car. They used variables that predict the purchase of an electric vehicle from the implementation of an algorithm based on computational intelligence. The study contrasts these results with two panels of experts in consumer behaviour and the automobile sector. An empirical study was carried out with 404 potential consumers in Spain with regard to their beliefs, attitudes and purchase intention. The results show that range, incentives and reliability are the most reliable predictors of purchase intention. Likewise, the experts posit that the selection of these three variables would be sufficient to know the purchase intention of potential buyers of electric vehicles (Higueras-Castillo *et al.*, 2021).

Another study highlighted that attitude (ATT), subjective norm (SN), and perceived behavioural control (PBC) significantly influenced users’ sustainable consumption intentions. Environmental concern significantly influenced ATT, SN, PBC, and sustainable consumption intention of the users. Not only measurements of vehicle performance, namely safety, reliability, and range, but other factors, such as purchasing price, charging facility, and maintenance and battery cost also influenced consumers’ sustainable consumption intentions. The study concludes that Taiwanese are primarily concerned about the greenhouse effects on the environment, which reflected their sustainable consumption intentions (Dutta and Hwang, 2021).

The positive thoughts and information spreading through word of mouth can have a significant and persuasive impact, as previous buyers share them with prospective vehicle buyers on various social media platforms. A related study aims to understand the general perception of electric vehicles among consumers and the barriers to their widespread adoption. The study focuses on identifying and understanding the factors involved in their purchase with a wider range of expression using thematic analysis unlike traditional survey techniques. Further, the role of emotions is also considered in the study which is normally overlooked. eWOM (electronic word of mouth) is used as data for the study as it is relevant for electric vehicles as people majorly use internet mediums to freely share their thoughts. This method helps in finding all gaps (tangible and intangible) present in the offering (EVs) and expectations of a consumer (Krishna, 2021).

Another study aimed to explore and identify distinct sets of potential buyer segments for electric vehicles (EVs) based on psychographic, behavioural, and socio-economic characterization by employing an integrated research framework of ‘perceived benefits-attitude-intention’. Market segmentation becomes a crucial tool for evolving transportation technology such as EVs in emerging markets to explore and implement for extensive adoption. The study applied robust analytical procedures including cluster analysis, multiple discriminant analysis and Chi-square test to operationalize and validate segments from the data collected of 563 respondents using a cross-sectional online survey. The findings posit that the three distinct sets of young consumer groups have been identified and labelled as ‘Conservatives’, ‘Indifferent’, and ‘Enthusiasts’ which are deemed to be budding EV buyers (Jaiswal, Deshmukh and Thaichon, 2022)

An unusual approach has been used in a study that focuses on normative and hedonic goals to understand the impact of innovativeness and driving hedonism and their interaction with user experience and pro-environmental attitudes of consumers choosing between conventional, hybrid and electric cars. The study finds that the interaction between driving hedonism and BEV ‘trialability’ is positively related to the adoption of HEVs rather than of BEVs. Compared to environmental consumers who lack driving hedonism, the segment of innovative-environmentalists act as BEV adoption pioneers and the segment of innovative-environmentalist-hedonists are HEV adoption pioneers (Tchetchik *et al.*, 2020). Another study examines the factors related to willingness of potential Chinese consumers to further adopt EVs. The study utilizes a survey instrument among a large national sample (805 respondents across all Chinese provinces) to solicit perceptions of Chinese consumers about their willingness to adopt EVs, and the importance of different types of motivations, controlling for socio-demographic variables. Using descriptive statistics as well as multivariate analysis and principal component analysis, the study finds that willingness to adopt EVs is associated with performance features of electric vehicles, the perceived benefits of driving an electric vehicle and policy support for the promotion of electric vehicles (Sovacool *et al.*, 2019).

Different factors that affect a consumer’s adoption of an electric vehicle (EV) were examined in India using data from existing car owners and analysing it using Structured Equation Modelling (SEM). The study found that attitude (ATT) emerged as a strong mediator, influencing the adoption of electric cars. The study also found that perceived economic benefit (PEB) is not related to the behavioural intention (BI) to adopt EVs. Instead, it has a strong positive effect on ATT. Environment (EC) and social influence (SoC.In) are partial predictors of BI but significantly affect ATT. Self-image (IM) emerged as a stable predictor of BI. It influences ATT as well towards the adoption of an EV. These findings reveal that ATT is a significant predictor of BI (Khurana, Kumar and Sidhpuria, 2020).

A study conducted a systematic review of recent international literature to identify the key determinants influencing consumer adoption of electric vehicles (EVs). Using the PESTLE approach, which considers political, economic, social, technological, legal, and environmental factors, the study categorized motivators and barriers for EV adoption. However, the literature lacks consensus on the most influential determinants. Surprisingly, the study found that environmental aspects are considered less important by consumers, despite concerns about climate change and renewable energy. Kumar and Alok's research specifically categorized factors into technical and product features, such as ownership costs and vehicle performance, and government policies, including charging infrastructure and incentives (Anastasiadou and Gavanas, 2022).

A study highlighted the significance of comprehensive community modelling in understanding the serious health impacts of air pollution from transportation sources. The study recommends a detailed approach to examine the link between local air pollution levels and transportation. This research adds to the ongoing efforts to achieve environmental justice and fair distribution of environmental risks and benefits.(Heyer, 2021). A study assessed the personal traffic-related air pollution (TRAP) exposures of the bus transit systems of Toronto, Ottawa, and Vancouver, Canada. The study found that bus commuting contributed significantly toward daily exposures of fine-fraction Ba and Fe as well as BC. Enclosed bus stations were found to be hotspots of PM2.5 and BC. Buses with diesel particulate filters (DPFs) and hybrid diesel/electric propulsion were found to have significantly lower in-bus PM2.5, UFP, and BC relative to 1983-2003 diesel buses in each city with the exception of UFP in Vancouver. These associations suggest the use of hybrid diesel/electric buses equipped with diesel particulate filters have improved air quality for riders (Van Ryswyk *et al.*, 2021). Air pollution negatively impacts traffic vitality, as the air quality index (AQI) increases, the traffic vitality area shrinks. A study identified three main characteristics:

* Traffic vitality varies under different transportation models and location conditions. Traffic vitality in the north-south areas of Nanjing’s periphery has declined significantly compared to the urban core area.
* Air pollution inhibits public and self-driving traffic vitality differently. About one-tenth of traffic activities may be inhibited by air pollution.
* The inhibitory effect of air pollution on traffic vitality varies under different transportation infrastructure environments.

The suppression effect of air pollution is more obvious in areas with higher public transportation station density and frequency. (Cao *et al.*, 2022).

Hristova and Manousakas discussing a special issue covers various aspects of urban aerosol observations, including particulate matter chemical characterization and human exposure assessment. The key findings of this special issue include source apportionment of particulate air pollutants, their trends, deposition sinks, and inter-urban and regional transport. The issue highlights the importance of considering all possible affected areas within a city when assessing the impact of air pollution sources and sinks. It also provides valuable insights into the potential benefits of different traffic management strategies for improving air quality and public health in urban areas (Hristova and Manousakas, 2023). Optimising the average travel time also could lead to reduced CO2 emissions. The optimization results show that the total amount of CO2 emissions can be reduced by 9.23%, whereas the average travel time can in fact be reduced by 9.96%. The key finding of this study is that selecting an environmentally friendly transport mode can be an effective approach for individuals to reduce air pollution in daily life. The study’s simulation method provides a valuable tool for assessing the potential impacts of eco-friendly transportation selections on air pollution reduction (Ochiai *et al.*, 2021).

We probably won't remember the pandemic for this, but it had an undeniable impact on pollution levels, which were largely attributable to various travel restrictions. Studies confirm how the decline in car traffic had beneficial effects on air quality. A study tested the hypothesis that the lockdown response to COVID-19 has reduced tropospheric and ground-level air pollution concentrations and found that during the lockdown period, weather changes positively impacted the concentration of nitrogen dioxide (NO2) and fine particulate matter (PM2.5), while simultaneously increasing the ozone layer in the 34 countries observed. The study suggests that while the state of global lockdown is not sustainable, these findings allude to the potential for mitigating public health risk by reducing “business as usual” air pollutant emissions from economic activities (Venter *et al.*, 2020). This unprecedented and unintended decrease of emissions of air pollutants during the COVID-19 lock-down in 2020 could lead to declining seasonal ozone concentrations and positive impacts on crop yields. The air pollution can negatively impact the crop yields, because some pollutants like nitrogen oxides can harm plant cells, thus promoting ozone formation, which later decreases the crop yields. Particulate matter aerosols can also absorb and scatter sunlight away from crops. The expected magnitude of ozone precursor emission reductions during the Northern Hemisphere growing season in 2020 presents an opportunity to test and improve crop models and experimentally based exposure response relationships of ozone impacts on crops, under real-world conditions (Dentener *et al.*, 2020).

