Well to Wheel Comparison Study between the Electric Vehicle (Tesla Model S 100D) and Internal Combustion Engine Vehicle (Hyundai Sonata 2.4 L)

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Abstract

Transportation is leading energy usage and the primary cause of environmental pollution of carbon dioxide (CO2) or Greenhouse Gas (GHG) emission. The use of Electric vehicles (EV) will reduce the GHG emission that contributes to ozone depletion. In general, EV is considered environmentally friendly with no emissions at all. However, EV still contribute the GHG emission during battery charging and the electric vehicle manufacturing process. A 'Well to wheel analysis' is performed to determine the upstream pollution for both EV and Internal Combustion Engine Vehicle (ICEV) to acquire the total GHG produced by both types of vehicles. The analysis is done for Tesla Model S 100D (EV) with 2.4 L Hyundai Sonata (ICEV), which covers the emission emitted from both vehicles in one year with an annual driving range of 21000 km. The analysis can show the total emission produced by EV so that more awareness is created among the public about upstream pollution.

Keywords: electric vehicle, greenhouse gas, well-to-wheel analysis

1.0 Introduction

Transportation is leading energy usage and the primary cause of environmental pollution of carbon dioxide (CO2) or Greenhouse Gas (GHG) emission. According to Husain (2010), if 10 % of automobiles are replaced with electric vehicles (EV), the air pollutant would be cut by 1,000,000 tons per year and 60,000,000 tons of GHG would be eliminated. The usage of EV will reduce the significant source of smog formation that contributes to ozone depletion and reduce GHG emissions.

EV had been introduced earlier in the 19th century. However, the invention of the starter motor, mass production of the internal combustion engine vehicle (ICEV), cheap oil price and inconvenience of charging battery leads to the EV downfall. Yet, current environmental problems mainly due to fossil fuels cause favourable alternative renewable energy such as EV (Gross, 2020). EV usage can provide zero-emission, which can gain back the world attention (Matulka, 2014).

An EV is a vehicle that does not require an internal combustion engine (ICE) in its driving mechanism instead equipped with batteries and an electric motor. The electric motor is powered by a battery or fuel cell. EV is an energyefficient vehicle that converts about 59 % to 62 % of the electrical energy supplied to the wheels. Conventional gasoline vehicles convert about 17 % to 21 % of the energy stored in fossil fuel to power the wheels (Septon, 2017).

Generally, an EV considers environmentally friendly with no emissions at all. According to the European Environment Agency (2018), EV has less noise and air pollution than the ICEV and it has little effect on the environment directly. However, Mi et al. (2011) stated that even though EV is a zero-emission vehicle if tracing backwards from the battery usage to the manufacturing industry, it will be found that EV still contributes to GHG emission. This is called upstream pollution.

The upstream pollution from EV can consist of electric power generation and consumption, vehicle manufacturing, and EV battery production processes. The upstream pollution from electric power generation, mainly from coal electrical power plants, contributes indirectly to EV usage. The upstream pollution from electric power generation can be reduced using more environmentally friendly electrical power plants such as nuclear, hydro, solar, and wind. Meanwhile, ICEV usage contributes to fuel combustion, vehicle manufacturing, and fossil fuel refining/production processes.

The 'Well to wheel analysis' is performed to determine the upstream pollution for both EV and ICEV to acquire the total GHG produced by both types of vehicles. The analysis includes the amount of CO^2 emitted from the fuel source's production and the manufacturing process until fuel consumption in the car. From the study, the total emission produced by EV can be identified and reduced so that less upstream emission is produced.

2.0 Literature Review

According to Husain (2010) EV is a vehicle that does not require an internal combustion engine (ICE) in its driving mechanism instead equipped with batteries and an electric motor. As shown in Figures 1 and 2, EV consists of several components such as an electric motor, power sources such as a battery or fuel cell, controller system, and transmission working together to smooth operation. The electric motor is the driving mechanism in an electric car powered by a rechargeable battery pack or fuel cell. The electric motor provides instant torque, creating strong and smooth acceleration. EV has an electric motor that can generate very smooth torque with silent operation and a very high efficiency of 90% compared to ICE. The EV typically use 10 to 23 kW·h/100 km for moving the vehicle. About 20 % of power consumption is due to inefficiencies in charging the batteries and reliance on the controller system's efficiency.

