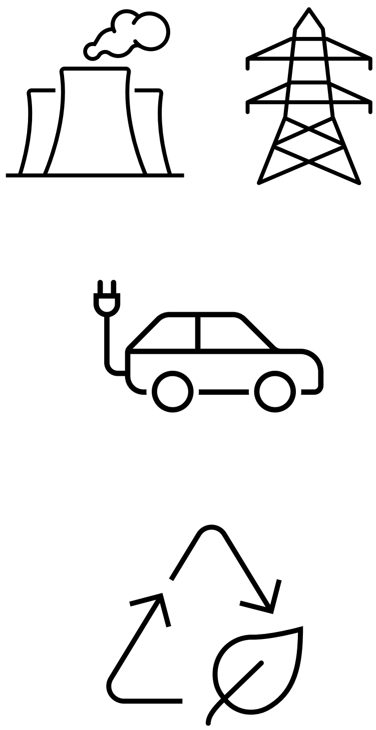

# ARE ELECRIC CARS BETTER FOR THE ENVIRONMENT

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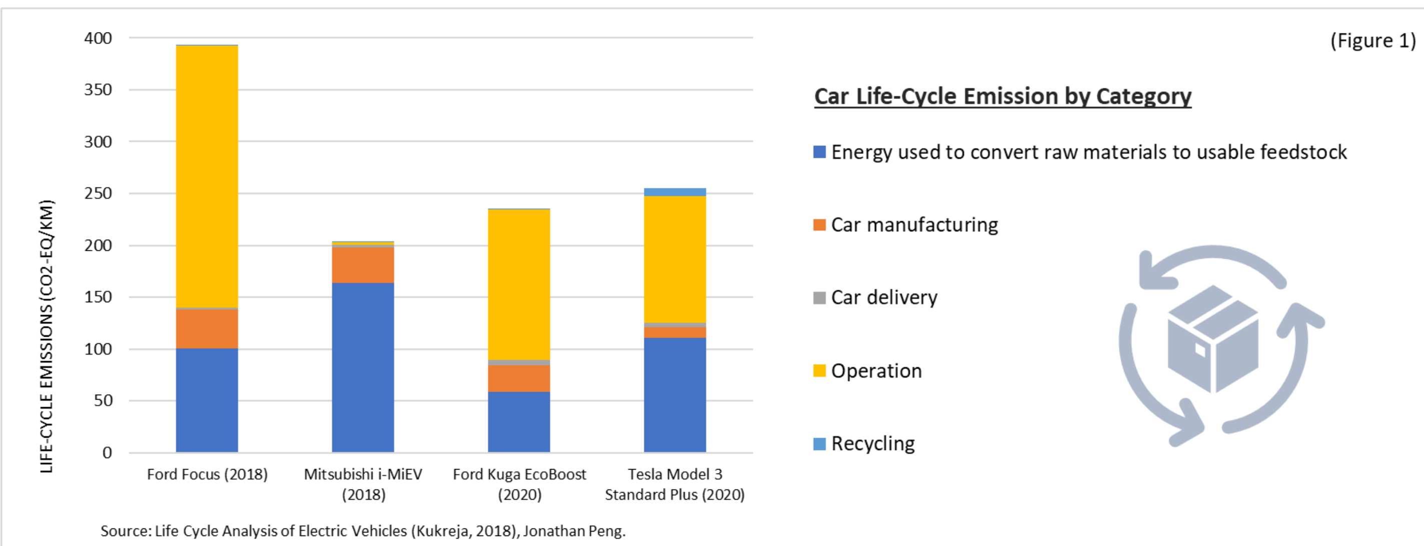
## EXECUTIVE SUMMARY

Is driving an electric vehicle always better for the environment than driving a traditional car? In Life Cycle Analysis of Electric Vehicles (Kukreja, 2018) prepared for the city of Vancouver, Kukreja found that driving a hybrid vehicle in Vancouver decreases the carbon emission by almost 50% over the life of the car, when an average lifespan of 150,000 km is assumed. Would driving an electric or hybrid car achieve similar environmental benefits in a different location like Taiwan?

This study explores the environmental impacts of Internal Combustion Engine Vehicles (ICEVs) and Electric Vehicles (EVs) in Taiwan. Similar to the Vancouver report, two Light Duty Vehicles (LDVs) of similar sizes were selected for the performance of a Life Cycle Analysis (LCA), which estimates the greenhouse gas (GHG) emissions for the entire life of a car. Thus, not only when the car is in operation, but also during its raw material production, manufacturing, delivery from factory to dealer, and its ultimate disposal.