Several studies have examined the impact of the pandemic on pollution levels, including studies conducted in Ireland. A study about COVID-19 transport restrictions in Ireland examined the relationship between COVID-19 transport restrictions and hospital admissions due to respiratory system diseases (RSDs) in Dublin city and county for 2020 and found that during the period of transport restrictions, there was a reduction annually from NO2 from 25 μg/m3 to 17 μg/m3 (P < 0.001), and decreases in hospital admissions for RSD were observed. The study suggests that decreases in ambient NO2 as related to COVID-19 transport restrictions were significantly associated with lower asthma and chronic obstructive pulmonary disease admissions as air pollution highly depends on the volume of the traffic especially at urban roadside locations (Quintyne *et al.*, 2021). This relationship was also examined in a study that focused on Dublin city and county for 2020. The study discovered that weather patterns can influence pollution episodes and that mathematical models can enhance the analysis of pollution transport. It also revealed that land-sea and mountain-valley breezes can intensify certain pollution episodes and that orographic features can sometimes favour recirculation processes. Furthermore, the study showed that local meteorological variables significantly impact calculations made with the Gaussian plume model. The Gaussian plume model is a widely used air pollution model in air quality modelling and environmental consultancy. It uses a straightforward formula to represent the three-dimensional concentration field created by a stationary point source. The model can demonstrate various phenomena, including the impact of wind fluctuations/speed on pollutant concentrations and the effect of vertical stability on ground-level mixing and concentrations (Pérez *et al.*, 2020). Another study analysed the variations in air quality between monitoring stations in Dublin during COVID-19 restrictions and shown that pollutants such as PM2.5, NO2, and O3 showed more significant spatial and temporal changes at urban or traffic monitoring sites than suburban background sites. The study suggests that the representativeness of monitoring stations will change with the adoption of greener transport and that air quality during COVID-19 can serve as a benchmark for new clean air policies. This emphasizes the importance of selecting appropriate monitoring sites for accurately reporting air quality and informing policy to improve urban air quality.(Perillo *et al.*, 2022).

The studies discussed so far have extensively elaborated on the negative impact of internal combustion engine vehicles on air quality, which showed temporary improvement during the pandemic period. However, the ultimate goal is the long-term normalization of pollution indicators, which further studies see achievable through advancements in electromobility. The study found that the positive benefits of EVs for reducing greenhouse gas emissions and human exposure depend on several factors including the type of EV, source of energy generation, driving conditions, charging patterns, availability of charging infrastructure, government policies, and climate of a region. Electric vehicles powered by electricity from natural gas or wind, water, or solar power are best for improving air quality (Requia *et al.*, 2018).

Promoting electric vehicles is an efficient measure to control all road traffic related emissions and improve urban air quality as a study has examined in Shanghai City. The study analysed the characteristics of vehicle emissions in Shanghai over the past five years and evaluated the potential reduction in road traffic related emissions due to the promotion and application of electric vehicles. The results indicate that electric vehicles have great potential to minimize the external impacts of road transportation, including air pollution and associated health impacts on urban population (Hu *et al.*, 2021). Similar conclusions have been found by a study that looked at how much greenhouse gas emissions are produced by plug-in electric vehicles compared to gasoline vehicles in different provinces of China in 2017. They looked at the entire process from producing the fuel or electricity to actually driving the car. The study considered the heterogeneity in the consumption-based electricity mix and climate impacts on vehicle fuel economy. This study highlighted about that greenhouse gas emissions by battery electric and plug-in electric vehicles can be varied between different provinces in China, however emissions of gasoline powered and gasoline hybrid vehicles more likely consistent across this provinces. Due to the GHG-intensive coal-based electricity and cold weather, WTW GHG emission intensities of BEVs and PHEVs were higher than those of gasoline ICEVs in seven and ten northern provinces in China. The analysis suggests that province-specific PEV and electric grid development policies should be considered for GHG emission reductions of on-road transportation in China (Gan *et al.*, 2021).

In 2007, Minnesota set a goal of reducing greenhouse gas emissions 80% below 2005 levels by 2050. The goal includes benchmarks of a 15% reduction by 2015 and a 30% reduction by 2025. Since then, Minnesota has successfully changed the trajectory of its emissions profile, so it is no longer increasing. In March 2021, the Minnesota Legislature introduced legislation that aims to establish a clean fuels standard. This legislation would entail a 20% reduction in the carbon emissions of the transportation sector within the state by 2035 when compared to a 2018 baseline. Minnesota’s freight transportation system plays a critical role in supporting the region’s economic competitiveness and quality of life. However, concerns over GHGs have led state government authorities to create a plan for electric freight vehicles to replace conventional diesel trucks, which produce approximately 12% of GHG emissions in the state (Khani and Emami, no date).

The impact of an electric vehicle policy on air quality in Taiwan end examine the health benefits of generating additional power for electric vehicles in different areas and found that increasing power generation in the north, center, or south of Taiwan would result in a decrease in the average annual concentration of PM2.5 by 2.88, 2.90, and 2.92 μg/m3 respectively. This would lead to health benefits valued at 43.35 billion, 43.40 billion, and 43.54 billion USD (Lin *et al.*, 2020). A study found that in 2050, the target year for carbon neutrality, the active travel - where you are travelling with a purpose , using your own energy - scenario avoided 167,000 deaths and gained 2.5 million disability-adjusted life years, monetized at $1.6 trillion using the value of a statistical life. Carbon emissions were reduced by 24% from baseline. The study concluded that to achieve carbon neutrality in transportation and maximize health benefits, active travel should have a prominent role along with electric vehicles in national blueprints (Maizlish, Rudolph and Jiang, 2022).

An American study evaluated the net long-term emission implications of large-scale electric vehicle (EV) adoption in the US over widely differing pathways of the evolution of the electric sector. The study found that high EV adoption would decrease net CO2 emissions through 2050, even for a scenario where all electric sector capacity additions through 2050 are fossil fuel technologies. Greater net CO2 reductions would be realized for scenarios that emphasize renewables or decarbonization of electricity production. The study suggests that coordinated, multi-sector planning can greatly enhance the climate and environmental benefits of EVs. Electric vehicle deployment reduces emissions by replacing fossil fuel-powered vehicles with vehicles that produce zero tailpipe emissions. While producing the electricity to power electric vehicles can generate emissions, those emissions levels are far lower than the pollution emitted by conventional vehicles (Ou *et al.*, 2021).

The study by Ma et al. (Ma, Madaniyazi and Xie, 2021) proposed an environmental and health impact approach to evaluate the effects of electric automobile policies in the BTH (Beijing-Tianjin-Hebei) integrated region. They used an assessment model that involved three steps. First, they projected the energy consumption in the road transport sector from 2010 to 2030 under two scenarios. Second, they estimated the environmental impact by using GAINS-China with the energy consumption data. Third, they analysed the health impact by applying the IMED|HEL model. The results showed that electric automobile policies could significantly reduce fossil energy consumption and improve air quality. They estimated that fossil consumption could be cut by 33% in 2030 compared to the scenario without policies. They also predicted that the local emission of various harmful gases would decline substantially in the BTH region.

Based on a theoretical approach (Hao *et al.*, 2017) of banning the sale of traditional fossil fuel vehicles in China a Logistic model was implemented on vehicle market under different timing of banning the sale of traditional fuel vehicle.  The study focus on how new energy vehicles can save fossil energy and reduce greenhouse gas emissions from a life cycle perspective under different energy scenarios. It finds that battery electric vehicles have much lower life cycle emissions and energy consumption than gasoline-powered vehicles in China’s current electricity mix. Specifically, the life cycle GHG emissions intensity and fossil energy consumption intensity of battery electric vehicles are about 40.94% (120.04 g CO2-eq/km) and 45.90% (1.68 MJ/km) lower than those of gasoline-powered vehicles, respectively. It also predicts that by 2050, switching to battery electric vehicles can cut emissions and energy usage by more than half if renewable electricity increases. According to the model, replacing traditional fuel vehicles with battery electric vehicles can reduce GHG emissions and fossil energy consumption by up to 58.26% (83.85g CO2-eq/km) and 53.03% (0.86 MJ/km), respectively.

