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Energy Resilience: Analyzing the Viability of Electric Vehicle Implementation

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Abstract: The US Army climate strategy is directing installations to be environmentally sustainable (Office of the Assistant Secretary of the Army for Installations, 2022). As a result, the resilience capstone team has focused on a range of topics concerning sustainability. For AY-22, Team Resilience has had a focus on the implementation of fully electric non-tactical fleets within Army Installations, Aspects of resilience, and lifecycle analysis.

Keywords: Resilience, Electric Vehicles, Charging Infrastructure, V2G

1. Introduction

The goal of Team Resilience is to identify opportunities and best practices to improve how the Army obtains, distributes, and maintains energy and water services at its installations. In 2021-2022, there has been a particular focus on the viability of fielding electric vehicles in response to recent Executive Orders 14008 and 14057, Army Directive 2020-03, and the US Army Climate Strategy. The solutions must cost-effectively address system weaknesses with the goal of increasing efficiency and resilience while also seeking to minimize the environmental footprint of Army installations.

2. Lifecycle Analysis

From the time a vehicle begins production until its first able to be driven, components must be manufactured to complete the construction of a vehicle. Raw materials are extracted from the ground during the manufacturing process which contribute to the release of pollutants. Steel, Iron, aluminum as well as glass, rubber and plastic contribute to the construction of a vehicle (Qiao, 2017). Additionally, emissions are released during the assembly process of a vehicle. Figure 1 below describes the components of each type of vehicle and compares the CO_2 emitted between EVs (Electric Vehicles) and ICEVs. (Internal Combustion Engine Vehicles) EV-NCM (Nickel Cobalt Manganese) and EV-LFP (Lithium Iron Phosphate) are popular types of Lithium batteries and thus, are used for this comparison (Qiao, 2017).

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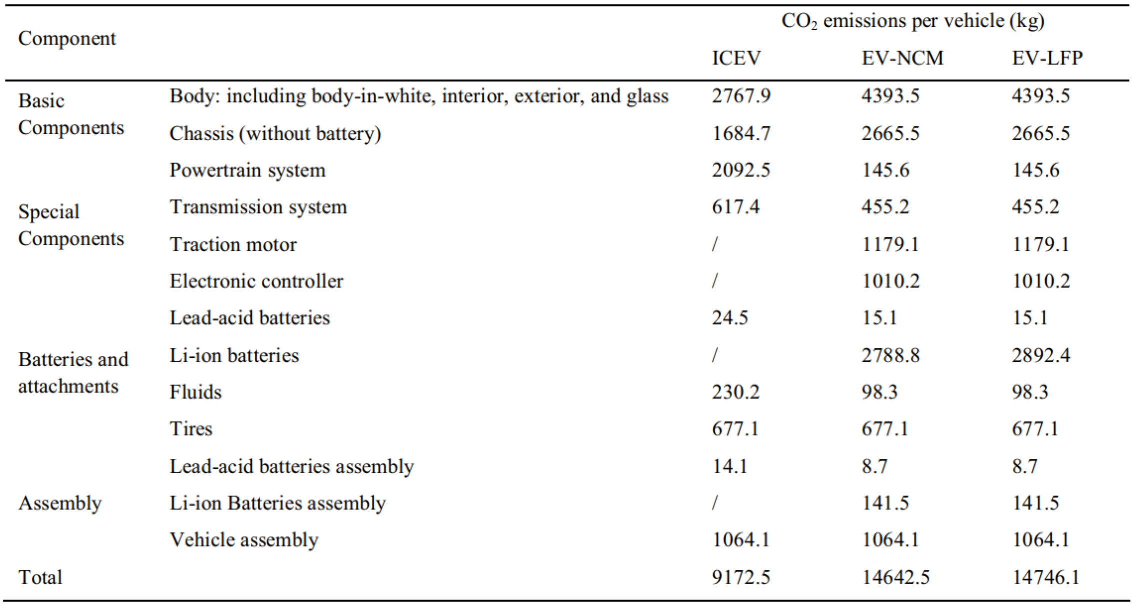


Component		CO$_2$ emissions per vehicle (kg)		
		ICEV	EV-NCM	EV-LFP
Basic Components	Body: including body-in-white, interior, exterior, and glass	2767.9	4393.5	4393.5
	Chassis (without battery)	1684.7	2665.5	2665.5
Special Components	Powertrain system	2092.5	145.6	145.6
	Transmission system	617.4	455.2	455.2
	Traction motor	/	1179.1	1179.1
	Electronic controller	/	1010.2	1010.2
Batteries and attachments	Lead-acid batteries	24.5	15.1	15.1
	Li-ion batteries	/	2788.8	2892.4
	Fluids	230.2	98.3	98.3
	Tires	677.1	677.1	677.1
Assembly	Lead-acid batteries assembly	14.1	8.7	8.7
	Li-ion Batteries assembly	/	141.5	141.5
	Vehicle assembly	1064.1	1064.1	1064.1
Total		9172.5	14642.5	14746.1

Figure 1. Comparison of vehicle components between EVs and ICEVs regarding CO$_2$ emissions [2].