The Vancouver LCA compared the Ford Focus, an ICEV, and the Mitsubishi i-MiEV, a hybrid. For the Taiwan study, the Ford Kuga EcoBoost 180 (ICEV), a car manufactured in Michigan like the Focus, is compared to the Tesla Model 3 Standard Plus Model (EV), which of all the Tesla models, is closest to the Kuga in size. Furthermore, both vehicles are assumed to have an operating lifespan of 150,000 km, like the two cars in the Vancouver LCA.

Surprisingly, the results of the analysis show that EVs in Taiwan are not necessarily the cleaner option relative to ICEVs (Figure 1). In fact, the Tesla Model 3 generates almost 5% more GHGs than the Ford Kuga throughout its entire life (**254.8gCO2-eq/km** versus **235.7gCO2-eq/km**), rejecting the belief that EV adoption can alleviate climate change.




It is well-known that due to the amount of rare earth metals required to construct lithium-ion batteries, EVs (and hybrid vehicles) produce significantly higher levels of GHGs than ICEVs in the initial raw material production stage; however, that high level is usually offset later by the very low level of emission during the operation phase, as is the case for the Mitsubishi hybrid in Vancouver. But when applying the LCA to EVs in Taiwan, this "clean" operational advantage no longer holds. This is a result of Taiwan's high grid emissions factor of 509 gCO2-eq/kWh, a measure which defines the amount of carbon emissions from electricity generation in a certain area. Taiwan's "dirty" grid emissions factor, which is almost 50 times higher than Vancouver's, is the direct result of its power plants using mostly fossil fuels (coal and natural gas) to generate electricity. In order for EVs operating in Taiwan to achieve a low carbon footprint, it is essential that Taiwan strives to generate more of its electricity from cleaner resources.

## LIFE CYCLE ANALYSIS

The following sections detail the methodology for calculating the CO2-equivalent emission for each of the five stages of a car's life cycle.

*Raw Material Production*

This study assumes that the raw material inputs for both the Ford Kuga and Tesla Model 3 are produced in the United States and with the same energy intensity as the two cars in the Vancouver LCA. After adjusting for the heavier weight of the two cars in the Taiwan LCA, and assuming that the heavier the car the more raw materials it uses, the energy used for raw material production is 82.4 GJ for the Kuga and 156 GJ for the Tesla.

Based on the US grid emissions factor (2019) of 383 gCO2-eq/kWh and assuming an average lifespan of 150,000 km for both vehicles, the carbon intensity for raw material production translates to **58.4 gCO2-eq/km** and **110.6 gCO2-eq/km** for the Ford Kuga and Tesla Model 3, respectively.

The lithium-ion battery of a Tesla requires rare earth metals, which are mined, causing large amounts of carbon emissions. As a result, the EV in this study has double the amount of carbon emissions in the phase of raw material production compared to the ICEV, highlighting why for shorter lifespans, EVs usually emit more than ICEVs.

*Manufacturing*

Based on the Michigan grid emissions factor (2019) of 457 gCO2-eq/kWh and assuming that the heavier the car the more energy is required for manufacturing, the Ford Kuga's carbon intensity comes to **25.8 gCO2-eq/km**.

Since all Tesla Model 3s in Taiwan are made in California and given the state's lower grid emissions factor (2019) of 175 gCO2-eq/kWh, the carbon emissions from manufacturing the EV translates to **10.5 gCO2-eq/km**.

Producing a Ford Kuga leads to more than twice the amount of greenhouse gas emissions as a Tesla Model 3. This is primarily due to where both vehicles are made. The manufacturing stage for all automobiles produced in California have significantly lower amounts of carbon emissions than in a state like Michigan because most of the energy in California is generated from renewables (i.e., wind, solar). This highlights that the location of where a car is manufactured can have a significant effect on how climate-friendly the car is over its entire lifespan.

*Transportation*

The shortest distance for both vehicles from point of manufacturing to Taiwan is estimated, with energy consumption for transportation on land calculated using a 50-50 split between rail and truck. Values for energy intensity of both methods of car delivery are referenced from the Vancouver LCA.