The controller system is essential in charging and discharging the rechargeable battery and regulating motor speed or torque. The chemical reaction inside the battery pack provides electricity for the electric motor, which drives the vehicle. The EV batteries are charged externally by electricity supply through its onboard charging port. Charging stations available in public areas and houses are used to charge the vehicle. The drive controller controls the movement of the electric motor by regulating the speed and torque. The transmission is used to reduce the gear ratio so that the electric motor can achieve optimum strength with less effort. The drive train can be more straightforward by using fixed-ratio gearboxes in which a clutch is not needed. EV does not idle compared to ICEV. Another feature of EV is its regenerative braking system that can recover the energy frequently lost during braking.

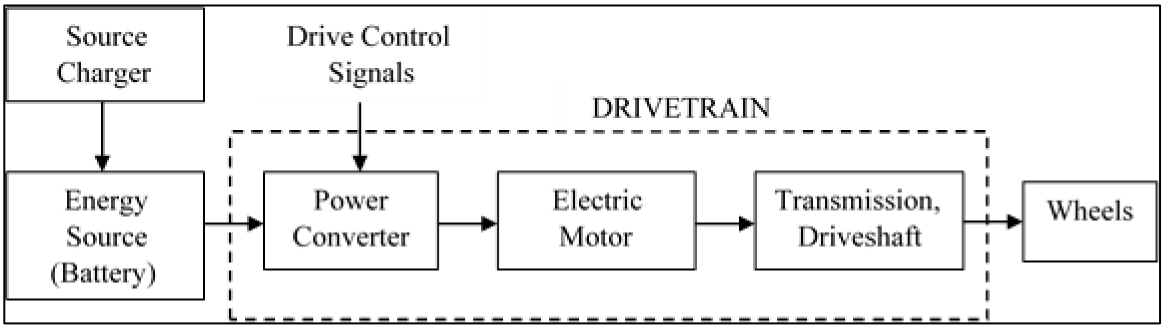

Figure 1: EV System
Source: Husain, 2010

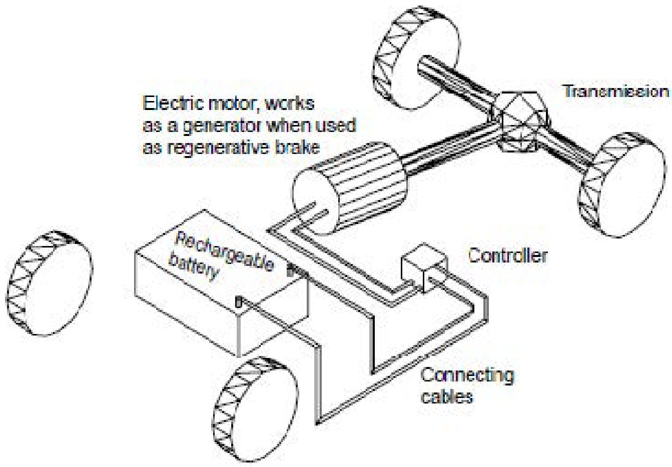

Figure 2: Battery Electric Vehicle (BEV) system layout
Source: Husain, 2010

The Tesla Model S is a full-sized / mid-size luxury all-electric five-door liftback car, produced by Tesla Inc and introduced on June 22, 2012 (Tesla, 2021). The United States Environmental Protection Agency (EPA) official range for the 2017 Model S 100D, equipped with a 100 kWh battery pack, is 539 km, higher than any other electric car. The EPA rated the 2017 100D Model S's energy consumption at 200.9 watt-hours per kilometre or 20.09 kWh/100 km for a combined fuel economy of 2.26 L/100 km gasoline-equivalent. The Tesla Model S was the top-selling plug-in electric car worldwide in 2015 and 2016 and, by the end of 2017, continued to rank as the second most-sold electric car in history after the Nissan Leaf. Tesla Motors indicates that the lithium-ion battery-powered vehicle's vehicle efficiency (including charging inefficiencies) is 20.09 kWh/100 km and the well-to-wheels efficiency (if the electricity is generated from natural gas) is 24.4 kW·h/100 km (Tesla Motors (2009)).

For EV, the source of the electrical energy is originated from the electrical power plant. The GHG emission is varied and depends on the type of power plant used to generate electrical energy. Liasi (2017) stated that electric vehicles require grid consideration since much electrical energy is needed to charge the vehicle batteries. Electrical demand should be considered in the distribution network. Shafiee et al., (2013) also support that EV requires a large amount of electrical energy for charging the batteries.