As shown in Figure 1, manufacturing one ICEV emits roughly 9172 kg (10.1 tons) of CO2 while one EV emits roughly 14700 (16.2 tons) of CO$_2$.One EV produces about 60% more CO$_2$ than the ICEV. CO$_2$ emission rates in the production phase are higher in EVs because of parts such as the battery that are only specific to EVs. Lithium batteries produce high amounts of CO$_2$ due to the mining of raw materials from the Earth such as Lithium, Cobalt, Nickel, and Manganese (Melin, 2019). Once extracted from the Earth raw materials go through a harsh refining process contributing to harmful emissions (“Lithium Extraction,” n.d.). Therefore, it can be concluded that EVs produce higher amounts of CO$_2$ during the production phase when compared to ICEVs.

It is important to note that the amount of CO$_2$ emitted depends on the type of vehicle. Figure 1 shows an average emission rate for each type of vehicle, but the exact amount of CO$_2$ released depends on the car being manufactured.

2.1 Usage

In this phase, one of the main differences between emissions from EVs and ICEVs stems from their respective power source. EVs rely completely on electricity, while ICEVs utilize gasoline. Since ICEVs run on gasoline, fuel is burned inside the engine which releases CO$_2$ into the atmosphere via the tailpipe. Argonne GREET Software estimates that roughly 2.1 kg of CO$_2$ is released for every gallon of gasoline produced (“Argonne GREET Model,” n.d.). The EPA estimates that about 8.9 kg of CO$_2$ is released for every gallon an ICEV uses (“Greenhouse Gas Emissions from a Typical Passenger Vehicle,” n.d.). For example, 25 MPG ICEV that travels 150,000 miles will release 12,600 kg (13.9 tons) of CO$_2$ due to producing gasoline and 53,400 kg (58.9 tons) of CO$_2$ due to tailpipe emissions. Conversely, EVs produce zero tailpipe emissions due them using batteries rather than burning gasoline (“Lithium Extraction,” n.d.).

However, EVs still produce CO$_2$ because the electricity that is used to charge the vehicle comes from energy sources such as but are not limited to coal, natural gas, and nuclear. Areas around the country use different combinations of these fuel sources to produce electricity depending on the resources available to them. The region in which an EV is charged has the largest impact on the amount of CO$_2$ released.

2.2 Regional Differences in Electricity Sources

Although EVs have zero tailpipe emissions, emissions may still be produced depending on the source of the electrical power. In geographic regions that use relatively low-polluting energy sources like wind, solar, or natural gas for electricity generation, EVs and PHEVs typically have lower well-to-wheel emissions than similar conventional vehicles running on gasoline or diesel. However, in regions that depend heavily on high-polluting energy sources like coal or oil, EVs and PHEVs might not outperform vehicles running on gasoline or diesel in terms of well-to-wheel emissions benefit.

The Union of Concerned Scientists (UCSUSA) developed a map of the US that delineates these different regions based on how well EVs perform there in terms of CO_2 emissions ("New Data Show Electric Vehicles Continue to Get Cleaner," n.d.). This map is shown below in Figure 2. These regional differences are due to a variety of factors to include geographical proximity to hydroelectric or coal plants, amount of solar PV systems installed, natural gas pipeline constraints, differences in prices due to emissions trading, or geographical isolation for states in non-continental US.

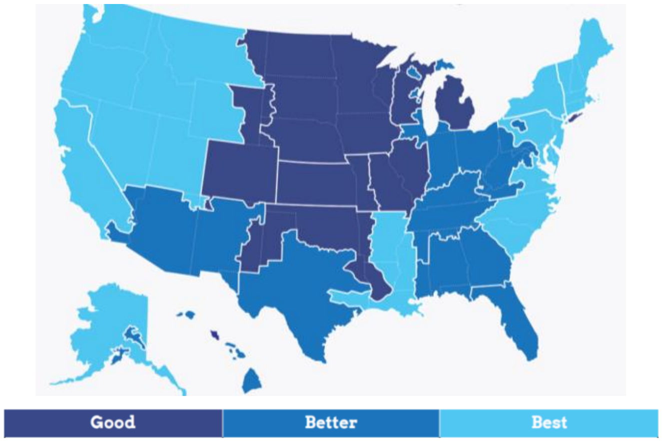


Figure 2. Map of the US in Terms of Electric Vehicle Emissions Benefits. Source: (Hill, 2013)

The Department of Energy Efficiency and Renewable Energy (EERE) made a tool that enables the user to pick a state and analyze emissions benefits of different types of vehicles based on the state's main sources of electricity ("Alternative Fuel Data Center," n.d.). Figure 3 below demonstrates that in Georgia, where the dominant electricity sources are natural gas and nuclear energy, electric vehicles produce significantly less CO_2 than gasoline vehicles and hybrids (Hill, 2013).

