Energy Policy 194 (2024) 114335

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Hidden effects and externalities of electric vehicles

Milad Haghani [a,*], Hadi Ghaderi [b], David Hensher [c]

[a] Research Centre for Integrated Transport Innovation (rCITI), School of Civil and Environmental Engineering, The University of New South Wales, UNSW Sydney, Australia
[b] Department of Management and Marketing, Swinburne University of Technology, Melbourne, Australia
[c] Institute of Transport and Logistics Studies (ITLS), The University of Sydney Business School, Australia

ABSTRACT

The global drive towards sustainability has ushered in a new era of transportation, prominently featuring the rise of Battery Electric Vehicles (BEVs). The rapid rise of BEVs has been widely and rightfully hailed as a crucial milestone in promoting sustainable transportation and combating climate change. The existing empirical evidence provides undeniable support for the essential role of BEVs to support net zero targets. However, like most disruptive or emerging technologies, BEVs are not without their hidden effects. This paper seeks to explore and analyse these lesser-known effects, i.e., externalities, of BEV adoption. In doing so, it sheds light on the environmental, infrastructure, socio-economic and safety externalities of BEVs, aiming to promote a holistic understanding of their impact and to facilitate informed policy making. Furthermore, it highlights the critical role of public awareness and user education campaigns in maximising the benefits and mitigating the externalities of BEVs, along with the importance of maintaining a balance of information in developing such campaigns. It is argued that providing individuals and policymakers with accurate information, dispelling misconceptions, and promoting responsible BEV practices are essential for minimising the externalities. At a broader level, these discussions emphasise the importance of moving beyond mere tailpipe emissions towards a holistic, life-cycle-based approach in setting climate-change targets.

1. Introduction

Battery Electric Vehicles (BEVs) have gained significant traction in recent years, spurred by the need to transition towards greener mobility solutions (Pagani, 2021) and advancements in vehicular and battery technologies. Propelled by their potential to curb emissions and mitigate climate change, BEVs stand as beacons of hope in the pursuit of a cleaner future. Governments, industries, and consumers alike have embraced BEVs as a sustainable alternative to conventional Hydrocarbon vehicles (HCVs). As the world seeks to reduce carbon emissions and combat climate change, electric cars and trucks have emerged as pivotal players in the quest for greener and more efficient transportation systems (Eberle and von Helmolt, 2010; Ouyang and Xu, 2022).

At a time when the transition to BEVs gathers momentum, we must not overlook the intricacies that could shape the trajectory of this mobility revolution. As BEVs become an increasingly integral part of our transportation ecosystem, it is essential to uncover the multifaceted effects that lie beyond the surface of their publicised benefits. While the environmental advantages of BEVs are well-documented (Buekers et al., 2014; Haghani et al., 2023; Holland et al., 2016), an all-encompassing understanding of their impact, both in the realms of urban transportation as well as freight, demands a comprehensive evaluation. In other words, it is essential to critically examine and foresee the possible hidden and unintended consequences of the widespread adoption of BEVs, particularly those associated with the role of context-specific and local factors (Buekers et al., 2014; Gan et al., 2021; Holland et al., 2016; Requia et al., 2018). Such perspective is, in fact, essential to address the shortcomings of BEV technologies without undermining their well-known sustainability benefits that could support minimising the negative consequences of transport activity.

By acknowledging the social and economic dimensions that accompany the widespread adoption of BEVs in both personal mobility and freight transport contexts, this discussion aims to present a balanced assessment, covering both the positive and negative aspects of BEV integration. The aim is to explore the intricate interactions between BEV adoption and various aspects of transportation and society, in particular user behaviour. The examination of charging infrastructure, energy demand patterns, changes in travel behaviour, and implications for urban mobility allows us to navigate the complexities that arise from this transition. Borrowing from the existing empirical evidence, the discussion sheds light on these less apparent aspects and seeks to paint a more balanced and inclusive picture of the true implications of large uptake of BEVs. In doing so, we investigate potential externalities of BEVs that relate to *environment* (Hawkins et al., 2012; Holland et al., 2016),

* Corresponding author.
E-mail address: milad.haghani@unsw.edu.au (M. Haghani).

https://doi.org/10.1016/j.enpol.2024.114335
Received 6 October 2023; Received in revised form 27 August 2024; Accepted 28 August 2024
Available online 31 August 2024

infrastructure (Das et al., 2020), *socio-economic* (Lee and Brown, 2021; Malmgren, 2016) as well as *safety* aspects (Guirong and Henghai, 2012). By delineating the nuanced effects of BEV adoption, it is our hope that this study serves as a steppingstone towards a more comprehensive and holistic understanding of BEV deployment, guiding us towards a greener, more inclusive transportation future.

It is crucial to emphasise that the objective is not to undermine the substantial and well-documented environmental and societal benefits that BEVs have to offer, rather to shed light on the potential externalities and unintended consequences that may accompany the widespread adoption of BEVs. The discussion further highlights why these intricacies need to be brought to the attention of policymakers and also enter the realm of public information, through public awareness campaigns and education packages, to help consumers make informed decisions, free of misconceptions, an essential step for the maximising the potential benefits of BEVs. It is also important to clarify that this paper does not cover other types of electric vehicles such as Plug-in Hybrid Electric Vehicles (PHEVs) or Fuel Cell Electric Vehicles (FCEVs). The exclusion of these vehicle types is deliberate, as they involve different technologies and energy systems that warrant separate consideration and discussions.

2. The promising benefits of transportation electrification

The environmental benefits of BEVs are undeniable (Du and Ouyang, 2017; Holland et al., 2016). One of the most significant advantages of BEVs is their ability to reduce greenhouse gas emissions (Requia et al., 2018). Unlike HCVs that emit carbon dioxide and other pollutants, BEVs produce zero tailpipe emissions when powered by electricity from renewable sources, thus contributing to lower carbon footprints (Li et al., 2022; Xia et al., 2022). The shift towards BEVs helps improve local air quality and reduce air pollution inequality by reducing emissions of harmful pollutants like nitrogen oxides (NOx) (Brady and O'Mahony, 2011; Chang et al., 2023; Soret et al., 2014). This has direct health benefits, particularly in urban areas with high traffic congestion and population density (Li et al., 2016). BEVs are also generally more energy-efficient (Stevic and Radovanovic, 2012; Wu et al., 2015). Electric motors convert a higher percentage of energy from the grid to power the wheels, reducing overall energy consumption compared to HCVs. BEVs also operate more quietly than traditional vehicles, contributing to reduced noise pollution in urban environments (Campello-Vicente et al., 2017; Jabben et al., 2012; Qin et al., 2020). Furthermore, the new generation of BEV batteries can act as energy storage devices, enabling the integration of renewable energy sources like solar and wind power into the electricity grid. This can enhance grid stability and increase the share of renewables in the energy mix (Conti et al., 2018; Joseph and Elangovan, 2018; Nishanthy et al., 2022; Nunes et al., 2016). However, it is crucial to consider the potential drawbacks associated with using BEVs for grid stabilisation. Frequent charging and discharging can indeed accelerate battery wear, potentially reducing the battery's overall lifespan and leading to earlier vehicle retirement due to the high cost of battery replacements. To mitigate such effects, simpler strategies can be implemented. For example, introducing a managed delay of a few minutes in charging start times can significantly benefit grid management without the intense cycling of the battery.

Introduction of BEVs into the freight industry can similarly bring forth a broad range of benefits (Mulholland et al., 2018; Suarez et al., 2019). Road freight sector is one of the largest consumers of fossil fuels and its decarbonisation can contribute significantly to reduced global emission (Mulholland et al., 2018). Furthermore, as transport electrification technologies advance, it is expected that electric trucks have lower operating and maintenance costs compared to their HCV counterparts due to fewer moving parts and simplified systems (Feng and Figliozzi, 2012). This could eventually lower the overall supply chain costs (Monios and Bergqvist, 2019). Advanced features such as regenerative braking that capture energy during braking and convert it back into electricity, further improve energy efficiency of electric trucks and extending their driving range (Chandak et al., 2017). It also significantly reduces brake wear, thereby lowering particulate emissions from braking systems. However, it is important to note that the increased weight of BEVs, due to heavier batteries, might offset some of these benefits by contributing to greater brake wear under certain conditions.

Electric trucks are particularly well-suited for what is commonly referred to as 'last mile' delivery in logistics and freight operations. (Iwan et al., 2021; Zhou et al., 2019). This term denotes the final segment of the delivery process where goods are transported from transportation hubs to their ultimate destinations in urban areas, typically involving frequent stops. This is distinct from the concept of 'first-last mile' trips, which generally refers to the use of micromobility solutions for connecting travellers from their starting points to major transportation hubs, or vice versa. The ability to deliver goods directly to the end customer efficiently and on time can make electric trucks a preferred option for e-commerce and retail logistics (Ehrler et al., 2021; Zhou et al., 2019). The literature has been increasingly emphasising on the growing demand for green and zero emission last mile delivery by customers and other stakeholders (Comi and Savchenko, 2021; Kiba--Janiak et al., 2021). Therefore, adopting electric trucks can enhance the public image of freight companies as environmentally responsible and contribute to corporate social responsibility efforts, demonstrating a commitment to sustainability and environmental responsibility (Altenburg et al., 2017).

