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Article

Comparative analysis of CO_2 emissions of electric ride-hailing vehicles over conventional gasoline personal vehicles

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SUMMARY

Ride-hailing services have become popular due to their convenience, affordability, and accessibility. Increasing cost of car ownership, traffic congestion and parking shortages are fostering this global market growth. Though four-wheeler ride-hailing vehicles are fuel efficient, researchers have determined that the emission reductions from fuel efficiency alone cannot compensate for the additional emissions caused by "deadheading," the issue of driving without passengers on ride-hailing trips. We suggest that electric vehicle-based ride-hailing services have the potential to reduce utilization CO_2 emissions, which are emissions released while using (driving) the vehicle. However, skeptics challenging this hypothesis cite CO_2 released during electricity generation (carbon intensity) needed for recharging batteries and the inherent issue of deadheading in ride-hailing services. We compared ride-hailing vehicles to gasoline-powered passenger cars, the largest source of carbon emissions within the transportation sector. In many cases, ride-hailing vehicles are electric and have newer models, so they emit less CO_2 per kilometer. We conducted a quantitative analysis, using a mathematical model to estimate the utilization of CO_2 emissions for electric vehicles per ride-hailing trip kilometer, considering carbon intensity of electricity generation, electric vehicle fuel efficiency, and deadheading. We compared our results with average estimated utilization CO_2 emissions to gasoline-powered passenger cars. Additionally, we performed a sensitivity analysis, which involved adjusting the input variables within plausible ranges to assess their impact on our model results. According to our analysis, despite deadheading, improved vehicle fuel efficiency and cleaner electricity generation result in lower CO_2 emissions for electric ride-hailing vehicles than gasoline personal vehicles.

INTRODUCTION

Global warming is the long-term increase in Earth's average surface temperature due to the greenhouse effect, which is primarily caused by the accumulation of greenhouse gases in the atmosphere (1). Greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), trap heat from the Sun, preventing it from escaping back into space. This trapped heat causes the planet to warm over time. Global temperatures have risen by 1 °C due to human influence in the past century, and if current emissions continue, they will rise by at least 4 °C to 6 °C by 2100 (2). Global warming consequences, such as more frequent and severe heatwaves, droughts, storms, and sea-level rise, pose substantial threats to human health, ecosystems, and infrastructure (2). The global transportation sector significantly contributes to CO_2 emissions, a principal greenhouse gas that leads to global warming (3). Gasoline-powered passenger cars represent the largest source of carbon emissions within this sector accounting for about 39% of total emissions (4). Thus, personal passenger vehicles provide a key area of focus for reducing CO_2 emissions. The emergence of ride-hailing, a form of transportation service provided through platforms where riders and drivers connect, such as Uber and Lyft, can potentially reduce CO_2 emissions as it enhances urban mobility and encourages residents to drive less (5).

Ride-hailing services have become increasingly popular because of their convenience, affordability, and accessibility. We expect that the global ride-hailing revenue will grow by 15.7% from 2022 to 2030 to reach $104.93 billion USD (6). However, some studies have shown that the increasing demand of ride-hailing services has led to more vehicles on the road, contributing to air pollution, traffic congestion, and carbon emissions (7). Furthermore, ride-hailing services contribute to CO_2 emissions through "deadheading" (8). Deadheading refers to the issue of driving with no passengers in vehicle after dropping off passengers and on the way to pick up new passengers, leading to unnecessary carbon emissions. Studies have estimated that deadheading contributes about 40% of total emissions to ride-hailing services (8). On the other hand, it is worth noting some studies have found ride-hailing services reduce vehicle ownership as passengers who use them forego or delay purchasing their own vehicles (9). This trend is particularly noticeable in densely populated urban areas, where owning a car can be more of a hassle than a convenience (9). As this shift in transportation behavior continues, we need to understand the environmental implications, especially the CO_2 emissions associated with these services (7,9). To gain a comprehensive understanding of the impact of this transition, we chose to compare the utilization CO_2 emissions resulting from the prevalent use of ride-hailing services to those produced by gasoline-powered passenger cars. The gasoline-powered passenger cars were selected for comparison for essentially two main reasons. Firstly, ride-hailing vehicles are typically newer models and, in many cases, electric, which generally results in less CO_2 emissions per kilometer traveled than the average personal gasoline-powered car (10). Ride-hailing

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electrification in China and Europe has outpaced personal passenger vehicle electrification in the US. Almost 40% of China's ride-hailing vehicles are now electric (10). Secondly, gasoline-powered passenger cars are the largest source of global carbon emissions within the transportation sector, making them a relevant point of comparison (4).

