Paper ID #49552

Systematic Review of Wind Energy Vehicle Integration

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Abstract

Environmental impacts from climate change continue propelling societies towards renewable and sustainable lifestyles. In the transportation sector, electric vehicles represent a pivotal solution for sustainable mobility but face challenges regarding education, adoption, charging times, infrastructure, materials, cost, driving range, battery life, and cold weather performance. The following literature review explores innovative strategies to enhance electric vehicle technology by integrating wind energy technologies for a Ph.D. dissertation. The review synthesizes findings from various studies highlighting renewable energy integration into transportation systems to achieve sustainable mobility options. Options that appear achievable will undergo further investigation for future a Ph.D. dissertation. Research indicates that incorporating alternative energy sources can significantly reduce greenhouse gas emissions and enhance energy security within the transportation sector. This review aims to contribute to the discourse and education on sustainable transportation by comprehensively analyzing existing literature, identifying research gaps, and proposing future directions for integrating wind energy technologies into electric vehicles.

Introduction

Automobiles and renewable energy date back centuries, evolving over time with technological advances. The technological advancements provided increasing creature comforts and opportunities for industrialization, manufacturing, and more. However, the increasing technological developments throughout society slowly led to environmental issues for both urban and rural areas around the world. During the 1900s, individuals began taking notice of the harm caused by societal advancement, sparking a desire for change. Of the many issues and potential solutions, renewable energy generation coupled with electric appliances became a possibility for maintaining modern comfort while causing minimal environmental harm. People continue looking for ways to maintain modern comforts as new ideas are investigated, including integrating renewable energies with vehicles for a more sustainable form of transportation.

Literature Review

Automobile evolution began as horse drawn carriages retrofitted with steam, gasoline, and electric propulsion. Over time, technological advancements saw the creation of modern-day automobiles with gasoline and diesel rising as the main energy source. However, the burning of fossil fuels began having noticeable negative environmental impacts by the 1970’s, sparking a debate for change to alternative forms of energy. People hoped to create a purely electric society powered by solar, wind, and other forms of “sustainable” and renewable energy sources.

Alternative Energy Sustainability Considerations

All goods, including renewable energies and vehicles, require some form of raw materials to be mined, refined, transported, manufactured, and assembled into a final product. Vehicles and renewable energies can include thousands of different materials and manufacturing processes with associated transportation and emissions. The size and type of vehicle or renewable energy may require different materials and manufacturing processes that have different amounts of environmental impact from creation alone. [1-4].

Once manufactured and transported to consumers, the use phase becomes the next and largest contributor to environmental impacts for vehicles when powered by fossil fuels. Transportation requires large amounts of energy to move mass and overcome rolling and air resistance. Visually, people see internal combustion engine (ICE) vehicles using fossil fuels and creating emissions when driving compared to battery electric vehicles (BEVs). Many individuals look to BEVs as the future for “clean” transportation due to the absence of visual emissions. However, the BEVs electricity source must come into question, as most electricity in the United States comes from fossil fuel power plants. If a BEV electricity come from fossil fuel power plants, the emissions are simply being outsourced, having little improvement as shown in Figure 1 [5, 6]. Figure 1 shows different amounts of CO2 emissions per km driven by different vehicle powertrains including ICE, HEVs, Fuel Cell Vehicles (FCV), Flex Fuel Vehicles (FFV), and BEVs. The BEVs and FCVs show the least impact when using “renewable” hydroelectricity to create the fuel/energy source. However, when using fossil fuels, the environmental impacts are similar to other vehicles on the market. [1-5, 7, 8].