While BEVs offer numerous environmental benefits and energy efficiencies, it is also essential to recognise and address the hidden adverse effects they may pose. Motivated by demystifying such implications, the intention of this study is to pave the way for understanding the most sustainable pathways for production, use and recycling of BEVs to address the global decarbonisation challenges.

3. Potential externalities created by widespread adoption of BEVs

3.1. Environmental externalities of BEVs

The production of BEVs requires raw materials like lithium, cobalt, and nickel, which are often extracted through resource-intensive processes. The mining and manufacturing of batteries can result in harmful environmental impacts and carbon emissions (Agusdinata et al., 2018; Hawkins et al., 2012; Kaunda, 2020; Notter et al., 2010; Yu et al., 2021). In addition, as the number of BEVs grows, so does the volume of used BEV batteries that need appropriate disposal and/or recycling (Rajaeifar et al., 2022). Considering the absence of established reverse supply chains and low recovery rate of depleted batteries, to address the current demand, it is expected that mining will be the main source of material supply (Agusdinata and Liu, 2023). As a result, it is expected that around 384 new mines are needed to address battery demand by 2035.[1] Additionally, considering the limited lifespan of BEV batteries, the total ownership cost of BEVs could potentially increase dramatically in the event of battery replacement during the lifetime of the vehicle (Ouyang et al., 2021). Battery replacement could even exceed the vehicle value, causing premature end of life (Andwari et al., 2017). Such effects could lead to undesirable demand for new vehicles. Therefore, ensuring effective recycling practices and minimising waste is essential to prevent potential environmental harm (Beaudet et al., 2020; Hua et al., 2021; Pražanová et al., 2022; Skeete et al., 2020; Wang et al., 2020).

While the current recycling capabilities for BEV batteries are still developing, it is reasonable to anticipate significant advancements in this area. As pressure mounts due to the finite nature of essential minerals like lithium, cobalt, and nickel, the need for robust recycling

[1] https://source.benchmarkminerals.com/article/more-than-300-new-mines-required-to-meet-battery-demand-by-2035.

systems becomes increasingly critical. These advancements are expected not only to improve the efficiency of resource use but also to alleviate some of the environmental impacts associated with the extraction of raw materials. Thus, innovation in recycling technologies and enhancing reverse supply chains will be vital in sustaining the growth of the BEV industry while minimising its environmental footprint.

Also, the environmental benefits of BEVs largely depend on the sources of electricity used for charging. If electricity generation relies heavily on fossil fuels, the overall emissions reduction potential may be compromised (Faria et al., 2013). In 2019, almost two-thirds (63.3%) of global electricity mix were generated from fossil fuels, and of the 36.7% low-carbon sources, renewables and nuclear energy accounted for 26.3% and 10.4%, respectively.[2] In order to fully capitalise on the environmental benefits of BEVs, energy mix should comprise of larger share of renewables. This issue exhibits parallels with the increasing concerns around recycling and re-use of solar panels and wind turbines (Xu et al., 2018).

Another issue that has been less discussed with respect to BEVs is the higher rate of tyre wear as the result of battery mass and higher torque. According to Hyundai,[3] BEV tyres wear 20% quicker than HCV vehicles, attributed to higher acceleration that generate instantaneous power. Car tyres comprise of a combination of synthetic and natural rubbers. Accordingly, tyre wear releases very small harmful particles in the micrometre scale which can be classified as microplastics. Such microplastics released in the environment remain airborne for weeks and eventually washed down to water resources (Kole et al., 2017). However, within this realm there is also a contrasting and balancing aspect to consider. A notable advantage of BEVs in heavy goods transportation, which contrasts with the typical tire wear concerns, is the elimination of gear shifting (Rodrigues, 2018; Zhao et al., 2019). BEVs, using direct drive systems, do not experience the slight tire slippage associated with gear changes in conventional vehicles. This slippage, common in hydrocarbon heavy goods vehicles, contributes significantly to tire wear. The direct drive system in BEVs allows for smoother acceleration and deceleration, which can potentially reduce tire wear over time.

3.2. Infrastructure externalities of BEVs

The widespread adoption of BEVs will require significant investment not only in charging infrastructure but also in the broader electrical grid, including cable networks necessary to support increased demand. The construction and maintenance of charging stations could impose burdens on local resources and potentially affect land use and aesthetics (Deveci et al., 2023; Pardo-Bosch et al., 2021; Wang et al., 2022; Zhang et al., 2021b). Understanding the infrastructure impacts is crucial for effectively accommodating the growing demand for BEVs, while addressing potential challenges and opportunities. The transition to a fully electric fleet requires a robust charging infrastructure (Morrissey et al., 2016). Insufficient charging stations, slow charging times, and grid limitations can hinder widespread BEV adoption and lead to stranded BEVs. The deployment of public charging stations at strategic locations, such as shopping centres, workplaces, and along highways, promotes greater BEV adoption and alleviates range anxiety (Pevec et al., 2020; Xu et al., 2020). Building charging stations, especially fast-charging stations and kerbside charging (Unterluggauer et al., 2022), requires substantial land use planning, impacting available space and urban resources (Carlton and Sultana, 2022; Orsi, 2021; Zhang et al., 2021b). Ensuring equitable access to charging infrastructure is another crucial aspect to avoid "charging deserts" and ensuring that underserved communities can benefit from the BEV transition (Desai et al., 2022).

Furthermore, balancing the grid's load during peak charging periods becomes essential to ensure stable electricity supply and avoid potential blackouts (Jaiswal and Ballal, 2017; Mahmud et al., 2018; Ovalle et al., 2016; Singh et al., 2013). Particularly, this issue is more challenging for heavy BEVs as their battery size is large demanding much more electricity and charging time. For example, Tesla's Semi[4] has a battery capacity of 850 kwh, more than ten times of Model Y. On the other hand, BEVs have the potential to act as distributed energy storage systems. Smart charging and vehicle-to-grid (V2G) technology enable bi-directional energy flow, allowing BEVs to supply power back to the grid during peak demand periods, enhancing grid stability and reducing the need for costly grid upgrades (Mal et al., 2013; Quinn et al., 2012; Turker and Bacha, 2018).

In addition to the above, the shift of freight transportation from rail to electric trucks, to some extent, can impact infrastructure development. Increased adoption of electric trucks may require improvements to road infrastructure and higher cost of maintenance to accommodate their heavier weights (Kast et al., 2017; Low et al., 2023; Qiu et al., 2022; Timmers and Achten, 2016). Furthermore, electric trucks would travel to regional and diverse terrains, where the infrastructure is not capable of accommodating heavier weights and supporting charging (e.g., bridges with limited gross mass permitted). It is also important to consider the implications of weight constraints imposed by regulation or existing infrastructure capacities. The inherently heavier weight of BEVs means that, in regions where vehicle weight is limited by infrastructure capabilities or regulatory measures, more vehicle movements may be required to transport the same amount of goods. In other words, BEVs could potentially reach these weight limits with less cargo. This means that to transport the same amount of goods, more vehicle movements (i.e., trips) might be necessary when using BEVs as opposed to lighter trucks. This could lead to an increase in traffic, elevated operational costs, and additional strain on transportation infrastructure.

The transition to electric trucks may also require workforce upskilling and training to handle new technologies, maintenance procedures, and charging infrastructure management (Kotz et al., 2023). Finally, As BEV adoption increases and reliance on gasoline decreases, it can lead to a reduction in fuel and gas tax revenues. These revenues typically support transportation infrastructure, and policymakers may need to consider alternative funding sources for maintenance and upgrades (Jenn et al., 2015; Zhao et al., 2015).

3.3. Socio-economic externalities of BEVs

While BEVs often have lower operating costs due to generally cheaper electricity compared to gasoline, this advantage can vary significantly by region, and the type of charging infrastructure used. Therefore, while BEVs typically entail higher upfront purchase costs, their operating costs can vary and are influenced by local energy prices and charging infrastructure (Breetz and Salon, 2018; Chen et al., 2020; Dong et al., 2020; Lu et al., 2022; Ouyang et al., 2020). This can affect consumer purchasing decisions, and governments may need to consider various incentives and policies to stimulate adoption. Additionally, BEVs disrupt the traditional automotive supply chain, affecting the associated jobs and requiring major changes in manufacturing practices, maintenance and other services (Borgstedt et al., 2017; Günther et al., 2015).

The widespread adoption of BEVs can potentially exacerbate social inequities if it leads to the neglect of public transportation and affects low-income communities, disproportionately. Limited access to BEV

[2] https://ourworldindata.org/electricity-mix#:~:text=In/202019/2C/20almost/20two/2Dthirds, been/20pretty/20stagnant/20for/20decades.