Battery electric vehicles combine an efficient powertrain and a de-carbonized supply of electricity cause lower life cycle GHG emissions than gasoline hybrid vehicles (Sacchi *et al.*, 2022). In countries with significant proportions of renewable or nuclear energy, such as France, Norway, and Sweden, transitioning from a Gasoline-fueled hybrid electric vehicle (HEV) to a Battery electric vehicle (BEV) can lead to a noteworthy reduction in greenhouse gas (GHG) emissions. This is because BEVs utilize decarbonized electricity sources, resulting in lower emissions throughout their life cycle (Zhang *et al.*, 2023). In Bulgaria, Estonia, or Poland, where coal-fired power plants play a vital role in electricity generation, operating a BEV currently does not contribute to GHG emissions reduction due to the carbon-intensive nature of their energy sources. The current situation could be changed if these countries successfully accomplish their decarbonization objectives in the next 5 to 10 years. As they make the transition towards cleaner energy sources and decrease their dependency on coal, the operation of Battery electric vehicles (BEVs) would result in a substantial decrease in greenhouse gas (GHG) emissions. This shift would be in line with their sustainability goals, facilitating a more environmentally friendly transportation sector. Another study (Kazemzadeh, Koengkan and Fuinhas, 2022) that examined the impact of electric vehicles (EVs) on fine particulate matter (PM2.5) emissions in 29 European countries. It used a panel data set from 2010 to 2019 and a method of moments quantile regression (MM-QR) to analyse the relationship between EVs and PM2.5. This research is innovative in two main perspectives:

* by connecting the increasing use of electric vehicles with PM2.5 emissions
* by using the MM-QR to explore the relationship between electric vehicles and PM2.5 emissions

The study takes into account factors such as energy intensity, GDP, urban population, and fossil fuel consumption when estimating the impact of electric vehicles on PM2.5 levels. The study finds that both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) can reduce air pollution if they use green energy sources and have high efficiency. It also finds that economic growth can lower PM2.5 because it enables the adoption of cleaner and more efficient energy technologies. It suggests that this implies a lower reliance on fossil fuels for growth and a higher productivity and environmental performance of the economy.

Time series analysis is essential for extracting valuable insights from real-time air pollution data. An intriguing point is highlighted by a recent study (Atkinson and Metsis, 2020) that demonstrates the importance of deploying time series analysis in such applications. The article introduces a method for removing label noise from time-series datasets, which requires minimal input from the end-user. The approach uses a synthetic dataset generation technique and initialization variables to produce reliable classes for similar signals. The system flags a small percentage of the dataset for review and assumes a greater vector length for time-series data than mislabelling. The experiments show that the accuracy and F1 score of the classifiers improve up to 7.5% and 4.2%, respectively, when trained and evaluated on cleaned data. However, noise removal may also remove edge cases or ambiguous classes, and flagged instances should be reviewed to avoid mislabelling.

A study provides a comprehensive evaluation method of environmental efficiency for new energy vehicles (NEVs), especially electric vehicles (EVs), using the life cycle analysis (LCA) model. The study analysed 282 related studies from the Web of Science database and found that the stages of energy resource extraction and collection, carrier production and energy transportation, maintenance, and replacement are not considered to be research links. The study concludes that hydrogen fuel cell electric vehicles (HFCEVs), vehicle type classification, the water footprint, battery recovery and reuse, and battery aging are the focus of further research. The study also found that well-to-wheel (WTW) average carbon dioxide (CO2) emissions of EVs and hybrid power vehicles have been less than those in the same period of gasoline internal combustion engine vehicles (GICEV) (Wang and Tang, 2022).

Electric mobility is becoming increasingly popular not only among individual consumers but also in public transportation and agriculture. A study by Yao, Liu, Lu, and Yang proposes a two-stage solution approach for an electric vehicle scheduling problem (EVSP) in public transport. The proposed method reduces annual total scheduling costs by 15.93% compared with the conventional method and can provide transit agencies with comprehensive guidance on the effective scheduling of EBs for multiple vehicle types and the reasonable deployment of chargers (Yao *et al.*, 2020). A cooperative study was concluded in Argentina where diesel, hybrid, hydrogen and electric powered urban buses environmental impact were analysed. The study found that electric vehicles are markedly superior in the tank to wheel step. However, actions to improve their energy and environmental performance should focus on how to generate clean energy within the electricity mix and with what technologies. For fuel cell powered buses to be competitive, the production share of hydrogen from wind or other zero emission technologies should be more than 50% (Correa, Muñoz and Rodriguez, 2019).

According to Gang Xu (https://www.bcg.com/about/people/experts/gang-xu, 2022), the global shift towards green trucks poses challenges for truck manufacturers and fleet operators in transitioning to zero-emission engines. The study emphasizes the need for new strategies to survive in the face of increasing demand and regulatory pressures. One crucial step is convincing fleet operators and creating the necessary charging infrastructure. Anderhofstadt and Spinler (Anderhofstadt and Spinler, 2019) conducted a Delphi study in Germany to identify factors influencing the adoption of alternative fuel-powered heavy-duty trucks (HDTs). Their research highlighted key factors such as truck reliability, available fueling/charging infrastructure, low-emission zone access, and fuel costs. Promising technologies to reduce emissions from HDTs include battery electric, fuel cell electric, compressed natural gas, and liquefied natural gas.

Konstantinou and Gkritza (Konstantinou and Gkritza, 2023) conducted a study in the United States, where they identified ten barrier groups to the adoption of electric trucks (ETs). Through a stated preference survey of truck fleet managers/owners, they found that business models, partnerships, product availability, and charging time were the top cause factors. Addressing these barriers would also help overcome challenges related to operational reliability, grid resiliency, and customer acceptance and expectations. Nykvist and Olsson (Nykvist and Olsson, 2021) modelled battery electric trucks and emphasized the underestimated economic feasibility of heavy battery electric trucks. They highlighted the relationship between weight, load capacity, and energy savings, while acknowledging the sensitivity of competitiveness to assumptions about battery cost per kilowatt-hour and lifetime.

The Hewlett Foundation's Zero-Emissions Road Freight Strategy (The Hewlett Foundation, 2020) aims to achieve deep decarbonization in major emitting regions. This strategy focuses on road freight and includes interventions to accelerate zero-emission trucks, deploy charging/fuelling infrastructure, and broaden support for the transition. Forrest et al. (Forrest *et al.*, 2020) evaluated the potential electric load demand and feasibility of electric vehicles (EVs) in meeting medium and heavy-duty travel demand. They found that EVs can support a significant portion of commercial vehicle miles travelled, but further improvements in vehicle range, fuel efficiency, and charging infrastructure are needed.

In their study, Sendek-Matysiak et al. (Sendek-Matysiak *et al.*, 2022) compared electric and combustion-powered commercial vehicles for urban freight transport. They developed a formula to calculate the total cost of ownership and assessed the competitiveness of electric vehicles in current market conditions. These studies collectively highlight the challenges, factors influencing adoption, economic feasibility, and strategies for successful implementation of electric trucks in various contexts.

The adoption of electrically powered vehicles is attributed not only to environmentally conscious users but also to the beneficial effects of government incentives that partly stimulate the demand. The popularity of electric vehicles is tangible, as supported by the following study. In spite of the hurdles presented by supply chain disruptions and the persistent Covid-19 pandemic, the International Energy Agency (IEA) reports that electric car sales soared to unprecedented heights in 2021. The sales volume almost doubled with 6.6 million units sold, which represented an outstanding 9% of the total sales. Consequently, the overall count of electric cars actively in use on the roads has now reached an impressive milestone of 16.5 million. The sales share of electric cars increased by 4 percentage points in 2021 (*Electric Vehicles – Analysis*, no date).

State regulations play a crucial role in the current presence of electric vehicles and perhaps an even greater role in the future regarding legislation. A report identifies and discusses recent developments in electric mobility across the globe and is developed with the support of the members of the Electric Vehicles Initiative (EVI). Combining historical analysis with projections to 2030, the report examines key areas of interest such as electric vehicle and charging infrastructure deployment, energy use, CO2 emissions, battery demand and related policy developments. The report includes policy recommendations that incorporate lessons learned from leading markets to inform policy makers and stakeholders regarding to policy frameworks and market systems for electric vehicle adoption. This edition features an in-depth assessment of the EV battery supply chain and reviews government targets and strategies in this area. It assesses charging infrastructure development targets in key regions. A section on the integration of EVs into the distribution grid is also included (‘Global Electric Vehicle Outlook 2022’, 2022). However another study found that even though fuel prices, driving patterns, and subsidies vary between regions, the economic benefits and challenges of electric vehicles are generally similar. People who are most likely to buy electric vehicles for economic reasons also have the greatest environmental benefits. These “priority” customers can reduce their greenhouse gas emissions by 32% to 63% compared to average drivers (He *et al.*, 2019).

Another study explores the factors that influence the willingness to pay (WTP) on behalf of citizens to reduce air pollution generated by road transport. The study by proposing two fundamental theoretical frameworks to explain individual behaviour towards environmental actions and highlighting the importance of psychological aspects as predictors of pro-environmental behaviours, the study provides valuable insights into how governments and educational policies can enhance positive attitudes towards environmental actions and promote environmental protection (Sánchez-García *et al.*, 2021).