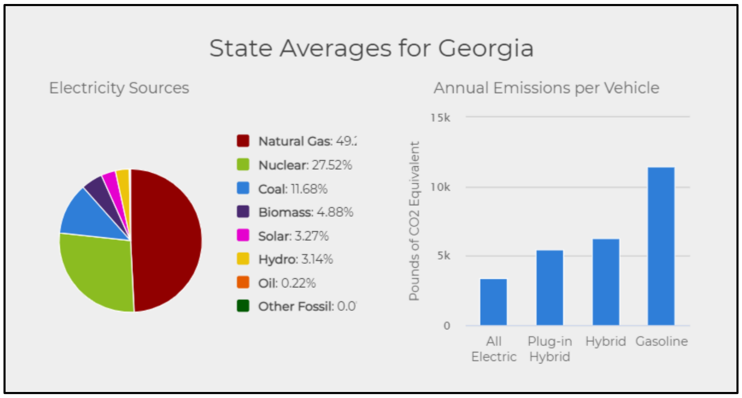


Figure 3. Electricity Sources and Corresponding Emissions Benefits for Georgia. Source: ("Lithium Extraction,", n.d.)

In contrast, Figure 4 shows that in a state like Wyoming where the main electricity source is coal, electric vehicles do not perform as well as hybrids in terms of CO_2 emissions ("Lithium Extraction," n.d.).

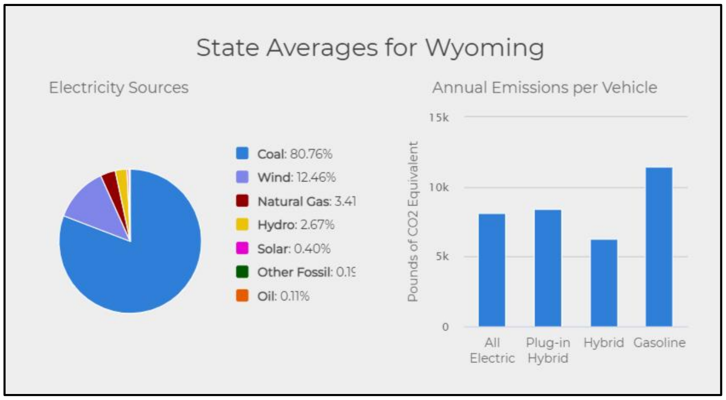


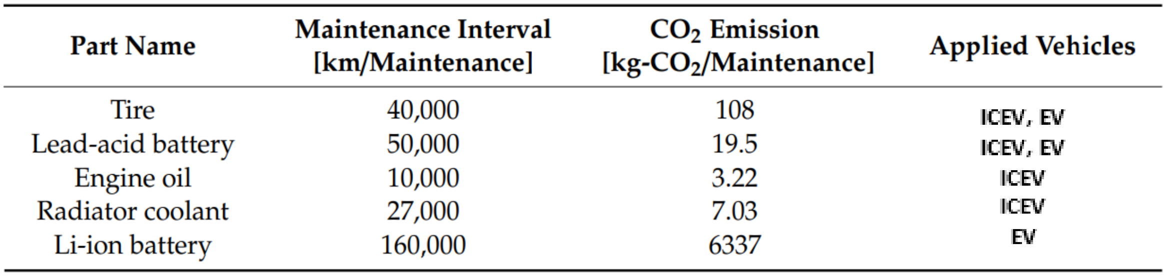
Figure 4. Electricity Sources and Corresponding Emissions Benefits for Wyoming. Source: ("Lithium Extraction," n.d.).

This tool relies on a multitude of data sources and assumptions to calculate the emissions, fuel use, and electricity sources for conventional and electric-drive vehicles. The annual vehicle emissions were calculated using both mpg values from the 2016 Fuel Economy Guide published by the US Department of Energy and the US Environmental Protection Agency and the weighted average from the 2016 model year vehicle sales in 2015 from the Alternative Fuels Data Center ("Greenhouse Gas Emissions," n.d.) ("Explaining Electric," n.d.). Though the annual vehicle emissions values are based upon 2016's values, due to the nature of these values, they are unlikely to change drastically over the course of a few years.

The data used to show electricity sources, however, comes from the U.S. Energy Information Administration's Open Data API for Electricity Net Generation ("U.S. Energy," n.d.). This data is updated annually based on data from the previous year, which is critical for the tool to stay up to date as more regions begin to decarbonize.