[3] https://www.hyundaimotorgroup.com/story/CONT0000000000050465#:~:text=The/20tires/20of/20electric/20vehicles, that/20generate/20strong/20instantaneous/20power.

[4] https://www.forbes.com/sites/alistaircharlton/2023/04/06/tesla-master-plan-part-three-reveals-two-semi-battery-sizes-hints-at-three-new-vehicles/?sh=3fefe539607d.

charging infrastructure in certain areas could create transportation disparities (Carlton and Sultana, 2023; Caulfield et al., 2022; Guo and Kontou, 2021; Sovacool et al., 2019; Wells, 2012).

Another noteworthy consideration is the phenomenon known as the "rebound effect" or "Jevons Paradox" (Alcott, 2005; York and McGee, 2016), as a potential hidden effect associated with widespread BEV adoption (or any other energy-efficient technologies). The rebound effect refers to the situation where an increase in energy efficiency leads to an increase in overall energy consumption, offsetting some of the anticipated environmental benefits. When the efficiency of a technology or system improves, leading to reduced energy consumption per unit of output or activity, the overall energy savings are partially offset by an increase in the volume of that activity, leading to less than expected net energy savings (Freire-González and Puig-Ventosa, 2015; Giampietro and Mayumi, 2018). In the context of BEVs, the rebound effect manifests when consumers, once they switch to a BEV, may engage in additional trips or travel longer distances than they would have with a conventional HCV. This increase in travel could be due to several factors. BEVs typically have lower operating costs compared to gasoline vehicles. Lower fuel costs might encourage BEV owners to take more trips or drive longer distances. Owning a BEV may lead some individuals to feel they are making a positive contribution to the environment. As a result, they might feel less guilty or more justified in taking additional trips, assuming their overall impact is lower due to the vehicle's reduced emissions. As BEV charging infrastructure improves and BEVs offer longer ranges, the fear of running out of charge (range anxiety) diminishes (Ouyang et al., 2021; Palmer et al., 2018; Pevec et al., 2020). This could lead to more frequent and longer trips.

In addition to the above, as more people adopt BEVs and as they become more cost competitive, the visibility, social acceptance and affordability of BEVs may increase, potentially influencing others to purchase BEVs and thereby contributing to increased car ownership and overall travel (Yang et al., 2017). While BEVs can help reduce local emissions, they do not eliminate traffic congestion. In fact, if BEV adoption leads to an overall increase in vehicle usage or induces more vehicle miles travelled, it could exacerbate traffic congestion in urban areas. Increased congestion can have economic and social implications, affecting productivity, air quality, and quality of life. It should be noted that, while the rebound effect is a valid concern, its extent can vary based on individual behaviours, regional differences, and government policies (Freeman et al., 2016; Freire-González, 2021; Hamant, 2020; Lange et al., 2021; Polimeni and Polimeni, 2006; Siami and Winter 2021; Sorrell, 2009).

From a supply chain point of view, battery production, especially in the context of BEVs, could impose several social and environmental risks across various stages of the value chain. Minerals such as cobalt and lithium for battery production are often extracted from mines in developing countries with loose labour and environmental legislation (Babbitt, 2020; Jones et al., 2023). As such, this could lead to exploitative labour practices, unsafe working conditions, and child labour. It is important to note that mining companies rely on a range of third-party contractors to extract, process and transport minerals. Oftentimes, the absence of a mandatory chain of responsibility results in sub-optimal supply chain reporting and transparency, which remains a major challenge. (Jones et al., 2023).

3.4. Safety externalities of BEVs

BEVs generally have a strong safety record, but like any other form of transportation, they come with specific safety considerations. Some of the major safety concerns associated with BEVs include: The lithium-ion batteries used in BEVs store a large amount of energy, and while incidents are rare, there have been instances of battery fires or thermal runaway (Aalund et al., 2021; Huang et al., 2021; Pistoia and Liaw, 2018; Rezvanizaniani et al., 2014; Zhang et al., 2018). Proper battery management systems and safety protocols are crucial to minimise these risks (Christensen et al., 2021). This is particularly more important when operating in harsher climate conditions where higher temperature could be a confounding factor. Furthermore, emergency responders need specific training to handle BEV accidents safely due to the presence of high-voltage electrical systems and potentially hazardous battery packs (Bisschop et al., 2020; Grant and Quincy, 2014; Quinn et al., 2012; Liu et al., 2023; Park, 2013). Moreover, proper knowledge and protocols are necessary to ensure the safety of both first responders and victims in cases of BEV crashes (Petit Boulanger et al., 2015; Wöhrl et al., 2021; Zhang et al., 2022).

Safety hazards related to BEV charging can also arise if charging equipment is not properly installed or maintained (Gao et al., 2016; Jiang et al., 2012; Wang et al., 2019). Electric shock, fire hazards, or short circuits or even cyberattacks can occur if charging stations are not up to safety standards (Bhusal et al., 2021; Garofalaki et al., 2022; Gottumukkala et al., 2019; Metere et al., 2021; Pourmirza and Walker, 2021). Safe recycling and disposal of BEV batteries are also essential to prevent environmental hazards and ensure the responsible handling of potentially hazardous materials (Harper et al., 2019).

BEVs are also quieter at low speeds compared to traditional vehicles, making them less noticeable to pedestrians (Cocron and Krems, 2013; Konet et al., 2011; Wogalter et al., 2001). This 'silent car' effect can pose a safety risk for pedestrians, particularly in urban areas or parking lots, where they might not expect a vehicle to approach silently. Without the auditory cues provided by traditional engine noise, pedestrians may fail to recognise the presence of a vehicle, potentially increasing the risk of accidents. In addition to the 'silent car' effect, the increased weight of BEVs could pose another safety concern, especially in the event of collisions with pedestrians and other vulnerable road users. The heavier batteries make BEVs significantly heavier than their ICE counterparts, potentially increasing the severity of injuries in accidents.[5]

4. The role of public awareness and educational campaigns

The behaviour and patterns of use on the part of current and future users and consumers can significantly impact the materialisation of BEV benefits. A shift towards BEV adoption alone may not fully realise the potential benefits if consumers do not embrace certain practices and habits that optimise their usage. An informed consumer is also better equipped to assess the suitability of a BEV for their lifestyle, driving habits, and budget. Addressing common misconceptions and myths about BEVs can dispel doubts and encourage more consumers to consider BEVs, systematically. Consumers who understand the environmental benefits of BEVs are more likely to make sustainable choices and actively contribute to reducing their carbon footprint. A well-informed consumer base can drive increased demand for BEVs, prompting automakers to invest in further research and development, leading to improved BEV offerings. Educating the public about BEVs fosters acceptance and support for sustainable transportation initiatives, garnering more significant public and political backing. Furthermore, an informed consumer base will enforce automakers to be actively involved in circular economy activities, such as development of technologies and processes for recycling and re-use of batteries.

Providing consumers with a BEV education package is, therefore, essential to ensure they can make informed decisions about purchase and use. Such a package would serve to raise awareness, offer comprehensive information, and address common misconceptions and concerns related to BEV adoption (Bailey et al., 2015; Ebron, 2012; Jin and Slowik, 2017). The goal would be to empower consumers with the knowledge needed to evaluate the benefits and challenges of owning a BEV and to make choices that align their individual needs with societal and environmental goals (Krause et al., 2013; Okada et al., 2019; Zhang

[5] https://www.iihs.org/news/detail/as-heavy-evs-proliferate-their-weight-may-be-a-drag-on-safety.

et al., 2011). The package should highlight the environmental advantages of BEVs, such as reduced greenhouse gas emissions and improved air quality. It can include data on the lifecycle emissions of BEVs compared to traditional gasoline vehicles, emphasising the positive impact on combating climate change. One of the significant attractions of BEVs is their lower operating costs (Pal et al., 2017). The education package should provide a detailed breakdown of the cost savings associated with BEV ownership, including electricity versus gasoline prices, maintenance costs, and potential incentives or tax credits for BEV buyers, if any. Addressing concerns about charging infrastructure would also be crucial (Chhikara et al., 2021). The package should not only inform consumers about the availability and accessibility of charging stations in their area and highlight advancements in fast-charging technology to reduce charging times but also directly address the common concern of *charging anxiety* (Bailey et al., 2015; Mashhoodi and van der Blij, 2021; Zhang et al., 2021a). Charging anxiety (Alsabbagh and Ma, 2019), akin to the well-known *range anxiety* (Noel et al., 2019), refers to the stress or worry experienced by BEV users regarding the availability of charging infrastructure and the time required to recharge their vehicles. This anxiety can be a significant barrier to BEV adoption, as potential users may worry about the feasibility of long trips or the inconvenience of daily recharges. To mitigate these concerns, the education package could include detailed information about the current state and future plans for charging infrastructure expansion, especially in underserved regions. It should also offer practical guidance on managing travel and charging schedules to minimise inconvenience. Furthermore, showcasing real-world testimonials and case studies where individuals successfully integrate BEV charging into their routines can help demystify the process and alleviate potential anxieties.