Lifecycle emissions refer to a vehicle's environmental impact over its entire lifespan, including production, utilization, and recycling (11). In a vehicle, production emissions refer to the greenhouse gases emitted during manufacturing, utilization emissions during operation, and recycling emissions during the process of recycling the vehicle. We hypothesized that ride-hailing services based on electric cars emit less CO_2 during the operating phase of their lifecycle (utilization emissions) than those based on gasoline-powered vehicles. However, detractors argue that the inherent issue of deadheading in ride-hailing services and the carbon intensity of the electricity generation required to recharge electric vehicles may offset the overall CO_2 emissions reduction (12). Carbon intensity of electricity generation, defined as CO_2 emissions per unit of electricity generated, varies based on factors such as energy source mix, power plant efficiency, and use of carbon capture technologies (13,14). For example, coal-fired power plants have high carbon intensity due to substantial CO_2 emissions, while renewable sources like wind, solar, and hydroelectric power, which do not burn fossil fuels, have low carbon intensity (14). It has therefore been argued that electric vehicles that are powered by coal-fired power plants will emit more CO_2. Fossil fuels generate about 60% of the U.S. electricity generation, with nuclear and renewable sources contributing 18% and 22%, respectively (15).

In this study, we tested the hypothesis that utilization CO_2 emissions can be reduced by switching from personal gasoline vehicles to electric ride-hailing services. We also compared the utilization CO_2 emissions resulting from a switch from personal gasoline vehicles to gasoline ride-hailing services. To test our hypotheses, we modeled the utilization CO_2 emissions of electric vehicles per ride-hailing trip kilometer and compared the results to the average estimated utilization CO_2 emissions for gasoline-powered passenger cars. Previous studies demonstrate that gasoline-powered cars emit a larger portion of lifecycle emissions during the utilization phase compared to production and recycling emissions (11). Due to their first-order impact on the results, we excluded production and recycling emissions from our lifecycle emission analysis, considering only the emissions from the use phase of vehicle lifecycle.

Our analysis leads us to conclude that improved vehicle fuel efficiency, which represents the distance an electric vehicle can travel on a given quantity of electricity, and cleaner energy generation from renewable sources result in lower utilization CO_2 emissions from electric ride-hailing vehicles than gasoline vehicles, despite deadheading. Electric vehicles benefit from improved fuel efficiency because a fuel-efficient vehicle is capable of driving for longer on a single charge, and its battery charging creates fewer emissions. In this way, electric vehicles charging from an electricity grid with higher carbon intensity will not need frequent charging, resulting in fewer emission (16). A better understanding of how ride-hailing services affect climate change is important to guide policies and consumer choices. If the shift towards ride-hailing services increases CO_2 emissions, then it might be necessary to implement measures to mitigate this, such as encouraging ride-hailing companies to use more electric vehicles with improved fuel efficiencies, improve vehicle occupancy rates, and support public transportation as a complement to their services.

RESULTS

The CO_2 emissions generated by electric vehicles are influenced by factors such as the carbon intensity of electricity generation and the fuel efficiency of the electric vehicles themselves (16,17). Our study compared the CO_2 emissions of personal gasoline vehicles to electric ride-hailing services, with the impact of deadheading considered. We developed a model to estimate and compare the utilization CO_2 emissions of both electric and gasoline vehicles for each kilometer traveled during a ride-hailing trip. The model's data inputs included the carbon intensity of gasoline consumption (measured in grams of CO_2 released per liter of gasoline consumed), the fuel efficiency of gasoline vehicles (measured in kilometers traveled per liter of gasoline), the carbon intensity of electricity generation (measured in grams of CO_2 released per kilowatt-hour of electricity produced for charging electric vehicles), fuel efficiency of electric vehicles (measured in kilometers per kilowatt-hour of electricity consumed), overhead percentage to account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity and deadheading factor. We collected model input data for vehicle carbon intensity and vehicle fuel efficiencies from the Environmental Protection Agency (EPA) automotive trends report for the year 2021 (18). We obtained carbon intensity of electricity generation from the Ember's yearly electricity generation data (19). We obtained the overhead percentage and deadheading factor from previous published research (8).

