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Viewpoint

Fifteen Pathways between Electric Vehicles and Public Health: A Transportation–Health Conceptual Framework

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ABSTRACT: The health impact of electric vehicles (EVs) is complex and multifaceted, encompassing reductions in air pollutants, improvements in road safety, and implications for social equity. However, existing studies often provide fragmented insights, lacking a unified framework to comprehensively assess these public health implications. This paper develops a comprehensive framework to summarize the health outcomes of EVs in urban areas, where the health impacts are more pronounced due to higher levels of traffic congestion and air pollution. Building on previous conceptual work that identified pathways linking general transportation and health, our model illustrates how the characteristics of EVs influence public health through various pathways compared to traditional transportation systems. Additionally, we address socioeconomic factors that introduce variability in EV-related health outcomes, emphasizing the need to consider potential health disparities in policy and intervention development. This comprehensive approach aims to inform holistic policies that account for the complex interplay between transportation, environment, and public health.

1. INTRODUCTION

The health impact of electric vehicles (EVs) is multifaceted. While individual studies have examined specific aspects of the health impact of EVs, such as the reduction of air pollutants emissions,[1] road safety[2] and social equity,[3] there is a lack of integration and synthesis across different dimensions. There remains a notable gap in the development of a complete and unified analytical framework to comprehensively assess the public health implications of EVs. As a result, existing research often provides fragmented examinations into the health implications of EVs, making it challenging to develop holistic policies and interventions that account for the complex interplay between transportation, environment, and public health. We develop a framework summarizing the health outcomes of EVs building on the existing studies on traditional transportation and health.[4] We concentrate our discussion on urban areas as those areas often experience higher levels of air pollution due to traffic congestion,[5] making the health benefits of EV more noticeable.

Figure 1 illustrates how EV characteristics impact public health compared to traditional transportation. We identify four key transportation elements, that is, vehicles, infrastructure, energy, and terminals,[6] which shape EV adoption and its health effects. These elements interact with each other and shape EV adoption patterns, providing four crucial perspectives in understanding the pathways linking EV and public health. For instance, the energy used EVs is mainly from electricity, so the EV improves public health compared to traditional vehicles through reducing air pollution and greenhouse gas emissions along the roads. Boxes 2–4 detail 15 pathways linking EVs and public health, categorized by how EVs improve health outcomes compared to traditional transportation. Box 5 shows that socioeconomic status introduces variability in EV-related health outcomes, raising concerns about potential health disparities.

2. EVS IN THE CONTEXT OF TRANSPORTATION

We first characterize electric vehicles relating to the four elements of a transportation system, i.e., vehicle, way, energy, and terminals, which affect public health through various pathways. Their descriptions are as below.

2.1. Vehicle

EVs are vehicles fully or partially powered by electrical energy stored in batteries or obtained from an external source, such as a fuel cell, to power their propulsion systems. As vehicles, EVs play a crucial role in transportation systems, offering mobility independence and facilitating social inclusion by providing individuals with the means to travel to work, access healthcare services, engage in leisure activities, and participate in community life.[7] However, like traditional vehicles, EVs also pose certain challenges to public health, such as road injuries.[2]

2.2. Way

EVs offer a range of impacts in pathway itself and the surroundings which includes elements such as pedestrians' safety, the condition of the pathway infrastructure, and factors like noise levels. They can contribute to the reduction of transportation noise,[8] alleviate tailpipe emissions and oil leaking,[9] and improve air quality along their routes.[10]