Some consumers may have concerns about the driving range and performance of BEVs. The education package can explain the range capabilities of various BEV models and how factors like driving habits and weather conditions can affect range (Pevec et al., 2020; Rauh et al., 2015). To alleviate concerns about battery life and waste, the package should provide information on the advancements in battery technology, warranties, and recycling programs for used batteries. Objective comparisons between BEVs and HCVs can help consumers understand the pros and cons of each option and make a more informed choice based on their specific needs. Educating BEV owners about proper maintenance, battery care, and recycling practices can prolong the lifespan of BEVs and ensure the responsible disposal of battery waste. Furthermore, educating consumers about charging etiquette, such as being mindful of public charging station usage and the benefits of off-peak charging, can promote responsible BEV ownership (Asensio et al., 2022; Caperello et al., 2013; Helmus and Wolbertus, 2023). The package should inform consumers about government incentives, rebates, and policies that encourage BEV adoption, along with any upcoming regulations that may impact the BEV market (Bjerkan et al., 2016; Hardman et al., 2017; Jenn et al., 2018). Highlighting the community and social benefits of BEV adoption, such as reduced noise pollution and improved public health, can further motivate consumers to choose BEVs.

Collaborative efforts from governments, automakers, NGOs, and other stakeholders are crucial to developing and disseminating these educational resources effectively. However, it is crucial to ensure that educational programs provide a balanced view by neither overstating the benefits of BEVs nor understating their potential hidden effects. A balanced approach empowers individuals to make informed decisions. When educational programs present both the benefits and challenges of BEV adoption, consumers can weigh the pros and cons based on their unique circumstances and needs. Balanced education encourages responsible consumer behaviour. Consumers are more likely to embrace BEVs responsibly when they are aware of factors like charging infrastructure, range limitations, and battery disposal, making them better equipped to utilise the technology effectively. Providing a comprehensive view also aids policymakers and regulators in making well-informed decisions. Policymakers can develop effective regulations and incentives by understanding the potential impacts and externalities associated with BEV adoption. Greenwashing (i.e., the practice of exaggerating or misrepresenting environmental benefits), can erode public trust. A balanced approach helps avoid greenwashing and ensures that consumers have a clear understanding of the real impact of BEVs. Educational packages can be seamlessly integrated into broader climate and sustainability campaigns to maximise their impact (Raducu et al., 2020).

5. Conclusion and policy implications

As the world shifts gears to embrace cleaner and greener mobility solutions, BEVs have emerged as a promising alternative to traditional HCVs and a path to a more sustainable future. Undoubtedly, the adoption of BEVs has garnered well-deserved acclaim for its positive impact on the environment and public health, but beneath also lies a realm of intricacies yet to be fully understood. In this short discussion, we shed a spotlight on the less-visible facets of BEV adoption. While the environmental benefits are undeniable, it is essential to navigate the labyrinth of potential challenges and consider the holistic consequences of this paradigm shift. Our intention was not to undermine the immense potentials of BEVs, but rather to navigate the less explored territories with respect to the widespread adoption of BEVs. In doing so, we highlighted potential externalities in four major categories including *environment* and *infrastructure* as well as *socio-economic* and *safety* characteristics.

Fig. 1 presents a summary of these effects. By recognising the hidden effects of BEVs, we can help pave the way for a sustainable transportation landscape that not only reduces emissions but also addresses social equity, infrastructure needs, and long-term viability. It should also be noted that, due to the multifaceted nature of the topic under investigation, the current paper only focuses on battery electric vehicles, not other forms such as hydrogen fuel-cell vehicles. The latter requires a dedicated discussion, particularly given the current level of technology maturity and further complexities in the hydrogen production value chain.

To harness the *environmental benefits* of BEVs and address potential negative impacts, governments and energy providers can accelerate the transition to renewable energy sources to power BEVs, ensuring a cleaner energy supply for charging. An essential component of the whole of life analysis of BEVs is the manufacturing process of BEV batteries, which is notably emission-intensive. As highlighted in studies such as Philippot et al. (2019), the production of lithium-ion batteries, which are central to the operation of BEVs, involves substantial energy consumption and the emission of significant amounts of greenhouse gases. This process includes the extraction and processing of raw materials such as lithium, cobalt, and nickel, which not only require high energy inputs but also generate considerable environmental pollution. To address these concerns, it is imperative to consider advancements in battery technology that focus on improving energy efficiency and reducing the carbon footprint of production processes. Additionally, enhancing the recycling capabilities and extending the life cycle of batteries can mitigate the environmental impact associated with their initial production. Investing in research and infrastructure for battery recycling and reuse can minimise waste and resource depletion, creating a more sustainable circular economy. Advancements in battery technology and the use of sustainable materials can reduce the environmental footprint of BEV production. Implementing smart charging solutions and grid integration can optimise energy use and mitigate grid stress during peak charging periods. Furthermore, conducting comprehensive life cycle assessments is essential to understand the net environmental impacts of BEVs, considering their entire life cycle, from raw material extraction to manufacturing, use, and disposal. Currently, more than 70 jurisdictions around the globe, including the biggest polluters such as China, the United States, and the European Union, have set a net-zero target, aiming to reduce GHG emissions to as close to zero by 2050. For the transport sector, these targets are specifically designed to minimise tailpipe emissions as the result of fossil fuel combustion. BEVs

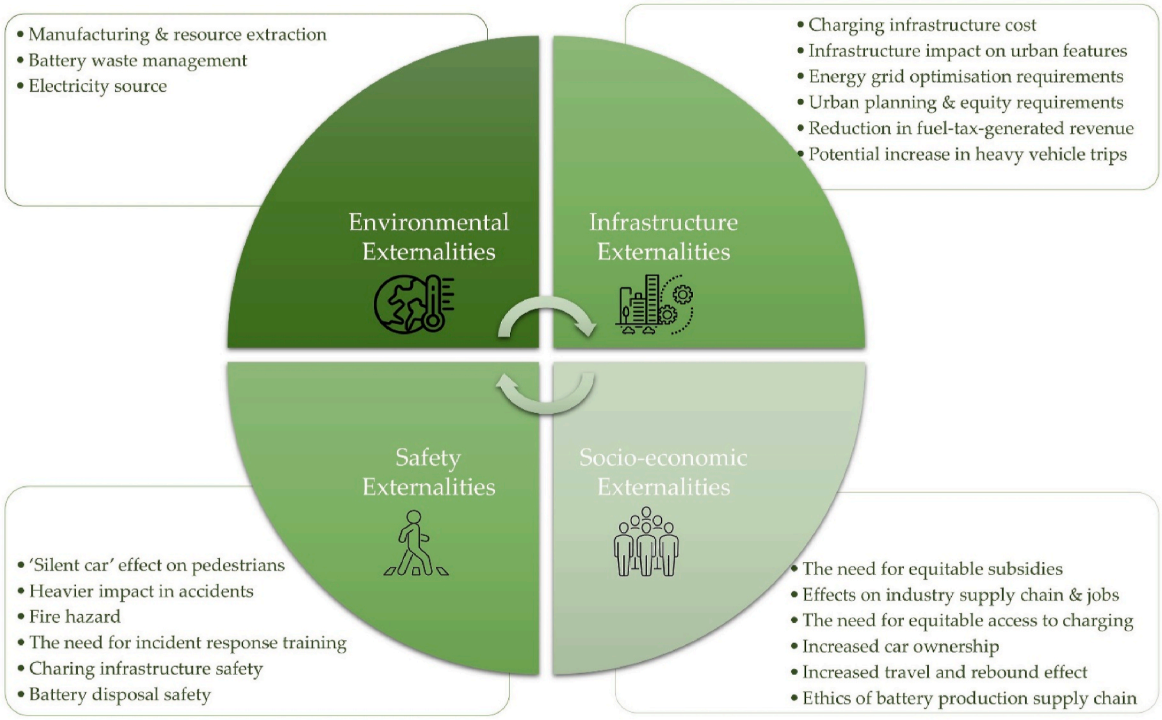

Fig. 1. Potential externalities of BEVs.

and plug-in hybrid electric vehicles (PHEVs) running on electricity produce zero direct tailpipe emissions. However, this does not eliminate the wider environmental impacts of the full life cycle of a vehicle, from raw materials extraction, manufacturing, use, and disposal or recycling. While many of these processes and materials are commonly shared among different vehicle types (HCVs, BEVs and PHEVs), some are unique to each type. For example, while HCV vehicles produce tailpipe emissions, their production does not require significant amount of rare minerals, as needed in BEV battery. The global momentum to combat climate change and preserve a liveable planet for the next generations is a unique opportunity that should not only focus on minimising tailpipe emissions. Therefore, our efforts to minimise the environmental impacts of transport activity should not solely be focused on eliminating tailpipe emission, rather it should expand across the end-to-end life cycle of vehicles. For the reasons discussed above, there is a necessity to shift our strategies from meeting 'decarbonisation' goals to a wider view of 'planetisation' that is about improving the overall sustainability of human footprint on the planet.