Finally, to strengthen the validity of our findings and explore the impact of various input data on our modeled CO_2 emissions, we conducted a sensitivity analysis. This involved systematically altering the carbon intensity of electricity generation and the fuel efficiency of electric vehicles as inputs to our model. By doing so, we were able to examine how these factors influenced the CO_2 emissions of electric vehicles in ride-hailing services under different scenarios and conditions. The sensitivity analysis allowed us to identify the specific situations where electric ride-hailing vehicles are most advantageous in terms of CO_2 emissions reduction. Moreover, it enabled us to better understand the interplay between the carbon intensity of electricity generation and the fuel efficiency of electric vehicles, and how these parameters contribute to the overall environmental impact of electric vehicles in ride-hailing services. Our model estimated that electric vehicles engaged in ride-hailing services, including the impacts of deadheading, exhibited utilization CO_2 emissions ranging from 59 and 203 g CO_2/km. This large variation resulted from vehicle fuel efficiencies and carbon intensity of electricity generation. This range represented a marked reduction in CO_2 emissions compared to the average utilization emissions of gasoline-powered passenger cars, which was estimated to be 262 g CO_2/km from the EPA automotive trends report for the year 2021 **(Figure 1)**. Compared to personal gasoline vehicles, electric ride-hailing services reduced emissions by 22.5%–77.5%.

On the other hand, our model estimated utilization CO_2

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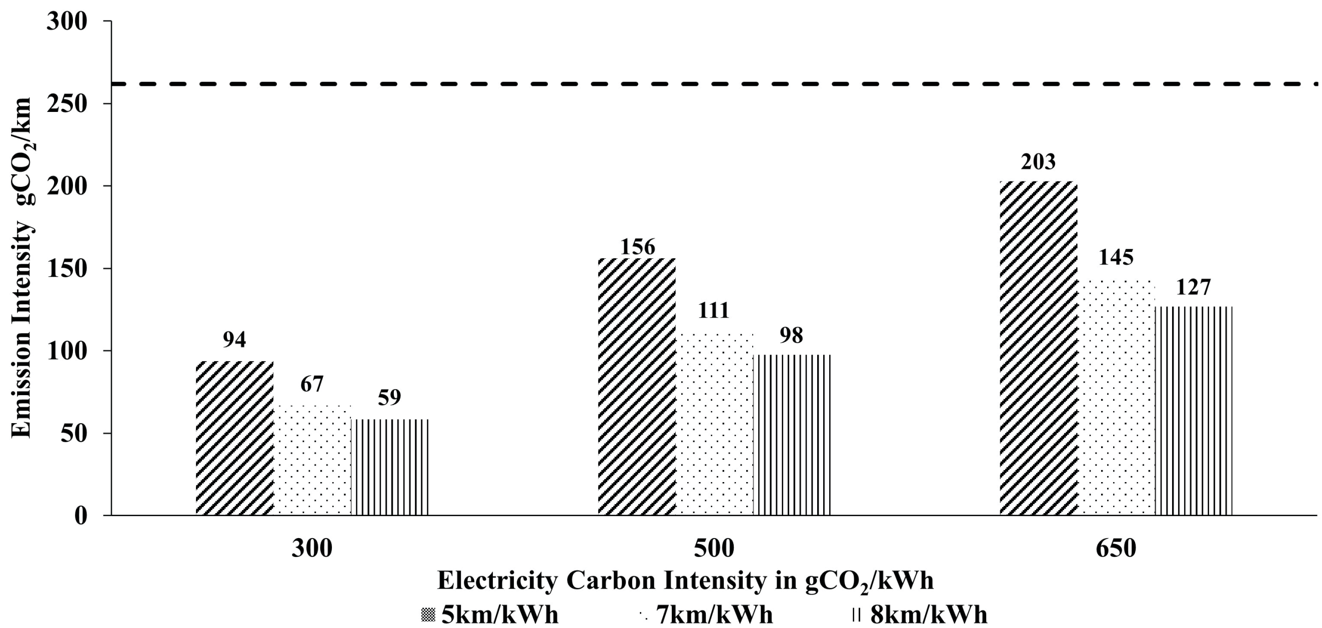

Figure 1: Predicted utilization CO_2 emissions for ride-hailing electric vehicles. Predicted utilization CO_2 emission per kilometer (g CO_2/km) for ride-hailing electric vehicles with different fuel efficiency and electricity carbon intensity with 30% deadheading. Modeled CO_2 emissions per kilometer from electric vehicles used in ride-hailing services with 30% deadheading, and varying carbon intensity from electricity generation and vehicle fuel efficiency of 5 km/kWh (diagonal stripes), 7 km/kWh (dotted), and 8 km/kWh (vertical stripes). To account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity a constant 20% overhead was applied to the calculation. The modeled CO_2 emissions per kilometer from electric vehicles were compared with the average estimated utilization CO_2 emissions for gasoline-powered passenger cars, which stood at 262 gCO_2/km (horizontal dashed line).

emissions of gasoline vehicles deployed in ride-hailing services, including the effects of deadheading, spanned between 270 and 453 g CO_2/km **(Figure 2)**. This large variation resulted from gasoline vehicle fuel efficiencies and represented a relative increase of 3% to 73% in CO_2 emissions when compared to the average utilization emissions of gasoline-powered passenger cars.