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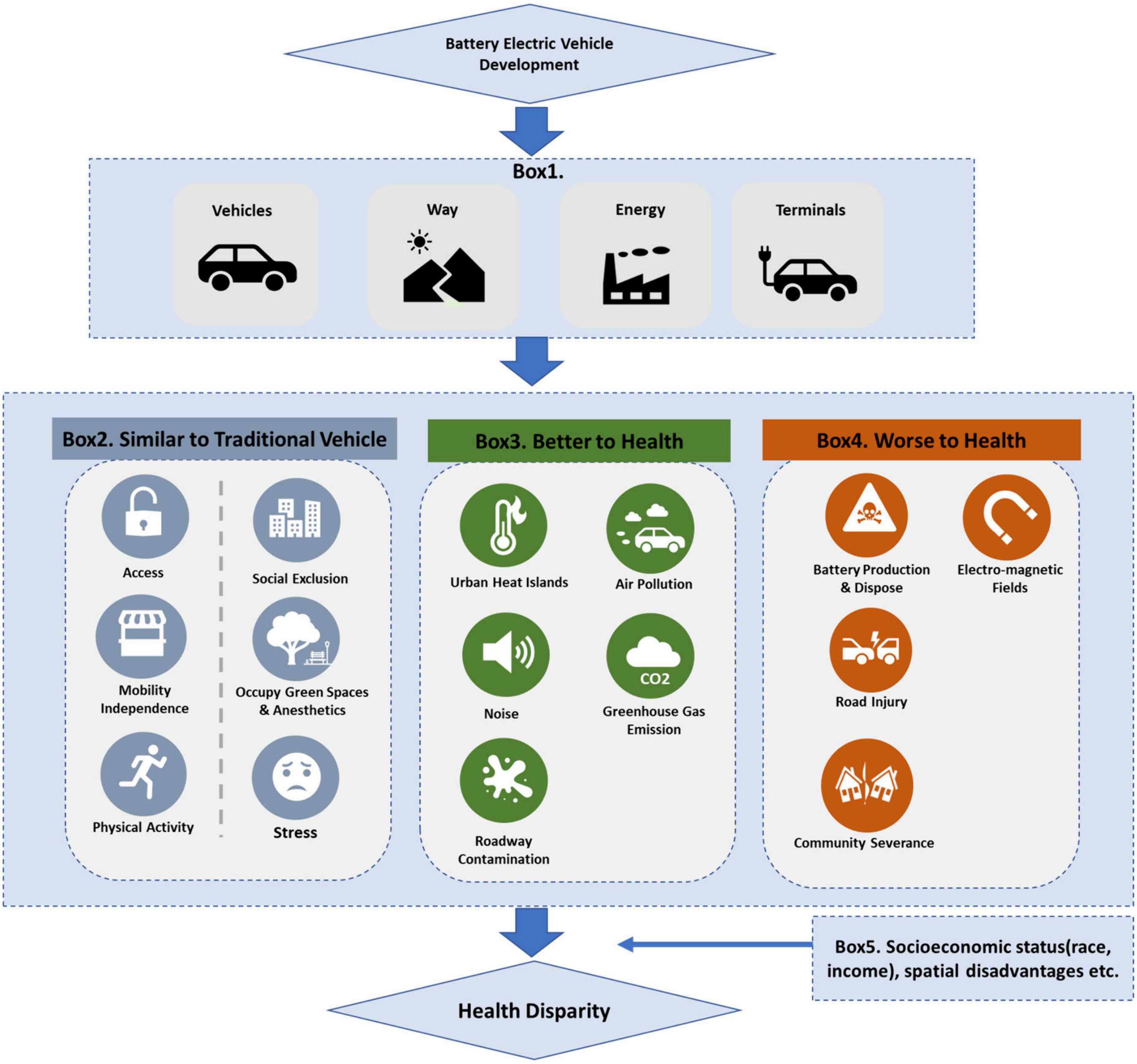

Figure 1. Impact of Electric Vehicle on Public Health. Notes: This figure depicts the model of how electric vehicles impact public health. Box 1 outlines four key aspects of EV adoption: vehicles, way, energy generation, and terminals (such as charging stations), which encompass various pathways between EVs and public health. Boxes 2–4 classify the 15 pathways into four groups based on whether the health outcomes of EVs are similar/better/worse compared to those of traditional vehicles. The effects of these pathways can vary depending on various factors listed in Box 5, leading to health disparities. The definitions for each path are listed in Appendix 1.

However, it is important to note that heavier EVs may pose an increased risk of injuries in the event of crashes.[11] Additionally, the weight of these vehicles can accelerate tire wear, consequently amplifying nonexhaust pollution and damage to road infrastructure.[12]

2.3. Energy

EVs can only be as green as the electricity used to power them. On the one hand, EVs are supported by powerful batteries. Challenges arise from battery production and disposal.[13] On the other hand, the energy source used for electricity generation plays a significant role in determining the full chain environmental impact of EVs. Electricity generation for EV charging can exacerbate traditional transportation's detrimental effects by increasing air pollution and greenhouse gas emissions.[14]

2.4. Terminals

The widespread of EV adoption depends on the availability of and accessibility to charging infrastructure built at various terminals. Transportation terminals, such as parking lots, shopping centers, and residential units, are crucial sites for EV charging infrastructure. Service areas along highways and major roadways facilitate long-distance travel using EVs. The characteristics of charging stations (location, charging speed, etc.) can affect the route selection of EV trips, the range anxiety of EV owners, and the appeal of EV ownership for both local commuting and intercity journeys.[15]

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3. FIFTEEN PATHWAYS BETWEEN ELECTRIC VEHICLES AND HEALTH

This section outlines 15 pathways illustrating how EV's characteristics influence health outcomes, considering factors such as socioeconomic status, income levels, racial groups, and the locations of EV infrastructures.