With respect to *infrastructure*, governments can offer incentives or subsidies to encourage private and public entities to invest in charging infrastructure, particularly the vehicle-to-grid technology. Collaboration between governments and private companies can facilitate the deployment of charging infrastructure, leveraging expertise and resources. Strategic location planning for charging infrastructure should prioritise areas with high BEV demand and consider equitable distribution. Governments and stakeholders should develop long-term infrastructure plans that anticipate BEV adoption rates and proactively address infrastructure needs.

With respect to *socio-economic* impacts, the rebound effect (Freire-González, 2021; Lange et al., 2021) is a real concern that can partially offset the anticipated energy and environmental benefits of BEVs. One significant concern is the potential increase in travel demand as BEVs become more accessible and cost-effective. This phenomenon suggests that improvements in vehicle efficiency and lower operating costs could lead to increased vehicle usage, potentially negating some of the environmental benefits. For example, the convenience and reduced cost of driving a BEV might encourage longer commutes and increase the total number of vehicles on the road, exacerbating traffic congestion and urban sprawl. Such patterns could diminish the expected reductions in greenhouse gas emissions and might shift rather than eliminate the environmental burdens associated with transportation. Furthermore, as BEVs become more integrated into the mainstream, there is a risk that the focus on electrification could overshadow the need to invest in and promote other sustainable forms of transportation, such as public transit, and active transport. Prioritising BEVs without a concurrent emphasis on these alternatives could lead to a less diverse transportation system that still relies heavily on single-occupancy vehicles, regardless of their power source. By adopting a comprehensive approach that addresses not only the supply side but also the demand side (i.e., consumer behaviour and travel patterns), we can work towards effectively harnessing the potentials of BEVs in combatting climate change. For example, integrated and holistic transportation planning can promote electric mobility in tandem with public transit and active transportation options, reducing overall travel demand and congestion. Focus on promoting sustainable transportation options like public transit, biking, and walking to reduce the overall demand for individual car trips will, in fact, be essential steps that need to be taken concurrently with the deployment of BEVs. Another measure could be implementing dynamic pricing mechanisms for electricity and road usage that discourage excessive driving and incentivise off-peak charging for BEVs. But most importantly, we can educate consumers and raise awareness about the rebound effect and encourage responsible use of BEVs, emphasising the importance of reducing overall travel to maximise environmental gains.

It is also important to note that automakers and regulatory agencies must continuously work to improve BEV *safety* standards. As the technology evolves and becomes more widespread, addressing safety-related externalities remains a priority to build public confidence and promote the adoption of BEVs. These externalities include the broader safety impacts that arise from the widespread adoption and use of BEVs, beyond the direct safety effects on individual drivers and passengers. Advancements in battery technology, safety features, and regulations contribute to enhancing the overall safety of BEVs. Consumers can further ensure their safety by following recommended guidelines for charging, maintenance, and driving practices.

In conclusion, the importance of public awareness campaigns and educational programs in promoting the responsible adoption of BEVs cannot be overstated. It will be critical to raise awareness among BEV users and the general public about the potential externalities and encourage responsible BEV adoption and usage. By providing balanced and accurate information to the public, we can empower individuals to make informed decisions about BEV adoption. Public awareness campaigns can also play a pivotal role in dispelling myths, addressing misconceptions, and fostering a positive attitude towards BEVs. Moreover, education initiatives can raise awareness about the existing charging infrastructure, available incentives, and the long-term cost savings associated with BEV ownership. By leveraging a combination of various delivery modes and strategies, public awareness about BEVs can be widely disseminated, making it common knowledge among the public. Enhanced awareness will lead to informed choices and will help create collective commitment towards sustainable mobility at a societal level (i.e., a culture of sustainability), as an important milestone in unlocking the full potential of BEVs.

CRediT authorship contribution statement

Milad Haghani: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Hadi Ghaderi:** Writing – review & editing, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **David Hensher:** Writing – review & editing, Methodology, Investigation.

Declaration of competing interest

Authors do not have any conflict of interest to declare in relation to this publication.

Data availability

No data was used for the research described in the article.

Acknowledgments

Milad Haghani acknowledges the financial contribution of Australian Research Council (Grant No. DE210100440).

References

Aalund, R., Diao, W., Kong, L., Pecht, M., 2021. Understanding the non-collision related battery safety risks in electric vehicles a case study in electric vehicle recalls and the LG Chem battery. IEEE Access 9, 89527–89532.

Agusdinata, D.B., Liu, W., 2023. Global sustainability of electric vehicles minerals: a critical review of news media. Extr. Ind. Soc. 13, 101231.

Agusdinata, D.B., Liu, W., Eakin, H., Romero, H., 2018. Socio-environmental impacts of lithium mineral extraction: towards a research agenda. Environ. Res. Lett. 13, 123001.

Alcott, B., 2005. Jevons' paradox. Ecol. Econ. 54, 9–21.

Alsabbagh, A., Ma, C., 2019. Distributed charging management of electric vehicles with charging anxiety for charging cost reduction. In: 2019 IEEE 28th International Symposium on Industrial Electronics (ISIE). IEEE, pp. 2489–2494.

Altenburg, M., Anand, N., Balm, S., van Amstel, W.P., 2017. Electric freight vehicles in city logistics: insights into decision making process of frontrunner companies, European Battery. In: Hybrid and Fuel Cell Electric Vehicle Congress.

Andwari, A.M., Pesiridis, A., Rajoo, S., Martinez-Botas, R., Esfahanian, V., 2017. A review of Battery Electric Vehicle technology and readiness levels. Renewable Sustainable Energy Rev. 78, 414–430.

Asensio, O.I., Apablaza, C.Z., Lawson, M.C., Walsh, S.E., 2022. A field experiment on workplace norms and electric vehicle charging etiquette. J. Ind. Ecol. 26, 183–196.

Babbitt, C.W., 2020. Sustainability perspectives on lithium-ion batteries. Clean Technol. Environ. Policy 22, 1213–1214.

Bailey, J., Miele, A., Axsen, J., 2015. Is awareness of public charging associated with consumer interest in plug-in electric vehicles? Transport. Res. Transport Environ. 36, 1–9.

Beaudet, A., Larouche, F., Amouzegar, K., Bouchard, P., Zaghib, K., 2020. Key challenges and opportunities for recycling electric vehicle battery materials. Sustainability 12, 5837.

Bhusal, N., Gautam, M., Benidris, M., 2021. Cybersecurity of electric vehicle smart charging management systems. In: 2020 52nd North American Power Symposium (NAPS). IEEE, pp. 1–6.

Bisschop, R., Willstrand, O., Rosengren, M., 2020. Handling lithium-ion batteries in electric vehicles: preventing and recovering from hazardous events. Fire Technol. 56, 2671–2694.

Bjerkan, K.Y., Norbech, T.E., Nordtomme, M.E., 2016. Incentives for promoting battery electric vehicle (BEV) adoption in Norway. Transport. Res. Transport Environ. 43, 169–180.

Borgstedt, P., Neyer, B., Schewe, G., 2017. Paving the road to electric vehicles – a patent analysis of the automotive supply industry. J. Clean. Prod. 167, 75–87.

Brady, J., O'Mahony, M., 2011. Travel to work in Dublin. the potential impacts of electric vehicles on climate change and urban air quality. Transport. Res. Transport Environ. 16, 188–193.

Breetz, H.L., Salon, D., 2018. Do electric vehicles need subsidies? Ownership costs for conventional, hybrid, and electric vehicles in 14 U.S. cities. Energy Pol. 120, 238–249.

Buekers, J., Van Holderbeke, M., Bierkens, J., Panis, L.I., 2014. Health and environmental benefits related to electric vehicle introduction in EU countries. Transport. Res. Transport Environ. 33, 26–38.

Campello-Vicente, H., Peral-Orts, R., Campillo-Davo, N., Velasco-Sanchez, E., 2017. The effect of electric vehicles on urban noise maps. Appl. Acoust. 116, 59–64.

Caperello, N., Kurani, K.S., TyreeHageman, J., 2013. Do You Mind if I Plug-in My Car? How etiquette shapes PEV drivers' vehicle charging behavior. Transport. Res. Pol. Pract. 54, 155–163.

Carlton, G., Sultana, S., 2023. Transport equity considerations in electric vehicle charging research: a scoping review. Transport Rev. 43, 330–355.

Carlton, G.J., Sultana, S., 2022. Electric vehicle charging station accessibility and land use clustering: a case study of the Chicago region. Journal of Urban Mobility 2, 100019.

Caulfield, B., Furszyfer, D., Stefaniec, A., Foley, A., 2022. Measuring the equity impacts of government subsidies for electric vehicles. Energy 248, 123588.