The demand for electrical power would likely have negative impacts on the distribution grid specifications. The electrical power plant will emit more emissions to generate electrical power to be used in EV. The emission produced from the electricity generation is varied according to the region, the availability of renewable sources, and the efficiency of fossil fuel-based generation. Mainly electric power generated from coal electrical power plants contributes to the highest emission of GHG. Other types of power generation such as solar, wind, nuclear or hydropower produce significantly lower emissions than the coal type electrical plant. Electrical power generated from coal has high GHG from mining, refining, transportation, and efficiency from fossil fuels.

3.0 Methodology

The analysis from the well to analysis as shown in Figure 3, includes the fuel source production and the manufacturing process until the fuel consumption in the vehicle. A certain amount of CO2 will be produced in each of these processes. The fuel consumption or energy can be calculated from fuel consumption (litres) per 100 km. This is also known as Tank-to-wheel efficiency.

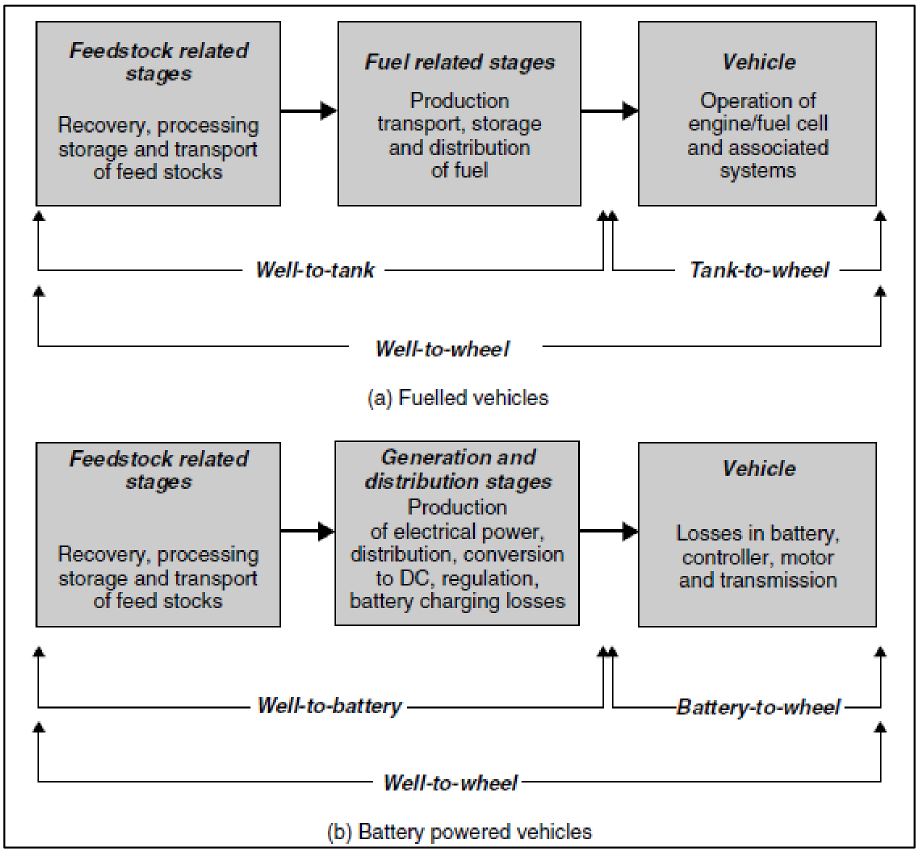

Figure 3: Scope of a well to wheels analysis
Source: Larminie & Lowry, 2012

In this research, well to wheel analysis is done to determine the upstream pollution for both EV and ICEV. The analysis includes the total GHG produced by both types of vehicles. The Tesla Model S 100D is selected to represent the electric vehicle for the analysis. The power generated by Tesla Model S 100D is equivalent to a 2.26 L ICE. For comparison, the 2.4 L Hyundai Sonata ICEV is selected for the analysis. The general specifications for both vehicles are shown in Table 1.