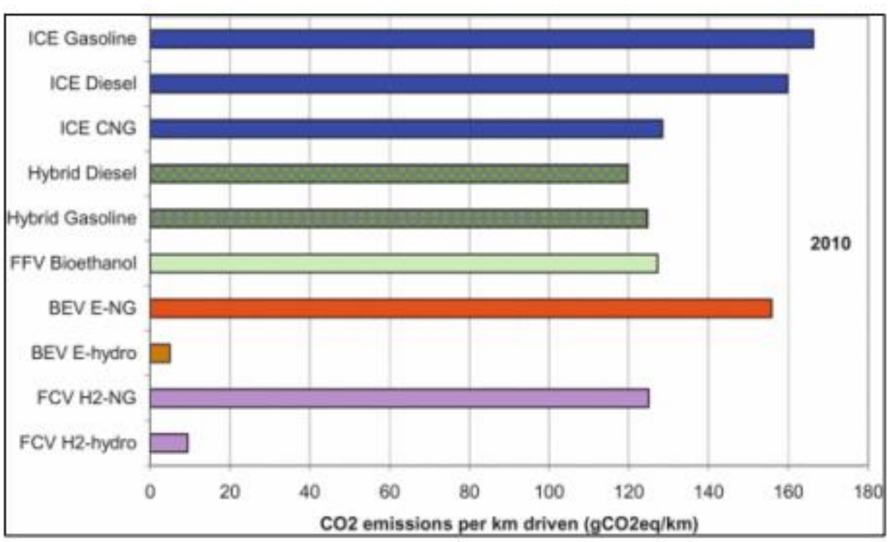


Figure 1: Comparison of vehicle powertrain and CO2 emissions [5].

Furthermore, renewables energies like wind and solar, like BEVs, have associated environmental impacts from operation such as cleaning, lubrication, and maintenance. Figure 1 above clearly demonstrates the potential for decreasing automobile environmental impacts when combining of BEVs and renewable energies. However, there will always be some environmental costs from manufacturing like any other products along with operation and disposal of plastics and rare minerals such as lithium, cobalt, and more [1-5].

Solar Electric Vehicles

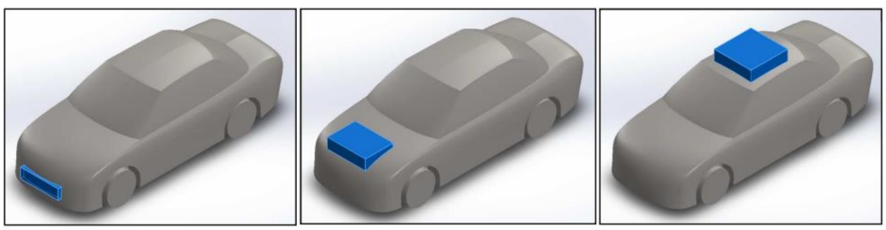
For transportation, another solution integrated solar photovoltaic (PV) panels into BEVs as an alternative to carbon, fossil fuel energy sources. The solar electric vehicle (SEV) utilized PV panels as bodywork to generate electricity for charging and driving the vehicle. The SEV in theory could operate independently from the electric grid and charge while parked or driving. If enough solar energy was present, the SEV could drive indefinitely in theory without having to stop. However, technology and economic limitations kept SEVs at a research and sports level for decades [9-14]. Once technology and economics became more favorable, automakers began introducing solar PV panels into vehicles. Toyota became one of the first auto manufacturers to release a Prius with a solar PV roof [10]. Adding the solar panel to the hybrid electric vehicle (HEV) improved fuel economy 10%. Other companies such as Fisker, Hyundai, and Volkswagen later to followed suit [9-11, 14]. Around the same time period, a company named Aptera Motors emerged with a pure SEV concept achieving speeds up to 110 mph and 1000 miles of driving range. The vehicle had PV body panels that could provide up to 45 miles of rechargeable range per day depending on sunlight and location. However, the company remains at a research level with few vehicles on the road [15].

Along with traditional PV solar panels, researchers continue investigating new chemistries and materials for improved performance and applications. Among the different chemistries discovered, transparent photovoltaics (TPVs) emerged as an option to replace windows on buildings. The TPVs chemistry provided light transmission and visibility between a building’s interior and exterior while converting some of the sunlight to electricity. The new TPV technology posed potential for application for any clear surfaces including screens and automotive windshields. Similar to PV body panels, TPVs could be integrated into vehicles as windshields to power appliances or recharge the battery. TPV vehicle integrations remain purely theoretical at the moment while questions regarding economics, energy generation, engineering, repairability, safety, and environmental impacts remain [16-19].

Wind Energy Automobile Research

Along with solar, wind energy has been considered for electric vehicle integration for similar reasons. Many examples have been presented showcasing the idea of recapturing the wind from driving to increase range. However, basic thermodynamics indicates that some ideas are unlikely to work. A vehicle's propulsion system (motor) is the main source for creating the wind experienced while moving. If resistance increases, more energy is required from the propulsion system to drive. Based on thermodynamic laws, much of the energy needed to overcome the resistance cannot be recovered. Therefore, if more drag is created from integrating a wind turbine device into a vehicle, the energy generated will not outperform the increase in load, making the system more inefficient.