Chandak, G.A., Bhole, A.A., Ieee, 2017. A review on regenerative braking in electric vehicle. In: Conference on Innovations in Power and Advanced Computing Technologies (I-PACT), Vellore, INDIA.

Chang, S.Y., Huang, J., Chaveste, M.R., Lurmann, F.W., Eisinger, D.S., Mukherjee, A.D., Erdakos, G.B., Alexander, M., Knipping, E., 2023. Electric vehicle fleet penetration helps address inequalities in air quality and improves environmental justice. Communic. Earth Environ. 4, 135.

Chen, S., Wang, H., Meng, Q., 2020. Optimal purchase subsidy design for human-driven electric vehicles and autonomous electric vehicles. Transport. Res. C Emerg. Technol. 116, 102641.

Chhikara, R., Garg, R., Chhabra, S., Karnatak, U., Agrawal, G., 2021. Factors affecting adoption of electric vehicles in India: an exploratory study. Transport. Res. Transport Environ. 100, 103084.

Christensen, P.A., Anderson, P.A., Harper, G.D.J., Lambert, S.M., Mrozik, W., Rajaeifar, M.A., Wise, M.S., Heidrich, O., 2021. Risk management over the life cycle of lithium-ion batteries in electric vehicles. Renewable Sustainable Energy Rev. 148.

Cocron, P., Krems, J.F., 2013. Driver perceptions of the safety implications of quiet electric vehicles. Accid. Anal. Prev. 58, 122–131.

Comi, A., Savchenko, L., 2021. Last-mile delivering: analysis of environment-friendly transport. Sustain. Cities Soc. 74, 103213.

Conti, S., Di Mauro, S., Raciti, A., Rizzo, S., Susinni, G., Musumeci, S., Tenconi, A., 2018. Solar electric vehicles: state-of-the-art and perspectives. In: 2018 AEIT International Annual Conference. IEEE, pp. 1–6.

Das, H.S., Rahman, M.M., Li, S., Tan, C., 2020. Electric vehicles standards, charging infrastructure, and impact on grid integration: a technological review. Renew. Sustain. Energy Rev. 120, 109618.

Desai, J., Mathew, J.K., Li, H., Bullock, D.M., 2022. Leveraging connected vehicle data to assess interstate exit utilization and identify charging infrastructure investment allocation opportunities. World Electric Vehicle J. 13, 167.

Deveci, M., Erdogan, N., Pamucar, D., Kucuksari, S., Cali, U., 2023. A rough Dombi Bonferroni based approach for public charging station type selection. Appl. Energy 345, 121258.

Dong, X., Zhang, B., Wang, B., Wang, Z., 2020. Urban households' purchase intentions for pure electric vehicles under subsidy contexts in China: do cost factors matter? Transport. Res. Pol. Pract. 135, 183–197.

Du, J.Y., Ouyang, D.H., 2017. Progress of Chinese electric vehicles industrialization in 2015: a review. Appl. Energy 188, 529–546.

Eberle, U., von Helmolt, R., 2010. Sustainable transportation based on electric vehicle concepts: a brief overview. Energy Environ. Sci. 3, 689–699.

Ebron, A., 2012. Advanced electric drive vehicle education program overview. World Electric Vehicle J. 5, 970–974.

Ehrler, V.C., Schöder, D., Seidel, S., 2021. Challenges and perspectives for the use of electric vehicles for last mile logistics of grocery e-commerce–Findings from case studies in Germany. Res. Transport. Econ. 87, 100757.

Faria, R., Marques, P., Moura, P., Freire, F., Delgado, J., de Almeida, A.T., 2013. Impact of the electricity mix and use profile in the life-cycle assessment of electric vehicles. Renewable Sustainable Energy Rev. 24, 271–287.

Feng, W., Figliozzi, M.A., 2012. Conventional vs electric commercial vehicle fleets: a case study of economic and technological factors affecting the competitiveness of electric commercial vehicles in the USA. Procedia-Soc. Behav. Sci. 39, 702–711.