Table 1: Specification for Tesla Model S 100D and Hyundai Sonata 2.4 L ICEV

Specification	TESLA MODEL S100D	HYUNDAI SONATA 2.4 L
Power Train	AWD (100D) Electric Motor with Lithium-ion 100 kWh battery	16-valve DOHC, naturally aspirated with variable intake valve timing
Range	EPA rated:539 km	875 km
Capacity	100 kWh battery storage	70-litre fuel tank capacity
Max. power, motor / engine	n/a	176 hp at 6,000 rpm
Max. power, battery	417 hp / 311 kW	n/a
Max. torque	660 N·m	228 Nm at 4,000 rpm
Energy Consumption	20.09 kWh/100 km	12.5 km/l 8 l/100 km
Powertrain to Wheel Efficiency	70 % (Mi et al., 2011)	5-10 % (Mi et al., 2011)
Well to Wheel Efficiency	14% (Husain, 2010)	15 % (Husain, 2010)

The efficiencies of both vehicles can be evaluated from the well-to-wheel analysis to determine the amount of carbon print emitted. The analysis will consider the amount of GHG produced from electric power consumption, vehicle manufacturing, and EV battery production. While for ICEV, the analysis of GHG gases are consists of fuel consumption, the vehicle manufacturing process and fossil fuel refining/production process. The analysis is assumed to be intended for one year and the annual driving range of 21000 km is selected based on the research conducted by Wong et al. (2010).

4.0 Result and Discussion

The well to wheel analysis done for the Tesla Model S100D and Hyundai Sonata 2.4 L includes the amount of carbon dioxide (CO2) emitted from the fuel source production, the manufacturing process until the fuel consumption in the vehicle. From the analysis done, the total emission produced can be compared side by side for further evaluation.

The manufacturing process of both EV and ICE emits GHG due to the complex manufacturing process consisting of raw material extraction, transporting, and assembly. The manufacturing of EV produces more GHG than ICE due to its more extended design, the material used and manufacturing process. This leads to the manufacturing plant for an EV producing about 8.8 tonnes of CO2, of which 43 % GHG come from EV battery manufacturing (Zemo Partnership News, 2011). Meanwhile, ICEV only produces 6 tonnes of CO2 to the atmosphere for manufacturing a sedan passenger car (Berners-Lee & Clark, 2010).

Watts (2017) stated that significant CO2 emission was emitted during EV battery production. The production of Lithium-ion batteries that are used in EV causes high emissions. For battery production analysis, the Tesla Model S100D battery capacity is about 100kWhr and produce roughly 3784 kg of CO2 emissions before leaving the factory. While for ICEV, the fuel used in combustion is derived from the petrol refining process involving the drilling and refining process. By referring Serpa (2008), 1 litre of fuel produces about 0.4535 kg CO2. For Hyundai Sonata tank capacity of 70 litres, the GHG emitted is about 31.745 kg of CO2 per full tank. The fuel refining process needed to supply fuel for the ICEV operation for one year up to 21000 km is about 24 cycles. This means the total GHG from the fuel refining process for the ICEV will produce about 761.88 kg of CO2.

The emission factors acquired from Malaysian Green Technology Corporation (MGTC 2017) is about 0.585 kg CO2-e /kWh. This means for Tesla Model S100D that consumes 20.09 kW·h/100 km, the total CO2 equivalent is approximately 11.75 kg CO2-e / 100km. For ICE engines, petrol is burned according to the vehicle consumption by how many litres of fuel is burned for 100 km. According to EPA (2018), 1 litre of petrol emits about 2.3 kg of CO2 to the atmosphere. The Hyundai Sonata uses approximately 8 litres of petrol per 100 km, producing 18.4 kilograms of CO2/ 100km emitted to the atmosphere. The total GHG emitted during the full charge of the Tesla Model S100D for a distance of 539 km is about 63.35 kg CO2 on a single full charge. At the same time, the ICEV emits five times more GHG for its travel distance of 875 km, where about 161 kg CO2/full charge is released for its vehicle operation.

The vehicle operation for one year for 21000 km will produce 2407 kg CO2 for the Tesla operation of 38 cycles. Meanwhile for the ICEV selected will produce 3864 kg CO2 during the same period. The calculation of greenhouse gas (GHG) for Tesla Model S100D and Hyundai Sonata 2.4 L is summarized in Table 2. The overall total of CO2 for Tesla Model S100D is higher than Hyundai Sonata 2.4 L ICEV.