3.1. Similar to Traditional Vehicles

EVs fulfill their traditional role as a mode of transportation, providing access to health facilities, enhancing physical activity, and promoting mobility independence, similar to traditional vehicles (see Figure 1, Box 2, Left side). These pathways illustrate transportation impacts on health that are not specific to EVs.

Transportations allow people to get access to health facilities and more physical activity facilities, promoting opportunities for exercise and wellness.[7] Transportations also allow people to have mobility independence, which is vital for healthy aging, mental well-being, and self-esteem.[16]

However, they are detrimental to health through intensifying social exclusion, stress, and occupying green spaces (Figure 1 Box 2, Right side). Social exclusion from fear of public transportation[17] can contribute to poor health outcomes through unhealthy lifestyles like smoking, excessive drinking, poor diet, and lack of exercise.[18] Stress from congestion, searching for parking and charging stations, and interactions with other drivers in traffic can result in anxiety, depression, mental health-related QOL, substance use, unhealthy diet, sleeplessness, heart disease, hypertension, etc.[19,20] Transportation infrastructure can occupy green and blue spaces, reducing mortality risk, improving cardiovascular and respiratory health, stress reduction, and enhancing mental health.[21]

3.2. Reducing Detrimental Effect on Health

The adoption of EVs diminishes the negative health impacts associated with traditional vehicles (Figure 1 Box 3). First, EVs, being quieter than traditional vehicles, reduce noise levels in urban areas[22] and noise-induced health issues such as cardiovascular diseases, diabetes, hypertension, obesity, sleep disturbance, annoyance, cognitive impairment etc.[8] Second, EVs with battery engines mitigate the impact of harmful substances through avoiding the leakage of chemicals and pollutants like oil leakage oils, gasoline, heavy metals, and particulate matter released by traditional vehicles onto road surfaces.[9] Third, EVs help mitigate the urban heat islands (UHIs) effect by producing less exhaust heat than traditional vehicles due to their high engine efficiency and reducing air pollutants, such as ozone.[10] The cooling environment can reduce heat-related health risks, especially among kids and older people.[23]

EVs represent a shift toward cleaner transportation, reducing air pollution, such as NOx, particulate matter (PM), and ozone, which can lead to respiratory diseases, cardiovascular problems, and premature mortality.[24,25] However, the EV development can also increase air pollution due to electricity generation and tire wearing, as discussed in the next section.

3.3. Increasing Detrimental Effect on Public Health

EVs can harm public health by increasing road injuries, generating hazardous materials from battery production and disposal, exposing people to EMFs, intensifying community severance, raising emissions from coal-fired power plants, and producing nonexhaust emissions from tire wear.

First, the production and disposal of lithium-ion batteries (LIBs) in EVs increase harmful metals like lithium, chromium, and cobalt in the environment, posing serious health risks, including cancer.[26] Metal extraction and battery manufacturing, particularly when using nonrenewable energy, degrade the environment and harm nearby communities.[27] LIBs last 8−10 years, but less than 5% are recycled, with most ending up in landfills, where they release toxic chemicals into the soil and water.[13] These impacts disproportionately affect low-income and minority communities near mining operations.[28]

Second, EV charging introduces electromagnetic fields (EMFs) from moving charged particles. Since EVs generally have shorter range and longer charging times than fuel-efficient internal combustion vehicles,[29] wireless power transfer (WPT) is being developed to extend travel distances through dynamic charging, which generates EMFs during operation.[30] However, EMFs can harm health by inducing oxidative stress,[31] increasing miscarriage risk,[32] and impairing cognitive performance, particularly in children.[33]

Third, the high weight of EVs raises safety concerns in crashes and increases nonexhaust emissions. Electrified drivetrains and large battery packs make EVs 4%−41% heavier than traditional vehicles,[34] leading to a 12% rise in passenger fatalities for every 500-kg weight difference.[35] The added weight also heightens tire and road wear, boosting nonexhaust emissions, particularly particulate matter (PM), which is linked to respiratory diseases and premature death.[36]

Fourth, EVs increase electricity demand, leading to higher emissions in coal-dependent areas, which diminishes their environmental benefits. Coal combustion releases pollutants like SO2, NOx, and PM, causing respiratory and cardiovascular issues.[24] These emissions can offset EV benefits, especially during high coal usage seasons, where the positive impact is moderate.[37]