Freeman, R., Yearworth, M., Preist, C., 2016. Revisiting Jevons' paradox with system dynamics: systemic causes and potential cures. J. Ind. Ecol. 20, 341–353.
Freire-González, J., 2021. Governing Jevons' Paradox: policies and systemic alternatives to avoid the rebound effect. Energy Res. Social Sci. 72, 101893.
Freire-González, J., Puig-Ventosa, I., 2015. Energy efficiency policies and the Jevons paradox. Int. J. Energy Econ. Pol. 5, 69–79.
Gan, Y., Wang, M., Lu, Z.F., Kelly, J., 2021. Taking into account greenhouse gas emissions of electric vehicles for transportation de-carbonization. Energy Pol. 155.
Gao, Y., Farley, K.B., Ginart, A., Tse, Z.T.H., 2016. Safety and efficiency of the wireless charging of electric vehicles. Proc. Inst. Mech. Eng. - Part D J. Automob. Eng. 230, 1196–1207.
Garofalaki, Z., Kosmanos, D., Moschoyiannis, S., Kallergis, D., Douligeris, C., 2022. Electric vehicle charging: a survey on the security issues and challenges of the open charge point protocol (OCPP). IEEE Communic. Surveys Tutorials 24 (3), 1504–1533.
Giampietro, M., Mayumi, K., 2018. Unraveling the complexity of the Jevons Paradox: the link between innovation, efficiency, and sustainability. Front. Energy Res. 6, 26.
Gottumukkala, R., Merchant, R., Tauzin, A., Leon, K., Roche, A., Darby, P., 2019. Cyber-physical system security of vehicle charging stations. In: 2019 IEEE Green Technologies Conference (GreenTech). IEEE, pp. 1–5.
Grant, C.C., Quincy, M., 2014. Responding to electric vehicle battery fires. Fire Vehicles.
Guirong, Z., Henghai, Z., 2012. Research of the electric vehicle safety. In: World Automation Congress 2012. IEEE, pp. 1–4.
Günther, H.O., Kannegiesser, M., Autenrieb, N., 2015. The role of electric vehicles for supply chain sustainability in the automotive industry. J. Clean. Prod. 90, 220–233.
Guo, S., Kontou, E., 2021. Disparities and equity issues in electric vehicles rebate allocation. Energy Pol. 154, 112291.
Haghani, M., Sprei, F., Kazemzadeh, K., Shahhoseini, Z., Aghaei, J., 2023. Trends in electric vehicles research. Transport. Res. Transport Environ. 123, 103881.
Hamant, O., 2020. Plant scientists can't ignore Jevons paradox anymore. Nat. Plants 6, 720–722.
Hardman, S., Chandan, A., Tal, G., Turrentine, T., 2017. The effectiveness of financial purchase incentives for battery electric vehicles - a review of the evidence. Renewable Sustainable Energy Rev. 80, 1100–1111.
Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K.S., Gaines, L., Anderson, P., 2019. Recycling lithium-ion batteries from electric vehicles. Nature 575, 75–86.
Hawkins, T.R., Gausen, O.M., Strømman, A.H., 2012. Environmental impacts of hybrid and electric vehicles—a review. Int. J. Life Cycle Assess. 17, 997–1014.
Helmus, J., Wolbertus, R., 2023. Cooperative behaviour at public electric vehicle charging stations. Travel Behav. Soc. 32, 100572.
Holland, S.P., Mansur, E.T., Muller, N.Z., Yates, A.J., 2016. Are there environmental benefits from driving electric vehicles? The importance of local factors. Am. Econ. Rev. 106, 3700–3729.
Hua, Y., Liu, X., Zhou, S., Huang, Y., Ling, H., Yang, S., 2021. Toward sustainable reuse of retired lithium-ion batteries from electric vehicles. Resour. Conserv. Recycl. 168, 105249.
Huang, W., Feng, X., Han, X., Zhang, W., Jiang, F., 2021. Questions and answers relating to lithium-ion battery safety issues. Cell Rep. Phys. Sci. 2.
Iwan, S., Nürnberg, M., Jedliński, M., Kijewska, K., 2021. Efficiency of light electric vehicles in last mile deliveries–Szczecin case study. Sustain. Cities Soc. 74, 103167.
Jabben, J., Verheijen, E., Potma, C., 2012. Noise reduction by electric vehicles in The Netherlands. In: Inter-Noise and Noise-Con Congress and Conference Proceedings. Institute of Noise Control Engineering, pp. 6958–6965.
Jaiswal, S., Ballal, M., 2017. Optimal load management of plug-in electric vehicles with demand side management in vehicle to grid application. In: 2017 IEEE Transportation Electrification Conference (ITEC-India). IEEE, pp. 1–5.
Jenn, A., Azevedo, I.L., Fischbeck, P., 2015. How will we fund our roads? A case of decreasing revenue from electric vehicles. Transport. Res. Pol. Pract. 74, 136–147.
Jenn, A., Springel, K., Gopal, A.R., 2018. Effectiveness of electric vehicle incentives in the United States. Energy Pol. 119, 349–356.
Jiang, H., Brazis, P., Tabaddor, M., Bablo, J., Ieee, 2012. Safety considerations of wireless charger for electric vehicles - a review paper. In: 9th Annual IEEE-Product-Safety-Engineering-Society's Symposium on Product Compliance Engineering, Portland, OR, pp. 51–56.
Jin, L., Slowik, P., 2017. Literature review of electric vehicle consumer awareness and outreach activities. Int. Counc. Clean Transport. https://www.theicct.org/sites/default/files/publications/Consumer-EV-Awareness_ICCT_Working-Paper_23032017_vF.pdf.
Jones, B., Nguyen-Tien, V., Elliott, R.J., 2023. The electric vehicle revolution: critical material supply chains, trade and development. World Econ. 46, 2–26.
Joseph, P.K., Elangovan, D., 2018. A review on renewable energy powered wireless power transmission techniques for light electric vehicle charging applications. J. Energy Storage 16, 145–155.
Kast, J., Vijayagopal, R., Gangloff, J.J., Marcinkoski, J., 2017. Clean commercial transportation: medium and heavy duty fuel cell electric trucks. Int. J. Hydrogen Energy 42, 4508–4517.
Kaunda, R.B., 2020. Potential environmental impacts of lithium mining. J. Energy Nat. Resour. Law 38, 237–244.
Kiba-Janiak, M., Marcinkowski, J., Jagoda, A., Skowrońska, A., 2021. Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. Literature review. Sustain. Cities Soc. 71, 102984.
Kole, P.J., Löhr, A.J., Van Belleghem, F.G., Ragas, A.M., 2017. Wear and tear of tyres: a stealthy source of microplastics in the environment. Int. J. Environ. Res. Publ. Health 14, 1265.
Konet, H., Sato, M., Schiller, T., Christensen, A., Tabata, T., Kanuma, T., 2011. Development of approaching Vehicle Sound for Pedestrians (VSP) for quiet electric vehicles. SAE Int. J. Engines 4, 1217–1224.
Kotz, A., Jeffers, M., Henao, A., Esterly, S., Lucas, H., 2023. USAID Colombia Young Leaders Workforce Training Program Action Plans: Early Adopters Work to Accelerate Electric Vehicle Transitions in Boyaca, Colombia. National Renewable Energy Lab.(NREL), Golden, CO (United States).
Krause, R.M., Carley, S.R., Lane, B.W., Graham, J.D., 2013. Perception and reality: public knowledge of plug-in electric vehicles in 21 US cities. Energy Pol. 63, 433–440.
Lange, S., Kern, F., Peuckert, J., Santarius, T., 2021. The Jevons paradox unravelled: a multi-level typology of rebound effects and mechanisms. Energy Res. Social Sci. 74, 101982.
Lee, R., Brown, S., 2021. Social & locational impacts on electric vehicle ownership and charging profiles. Energy Rep. 7, 42–48.
Li, N., Chen, J.-P., Tsai, I.C., He, Q., Chi, S.-Y., Lin, Y.-C., Fu, T.-M., 2016. Potential impacts of electric vehicles on air quality in Taiwan. Sci. Total Environ. 566–567, 919–928.
Li, P., Xia, X., Guo, J., 2022. A review of the life cycle carbon footprint of electric vehicle batteries. Separ. Purif. Technol. 296, 121389.
Liu, J., Xu, N., Shi, Y., Barnett, T., Jones, S., 2023. Are first responders prepared for electric vehicle fires? A national survey. Accid. Anal. Prev. 179, 106903.
Low, J.M., Haszeldine, R.S., Harrison, G.P., 2023. The hidden cost of road maintenance due to the increased weight of battery and hydrogen trucks and buses—a perspective. Clean Technol. Environ. Policy 25, 757–770.
Lu, T., Yao, E., Jin, F., Yang, Y., 2022. Analysis of incentive policies for electric vehicle adoptions after the abolishment of purchase subsidy policy. Energy 239, 122136.
Mahmud, K., Hossain, M.J., Ravishankar, J., 2018. Peak-load management in commercial systems with electric vehicles. IEEE Syst. J. 13, 1872–1882.
Mal, S., Chattopadhyay, A., Yang, A., Gadh, R., 2013. Electric vehicle smart charging and vehicle-to-grid operation. Int. J. Parallel, Emergent Distributed Syst. 28, 249–265.
Malmgren, I., 2016. Quantifying the societal benefits of electric vehicles. World Electric Vehicle J. 8, 996–1007.
Mashhoodi, B., van der Blij, N., 2021. Drivers' range anxiety and cost of new EV chargers in Amsterdam: a scenario-based optimization approach. Spatial Sci. 27, 87–98.
Metere, R., Neaimeh, M., Morisset, C., Maple, C., Bellekens, X., Czekster, R.M., 2021. Securing the electric vehicle charging infrastructure. arXiv preprint arXiv: 2105.02905.
Monios, J., Bergqvist, R., 2019. The transport geography of electric and autonomous vehicles in road freight networks. J. Transport Geogr. 80, 102500.
Morrissey, P., Weldon, P., O'Mahony, M., 2016. Future standard and fast charging infrastructure planning: an analysis of electric vehicle charging behaviour. Energy Pol. 89, 257–270.
Mulholland, E., Teter, J., Cazzola, P., McDonald, Z., Ó Gallachóir, B.P., 2018. The long haul towards decarbonising road freight – a global assessment to 2050. Appl. Energy 216, 678–693.
Nishanthy, J., Charles Raja, S., Praveen, T., Jeslin Drusila Nesamalar, J., Venkatesh, P., 2022. Techno-economic analysis of a hybrid solar wind electric vehicle charging station in highway roads. Int. J. Energy Res. 46, 7883–7903.
Noel, L., De Rubens, G.Z., Sovacool, B.K., Kester, J., 2019. Fear and loathing of electric vehicles: the reactionary rhetoric of range anxiety. Energy Res. Social Sci. 48, 96–107.
Notter, D.A., Gauch, M., Widmer, R., Wager, P., Stamp, A., Zah, R., Althaus, H.J., 2010. Contribution of Li-ion batteries to the environmental impact of electric vehicles. Environmental Science & Technology 44, 6550–6556.
Nunes, P., Figueiredo, R., Brito, M.C., 2016. The use of parking lots to solar-charge electric vehicles. Renew. Sustain. Energy Rev. 66, 679–693.
Okada, T., Tamaki, T., Managi, S., 2019. Effect of environmental awareness on purchase intention and satisfaction pertaining to electric vehicles in Japan. Transport. Res. Transport Environ. 67, 503–513.
Orsi, F., 2021. On the sustainability of electric vehicles: what about their impacts on land use? Sustain. Cities Soc. 66, 102680.
Ouyang, D., Ou, X., Zhang, Q., Dong, C., 2020. Factors influencing purchase of electric vehicles in China. Mitig. Adapt. Strategies Glob. Change 25, 413–440.
Ouyang, D., Zhou, S., Ou, X., 2021. The total cost of electric vehicle ownership: a consumer-oriented study of China's post-subsidy era. Energy Pol. 149, 112023.
Ouyang, X., Xu, M., 2022. Promoting green transportation under the belt and Road Initiative: locating charging stations considering electric vehicle users' travel behavior. Transport Pol. 116, 58–80.
Ovalle, A., Hably, A., Bacha, S., Ramos, G., Hossain, J., 2016. Escort evolutionary game dynamics approach for integral load management of electric vehicle fleets. IEEE Trans. Ind. Electron. 64, 1358–1369.
Pagani, D., 2021. Chapter Sixteen - the importance of green mobility. In: El Bassam, N. (Ed.), Distributed Renewable Energies for Off-Grid Communities, second ed. Elsevier, Boston, pp. 345–391.
Pal, S., Kumar, M., Kumar, R., 2017. Price aware residential demand response with renewable sources and electric vehicle. In: 2017 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE). IEEE, pp. 211–214.
Palmer, K., Tate, J.E., Wadud, Z., Nellthorp, J., 2018. Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. Appl. Energy 209, 108–119.
Pardo-Bosch, F., Pujadas, P., Morton, C., Cervera, C., 2021. Sustainable deployment of an electric vehicle public charging infrastructure network from a city business model perspective. Sustain. Cities Soc. 71.
Park, O., 2013. Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results. The Fire Protection Research Foundation, Quincy, MA. Report, F0F0.

Petit Boulanger, C., Thomazo, J., Azmi, B., Labadie, O., Poutrain, B., Gentilleau, M., Bazin, H., 2015. A partnership between renault and French first responders to ensure safe intervention on crash or fire-damaged electrical vehicles. In: 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV). National Highway Traffic Safety Administration.

Pevec, D., Babic, J., Carvalho, A., Ghiassi-Farrokhfal, Y., Ketter, W., Podobnik, V., 2020. A survey-based assessment of how existing and potential electric vehicle owners perceive range anxiety. J. Clean. Prod. 276, 122779.