The Ford Kuga is manufactured in Flint, Michigan, before being transported on land to Seattle, Washington, where it is shipped to Taiwan. After considering the distance of transportation, the weight of the vehicle, and energy intensity for all stages of delivery, the total implied carbon emissions for car delivery of the Ford Kuga translates to **4.9 gCO2-eq/km**.

Since all Tesla cars destined for the Taiwan market are manufactured near the coast of California, the main delivery method from California to Taiwan is shipping. Using a similar calculation methodology as for the Ford Kuga, the carbon emissions for transporting the Tesla Model 3 to Taiwan is **3.9 gCO2-eq/km**.

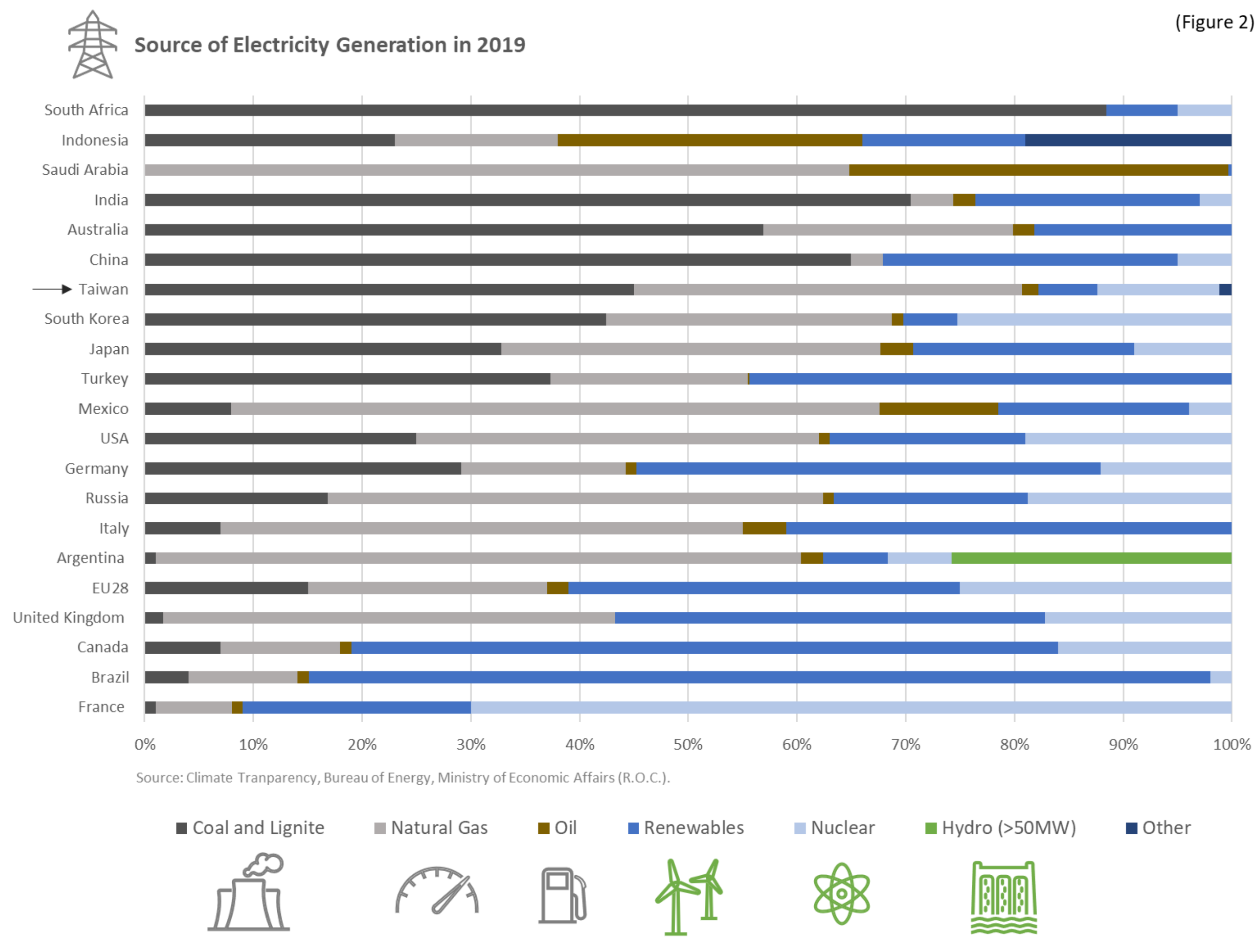
*Operation*

The Ford Kuga has a fuel efficiency of 6.3 liters/100 km. The product density of gasoline and energy density of gasoline were referenced from the Vancouver LCA and used to solve for the energy consumption – 31.5 MJ/liter, which translates to GHG emissions of **146gCO2-eq/km** for the ICEV.