Some ideas researchers have investigated include rooftop wind turbine vehicle integration [20-25]. However, the ideas are likely to increase drag and reduce overall performance compared to the traditional vehicle model due to turbine placement. Sofian et al. (2014) completed a study of a vehicle with different turbine location placements and the effects on overall drag shown in Figure 2. Figure 2 demonstrates the increase in drag from the basic vehicle model using the vehicle hood or roof as many researchers have investigated. Simple thermodynamics indicate that devices that increase drag will result in more inefficiencies. However, a turbine in line with the vehicle appears not to disrupt drag, showing theoretical potential.



Position	No wind turbine	Front	Hood	Roof
C_d	0.39	0.39	0.45	0.51

Figure 2: Three car models with different wind turbine positions and drag coefficients [26]

Front external wind energy devices have also been investigated and show potential for future BEV applications as shown in Figures 3 and 4 [26-28]. However, careful considerations must be made to not increase area and disrupt airflow, creating more drag as both Figures 3 and 4. By making designs internal, some of the concerns could be mitigated. Gupta & Kumar (2021) investigated the placement of a tube running through the vehicle to a wind turbine as shown in Figure 5. The investigations used computational fluid dynamics software and increased driving range by 22%. Having a tube through the vehicle reduces the difference between low and high pressure zones at the vehicles front and rear, reducing the drag with or without the turbines. Patents similar to Gupta & Kumar's idea exist and are shown below in figures 6 and 7. However, few investigations have occurred due to challenges regarding engineering, manufacturing, cost, aesthetics, and economics.

Figure 3: Vehicle front grill wind turbine integration [27]

(a) (b) (c)

Figure 4: Vehicle wind turbine integration with different turbine blade quantities [28]

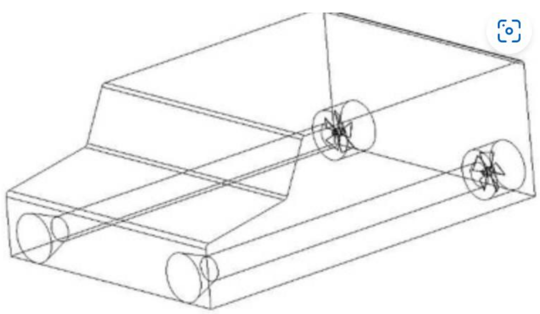


Figure 5: Vehicle with flow through wind turbine system [29]

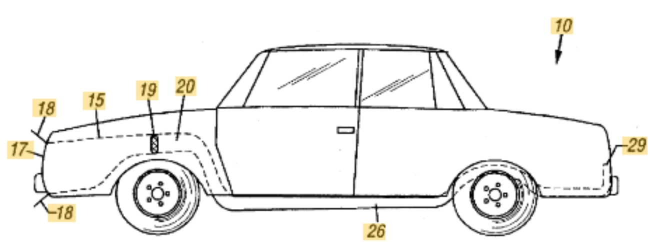


Figure 6: Patent US5680032A, wind power battery charging system [30]

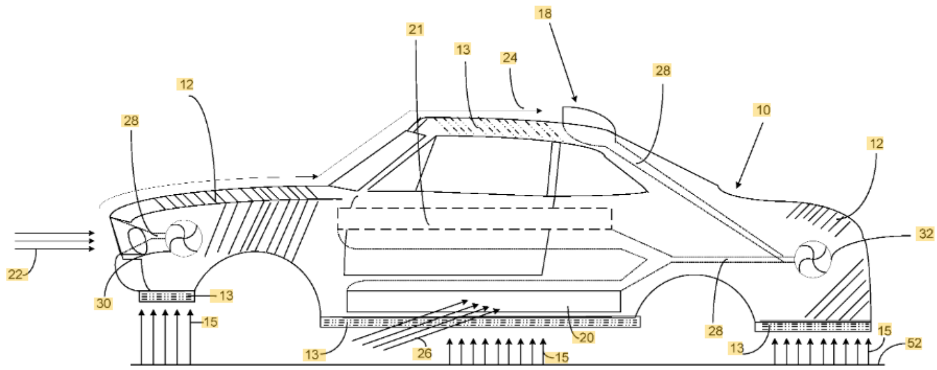


Figure 7: Patent US8220569B2, green electric vehicle utilizing multiple sources of energy [31]

Chellaswamy & Ramesh (2017) presented a wind turbine device integrated at the rear of a bus, shown in Figure 8. Removing the air duct and lowering the vehicle roofline would be more beneficial based on simple thermodynamics. However, a turbine placed at the rear of a vehicle could take advantage of aerodynamic vortices demonstrated by Figure 9. All vehicles experience rear low-pressure vortices from driving which companies continue trying to mitigate and smooth the air flow. Tractor trailer boat tails and skirts as well as sports car diffusers are just some examples of inventions to smooth airflow while maintaining the functionality of transporting people, goods, and services. However, issues such as cost, noise, vibrations, wind speed, safety, damage, visibility, repairability, esthetics and other factors will come into consideration for actual implementation of any wind energy vehicle integration.