According to our results, even the least fuel-efficient electric vehicle (5 km/kWh) used for ride-hailing services, charging at different electric grid intensities, and operating with a high percentage of deadheading emits less CO_2 compared to an average gasoline-powered passenger car **(Figure 3)**. CO_2 emissions of electric vehicles increased by 1.1% over those of personal gasoline vehicles only when the electricity used to charge batteries was obtained from a grid operating with emission intensity of 650 g CO_2/kWh **(Figure 3)**. Countries operating coal-fired power plants mainly observe such a high level of electricity grind emission intensity, as indicated by the Ember's yearly electricity generation data (19). Therefore, CO_2 emission estimations for ride-hailing electric vehicles need to take deadheading into account.

Contrastingly, for gasoline ride-hailing vehicles with the lowest fuel efficiency in our study (8 km/liter) and 70% deadheading factored in, the CO_2 emissions were higher than personal gasoline vehicles. They exceeded those from personal gasoline vehicles by 126% **(Figure 4)**.

DISCUSSION

The primary objective of our study was to compare the CO_2 emissions resulting from a transition from personal gasoline vehicles to electric and gasoline ride-hailing services, with the impact of deadheading considered. We investigated our hypothesis that four-wheeled electric vehicles used in ride-hailing services can potentially yield reduced CO_2 emissions, even when taking deadheading into account.

Our study demonstrated the dynamic interplay of various factors, including the carbon intensity of electricity generation, the fuel efficiency of vehicles, and the impact of deadheading, as we assess their collective influence on CO_2 emissions of ride-hailing electric vehicles in comparison to personal gasoline vehicles. Our results showed that even the least fuel-efficient electric vehicle in our study, operating in conditions that included deadheading and charging with electricity from grids with relatively high emission intensities, emits fewer CO_2 emissions compared to an average gasoline-powered passenger car.

Previous studies demonstrated that gasoline-powered cars emit a larger portion of lifecycle emissions during the utilization phase compared to production and recycling emissions (11). Due to their smaller impact on the results, production and recycling emissions were excluded from our analysis. We found that electric ride-hailing vehicles can have lower CO_2 emissions compared to gasoline personal vehicles. However, this advantage is contingent on maintaining low electricity grid emission intensity and high fuel efficiency for electric vehicles, as well as minimizing the deadheading impact. To achieve low electricity grid emission intensity, a strategic shift towards renewable energy sources, such as wind, solar, and hydropower, should be prioritized. For enhancing the fuel efficiency of electric vehicles,

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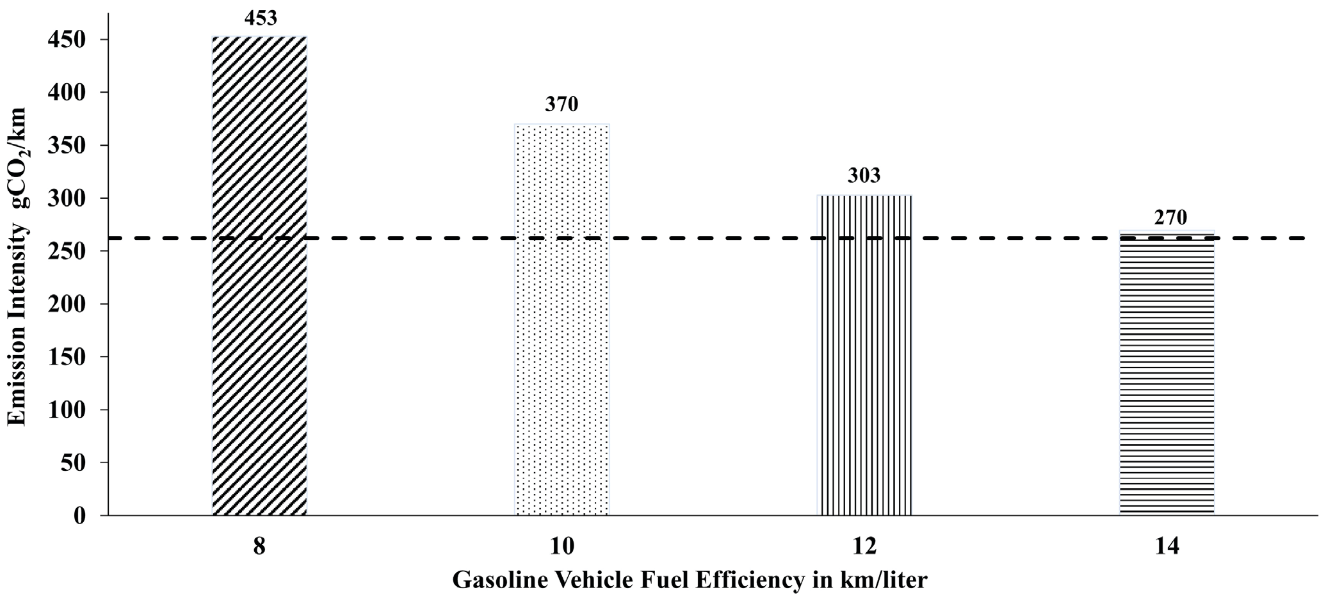