The Tesla Model 3 has an average energy efficiency of 0.24 kWh/km. Since the grid emissions factor for electricity generated in Taiwan is 509 tonCO2-eq/GWh, the carbon footprint for operating the EV is **122.2 gCO¬2-eq/km**.

ICEVs generally emit significantly higher levels of carbon than EVs during the phase of operation since EVs do not emit any GHGs. However, based on the location of operation, how electricity is generated for an EV significantly affects how clean driving an electric vehicle is. Because Taiwan generates more than 80% of its electricity from fossil fuels (Figure 2), leading to a high grid emissions factor of 509 gCO2-eq/kWh, it means that driving an EV in Taiwan is almost as polluting as driving an ICEV.

(Figure 2)



*Recycling*

Both vehicles go through the process of dismantling and shredding at the end of its life. All the components of each car are treated in this manner except for the lithium-ion batteries of the Tesla Model 3, which can be reused. The total energy needed to shred a vehicle and repurpose the battery for reuse is referenced from the Vancouver LCA.

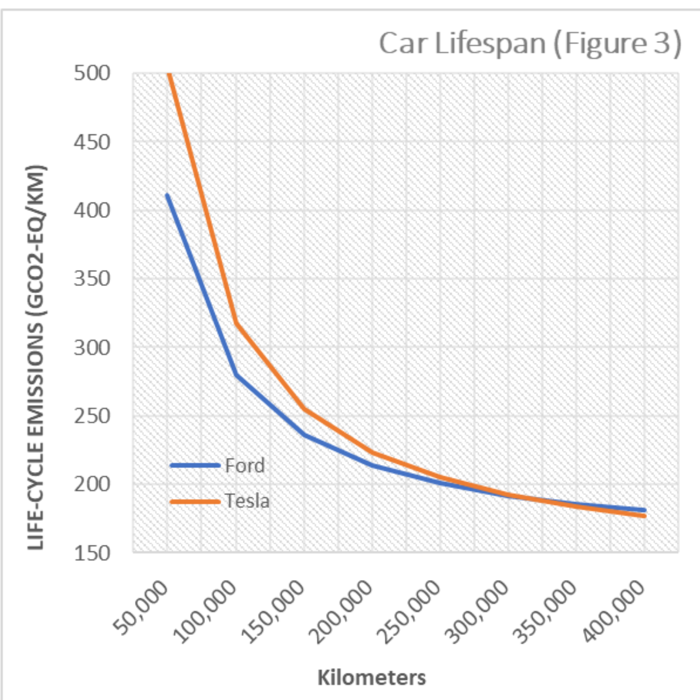
The weight of the Ford Kuga is 1525 kg, meaning that the energy required to recycle the entire vehicle translates to **0.62 gCO2-eq/km** in carbon emissions.

For the Tesla Model 3 the chassis and other components can be recycled separately from its battery. Using this method and factoring in the weights for the battery and the rest of the car, the energy necessary to recycle translates to **7.6 gCO2-eq/km** in GHG emissions.

Recycling processes are slightly different for ICEVs and EVs, resulting in total emissions from recycling being more than ten times for EVs in Taiwan. However, recycling does not contribute significantly to the total life cycle emissions of both vehicles. In fact, one EV car battery recycled means one less new battery that needs to be produced for a new car, contributing to negative emissions.