An earlier study builds a deeper understanding of purchase incentives and allows recommendations to be made on how to design purchase incentives so that they are most effective in promoting PEV market growth. Incentives should be applied when someone is buying a PEV, not afterwards. Incentives should promote BEVs and PHEVs with high electric ranges more than PHEVs with low electric ranges. VAT and purchase tax exemptions for PEVs are most effective. Incentives should not be available on high-end BEVs, education and awareness campaigns should promote incentives to consumers. [Finally, the premature removal of incentives could negatively affect PEVs therefore incentives should be designed with longevity in mind](https://www.sciencedirect.com/science/article/pii/S1364032117309012) (Hardman *et al.*, 2017). Financial and sustainability aspects are proven to be important according to the following study conducted in Ireland. A study aimed to analyse and compare the total cost of ownership (TCO) of internal combustion engine vehicles (ICEVs) and electric vehicles (EVs) from 17 car segments across short- and long-term ownership periods. The study concludes that EV options in the most popular Irish car segments have existing battery EV options with a TCO averaging 26% and 42% less than their equivalent petrol and diesel ICEV options over a 4-year ownership term when the current grant is included. This integrated method for granular TCO evaluation offers important insights for this market and affords scope to investigate how changes in travel patterns, car-segment pricing, taxation, grant policy, fuel costs, and carbon pricing and other transport policies can all affect TCO values over time across a broad range of market offerings (Guo, Kelly and Clinch, 2022).

Ireland’s Transport Minister Eamon Ryan recently unveiled a new strategy to improve the country’s EV charging infrastructure. Over the next three years, €100 million will be invested in public charging stations to make driving an EV even more practical. The strategy presents an ambitious pathway and practical steps for delivery of a national EV charging network which will see a pool of high-powered chargers every 60 km on their motorway network as well as home/apartment charging, residential neighbourhood charging (including new mobility hubs), destination charging and en-route charging. In addition to government initiatives, private companies are also investing in EV charging infrastructure. Big car manufacturers like Tesla and Volkswagen have their own charging networks, while companies such as ChargePoint and EV go run extensive public charging networks. There’s a growing understanding that better EV charging infrastructure is crucial for the shift to electric vehicles and for reducing greenhouse gas emissions (*First national electric vehicle charging infrastructure strategy published*, 2023).

The following study is an overseas example of applying government incentives to stimulate demand. The study develops a more comprehensive evaluation framework for plug-in electric vehicle (PEV) policies, considering five criteria like effectiveness at increasing PEV adoption in the long-term (2040), government spending, public support, policy simplicity and “transformational signal”, the latter being a measure of a policy’s ability to stimulate confidence and investment in a PEV transition. The study applies this framework to Canada by assessing eight policy types implemented across the country, as well as stronger versions of each policy. The study illustrates trade-offs by constructing three policy packages with similar effectiveness (i.e., PEVs making up 40% of light-duty vehicle sales by 2040). These packages include strong financial incentives ($6,000 CAD per PEV for 20 years), a Zero-Emissions Vehicle (ZEV) sales mandate (requiring 40% PEV sales by 2040) or strengthened light-duty vehicle emissions standards (decreasing to 71g CO2/km by 2040) (Melton, Axsen and Moawad, 2020).

An analysis procedure revealed many interesting insights related to research methods and region-specific developments. The review draws attention to relatively neglected topics such as dealership experience, charging infrastructure resilience, and marketing strategies as well as identifies much-studied topics such as charging infrastructure development, total cost of ownership, and purchase-based incentive policies. It also clarifies the mechanisms of electric vehicle adoption by highlighting important mediators and moderators. The findings would be beneficial to both researchers and policymakers alike, as there has been a dearth of earlier reviews that have analysed all sustainable consequence variables simultaneously and collectively (Kumar and Alok, 2020).

Despite the popularity, growing user base, and increasing usability of electric vehicles, there are several obstacles to the widespread adoption of electric mobility. From the consumer side, financing electric vehicles remains a challenge for many, as well as the availability of charging stations in sufficient density and the range limitations of fully electric vehicles. From the service provider side, establishing an adequate charging infrastructure and addressing the costs of battery production and recycling are areas that require solutions or further development. A recent study (Kene, Olwal and van Wyk, 2021) aims to review the development around sustainable electric vehicle transportation, and accomplishes four major objectives:

* it assesses the implication of large-scale EV integration to the electricity grid by looking at the impact on the distribution network.
* it provides energy management strategies for optimizing plug-in EVs load demand on the electricity distribution network.
* it provides a clear direction and an overview on sustainable EV charging infrastructure, which is highlighted as one of the key factors that enables the promotion and sustainability of the EV market and transportation sector.
* it concludes with some policy recommendations provided for the promotion of the electric vehicle market and widespread adoption in any economy of the world.

Another study uses a stated preferences UK dataset, and a discrete choice mode is applied, using an adaptive Lasso methodology, binomial logit and ordered logit regressions. The results suggest that the propensity of being a potential EV early adopter increases with youth, education, being a student, living in the more southern parts of UK, being married and, to a lesser extent, income. Additionally, purchase cost, performance, maximum range, and environmental friendliness are found to be important vehicle attributes for the potential buyers. Furthermore, two key barriers to wide EV adoption are identified – high purchase cost and low maximum range of the vehicle (Mandys, 2021).

A Croatian study aimed to identify which factors influence attitudes towards the purchase of electric vehicles in the Republic of Croatia. By this study the most significant factors influencing attitudes towards the purchase of electric cars are difficulties in servicing, the cost of battery replacement, lack of charging infrastructure, and the reduced impact on environmental pollution (Mutavdžija, Kovačić and Buntak, 2022).

A study discusses the role of electromobility in supporting smart city ideas and concepts and highlights that electromobility is a global trend that unequivocally supports the principles of sustainable development while being one of the basic elements of smart mobility. Smart mobility means using different ways to get around instead of relying on a gas-powered car. This includes options like ridesharing, car-sharing, public transportation, walking, and biking. The study critically addresses the barriers that currently exist and stand in the way of implementing the expected expansion of electric cars into urban markets. The authors highlight the current state and development level of the electric vehicle market, the market for light commercial vehicles (LCVs) (Tundys and Wiśniewski, 2023).

Li and Jenn (Li and Jenn, 2022) developed an integrated optimization model to assess the impacts of different charge pricing strategies on the EV charging behaviours and infrastructure planning in San Diego, CA. They aimed to provide new insights for policymakers and researchers on how to evaluate the effects of EV policies from an infrastructure perspective. They used three charge pricing scenarios: EV time-of-use residential rate, tier two residential flat rate, and real-time price. They found that their optimized charging platform could reduce energy consumption, cost, and carbon emissions by influencing the charging load profile. The profile was affected by various factors such as the dynamic electricity price, price elasticity of charging demand, travel and dwelling constraints, carbon price clustering effect as well as the home and nonhome charging options. The results of this research could be applied to other regions with similar data availability.

A study was made by Alimujiang and Jiang (Alimujiang and Jiang, 2020) found that the high cost of electric vehicles (EVs) and emissions from electricity sources such as power plants are major obstacles to reducing CO2 and air pollutant emissions through the promotion of EVs in the Chinese market. The development of more mature and low-cost battery technologies is crucial for reducing the cost of EVs and achieving effective co-benefits. Additionally, implementing clean energy power generation facilities and strengthening technical emission reduction measures in the power industry can increase the potential for synergistic emissions reduction through the use of EVs, thus achieving the best co-benefits.

Chidambaram et al. (Chidambaram *et al.*, 2023) conducted a study on the barriers to electric vehicle adoption and found that inadequate infrastructure, vehicle performance, costs, consumer behaviour, and government support are hindering EV adoption. The Consumer Perception Survey (CPS) revealed that consumers perceive the cost of installing household charging units as too high and conventional vehicles need more adaptable power replenishment units. However, consumers were unaware of issues related to energy production and battery waste management, disagreeing with the idea that EVs generate more emissions than conventional vehicles. Another study (Riccardo Boin, Timo Möller, Vadim Pokotilo, Andrea Ricotti, and Nicola Sandri, 2023) by McKinsey & Company supports the finding that charging issues are a top barrier for EV adoption in the US, led by slow charging speeds, charger inaccessibility, cost, and charging variance by vehicles. Addressing these issues is crucial to advancing the adoption of EVs.

The weakest point of electric vehicles so far has been the battery pack, which stores the energy required for propulsion. The range and battery capacity are closely related. The greater the desired range, the larger the battery pack needed, which not only adds weight but also increases costs. Additionally, the batteries in first-generation electric vehicles will eventually need to be replaced, and ensuring environmentally conscious recycling poses a significant challenge for developers. This weak point seriously affects the future of electric vehicles.

A study found that recycling of end-of-life electric vehicle battery packs is very effective in “closing the loop” and would enable driving the demand for all four metals back down to present levels by 2050, despite having achieved by then a complete shift to 100% electric vehicles. Additionally, repurposing end-of-life vehicle batteries for grid storage has been found to enable reducing purpose-built grid storage batteries to zero (Kamran, Raugei and Hutchinson, 2021). Finally, an additional scenario analysis indicated that a widespread behavioural shift from conventional vehicle ownership to shared mobility could even drive the demand for virgin battery metals into negative territory by 2040 (Amatuni *et al.*, 2020).