Figure 2: Predicted utilization CO_2 emissions for ride-hailing gasoline vehicles. Predicted utilization CO_2 emission per kilometer (g CO_2/km) for ride-hailing gasoline vehicles with different fuel efficiencies and 30% deadheading. Modeled CO_2 emissions per kilometer from gasoline vehicles with different vehicle fuel efficiencies, 8 km/liter (diagonal stripes), 10 km/liter (dotted), 12 km/liter (vertical stripes), and 14 km/liter (horizontal stripes), used in ride-hailing services with a constant 30% deadheading. To account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity a constant 20% overhead was applied to the calculation. The modeled CO_2 emissions per kilometer from gasoline vehicles used in ride-hailing services were compared with the average estimated utilization CO_2 emissions for gasoline-powered passenger cars, which stood at 262 g CO_2/km (horizontal dashed line).

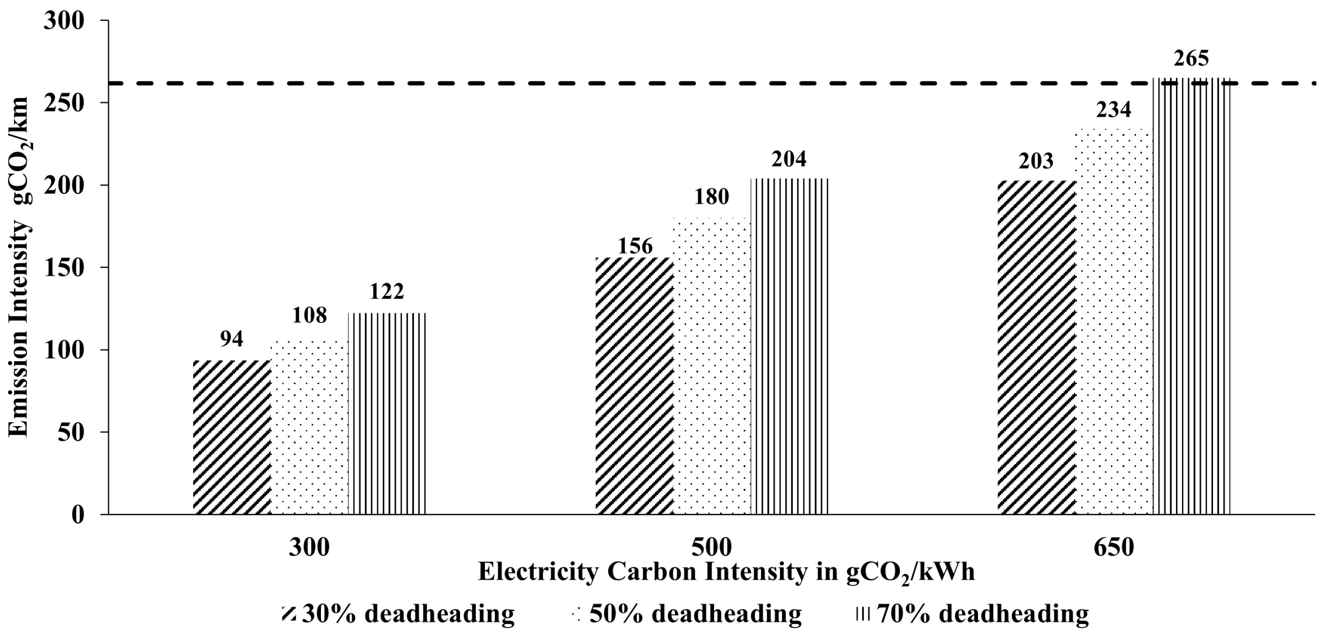

Figure 3: Impact of deadheading on the predicted utilization CO_2 emissions for ride-hailing electric vehicles. Predicted utilization CO_2 emissions per kilometer (g CO_2/km) for ride-hailing electric vehicles with 5 km/kWh fuel efficiency with different levels of deadheading. Modeled CO_2 emissions per kilometer from electric vehicles used in ride-hailing services with 5 km/kWh fuel efficiency, and varying carbon intensity of electricity generation and deadheading levels of 30% (diagonal stripes), 50% (dotted), and 70% (vertical stripes). To