2.3 Maintenance

Maintenance is a factor that relates to the usage phase of a vehicle's life. EVs and ICEVs vary slightly in the type of maintenance they receive, however, both vehicles periodically need upkeeping. Figure 5 shows type of maintenance related to EVs and ICEVs. Additionally, it shows the interval at which the maintenance is required and how much CO_2 is emitted for each part (Kawamoto, 2019).



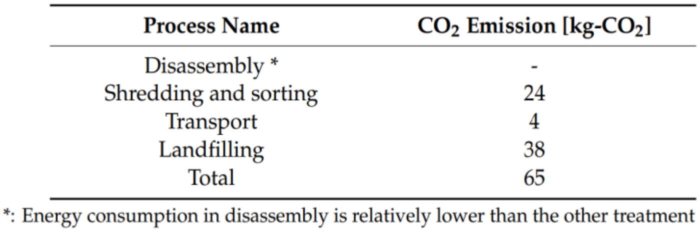
Part Name	Maintenance Interval [km/Maintenance]	CO_2 Emission [kg-CO_2/Maintenance]	Applied Vehicles
Tire	40,000	108	ICEV, EV
Lead-acid battery	50,000	19.5	ICEV, EV
Engine oil	10,000	3.22	ICEV
Radiator coolant	27,000	7.03	ICEV
Li-ion battery	160,000	6337	EV

Figure 5. Maintenance for EVs and ICEVs and their related CO_2 emissions (Kawamoto, 2019).

The CO_2 released in the usage phase of a vehicle's life relies on a multitude of factors. The source of electricity, how much a vehicle is driven, and how often maintenance is done on a vehicle all contribute to CO_2 emissions.

2.4 Disposal

At the end of a vehicle's life, parts can either be recycled or disposed. EVs and ICEVs have similar component that can be disposed. Figure 6 shows the components that are similar enough that can both be disposed for EVs and ICEVs (Kawamoto, 2019).



Process Name	CO_2 Emission [kg-CO_2]
Disassembly *	-
Shredding and sorting	24
Transport	4
Landfilling	38
Total	65

*: Energy consumption in disassembly is relatively lower than the other treatment

Figure 6. CO_2 emission rates related to disposal of EVs and ICEVs (Kawamoto, 2019).

Once an EV reaches the end of its life, most parts of the battery can be recycled. The two common methods to recycling a battery in an EV are hydrometallurgical and pyrometallurgical. Metals such as Nickel, Cobalt, Lithium, Manganese, and Aluminum can all be extracted from the battery and be reused again.

2.5 Real World Values

In 2020, a research team at the Environment Campus Birkenfeld in Trier wanted real-world measurements and data to compare the climate-related effects of EVs and ICEs (“Lifecycle assessment,” n.d.). By dismantling a VW Caddy with a 1.6-L petrol engine and rebuilding it with an electric drive, their research leads the way in terms of simulating real-world conditions (“Alternative Fuels Data Center,” n.d.).

In ‘Sensitivity Analysis in the Lifecycle Assessment of Electric vs Combustion Engine Cars under Real-World Conditions’, this team published “break-even mileages” that represent the number of miles an EV would have to travel to prove more climate-friendly than an ICEV [10]. For an EV with a small battery, defined as 25.9 kWh, charging with an electricity mix that roughly corresponds to the current European average, it is considered “cleaner” than its ICEV counterpart after approximately 31,000 miles, depending on whether one assumes second-life use or not (“Alternative Fuels Data Center,” n.d.). An EV with a battery twice as large (51.8 kWh), produced using a dirty electricity mix, does not reach break-even until around 190,000 miles (“Alternative Fuels Data Center,” n.d.).

As demonstrated by these values, the range of break-even mileages is significant and dependent on several variables. Some EVs reach the point of break-even quickly, while for others, the mileage is so high that few vehicles will achieve it. Factors such as where the battery is being produced, the source of the electricity, whether there is second-life use or not, etc., all play a large role in determining these break-even mileages. Since not all EVs are the same, it is necessary to conduct a case study to provide applicable and accurate results.

Future work is currently focused on presenting a case study on the Fort Benning fleet composition, modeling different inverters’ effect on resiliency, modeling the Time vs Power Output, and presenting the impact of charging profile on cost and resiliency. Expanding on the work we have completed thus far, our goal moving forward is to include an in-depth analysis of the Ford Lightning and other EVs for non-tactical fleet use. Furthermore, we would like to further refine and improve the list of methodologies for optimizing charging locations in order to present a “Best Practices” deliverable.

3. Conclusion

In conclusion, in order to properly implement Electric vehicles into government, non-tactical fleets across Army installations, there are many different factors to consider during a vehicle’s life cycle. More specifically, the factors of usage, regional electricity usage, maintenance, and disposal are all integral for Army Installations to consider.

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