Table 2: Summary of GHG per year vehicle travel 21000 km for Tesla Model S 100D and Hyundai Sonata 2.4 L ICEV

Well-wheel process	TESLA MODEL S100D	HYUNDAI SONATA 2.4 L
Vehicle Operation CO_2 emission / total capacity in 1 year (Assuming travel distance 21 000 km)	Frequency Of Electric Charge 21000 km / 539 km per full charge = 38 times CO_2 emission per year: = 63.35 kg CO_2 x 38 = 2407 kg CO_2	Frequency Of Fuel Top-up 21000 km / 875 km per tank = 24 times CO_2 emission per year: = 161 kg CO_2x 24 = 3864 kg CO_2
Vehicle Manufacturing Process CO_2 emission (excluding battery production)	5016 kg CO_2	5600 kg CO_2
Battery/ Fuel Production CO_2 emission (1 year)	Battery Production (Lithium-ion) 3784 kg CO_2	(Petrol refining process for 24 cycles) 761.88 kg CO_2
OVERALL TOTAL CO_2 (per year)	11207 kg CO_2	10225.8 kg CO_2

Referring to Figure 4, for EV the highest GHG emission is originated from the emission from the production plant, which about 45 % of GHG emission. In contrast, the production of a Lithium-ion battery produces about 34 % of total GHG emissions. The electricity generation needed for the EV to travel in 1 year in Malaysia emits 21 % kg CO2. Although Tesla Model S produces no GHG emission, the upstream GHG emission reduces the benefit of using EV for the time being.

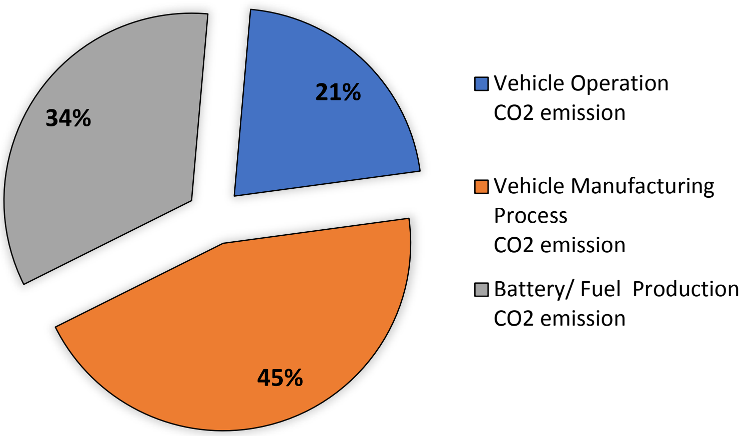

Figure 4: Total % kg CO_2 in upstream emission for Tesla Model S 100D

Figure 5 shows for ICEV that the highest GHG emission originated from the vehicle manufacturing process that produces about 55 % of total GHG emission. In comparison, emission from the vehicle is given about 38 % of GHG emission. The fuel used to travel in 1 year needs to emit about 7 % kg CO2 during the fuel refining process. The ICEV total operation emission depends on the efficiency of the vehicle.