Fifth, EVs can exacerbate community severance. First, the locations of charging infrastructure influences EV travel patterns. Wealthier areas tend to have higher EV adoption, boosting a greater number of charging stations.[15] Conversely, disadvantaged communities where minorities and low-income groups tend to concentrate, end up having fewer charging stations, leading to less EV usage in those regions.[38] Consequently, the benefits of EVs, such as reduced tailpipe pollution, are less likely to reach these marginalized groups.[39] It can also exacerbate the situation for low-income neighborhoods nearby those coal plants in both ways: limited access to EV benefits while in the meantime with heightened health risks from increased pollution due to coal-powered electricity generation.[38]

4. AN INEQUITABLE LANDSCAPE

The 15 pathways linking EVs and public health vary by socioeconomic factors and location, such as air quality, charging infrastructure, and energy sources. While EVs can reduce environmental injustice by lowering tailpipe pollution in areas with poor air quality, benefits like improved air quality and reduced noise pollution may not be evenly distributed. Communities near highways, industrial zones, or urban centers, often home to marginalized groups, face disproportionate pollution and health risks.

The transition to EVs can significantly improve public health by reducing emissions in polluted areas.[3] Electrifying heavy-duty vehicles can enhance air quality in areas where minority groups typically reside.[40] However, if not equitably imple-

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mented, EVs may worsen environmental injustice. High upfront costs deter disadvantaged communities, leading to continued use of older, polluting vehicles.[38] Unequal access to charging infrastructure leaves marginalized neighborhoods underserved, hindering EV adoption and exacerbating range anxiety.[15] Moreover, the environmental benefits of EVs depend on the energy mix. In regions reliant on fossil fuels, especially where minority communities live near emission sources like coal plants, pollution and health risks increase, reflecting environmental injustice.[14,41]

APPENDIX 1

The definitions of 15 pathways are as follows:

- **Access**: Access to jobs, education, healthcare, public transport, healthy food, and natural spaces.
- **Mobility Independence**: The ability to utilize various transportation modes to access commodities, facilities, and participate in activities independently.
- **Physical Activity**: Body movement which requires energy expenditure. Physical inactivity contributes significantly to the obesity epidemic and various diseases.
- **Social Exclusion**: The consequence of accessibility inadequacies and contributes to social isolation and loneliness, that are each associated with negative health outcome
- **Occupy Green Spaces and Anesthetics**: Occupying publicly accessible land covered with vegetation.
- **Stress:** Car use stress comes from congestion, parking, interactions with drivers, and safety worries, affecting well-being.
- **Urban Heat Islands:** Urban spaces with greater surface and air temperatures compared with surrounding areas.
- **Noise:** motorized vehicle sounds at levels that are detrimental to health.
- **Roadway Contamination:** Chemical pollutants, such as oil, heavy metals, and particulate matter, found on the roadway surface.
- **Air Pollution:** Air pollution results from the emission and dispersion of toxic substances in the air.
- **Greenhouse Gas Emissions:** Gases including carbon dioxide (CO2), methane, nitrous oxide, and fluorinated gases which trap heat in the atmosphere.
- **Battery Production and Dispose:** the manufacturing and end-of-life management processes of EV batteries, including their production, assembly, usage, recycling, and disposal.
- **Road Injuries:** Death, injury, or disability caused by motor vehicle crashes.
- **Community Severance:** The situation where transportation infrastructure or traffic that divides places and people, hindering access to goods, services, and networks.
- **Electro-magnetic fields (EMFs)**: An EMF is composed of moving electrically charged particles. It is issue of current concern in wireless power transfer to charge EVs.

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Notes

The authors declare no competing financial interest.

Biography

Kai Zhang, MS, MA, PhD, is an Empire Innovation Associate Professor in the Department of Environmental Health Sciences at the University at Albany, State University of New York (SUNY). Dr. Zhang is the awardee of the SUNY Empire Innovation Program in 2021. Dr. Zhang received a PhD degree in Environmental Health and a MA degree in Statistics at the University of Michigan, and an MS degree and a BS degree in Environmental Engineering from Tsinghua and Southeast University in China, respectively. Dr. Zhang's research interest focuses on characterizing climate-related exposures, reducing the human health effects associated with disasters, and exploring the role of social and environmental stressors (air pollution, natural environment, built environment, and green space) in relation to chronic diseases. His expertise includes exposure science, air quality, epidemiology, GIS, statistics, and data science. Dr. Zhang currently serves as Associate Editor for Science of the Total Environment and Journal of Exposure Science and Environmental Epidemiology. His research has been featured in prestigious international journals, including *Nature Communication*, *Science Advances*, *Circulation*, *Circulation Research*, *Environmental Health Perspectives*, and *Environmental Science & Technology*.

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