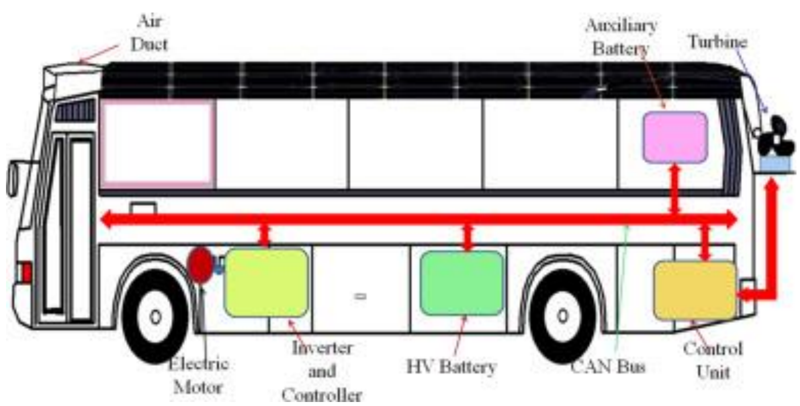


Figure 8: EV bus with renewable charging systems [32].

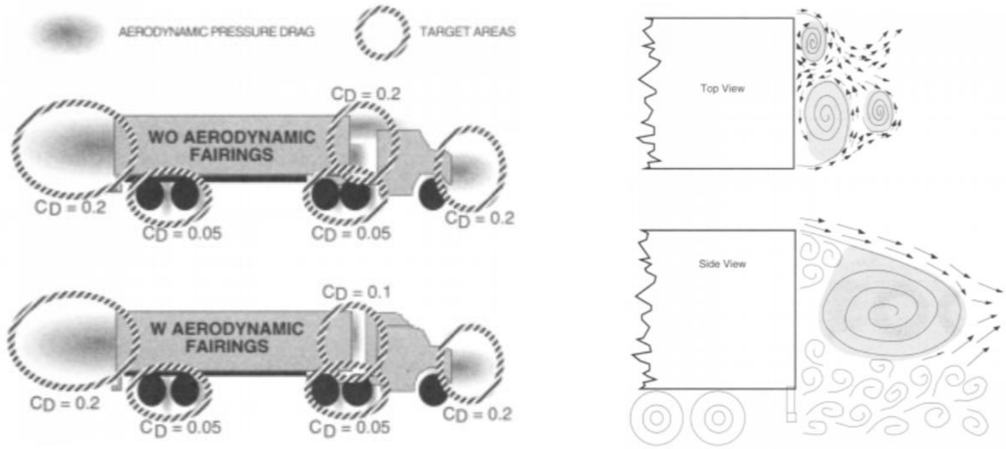


Figure 9: Graphics depicting aerodynamic drag and wake distribution for a tractor trailer [33].

While various innovative designs and patents have explored the integration of wind energy devices in vehicles, practical implementation remains challenging. The potential benefits, such as increased driving range and efficiency, must be weighed against engineering, manufacturing, economic, and policy constraints. Future research and development should focus on investigating and overcoming these hurdles to make wind energy integration a viable option for enhancing the efficiency and sustainability of electric vehicles.

Conclusion

Great technological achievements continue to be made over time, but achieving a sustainable energy future remains a challenge due to many factors. For transportation, vehicles are becoming more efficient and increasingly electrified, presenting opportunities for integration with renewable energy sources like solar and wind. While solar integration is relatively straightforward, wind energy integration is more complex. Literature suggests that vehicles' optimal points for wind energy integration are at the front and rear. However, further research is needed to explore the engineering and economic aspects of these solutions to achieve sustainable and self-sufficient transportation.

Additionally, the environmental impact of the lifecycle processes associated with these technologies must be considered. This includes extracting raw materials, manufacturing, transportation, usage, and end-of-life disposal or recycling. Each stage presents environmental challenges, such as energy consumption, greenhouse gas emissions, and waste generation. For instance, producing wind turbines can be resource-intensive and involve rare earth metals with significant environmental footprints. Therefore, a comprehensive lifecycle assessment is crucial to ensure that the overall environmental impact is minimized and that these technologies contribute positively to the sustainability goals of electric vehicles.

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