According to a study titled there are various sustainability challenges and risks across the supply and value chains of Lithium-ion batteries (LIBs) used in electric vehicles. These challenges range from mining, material supplies to Original Equipment Manufacturers (OEMs), users to final disposal. Some of the risks include increased raw material demands as well as economic risks due to price increment or political instabilities in some countries within the raw material supply chain (Rajaeifar *et al.*, 2022).

The study provides an environmental and economic assessment of the manufacturing of one specific lithium-ion battery chemistry. The study concludes that the electricity mix used to power the battery factory is a key parameter for the impact of battery manufacturing on climate change. To improve the eco-efficiency of battery manufacturing, a high production capacity and an electricity mix with low carbon intensity are suggested. Optimizing the process by reducing electricity consumption during manufacturing and combining it with higher pack energy density can result in the impact on climate change of pack manufacturing being as low as 39.5kg CO2 eq/kWh (Philippot *et al.*, 2019). Several studies have already dealt with the recycling of batteries. The rapid growth in the market for electric vehicles presents a serious waste-management challenge for recyclers at end-of-life. However, spent batteries may also present an opportunity as manufacturers require access to strategic elements and critical materials for key components in electric-vehicle manufacture: recycled lithium-ion batteries from electric vehicles could provide a valuable secondary source of materials. The study outlines and evaluates the current range of approaches to electric-vehicle lithium-ion battery recycling and re-use, and highlights areas for future progress (Harper *et al.*, 2019). Another study compares three recycling processes: pyrometallurgical and hydrometallurgical recycling processes, which reduce cells to elemental products, and direct cathode recycling, which recovers and reconditions ceramic powder cathode material for use in subsequent batteries retaining a substantial fraction of the energy embodied in the material from their primal manufacturing process. While pyrometallurgical and hydrometallurgical processes do not significantly reduce life-cycle greenhouse gas emissions, direct cathode recycling has the potential to reduce emissions and be economically competitive (Ciez and Whitacre, 2019).

According to Beaudet et al. (Beaudet *et al.*, 2020) the key economic and environmental drivers for recycling electric vehicle (EV) batteries, technical and financial challenges to large-scale deployment of recycling initiatives, and the main recycling process options currently under consideration. A number of policies and strategies are suggested (Apte, 2019) to overcome these challenges, such as increasing the funding for both incremental innovation and breakthroughs on recycling technology, funding for pilot projects, and market-pull measures to support the creation of a favourable economic and regulatory environment for large-scale EV battery recycling.

Electric car sales have been rising, but the growth has surpassed the development of charging infrastructure. Some studies provide valuable insights into various aspects of electric vehicle (EV) adoption and infrastructure planning. Some studies provide valuable insights into various aspects of electric vehicle (EV) adoption and infrastructure planning. Sweda, Dolinskaya, and Klabjan (Sweda, Dolinskaya and Klabjan, 2017) propose algorithms for finding optimal routing and recharging policies for EVs in a network, considering the availability of charging stations. They present heuristic methods for adaptive routing and recharging decisions. Sun et al. (Sun *et al.*, 2022) analyse trip, parking, and charging patterns of private EVs in Beijing, revealing statistical patterns and busy periods. They emphasize the importance of understanding these patterns for effective policy making and infrastructure planning. Bräunl et al. (Bräunl *et al.*, 2020) discuss the challenges of planning public EV charging networks and highlight the need for considering various variables, such as EV driver behaviours and future technology advancements. They emphasize the significance of optimal location and allocation of charging infrastructure. Adepetu and Keshav (Adepetu and Keshav, 2017) examine the impact of battery costs and prices on EV adoption using a simulation model. They find that affordability plays a more significant role than EV range in promoting adoption.

In conclusion of the literature review, it can be determined that comprehensive insights into the current state, popularity, and market penetration of electric mobility can be obtained based on the studies reviewed. This includes an examination of both the residential and industrial segments. Alongside factors influencing potential buyers, I discussed the pros and cons that influence purchasing decisions, the environmental impact and manifestations of conventional internal combustion engine vehicles, potential hindering factors to the widespread adoption of electric mobility, infrastructure and technological challenges, as well as government incentives.

In summary, despite all the hindering factors, it can be concluded based on the literature that electric mobility, as demonstrated in various studies, has the potential to be an effective solution for reducing harmful emissions, particularly in urban areas.

**Methodology**

Internal combustion engine cars harmful gas emission highly depends on the fuel they are using. Overall, it is widely acknowledged that the most harmful emissions include carbon dioxide (CO2), Nitrogen dioxide (NO2), Carbon monoxide (CO), and Particular matter (PM).

CO and PM are pollutants that can have detrimental effects human health if consistently inhaled in large quantities. Particular matter (PM) also known as particle pollution, is a term for a mixture of solid particles and liquid droplets found in the air (US EPA, 2016). These particles come from various sources including construction dust, unpaved roads, fires, power lants, industries where energy or heat is being created by burning fossil fuels or biomass, and also automobiles that do the same as big industrial emission source.

Vehicle exhaust emissions also contain greenhouse gases such as CO2, nitrous oxide (N2O), and methane (CH4). These gases allow sunlight to pass through the atmosphere and heat the surface of the Earth. The Earth’s surface then radiates part of this energy back to the space. If this gases present high density in the air then it absorbs some of this energy and block it to being radiated back to the space and traps the heat near to the surface of the Earth leading to a warmer climate than would be the case if these gases were not present (*Greenhouse effect | Definition, Diagram, Causes, & Facts | Britannica*, 2023).

To investigate the air pollution caused by vehicles equipped with internal combustion engines, I plan to work with databases from three areas. I will compare the air pollution data collected from Dublin’s monitoring centres with the number of electric vehicles put into circulation, observing how the increasing prevalence of electric vehicles in Ireland over the past years has affected the air pollution data of the capital. At the same time, it is important to consider that the development of Dublin’s road network generates more and more road traffic year by year, so as a third pillar, I bring the transit traffic into context with the air pollution data.

There are forty-one air pollution monitoring centres in Dublin, covering the entire capital, but mainly focusing on the downtown districts. These monitoring centres provide real-time data on the PM2.5, PM10, O3, SO2, NO2 content of the air, which they collect with gas analysers and particulate matter monitors and make publicly available.

I will examine the number of electric vehicles put into circulation using data issued by The Irish Department of Transport and the European Alternative Fuels Observatory (EAFO). These statistics include fully electric, plug-in hybrid cars, electric vans, electric motorcycles alike. The Irish Department of Transport’s statistics on vehicles put into circulation often contain data on trends and location. The statistics issued by the EOFO are approximately similar to the above, with the difference that statistics for other member states of the European Union are also available here, which can be useful in uncovering parallels or contrasts.

Data necessary for quantifying the transit road traffic are publicly available on the Central Statistics Office and Data.Gov.ie websites. These data show the number of vehicles in road traffic on a daily basis, which I will compare with air pollution data in the research of correlations.

Based on these three pillars, I will start my research on the topic to uncover how the increasing prevalence of electric driving affects the air quality in Dublin.

* **Data Collection**
* **Data Analysis**

**Results**

**Discussion**

**Conclusion**

**Research validity**

* **Accurate**: - the overview given by the literature review shows that the results of the study represents the real and true values of the examined areas without any bias, using the pure and clear facts.
* **Relevant**: - the research I conducted aimed to support the validity of the questions raised by the chosen topic with examples from previous studies conducted by others. The results obtained are closely related to the questions I formulated.
* **Reliable**: - the findings of my research, along with those of previous studies and inquiries conducted in the same domain, are highly reproducible and stem from reliable, credible, and verifiable sources.
* **Current**: - the sources and studies used represent the current state of the introduction and expansion of electric cars, as well as the associated difficulties. In order to address the formulated questions and the selected topic itself, I will need to rely on the most up-to-date data and sources available.

The primary data for my research will be derived from secondary sources, encompassing sales statistics, pollution data, and various quantitative indicators pertaining to the research topic. To enhance the robustness of my findings based on this secondary data, I intend to supplement it with primary data collected through in-depth interviews with subject matter experts in relevant domains. Through this qualitative research approach, my objective is to gather primary data that will corroborate and strengthen the conclusions and outcomes of my study. To achieve this, I plan to conduct comprehensive interviews with experts who possess in-depth knowledge and experience in areas including the environmental impact of internal combustion engine vehicles, the potential reductions in greenhouse gas emissions and air pollutants resulting from the transition to electric vehicles, the influence of government incentives on the expansion of the electric vehicle market, and the challenges impeding the widespread adoption of electric mobility in Dublin.

When selecting participants for these interviews, purposive sampling will be employed to identify experts who possess the necessary knowledge and experience in the aforementioned areas. This may include sales experts who can offer insights into market trends and consumer behavior, regulatory experts who can provide information on government incentives and policies, and air pollution experts who can contribute data on the impact of transportation on air quality. To optimize the outcomes of the interviews, a semi-structured interview approach will be adopted. While a general set of questions and topics will be prepared in advance, there will also be flexibility to deviate from the scripted questions and delve deeper into the interviewees' responses with additional inquiries. This approach fosters a more adaptable and open-ended conversation, facilitating the emergence of unforeseen insights and perspectives. The questions posed during the interviews must be appropriate in terms of content and format, as they constitute the backbone of the interview process and enable the acquisition of comprehensive and high-quality information from the participants. Moreover, it is crucial that the questions directly address the study's objectives or are closely aligned with them.

