Comparing the CO_2 emissions of three type of Vehicles

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Abstract. In the quest for sustainable transportation, this research delves deep into the lifecycle CO_2 emissions of Internal Combustion Engine Vehicles (ICEVs), Electric Vehicles (EVs), and Plug-in Hybrid Electric Vehicles (PHEVs), unveiling surprising intricacies. While ICEVs maintain a predictable emission pattern, the story for EVs and PHEVs is far more captivating, with emissions dancing to the rhythm of regional energy mixes, grid demands, and charging nuances. This study not only deciphers the complexities of vehicular emissions but also paints a vivid picture of the transformative potential of cleaner energy grids. As the narrative of EVs and PHEVs unfolds, the research spotlights the pivotal role they could play in sculpting a greener transportation future. Beyond mere data, this exploration beckons readers into a compelling journey from the heart of our current transportation landscape to the promising horizons of sustainable mobility. Dive in to discover the challenges, opportunities, and innovations that could redefine our relationship with the road.

Keywords: Electric Vehicle; CO_2 Emissions; Life Cycle; Sustainable Transportation; Vehicle Footprint

1. Introduction

Transportation is a significant source of carbon dioxide (CO_2), contributing extensively to global climate change [1]. Within this sector, automobiles powered by internal combustion engines (ICEs) have traditionally been the primary contributors [2]. As a response to the environmental concerns associated with these conventional vehicles, alternative forms of transportation such as EVs and PHEVs have been developed and promoted [1]. However, an essential question remains: How do these alternatives compare with ICEs in terms of CO_2 emissions over their lifecycle?

ICEs, which burn fossil fuels to generate the mechanical power necessary for propulsion, emit CO_2 directly during operation [2]. However, the emissions from EVs and PHEVs are not as straightforward to quantify. These vehicles derive their energy from electricity, the production of which may involve burning fossil fuels, depending on the energy mix of the region [3]. As such, the CO_2 emissions of EVs and PHEVs are largely dependent on the sources of electricity they utilize, which varies geographically and over time [4].

Furthermore, a comprehensive lifecycle analysis must consider not only the operational phase of these vehicles but also the manufacturing and disposal stages (Wang & Tang, 2022). While the operational phase generally represents the majority of emissions for ICEs, manufacturing can significantly contribute to the overall emissions of EVs and PHEVs due to the production of batteries [1]. These batteries, particularly those employing lithium-ion technology, require energy-intensive extraction and processing of materials, which can result in substantial CO_2 emissions [3].

By understanding the emission profiles of these vehicle technologies across their life cycles, a more complete picture of their environmental impacts can be accessed [1]. This knowledge can then inform policy and decision-making processes, potentially facilitating a more sustainable transportation future [4].

2. CO_2 Emissions from the Manufacturing Process

The automotive industry, a significant contributor to global CO_2 emissions, witnesses' variation in emission intensity across different vehicle types, especially during the manufacturing phase [5]. This paper endeavors to quantitatively analyze the carbon footprint associated with the manufacturing of EVs, PHEVs, and ICEVs.

ICEVs predominantly rely on fossil fuels for propulsion, necessitating manufacturing processes associated with combustion-specific components. Key contributors to the CO_2 emissions in the manufacturing of ICEVs include metal production, which entails significant energy consumption predominantly from non-renewable sources [6], synthesis of plastics and rubber, and the energy-intensive assembly phase.

EVs, on the other hand, while eliminating the need for combustion engines, introduce extensive battery systems. The manufacturing emissions of EVs are primarily influenced by battery production, especially the fabrication of lithium-ion batteries which is markedly energy-intensive [5]. Additionally, the production of electric motors and accompanying electronic systems, despite their relative simplicity compared to combustion engines, entails a discernible carbon footprint. The assembly phase for EVs, particularly when dependent on carbon-intensive energy grids, also contributes to the net emissions [7].

PHEVs, being a fusion of ICEVs and EVs, incorporate both a combustion engine and an electric motor, rendering their manufacturing emissions profile multifaceted. The engine for PHEVs might be of a different scale or design to accommodate hybrid functionalities, and the batteries, generally smaller than pure EVs, still demand intricate fabrication processes [8].

Preliminary analysis indicates that, in terms of manufacturing emissions, EVs might exhibit higher CO_2 output compared to ICEVs due to battery production. PHEVs, given their dual nature, could exhibit the highest emission footprint. However, variations in energy sourcing for manufacturing, advancements in battery production, and regional differences can influence these emission dynamics [9]. Further research should delve into the intricate nuances of material sourcing, regional energy grids, and technological advancements to provide a comprehensive emissions profile. Nonetheless, this preliminary examination underscores the importance of considering the entire vehicle lifecycle and regional energy sourcing in evaluating the environmental viability of automotive choices.

3. CO_2 Emission from Daily Usage

The operational phase of vehicles, particularly their daily usage, plays a pivotal role in determining their overall lifecycle carbon footprint. This phase is instrumental in understanding the environmental implications of various vehicle types, such as ICEVs, EVs, and PHEVs. The significance of this assessment is heightened when considering the intricate relationship between vehicular energy consumption and the carbon intensity of their respective fuel sources, as shown in fig.1.