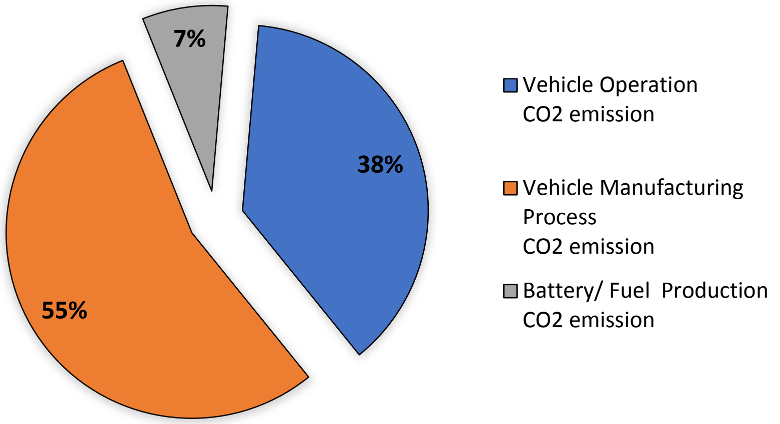

Figure 5: Total % kg CO_2 in upstream emission for Hyundai Sonata 2.4 L

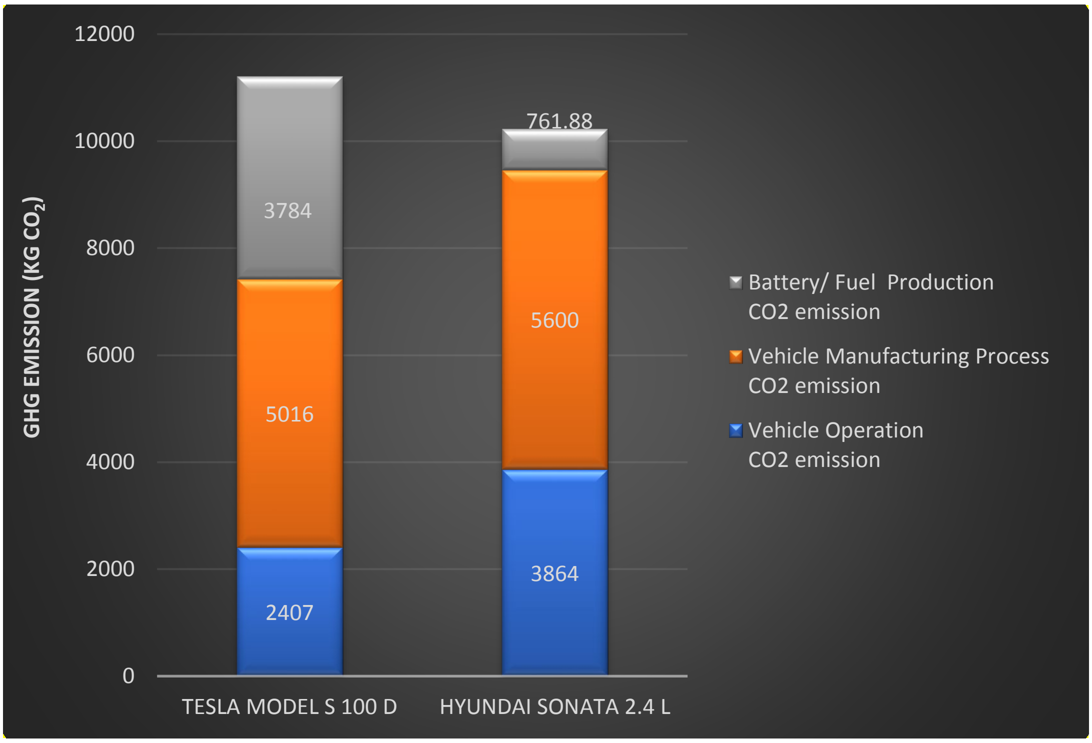

Figure 6: Well to wheel analysis for Tesla Model S100 D & Hyundai Sonata 2.4 L (1 year)

From Figure 6, it seems EV, mainly Tesla Model S, emits upstream GHG emission more than the Hyundai Sonata 2.4 L. EV is known to produce zero-emission; however, the carbon print from the EV battery production still contributes up to 3784 kg of GHG emissions. The ICEV fuel refining process only produces about 761.88 kg CO_2. The manufacturing process of the EV emits 5016 kg GHG without adding the EV battery production. This is relatively high because EV is not produced in huge-scale mass production such as ICEV.

However, considering the vehicle operation factor, the Tesla S model only produces about 60 % less emission than Hyundai Sonata 2.4 L during the 1-time charge of electricity to drive up to 539 km. This resulted in the EV creating about 2407 kg GHG for a travel distance of 21000 km during one year. This is about 37% less than the Hyundai Sonata 2.4 L GHG production for the same duration.

The data from the analysis also shows that if considering only the GHG emitted for the vehicle operation, it is about 2407 kg of CO2 during one year of operation with 21000 km travel distance. This is approximately 114 g CO_2 / km produced by the Tesla Model S 100D. The value is supported by the research done by Pistoia (2010), which found the vehicle operation creating 50-80 g CO_2 / km using electricity generated in Japan, the United States and Europe.

5.0 Conclusion

From the well to wheel analysis, even though EV, especially Tesla Model S emission, produces zero GHG, the upstream pollution from the electric power generation in Malaysia, primarily from coal electrical power plant, indirectly contributes 2407 kg to the total GHG. The total GHG from EV is worsening with the EV manufacturing process, especially in EV battery production emitting up to 8.8 tonne CO_2. The GHG emission of the Tesla Model S can be reduced if Tesla and other EV manufacturers find a healthier and cleaner way to produce the vehicle and acquire a breakthrough in battery technologies. Furthermore, increasing the EV driving range could reduce the GHG emission derived from electric generation. Further research can be conducted focusing on the vehicle GHG emission from the factory up to the vehicle life cycle.

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