I intend to incorporate observations into the research methodology by deploying sensors to measure air quality across various locations in the country, including different parts of Dublin. By contextualizing the gathered quantitative data with insights obtained from the in-depth interviews, I aim to establish a comprehensive understanding of the research topic. This combination of qualitative and quantitative techniques will facilitate a thorough exploration and lend support to the final conclusions of my study.

Based on my research topic and objectives, I have defined my population as current and potential EV owners in Dublin. To ensure a sample that accurately represents this population, I intend to employ a multistage probability sampling approach, integrating stratified, cluster, and simple random sampling methods. I will utilize stratified sampling to categorize the population into homogeneous subgroups, or strata, based on key variables such as gender, income, and geographic location. This stratification will enable the inclusion of diverse subgroups within the sample, ensuring adequate representation.

In the second stage, I will employ cluster sampling. This involves dividing each stratum into smaller geographic units or clusters and randomly selecting a subset of clusters from each stratum. This cluster-based approach allows for a more feasible and practical sampling process, particularly when a comprehensive list of all individuals in the population is difficult to obtain, and finally I will employ simple random sampling. This will involve selecting a random sample of individuals from each selected cluster. By employing this method, I can guarantee that every individual within the selected clusters has an equal opportunity to be included in the study.

Cluster sampling proves advantageous when faced with challenges such as incomplete population lists or logistical constraints. By selecting clusters instead of individual participants, I can streamline the research process, optimizing resource utilization, while still ensuring that the resulting sample is representative of the target population.

The primary source of data for my research will consist mainly of secondary data, including sales statistics, pollution data, and other numerical indicators relevant to the topic. To strengthen the findings derived from this secondary data, I plan to supplement it with primary data obtained through in-depth interviews conducted with experts in relevant fields. By employing this qualitative research technique, my aim is to gather primary data that will further substantiate the conclusions and outcomes of my study.

My research plan entails conducting comprehensive and in-depth interviews with subject matter experts who possess profound expertise in their respective fields. These individuals are highly knowledgeable and can provide invaluable insights pertaining to the various dimensions I intend to investigate. Specifically, I seek their expertise on critical subjects including the environmental ramifications associated with internal combustion engine vehicles, the potential for mitigating greenhouse gas emissions and air pollutants through the transition to electric vehicles, the influence of government incentives on the expansion of the electric vehicle market, and the multifaceted challenges impeding the widespread adoption of electric mobility in the context of Dublin.

To ensure a suitable selection of interview participants, I will use purposive sampling. This approach allows for the identification of experts who possess relevant knowledge and experience in the aforementioned areas. For instance, sales experts can offer insights on market trends and consumer behaviour, regulatory experts can provide information on government incentives and policies, and air pollution experts can contribute data on the impact of transportation on air quality. In addition to these experts, I also plan to include an expert from the production side to gain more insights into new battery technology and the recycling of used electric vehicle batteries. This expert will be able to provide valuable information on current methodologies and future plans in this area.

During the interviews, I will employ a semi-structured interview format. This approach entails having a general set of questions and topics to cover while also allowing flexibility to deviate from the script and delve deeper into the interviewee’s responses with additional questions. This flexibility facilitates open-ended conversations, often leading to unexpected insights and perspectives. The questions asked during the interviews must be well-crafted, ensuring they align with the content and format appropriate for obtaining comprehensive and high-quality information. Moreover, the questions should directly address the study’s objectives or closely relate to them.

Additionally, I plan to incorporate observational data by deploying sensors to measure air quality in various locations across the country, including different parts of Dublin. By contextualizing this gathered quantitative data with insights obtained from the in-depth interviews, I aim to establish a holistic understanding of the research topic. This combination of qualitative and quantitative techniques will enable a more comprehensive exploration and support the final conclusions of my study.

In my academic research on “The impact of widespread adoption of electric vehicles on air quality in Dublin”, it is vital to consider several ethical issues in regards of in-depth interviews and observational data collection. It is important that participants understand the purpose, procedures, potential risks, and benefits of the research and that their participation is voluntary. Another important consideration is maintaining confidentiality and anonymity to protect participants’ privacy and ensure their personal information is handled securely. Maintain the accuracy and integrity of data throughout the research process. Ensure that collected data is securely stored, analysed, and reported objectively and transparently. Avoid manipulation or misrepresentation of data to support preconceived conclusions. This includes safeguarding collected data from unauthorized access or disclosure. At the preparation stage of my study the potential of negative or uncomfortable feelings that participants may experience need to be considered when providing sensitive data during the data collection process. Important also to be mindful of cultural differences due to participants from different genders or backgrounds and to take steps to prevent any potential discrimination. Transparency is another important area of ethical considerations, research findings must be reported accurately and objectively to maintain the integrity of the research and contribute to the body of scientific knowledge. Applying these ethical considerations, I will be able to conduct the research in an ethical and responsible manner that protects the rights and well-being of all participants involved.

## **References**

*2020 climate & energy package* (no date). Available at: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2020-climate-energy-package\_en (Accessed: 28 March 2023).

*2030 climate & energy framework* (no date). Available at: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-energy-framework\_en (Accessed: 28 March 2023).

Adepetu, A. and Keshav, S. (2017) ‘The relative importance of price and driving range on electric vehicle adoption: Los Angeles case study’, *Transportation*, 44(2), pp. 353–373. Available at: https://doi.org/10.1007/s11116-015-9641-y.

Alimujiang, A. and Jiang, P. (2020) ‘Synergy and co-benefits of reducing CO2 and air pollutant emissions by promoting electric vehicles—A case of Shanghai’, *Energy for Sustainable Development*, 55, pp. 181–189. Available at: https://doi.org/10.1016/j.esd.2020.02.005.

Amatuni, L. *et al.* (2020) ‘Does car sharing reduce greenhouse gas emissions? Assessing the modal shift and lifetime shift rebound effects from a life cycle perspective’, *Journal of Cleaner Production*, 266, p. 121869. Available at: https://doi.org/10.1016/j.jclepro.2020.121869.

Anastasiadou, K. and Gavanas, N. (2022) ‘State-of-the-Art Review of the Key Factors Affecting Electric Vehicle Adoption by Consumers’, *Energies*, 15(24), p. 9409. Available at: https://doi.org/10.3390/en15249409.

Anderhofstadt, B. and Spinler, S. (2019) ‘Factors affecting the purchasing decision and operation of alternative fuel-powered heavy-duty trucks in Germany – A Delphi study’, *Transportation Research Part D: Transport and Environment*, 73, pp. 87–107. Available at: https://doi.org/10.1016/j.trd.2019.06.003.

Apte, R. (2019) ‘Ecosystem Feasibility and Sustainability of Aluminium - Air Battery Powered Electric Vehicle’, in. *Symposium on International Automotive Technology 2019*, pp. 2019-26–0115. Available at: https://doi.org/10.4271/2019-26-0115.

Atkinson, G. and Metsis, V. (2020) ‘Identifying label noise in time-series datasets’, in *Adjunct Proceedings of the 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2020 ACM International Symposium on Wearable Computers*. *UbiComp/ISWC ’20: 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and 2020 ACM International Symposium on Wearable Computers*, Virtual Event Mexico: ACM, pp. 238–243. Available at: https://doi.org/10.1145/3410530.3414366.

Beaudet, A. *et al.* (2020) ‘Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials’, *Sustainability*, 12(14), p. 5837. Available at: https://doi.org/10.3390/su12145837.

Bräunl, T. *et al.* (2020) ‘Determining the optimal electric vehicle DC-charging infrastructure for Western Australia’, *Transportation Research Part D: Transport and Environment*, 84, p. 102250. Available at: https://doi.org/10.1016/j.trd.2020.102250.

Cao, Y. *et al.* (2022) ‘Potential Effect of Air Pollution on the Urban Traffic Vitality: A Case Study of Nanjing, China’, *Atmosphere*, 13(10), p. 1592. Available at: https://doi.org/10.3390/atmos13101592.

Chidambaram, K. *et al.* (2023) ‘Critical analysis on the implementation barriers and consumer perception toward future electric mobility’, *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 237(4), pp. 622–654. Available at: https://doi.org/10.1177/09544070221080349.

Ciez, R.E. and Whitacre, J.F. (2019) ‘Examining different recycling processes for lithium-ion batteries’, *Nature Sustainability*, 2(2), pp. 148–156. Available at: https://doi.org/10.1038/s41893-019-0222-5.

Correa, G., Muñoz, P.M. and Rodriguez, C.R. (2019) ‘A comparative energy and environmental analysis of a diesel, hybrid, hydrogen and electric urban bus’, *Energy*, 187, p. 115906. Available at: https://doi.org/10.1016/j.energy.2019.115906.