account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity a constant 20% overhead was applied to the calculation. The modeled CO_2 emissions per kilometer from electric vehicles were compared with the average estimated utilization CO_2 emissions for gasoline-powered passenger cars, which stood at 262 g CO_2/km (horizontal dashed line).

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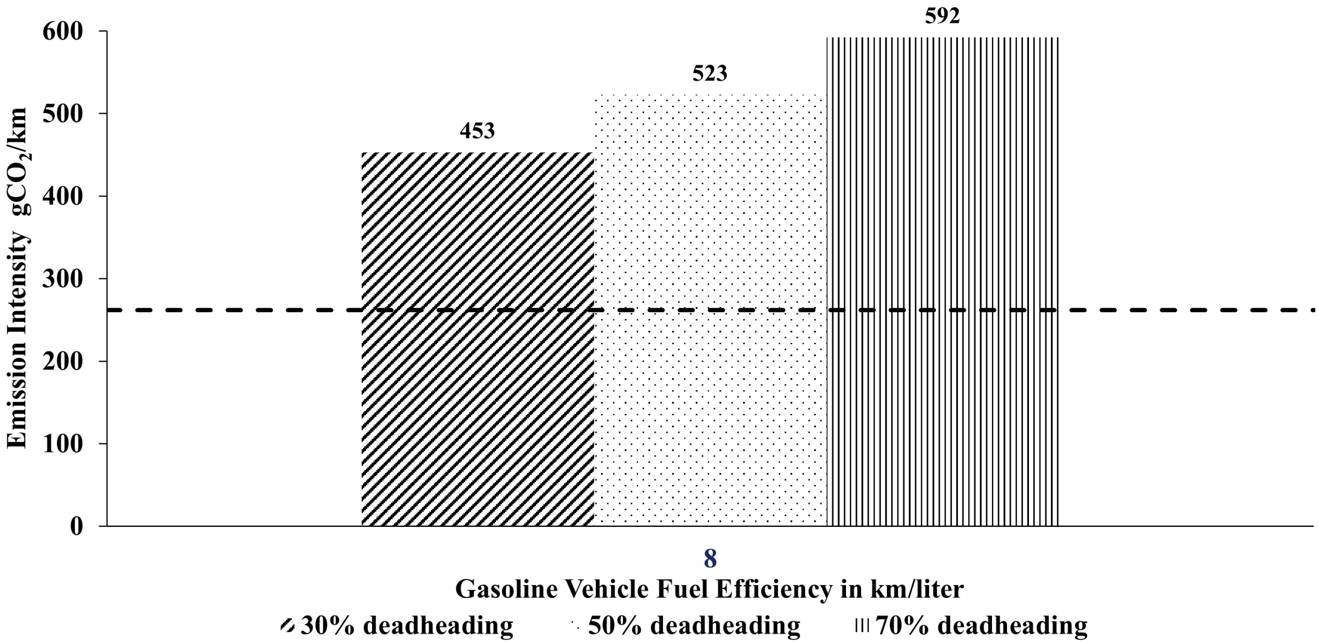

Figure 4: Impact of deadheading on the predicted utilization CO_2 emissions for ride-hailing gasoline vehicles. Predicted utilization CO_2 emissions per kilometer (g CO_2/km) for ride-hailing gasoline vehicles with 8 km/liter fuel efficiency and with different levels of deadheading. Modeled CO_2 emissions, at deadheading levels of 30% (diagonal stripes), 50% (dotted), and 70% (vertical stripes). To account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity a constant 20% overhead was applied to the calculation. The modeled CO_2 emissions per kilometer from gasoline vehicles were compared with the average estimated utilization CO_2 emissions for gasoline-powered passenger cars, which stood at 262 g CO_2/km (horizontal dashed line).

continuous research and innovation in battery technology are essential. Finally, to minimize the deadheading impact in ride-hailing services, companies can deploy advanced routing algorithms, real-time traffic data analytics, and rider-driver matching techniques to ensure that vehicles spend minimal time without passengers, thus optimizing route efficiency.