Philippot, M., Alvarez, G., Ayerbe, E., Van Mierlo, J., Messagie, M., 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, 23.

Pistoia, G., Liaw, B., 2018. Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety, and Cost. Springer.

Polimeni, J.M., Polimeni, R.I., 2006. Jevons' Paradox and the myth of technological liberation. Ecol. Complex. 3, 344–353.

Pourmirza, Z., Walker, S., 2021. Electric vehicle charging station: cyber security challenges and perspective. In: 2021 IEEE 9th International Conference on Smart Energy Grid Engineering (SEGE). IEEE, pp. 111–116.

Pražanová, A., Knap, V., Stroe, D.-I., 2022. Recycling of lithium-ion batteries from electric vehicles, Part I: recycling technology. Energies 15, 1086.

Qin, Y., Tang, X., Jia, T., Duan, Z., Zhang, J., Li, Y., Zheng, L., 2020. Noise and vibration suppression in hybrid electric vehicles: state of the art and challenges. Renew. Sustain. Energy Rev. 124, 109782.

Qiu, K., Ribberink, H., Entchev, E., 2022. Economic feasibility of electrified highways for heavy-duty electric trucks. Appl. Energy 326, 119935.

Quinn, C., Zimmerle, D., Bradley, T.H., 2012. An evaluation of state-of-charge limitations and actuation signal energy content on plug-in hybrid electric vehicle, vehicle-to-grid reliability, and economics. IEEE Trans. Smart Grid 3, 483–491.

Raducu, R., Soare, C., Chichirez, C.-M., Purcarea, M.R., 2020. Climate change and social campaigns. J. Med. Life 13, 454.

Rajaeifar, M.A., Ghadimi, P., Raugei, M., Wu, Y., Heidrich, O., 2022. Challenges and recent developments in supply and value chains of electric vehicle batteries: a sustainability perspective. Resour. Conserv. Recycl. 180, 106144.

Rauh, N., Franke, T., Krems, J.F., 2015. Understanding the impact of electric vehicle driving experience on range anxiety. Hum. Factors 57, 177–187.

Requia, W.J., Mohamed, M., Higgins, C.D., Arain, A., Ferguson, M., 2018. How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. Atmos. Environ. 185, 64–77.

Rezvanizaniani, S.M., Liu, Z.C., Chen, Y., Lee, J., 2014. Review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (EV) safety and mobility. J. Power Sources 256, 110–124.

Rodrigues, C.D.P., 2018. Design of a High-Speed Transmission for an Electric Vehicle.

Siami, N., Winter, R.A., 2021. Jevons' paradox revisited: implications for climate change. Econ. Lett. 206, 109955.

Singh, M., Kumar, P., Kar, I., 2013. A multi charging station for electric vehicles and its utilization for load management and the grid support. IEEE Trans. Smart Grid 4, 1026–1037.

Skeete, J.-P., Wells, P., Dong, X., Heidrich, O., Harper, G., 2020. Beyond the EVent horizon: battery waste, recycling, and sustainability in the United Kingdom electric vehicle transition. Energy Res. Social Sci. 69, 101581.

Soret, A., Guevara, M., Baldasano, J.M., 2014. The potential impacts of electric vehicles on air quality in the urban areas of Barcelona and Madrid (Spain). Atmos. Environ. 99, 51–63.

Sorrell, S., 2009. Jevons' Paradox revisited: the evidence for backfire from improved energy efficiency. Energy Pol. 37, 1456–1469.

Sovacool, B.K., Kester, J., Noel, L., de Rubens, G.Z., 2019. Energy injustice and nordic electric mobility: inequality, elitism, and externalities in the electrification of vehicle-to-grid (V2G) transport. Ecol. Econ. 157, 205–217.

Stevic, Z., Radovanovic, I., 2012. Energy Efficiency of Electric Vehicles. New Generation of Electric Vehicles.

Suarez, C., Martinez, W., Ieee, 2019. Fast and ultra-fast charging for battery electric vehicles - a review. In: 11th Annual IEEE Energy Conversion Congress and Exposition. ECCE, Baltimore, MD, pp. 569–575.

Timmers, V.R.J.H., Achten, P.A.J., 2016. Non-exhaust PM emissions from electric vehicles. Atmos. Environ. 134, 10–17.

Turker, H., Bacha, S., 2018. Optimal minimization of plug-in electric vehicle charging cost with vehicle-to-home and vehicle-to-grid concepts. IEEE Trans. Veh. Technol. 67, 10281–10292.

Unterluggauer, T., Rich, J., Andersen, P.B., Hashemi, S., 2022. Electric vehicle charging infrastructure planning for integrated transportation and power distribution networks: a review. eTransportation 12, 100163.

Wang, B., Dehghanian, P., Wang, S., Mitolo, M., 2019. Electrical safety considerations in large-scale electric vehicle charging stations. IEEE Trans. Ind. Appl. 55, 6603–6612.

Wang, L., Wang, X., Yang, W., 2020. Optimal design of electric vehicle battery recycling network–From the perspective of electric vehicle manufacturers. Appl. Energy 275, 115328.

Wang, Y., Chi, Y., Xu, J.-H., Yuan, Y., 2022. Consumers' attitudes and their effects on electric vehicle sales and charging infrastructure construction: an empirical study in China. Energy Pol. 165, 112983.

Wells, P., 2012. Converging transport policy, industrial policy and environmental policy: the implications for localities and social equity. Local Econ. 27, 749–763.

Wogalter, M.S., Ornan, R.N., Lim, R.W., Chipley, M.R., 2001. On the risk of quiet vehicles to pedestrians and drivers. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. SAGE Publications Sage CA, Los Angeles, CA, pp. 1685–1688.

Wöhrl, K., Geisbauer, C., Nebl, C., Lott, S., Schweiger, H.-G., 2021. Crashed electric vehicle handling and recommendations—state of the art in Germany. Energies 14, 1040.

Wu, X.K., Freese, D., Cabrera, A., Kitch, W.A., 2015. Electric vehicles' energy consumption measurement and estimation. Transport. Res. Transport Environ. 34, 52–67.

Xia, X., Li, P., Xia, Z., Wu, R., Cheng, Y., 2022. Life cycle carbon footprint of electric vehicles in different countries: a review. Separ. Purif. Technol., 122063

Xu, M., Yang, H., Wang, S., 2020. Mitigate the range anxiety: siting battery charging stations for electric vehicle drivers. Transport. Res. C Emerg. Technol. 114, 164–188.

Xu, Y., Li, J., Tan, Q., Peters, A.L., Yang, C., 2018. Global status of recycling waste solar panels: A review. Waste Manag. 75, 450–458.

Yang, X., Jin, W., Jiang, H., Xie, Q., Shen, W., Han, W., 2017. Car ownership policies in China: preferences of residents and influence on the choice of electric cars. Transport Pol. 58, 62–71.

York, R., McGee, J.A., 2016. Understanding the jevons paradox. Environm. Sociol. 2, 77–87.

Yu, M., Bai, B., Xiong, S., Liao, X., 2021. Evaluating environmental impacts and economic performance of remanufacturing electric vehicle lithium-ion batteries. J. Clean. Prod. 321, 128935.

Zhang, B., Bewley, R.L., Tanim, T.R., Walker, L.K., 2022. Electric vehicle post-crash Recovery—stranded energy issues and mitigation strategy. J. Power Sources 552, 232239.

Zhang, B., Niu, N., Li, H., Wang, Z., He, W., 2021a. Could fast battery charging effectively mitigate range anxiety in electric vehicle usage? Evidence from large-scale data on travel and charging in Beijing. Transport. Res. Transport Environ. 95, 102840.

Zhang, J., Zhang, L., Sun, F., Wang, Z., 2018. An overview on thermal safety issues of lithium-ion batteries for electric vehicle application. IEEE Access 6, 23848–23863.

Zhang, R., Zhang, J., Long, Y., Wu, W., Liu, J., Jiang, Y., 2021b. Long-term implications of electric vehicle penetration in urban decarbonization scenarios: an integrated land use–transport–energy model. Sustain. Cities Soc. 68, 102800.

Zhang, Y., Yu, Y., Zou, B., 2011. Analyzing public awareness and acceptance of alternative fuel vehicles in China: the case of EV. Energy Pol. 39, 7015–7024.

Zhao, B., Xu, N., Chen, H., Guo, K., Huang, Y., 2019. Stability control of electric vehicles with in-wheel motors by considering tire slip energy. Mech. Syst. Signal Process. 118, 340–359.

Zhao, Z., Guo, H., Coyle, D., Robinson, F., Munnich, L., 2015. Revisiting the Fuel Tax–Based Transportation Funding System in the United States, vol. 20. Public Works Management & Policy, pp. 105–126.

Zhou, M., Kong, N., Zhao, L., Huang, F., Wang, S., Campy, K.S., 2019. Understanding urban delivery drivers' intention to adopt electric trucks in China. Transport. Res. Transport Environ. 74, 65–81.