Dentener, F. *et al.* (2020) ‘Lower air pollution during COVID-19 lock-down: improving models and methods estimating ozone impacts on crops’, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 378(2183), p. 20200188. Available at: https://doi.org/10.1098/rsta.2020.0188.

Dutta, B. and Hwang, H.-G. (2021) ‘Consumers Purchase Intentions of Green Electric Vehicles: The Influence of Consumers Technological and Environmental Considerations’, *Sustainability*, 13(21), p. 12025. Available at: https://doi.org/10.3390/su132112025.

*Electric Vehicles – Analysis* (no date) *IEA*. Available at: https://www.iea.org/reports/electric-vehicles (Accessed: 2 May 2023).

Environmental Protection Agency (no date) *Latest emissions data*. Available at: https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/latest-emissions-data/ (Accessed: 30 March 2023).

*First national electric vehicle charging infrastructure strategy published* (2023). Available at: https://www.gov.ie/en/press-release/dc958-first-national-electric-vehicle-charging-infrastructure-strategy-published/ (Accessed: 1 May 2023).

Forrest, K. *et al.* (2020) ‘Estimating the technical feasibility of fuel cell and battery electric vehicles for the medium and heavy duty sectors in California’, *Applied Energy*, 276, p. 115439. Available at: https://doi.org/10.1016/j.apenergy.2020.115439.

Gan, Y. *et al.* (2021) ‘Provincial Greenhouse Gas Emissions of Gasoline and Plug-in Electric Vehicles in China: Comparison from the Consumption-Based Electricity Perspective’, *Environmental Science & Technology*, 55(10), pp. 6944–6956. Available at: https://doi.org/10.1021/acs.est.0c08217.

‘Global Electric Vehicle Outlook 2022’ (2022).

*Greenhouse effect | Definition, Diagram, Causes, & Facts | Britannica* (2023). Available at: https://www.britannica.com/science/greenhouse-effect (Accessed: 20 December 2023).

Guo, Y., Kelly, J.A. and Clinch, J.P. (2022) ‘Variability in total cost of vehicle ownership across vehicle and user profiles’, *Communications in Transportation Research*, 2, p. 100071. Available at: https://doi.org/10.1016/j.commtr.2022.100071.

Hao, H. *et al.* (2017) ‘Electric vehicles for greenhouse gas reduction in China: A cost-effectiveness analysis’, *Transportation Research Part D: Transport and Environment*, 56, pp. 68–84. Available at: https://doi.org/10.1016/j.trd.2017.07.025.

Hardman, S. *et al.* (2017) ‘The effectiveness of financial purchase incentives for battery electric vehicles – A review of the evidence’, *Renewable and Sustainable Energy Reviews*, 80, pp. 1100–1111. Available at: https://doi.org/10.1016/j.rser.2017.05.255.

Harper, G. *et al.* (2019) ‘Recycling lithium-ion batteries from electric vehicles’, *Nature*, 575(7781), pp. 75–86. Available at: https://doi.org/10.1038/s41586-019-1682-5.

He, X. *et al.* (2019) ‘Economic and Climate Benefits of Electric Vehicles in China, the United States, and Germany’, *Environmental Science & Technology*, 53(18), pp. 11013–11022. Available at: https://doi.org/10.1021/acs.est.9b00531.

Heyer, J.A. (2021) ‘Toward Community-Scale Modeling of Air Pollution: Transportation Equity Applications and Updated Ship Emission Factors’.

Higueras-Castillo, E. *et al.* (2021) ‘Adoption of electric vehicles: Which factors are really important?’, *International Journal of Sustainable Transportation*, 15(10), pp. 799–813. Available at: https://doi.org/10.1080/15568318.2020.1818330.

Hristova, E.S. and Manousakas, M.I. (2023) ‘Special Issue: Air Pollution at the Urban and Regional Level: Sources, Sinks, and Transportation’, *Atmosphere*, 14(1), p. 132. Available at: https://doi.org/10.3390/atmos14010132.

https://www.bcg.com/about/people/experts/gang-xu (2022) *What the Shift to Zero-Emission Vehicles Means for Commercial Transportation*, *BCG Global*. Available at: https://www.bcg.com/publications/2022/what-the-shift-to-zero-emission-vehicles-means-for-commercial-transportation (Accessed: 2 May 2023).

Hu, X. *et al.* (2021) ‘The Potential Impacts of Electric Vehicles on Urban Air Quality in Shanghai City’, *Sustainability*, 13(2), p. 496. Available at: https://doi.org/10.3390/su13020496.

Jaiswal, D., Deshmukh, A.K. and Thaichon, P. (2022) ‘Who will adopt electric vehicles? Segmenting and exemplifying potential buyer heterogeneity and forthcoming research’, *Journal of Retailing and Consumer Services*, 67, p. 102969. Available at: https://doi.org/10.1016/j.jretconser.2022.102969.

Kamran, M., Raugei, M. and Hutchinson, A. (2021) ‘A dynamic material flow analysis of lithium-ion battery metals for electric vehicles and grid storage in the UK: Assessing the impact of shared mobility and end-of-life strategies’, *Resources, Conservation and Recycling*, 167, p. 105412. Available at: https://doi.org/10.1016/j.resconrec.2021.105412.

Kazemzadeh, E., Koengkan, M. and Fuinhas, J.A. (2022) ‘Effect of Battery-Electric and Plug-In Hybrid Electric Vehicles on PM2.5 Emissions in 29 European Countries’, *Sustainability*, 14(4), p. 2188. Available at: https://doi.org/10.3390/su14042188.

Kene, R., Olwal, T. and van Wyk, B.J. (2021) ‘Sustainable Electric Vehicle Transportation’, *Sustainability*, 13(22), p. 12379. Available at: https://doi.org/10.3390/su132212379.

Khani, A. and Emami, B.D. (no date) ‘Benefits and Barriers to Electrification of the Freight System in Minnesota’.

Khurana, A., Kumar, V.V.R. and Sidhpuria, M. (2020) ‘A Study on the Adoption of Electric Vehicles in India: The Mediating Role of Attitude’, *Vision*, 24(1), pp. 23–34. Available at: https://doi.org/10.1177/0972262919875548.

Knez, M. *et al.* (2014) ‘The estimation of a driving cycle for Celje and a comparison to other European cities’, *Sustainable Cities and Society*, 11, pp. 56–60. Available at: https://doi.org/10.1016/j.scs.2013.11.010.

Konstantinou, T. and Gkritza, K. (2023) ‘Examining the barriers to electric truck adoption as a system: A Grey-DEMATEL approach’, *Transportation Research Interdisciplinary Perspectives*, 17, p. 100746. Available at: https://doi.org/10.1016/j.trip.2022.100746.

Krishna, G. (2021) ‘Understanding and identifying barriers to electric vehicle adoption through thematic analysis’, *Transportation Research Interdisciplinary Perspectives*, 10, p. 100364. Available at: https://doi.org/10.1016/j.trip.2021.100364.

Kumar, R.R. and Alok, K. (2020) ‘Adoption of electric vehicle: A literature review and prospects for sustainability’, *Journal of Cleaner Production*, 253, p. 119911. Available at: https://doi.org/10.1016/j.jclepro.2019.119911.

Li, X. and Jenn, A. (2022) ‘Energy, Emissions, and Cost Impacts of Charging Price Strategies for Electric Vehicles’, *Environmental Science & Technology*, 56. Available at: https://doi.org/10.1021/acs.est.1c06231.

Lieven, T. *et al.* (2011) ‘Who will buy electric cars? An empirical study in Germany’, *Transportation Research Part D: Transport and Environment*, 16(3), pp. 236–243. Available at: https://doi.org/10.1016/j.trd.2010.12.001.

Lin, W.-Y. *et al.* (2020) ‘Analysis of air quality and health co-benefits regarding electric vehicle promotion coupled with power plant emissions’, *Journal of Cleaner Production*, 247, p. 119152. Available at: https://doi.org/10.1016/j.jclepro.2019.119152.

Ma, C., Madaniyazi, L. and Xie, Y. (2021) ‘Impact of the Electric Vehicle Policies on Environment and Health in the Beijing–Tianjin–Hebei Region’, *International Journal of Environmental Research and Public Health*, 18(2), p. 623. Available at: https://doi.org/10.3390/ijerph18020623.

Maizlish, N., Rudolph, L. and Jiang, C. (2022) ‘Health Benefits of Strategies for Carbon Mitigation in US Transportation, 2017‒2050’, *American Journal of Public Health*, 112(3), pp. 426–433. Available at: https://doi.org/10.2105/ajph.2021.306600.

Mandys, F. (2021) ‘Electric vehicles and consumer choices’, *Renewable and Sustainable Energy Reviews*, 142, p. 110874. Available at: https://doi.org/10.1016/j.rser.2021.110874.