While our research provides valuable insights into the utilization phase of electric vehicles' lifecycle emissions, it should be noted that this approach has certain limitations. In our study, we compared the utilization CO_2 emissions from ride-hailing electric vehicle against the average carbon intensity of gasoline-powered cars. We did this while ignoring factors such as model and year of vehicle manufacture, which may affect our conclusions.

Our research does not account for the entire lifecycle of electric vehicles. The production and recycling phases are significant components of electric vehicles' total lifecycle emissions, and their omission could lead to an underestimation of the overall carbon footprint of electric vehicles used in ride-hailing services. The production phase is resource-intensive, often involving high greenhouse gas emissions, especially during the manufacturing of the battery systems (11, 20). Additionally, the recycling and disposal phase also contributes to the overall emissions, due to energy use in the recycling process or potential emissions from waste disposal (11, 20). Therefore, by focusing only on the utilization phase, our study provided only a partial picture of the environmental impact of electric vehicles, which might not be representative of their full lifecycle emissions.

As we move forward, the landscape of energy generation is anticipated to change significantly (21). We expect to generate at least 55% clean electricity, electricity generated from renewable sources, by 2035, even without making any policy changes, and an astonishing 90–100% by 2050 (21). Long term, grid intensity will have a lower impact than the level of least emission grid intensity (300 grams CO_2 per kWh) that we employed in our sensitivity analysis. Additionally, the CO_2 emissions reduction from electric ride-hailing vehicles is expected to outweigh the impact of deadheading as gasoline production becomes more carbon-intensive (22).

According to our results, an electric ride-hailing service has potential emission benefits over a personal gasoline vehicle to reduce CO_2 emissions. As ride-hailing services become more widely adopted, advances in electric vehicle technology could be accelerated, leading to improved energy efficiency and reduced carbon emissions. Furthermore, it could lead to increased infrastructure, such as charging stations, enabling a wider transition to electric vehicles (23). Ride-hailing services can play a vital role in the future of sustainable urban transportation due to their potential benefits in terms of sharing resources and reducing car ownership. Thus, city planners and policymakers should consider strategies to encourage electric ride-hailing services while minimizing deadheading and promoting cleaner energy.

Our research complements and aligns with previous studies on the topic of ride-hailing's climate impact due to deadheading and the escalation of overall car journeys (8, 24, 25). Our approach goes a step further by applying sensitivity analysis to CO_2 emissions per trip for electric ride-hailing vehicles, differing from the methodology employed in previous studies which used city-specific values to calculate emissions per trip (8, 24, 25). Our approach facilitates the identification of an optimal parameter set that includes low carbon grid intensity, high vehicle fuel efficiency, and low deadheading

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where electric ride-hailing services had lower CO_2 emission than gasoline passenger cars.

This study provides several directions for future research. To begin with, analyzing the lifecycle emissions of electric vehicles, which includes production, use, and recycling, would give a broader perspective on the environmental impact. Our study only focused on the utilization component of lifecycle emissions. A second strategy could be to examine consumer attitudes towards electric ride-hailing services and their associated economic implications. Finally, policymakers can gain valuable insight from research on the impact of policies encouraging electric vehicle use in the ride-hailing sector. We can develop more sustainable transportation systems by studying these suggested areas of study.

Overall, our study emphasizes the importance of a holistic approach to sustainable transportation. Besides comparing CO_2 emissions of ride-hailing services with personal gasoline vehicles, this study emphasizes the importance of evaluating electric vehicle lifecycles, fuel efficiencies, and the source of electricity needed to recharge batteries. In addressing these areas, we can create greener and more sustainable transportation systems, benefiting both society and the environment.

MATERIALS AND METHODS

To test our hypothesis, a model was created to calculate utilization CO_2 emissions per kilometer, considering key factors such as carbon intensity, fuel efficiency, overhead, and deadheading (8, 16, 22, 24, 25). Data for gasoline vehicle carbon intensity and fuel efficiency were collected from the EPA automotive trends report for 2021 (18). Ember's yearly electricity generation data was used to determine the carbon intensity of electricity generation (19). The overhead percentage and deadheading factor were obtained from previous published research (8). Carbon intensity of electricity generation is a measure of grams of CO_2 released during the production of a kilowatt hour (kWh) of electricity (13). Electricity made from fossil fuels is more carbon intensive compared to electricity generated from renewable sources, like solar or wind (14). The fuel efficiency of electric vehicles is the amount of electricity the car uses per kilometer (km/kWh). The more a car is fuel efficient, the higher will be its fuel efficiency figure. The ratio of the carbon intensity of electricity generation to the fuel efficiency of electric vehicles provides the grams of CO_2 released to travel one kilometer. Additionally, an overhead factor was applied to the calculated CO_2 emissions for electric vehicles and gasoline vehicles to account for emissions arising from the extraction, processing, transportation, and distribution of fossil fuel to produce gasoline or electricity. This is called the well-to-wheel phase of the fuel lifecycle (11). For electric and gasoline vehicles used for ride-hailing services, a deadheading factor is also applied. Here are the three equations that comprise the entire mathematical model used in our research:

The total grams of CO_2 utilization emissions per kilometer (gCO_2/km) for electric-powered vehicles used for ride-hailing service is given by:

$$\left(\frac{\mathrm{g\,CO_2}}{\mathrm{km}}\right) = \frac{\left(\frac{\mathrm{g\,CO_2}}{\mathrm{kWh}}\right)}{(\mathrm{km/kWh})}(1+oh)(1+d) \qquad \textbf{(1)}$$

Where, grams CO_2 per kilowatt-hour (g CO_2/kWh) represents the carbon intensity of electricity generation, kilometer per kilowatt-hour (km/kWh) represents the distance traveled per kWh of electricity, the energy efficiency of an electric vehicle and *d* represents the deadheading percentage and *oh* represents the overhead percentage to account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity. Similarly, for personal gasoline vehicles, the amount of CO_2 released per travel kilometer was calculated by taking the ratio of carbon intensity of gasoline consumption to the fuel efficiency of a gasoline vehicle and after considering the overhead percentage to account for CO_2 emissions for transporting fuels **(Equation 2)**. The carbon intensity of gasoline consumption measures grams of CO_2 released per liter of gasoline consumed and the fuel efficiency of a gasoline vehicle measures the distance traveled in kilometer per liter of gasoline. For gasoline vehicles used for ride-hailing services, a factor to account for deadheading was also included **(Equation 3)**.

The total grams of CO2 utilization emissions per kilometer (g CO_2/km) for gasoline personal vehicles is given by:

$$\left(\frac{\mathrm{g\,CO_2}}{\mathrm{km}}\right) = \frac{\left(\frac{\mathrm{g\,CO_2}}{\mathrm{L}}\right)}{(\mathrm{km/L})}(1+oh) \qquad \textbf{(2)}$$

The total grams of CO_2 utilization emissions per kilometer (g CO_2/km) for gasoline vehicles used for ride-hailing service is given by:

$$\left(\frac{\mathrm{g\,CO_2}}{\mathrm{km}}\right) = \frac{\left(\frac{\mathrm{g\,CO_2}}{\mathrm{L}}\right)}{(\mathrm{km/L})}(1+oh)\,(1+d) \qquad \textbf{(3)}$$

Where, grams of CO_2 per liter (g CO_2/L) represents the carbon intensity of gasoline consumption, and kilometer per liter (km/L) represents the distance traveled per liter of gasoline, the fuel efficiency of a gasoline vehicle, *oh* represents the overhead percentage to account for CO_2 emissions from producing and transporting a liter of fossil fuel to produce gasoline or electricity and d represents the deadheading percentage.

Microsoft Excel was used to perform the sensitivity analysis. This allowed for the manipulation of key variables, specifically the carbon intensity of electricity generation and the fuel efficiency of electric vehicles while holding deadheading and overhead factors constant. The carbon intensity of electricity generation was varied within the range of 300 to 650 grams of CO_2 per kWh, representing the lowest to the highest observed carbon intensities. This range corresponds to the average grid intensities observed in various nations employing a mix of renewable and non-renewable energy sources and was obtained from Ember's yearly electricity generation data (19). Fuel efficiency of electric vehicle was varied between 5 to 8 km/kWh, and gasoline vehicle fuel efficiency within the 8 to 14 km/liter range. These intervals represent the spectrum from the least to the most fuel-efficient vehicles, was sourced from EPA automotive trends 2021 report for gasoline vehicles and from online electric vehicle database for electric vehicles. (18, 26). For the estimation of utilization CO_2 emissions associated with electric and gasoline vehicles utilized in ride-hailing services, a consistent overhead and deadheading factor of 20% and 30%, respectively, were incorporated, which were obtained from previous research on electric ride-hailing vehicles (8, 27). Finally, the derived utilization CO_2 emissions for both electric and gasoline vehicles in the ride-hailing context were compared with the mean estimated utilization CO_2 emissions of gasoline-powered passenger cars. The

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reference data for utilization CO_2 emissions of gasoline-powered passenger cars was obtained from the EPA 2021 Automotive Trends Report (18).

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