ICEVs primarily operate on fossil fuels, specifically gasoline or diesel, which are products of crude oil refining. The carbon footprint of ICEVs can be bifurcated into two main components. Firstly, the combustion of these fossil fuels during vehicle operation directly releases CO_2. To provide a perspective, burning a single gallon of gasoline results in the emission of approximately 8,887 grams of CO_2. In contrast, diesel combustion emits around 10,180 grams for every gallon. Secondly, the entire process encompassing the extraction, refining, and transportation of these fossil fuels is also a significant source of CO_2 emissions. Location of the oil field and the intricacies of the refining process can have impact on the emission between 1,500 to 6,000 grams of CO_2 [10].

On the other hand, EVs are powered by electricity, the source of which can vary across regional grids, each having a unique blend of renewable and non-renewable energy. The CO_2 emissions associated with EVs are primarily linked to the electricity they consume. When an EV is in operation, it utilizes the electricity stored in its battery, which is subsequently recharged from the grid. The CO_2 emissions per kilowatt-hour (kWh) are contingent upon the energy mix of the grid. For instance, grids that are heavily reliant on coal might produce more than 900 grams of CO_2 for each kWh. However, grids that predominantly use renewable energy sources can significantly lower this value [11]. Additionally, the generation and transmission of electricity, especially when derived from fossil sources, inherently involve CO_2 emissions. It's essential to consider the "well-to-wall" emissions associated with power generation, which can vary based on the composition of regional grids.

PHEVs, with their dual operational capabilities, present a more complex carbon footprint. In their combustion mode, similar to ICEVs, PHEVs release CO_2 both from the combustion of fossil fuels and from the associated production and distribution chain. However, when operating in their electric mode, their emissions profile aligns more closely with that of EVs. Additionally, the efficiency of transitions between the electric and combustion modes and the overall system management can introduce energy inefficiencies, which might marginally impact the net CO_2 emissions [12].

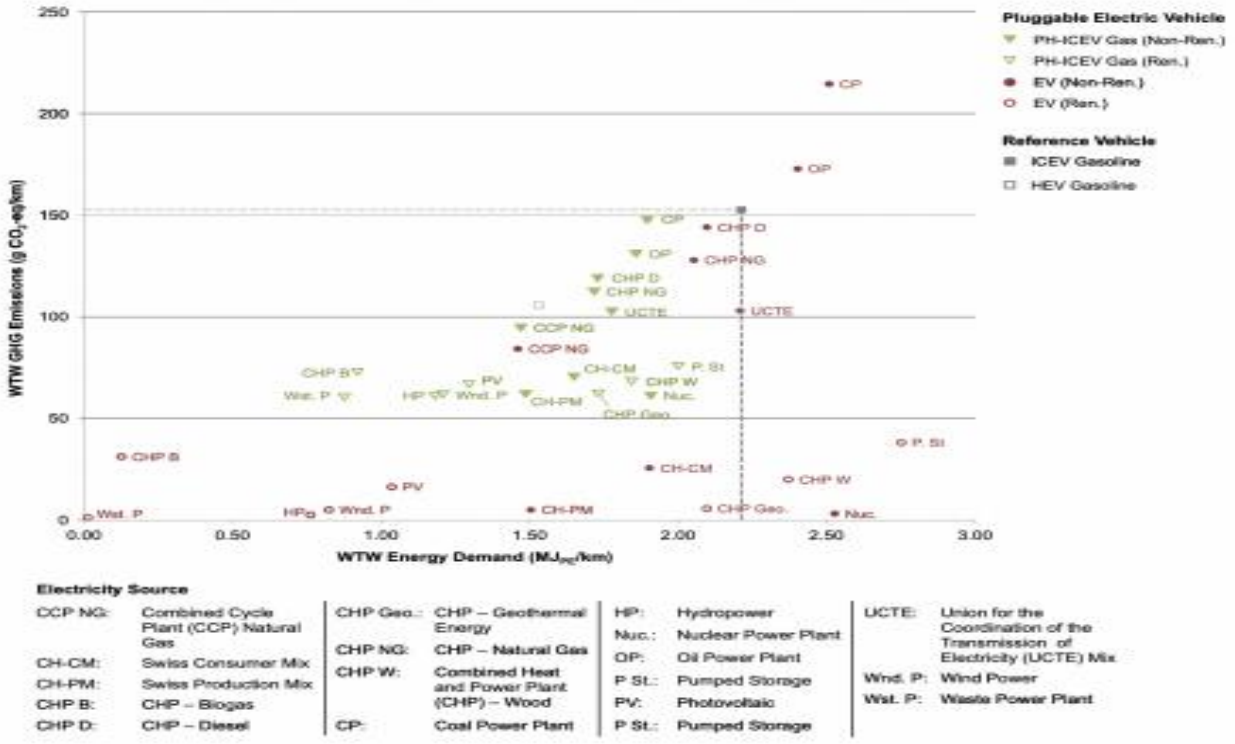


Fig 1. Energy demand and GHG emissions for EV and PH-ICEV [13].