Melton, N., Axsen, J. and Moawad, B. (2020) ‘Which plug-in electric vehicle policies are best? A multi-criteria evaluation framework applied to Canada’, *Energy Research & Social Science*, 64, p. 101411. Available at: https://doi.org/10.1016/j.erss.2019.101411.

Milojević, S. *et al.* (2018) ‘Alternative Drive Systems and Environmentaly Friendly Public Passengers Transport’, *Applied Engineering Letters : Journal of Engineering and Applied Sciences*, 3(3), pp. 105–113. Available at: https://doi.org/10.18485/aeletters.2018.3.3.4.

Mislyuk, O. *et al.* (2023) ‘Assessing Risk Caused by Atmospheric Air Pollution from Motor Vehicles to the Health of Population in Urbanized Areas: ОЦІНКА РИЗИКУ ДЛЯ ЗДОРОВ’Я НАСЕЛЕННЯ УРБАНІЗОВАНИХ ТЕРИТОРІЙ ВІД ЗАБРУДНЕННЯ АТМОСФЕРНОГО ПОВІТРЯ АВТОТРАНСПОРТОМ.’, *Eastern-European Journal of Enterprise Technologies*, 121(10), pp. 19–26. Available at: https://doi.org/10.15587/1729-4061.2023.274174.

Mutavdžija, M., Kovačić, M. and Buntak, K. (2022) ‘Assessment of Selected Factors Influencing the Purchase of Electric Vehicles—A Case Study of the Republic of Croatia’, *Energies*, 15(16), p. 5987. Available at: https://doi.org/10.3390/en15165987.

Nykvist, B. and Olsson, O. (2021) ‘The feasibility of heavy battery electric trucks’, *Joule*, 5(4), pp. 901–913. Available at: https://doi.org/10.1016/j.joule.2021.03.007.

Ochiai, K. *et al.* (2021) ‘Simulating the Effects of Eco-Friendly Transportation Selections for Air Pollution Reduction’. arXiv. Available at: http://arxiv.org/abs/2109.04831 (Accessed: 24 April 2023).

Ou, Y. *et al.* (2021) ‘Evaluating long-term emission impacts of large-scale electric vehicle deployment in the US using a human-Earth systems model’, *Applied Energy*, 300, p. 117364. Available at: https://doi.org/10.1016/j.apenergy.2021.117364.

Pérez, I.A. *et al.* (2020) ‘Key Points in Air Pollution Meteorology’, *International Journal of Environmental Research and Public Health*, 17(22), p. 8349. Available at: https://doi.org/10.3390/ijerph17228349.

Perillo, H.A. *et al.* (2022) ‘Spatiotemporal representativeness of air pollution monitoring in Dublin, Ireland’, *Science of The Total Environment*, 827, p. 154299. Available at: https://doi.org/10.1016/j.scitotenv.2022.154299.

Philippot, M. *et al.* (2019) ‘Eco-Efficiency of a Lithium-Ion Battery for Electric Vehicles: Influence of Manufacturing Country and Commodity Prices on GHG Emissions and Costs’, *Batteries*, 5(1), p. 23. Available at: https://doi.org/10.3390/batteries5010023.

Qin, D.-S. and Gao, C.-Y. (2022) ‘Control Measures for Automobile Exhaust Emissions in PM2.5 Governance’, *Discrete Dynamics in Nature & Society*, pp. 1–14. Available at: https://doi.org/10.1155/2022/8461406.

Quintyne, K.I. *et al.* (2021) ‘COVID-19 transport restrictions in Ireland: impact on air quality and respiratory hospital admissions’, *Public Health*, 198, pp. 156–160. Available at: https://doi.org/10.1016/j.puhe.2021.07.008.

Rajaeifar, M.A. *et al.* (2022) ‘Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective’, *Resources, Conservation and Recycling*, 180, p. 106144. Available at: https://doi.org/10.1016/j.resconrec.2021.106144.

Requia, W.J. *et al.* (2018) ‘How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health’, *Atmospheric Environment*, 185, pp. 64–77. Available at: https://doi.org/10.1016/j.atmosenv.2018.04.040.

Riccardo Boin, Timo Möller, Vadim Pokotilo, Andrea Ricotti, and Nicola Sandri (2023) *Solutions for smart mobility in urban areas | McKinsey*. Available at: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/infrastructure-technologies-challenges-and-solutions-for-smart-mobility-in-urban-areas#/ (Accessed: 30 March 2023).

Sacchi, R. *et al.* (2022) ‘When, where and how can the electrification of passenger cars reduce greenhouse gas emissions?’, *Renewable and Sustainable Energy Reviews*, 162, p. 112475. Available at: https://doi.org/10.1016/j.rser.2022.112475.

Sánchez-García, M. *et al.* (2021) ‘An extended behavior model for explaining the willingness to pay to reduce the air pollution in road transportation’, *Journal of Cleaner Production*, 314, p. 128134. Available at: https://doi.org/10.1016/j.jclepro.2021.128134.

Sendek-Matysiak, E. *et al.* (2022) ‘Total Cost of Ownership of Light Commercial Electrical Vehicles in City Logistics’, *Energies*, 15(22), p. 8392. Available at: https://doi.org/10.3390/en15228392.

Singh, Virender, Singh, Vedant and Vaibhav, S. (2020) ‘A review and simple meta-analysis of factors influencing adoption of electric vehicles’, *Transportation Research Part D: Transport and Environment*, 86, p. 102436. Available at: https://doi.org/10.1016/j.trd.2020.102436.

Sovacool, B.K. *et al.* (2019) ‘Pleasure or profit? Surveying the purchasing intentions of potential electric vehicle adopters in China’, *Transportation Research Part A: Policy and Practice*, 124, pp. 69–81. Available at: https://doi.org/10.1016/j.tra.2019.03.002.

Sun, M. *et al.* (2022) ‘Uncovering travel and charging patterns of private electric vehicles with trajectory data: evidence and policy implications’, *Transportation*, 49(5), pp. 1409–1439. Available at: https://doi.org/10.1007/s11116-021-10216-1.

Sweda, T.M., Dolinskaya, I.S. and Klabjan, D. (2017) ‘Optimal Recharging Policies for Electric Vehicles’, *Transportation Science*, 51(2), pp. 457–479. Available at: https://doi.org/10.1287/trsc.2015.0638.

Tchetchik, A. *et al.* (2020) ‘The joint effects of driving hedonism and trialability on the choice between internal combustion engine, hybrid, and electric vehicles’, *Technological Forecasting and Social Change*, 151, p. 119815. Available at: https://doi.org/10.1016/j.techfore.2019.119815.

Tundys, B. and Wiśniewski, T. (2023) ‘Smart Mobility for Smart Cities—Electromobility Solution Analysis and Development Directions’, *Energies*, 16(4), p. 1958. Available at: https://doi.org/10.3390/en16041958.

US EPA, O. (2016) *Particulate Matter (PM) Basics*. Available at: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics (Accessed: 17 December 2023).

Van Ryswyk, K. *et al.* (2021) ‘Personal exposures to traffic-related air pollution in three Canadian bus transit systems: the Urban Transportation Exposure Study’, *Journal of Exposure Science & Environmental Epidemiology*, 31(4), pp. 628–640. Available at: https://doi.org/10.1038/s41370-020-0242-2.

*Vehicles licensed for the first time December and Year 2022 - CSO - Central Statistics Office* (2023). CSO. Available at: https://www.cso.ie/en/releasesandpublications/ep/p-vlftm/vehicleslicensedforthefirsttimedecemberandyear2022/ (Accessed: 30 March 2023).

Venter, Z.S. *et al.* (2020) ‘COVID-19 lockdowns cause global air pollution declines’, *Proceedings of the National Academy of Sciences*, 117(32), pp. 18984–18990. Available at: https://doi.org/10.1073/pnas.2006853117.

Wang, N. and Tang, G. (2022) ‘A Review on Environmental Efficiency Evaluation of New Energy Vehicles Using Life Cycle Analysis’, *Sustainability*, 14(6), p. 3371. Available at: https://doi.org/10.3390/su14063371.

Yao, E. *et al.* (2020) ‘Optimization of electric vehicle scheduling with multiple vehicle types in public transport’, *Sustainable Cities and Society*, 52, p. 101862. Available at: https://doi.org/10.1016/j.scs.2019.101862.

Zarazua De Rubens, G. (2019) ‘Who will buy electric vehicles after early adopters? Using machine learning to identify the electric vehicle mainstream market’, *Energy*, 172, pp. 243–254. Available at: https://doi.org/10.1016/j.energy.2019.01.114.

Zhang, H. *et al.* (2023) ‘Life cycle environmental impact assessment for battery-powered electric vehicles at the global and regional levels’, *Scientific Reports*, 13(1), p. 7952. Available at: https://doi.org/10.1038/s41598-023-35150-3.

Zero Emission Road Freight Strategy. (2020). Available at: https://hewlett.org/wp-content/uploads/2020/04/Hewlett-Zero-Emission-Road-Freight-Strategy-2020-2025.pdf.

*‌*