In summation, while ICEVs consistently produce CO_2 emissions due to their inherent reliance on fossil fuels, the emissions from EVs and PHEVs are more dynamic, being closely tied to the carbon intensity of the regional electricity grids they draw power from. PHEVs, with their hybrid nature, exhibit an emissions profile that can average between that of ICEVs and EVs. However, the exact emissions are influenced by factors such as driving patterns and the extent of reliance on the grid. Crucially, the origin of the fuel source, the efficiency of energy conversion and transmission, and technological advancements in vehicle systems are all determinants of the exact carbon footprint. It's worth noting that while ICEVs are intrinsically linked to the carbon-intensive nature of fossil fuels, the emissions from EVs and PHEVs can be significantly reduced with the ongoing global transition towards cleaner energy grids [14]. As the world continues its march towards decarbonization, understanding the operational emissions of these vehicles becomes even more crucial in the broader context of global climate change mitigation efforts.

4. Variability Depending on Location and Time of Day

The carbon emissions associated with vehicular usage are multifaceted, with significant variability based on location and temporal factors. This is especially true for vehicles that derive power from electrical grids, such as EVs and PHEVs. The carbon intensity of these vehicles can fluctuate based on the regional energy mix and grid demand dynamics.

ICEVs, which predominantly operate on gasoline or diesel, generally exhibit a relatively stable carbon footprint across different locations and times of day. There can be minor fluctuations of emission due to variations in fuel quality across different regions, which can potentially affect combustion efficiency and emissions [15]. Additionally, operational conditions such as ambient

temperature and vehicle congestion, which can vary by time and location, can also slightly alter fuel efficiency and, consequently, CO_2 emissions.

The emission of EVs is substantially influenced by the local energy mix and grid dynamics. An EV charged in a region reliant on coal-fired power plants will have a higher carbon footprint than one charged on a grid dominated by renewables. For instance, an EV in a coal-centric grid might be indirectly responsible for upwards of 900 grams of CO_2 per kWh, whereas an EV in a renewable-rich environment might account for substantially less [16]. Furthermore, charging an EV during peak electricity demand hours can tap into more carbon-intensive energy sources. Utilities might resort to faster ramping, often fossil-based, power plants to meet the surge in demand. Conversely, off-peak or nighttime charging might draw more from base-load sources, which in many regions are cleaner or have higher efficiencies.

PHEVs, with their dual propulsion systems, manifest a composite emissions profile. Much like ICEVs, when PHEVs run on fossil fuels, their emission consistency remains relatively stable, influenced minutely by fuel quality and operational conditions. However, in electric mode, PHEVs inherit the emission variability of EVs. Their emissions depend largely on the regional energy mix and the specific time of day they are charged. The balance between electric and combustion modes, influenced by driving patterns and charging behaviors, can lead to significant emission variability for PHEVs across different locations and times [17].

While ICEVs present a relatively steady emission profile, the carbon footprints of EVs and PHEVs exhibit pronounced variability based on location and time-dependent factors. Such variability underscores the significance of transitioning to cleaner energy grids, especially if EVs and PHEVs are to play pivotal roles in decarbonizing transportation. Furthermore, smart charging strategies, which align EV and PHEV charging with periods of low grid carbon intensity, can further optimize the carbon footprint of these vehicles. This becomes particularly salient in regions with significant diurnal variations in the energy mix due to the integration of solar power or other variable renewable sources [18].

5. Conclusion

The comprehensive exploration undertaken in this research has shed light on the intricate dynamics of lifecycle emissions associated with various vehicle types. Our findings underscore that while ICEVs present a relatively consistent emission profile, the carbon footprints of EVs and PHEVs are subject to pronounced variability. This variability is influenced by factors such as the regional energy mix, grid demand dynamics, and charging behaviors. The results of this research have profound implications for the automotive industry, policymakers, and consumers alike. By providing a nuanced understanding of the emissions associated with different vehicle types, this study offers valuable insights that can guide decision-making processes, from vehicle manufacturing and purchasing decisions to policy formulation. The impact and meaning of this research extend beyond mere numbers and statistics. It emphasizes the interconnectedness of our energy choices and their environmental consequences. As the energy grid continues to evolve, with a growing emphasis on renewable sources, it would be pertinent to revisit and update the emission profiles of EVs and PHEVs. Additionally, the role of emerging technologies, such as improved battery storage, advanced charging infrastructure, and vehicle-to-grid integration, warrants in-depth exploration. Furthermore, understanding consumer behavior, adoption patterns, and the socio-economic implications of a shift towards cleaner transportation modes can provide a more comprehensive picture of the road to sustainable mobility. In conclusion, while the journey towards a carbon-neutral transportation sector is intricate and multifaceted, this research has illuminated key aspects of the path ahead. With informed decisions, collaborative efforts, and a commitment to continuous exploration, a sustainable transportation future is not just a possibility—it's a tangible goal within our reach.

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