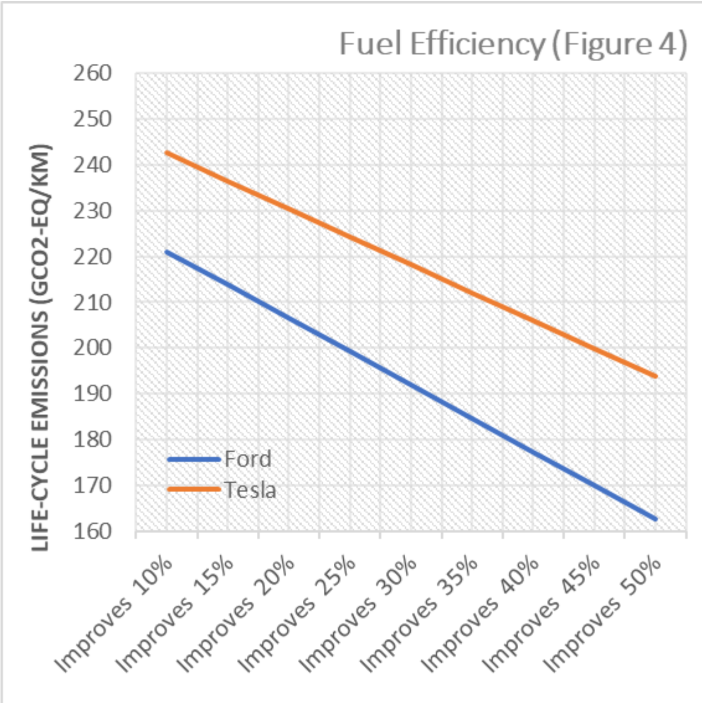
**SENSITIVITY ANALYSIS**

In order to explore the variables that have the greatest impact on the total carbon emissions of both vehicles, sensitivity analysis is performed. The effects of changing the lifespan, improving the fuel efficiency, and improving the grid emissions factor of Taiwan on the total life cycle emissions of both vehicles are considered.




As demonstrated in Figure 3, total implied carbon emissions are calculated for both vehicles as a function of variation in lifespan ranging from 50,000 to 400,000 km. The value for total carbon emissions for both vehicles operating in Taiwan is equal at a lifespan of 300,000 km. In other words, ICEVs operating in Taiwan have a lower amount of carbon emissions than EVs until the lifespan reaches 300,000 km. This means that purchasing an EV in Taiwan is only a more climate-friendly decision on the condition that its lifespan will exceed 300,000 km.

Calculated values for the total life cycle emissions as a function of changes in fuel efficiency are shown in Figure 4. The fuel efficiencies of the Ford Kuga and Tesla Model 3 are improved by up to 50% from their original values. As the fuel efficiency improves, the Ford Kuga's carbon emissions decrease at a faster rate relative to the Tesla Model 3. This highlights that improving the fuel efficiency for vehicles operating in Taiwan is effective at reducing life cycle carbon emissions but does not make the Tesla more climate-friendly than the Kuga.



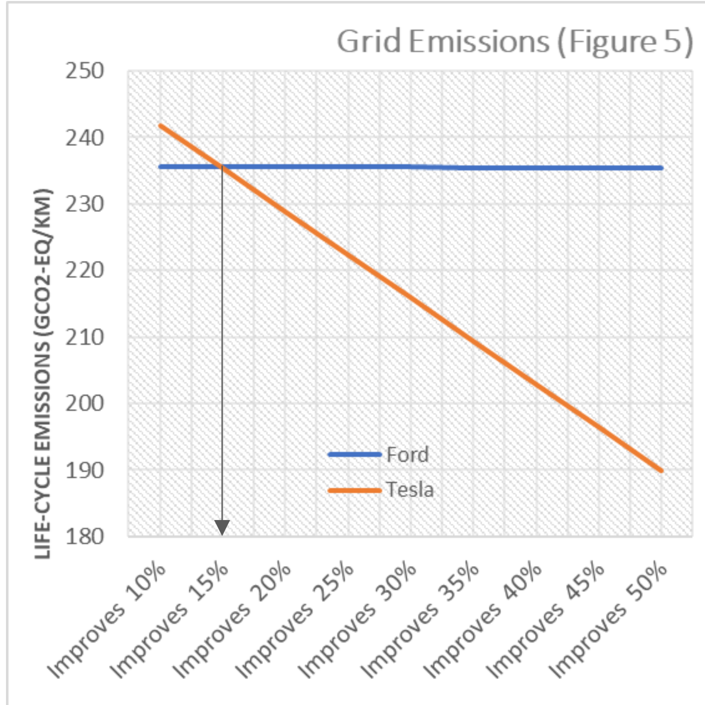




Figure 5 displays values calculated for the life cycle emissions of both vehicles based on changes to Taiwan's grid emissions factor. Taiwan's current grid emissions factor of 509 gCO¬2-eq/kWh is improved by up to 50%. This highlights that a decrease in Taiwan's grid emissions factor will dramatically decrease the life cycle emissions of EVs operating in Taiwan. In fact, Figure 5 illustrates that a mere 15% improvement in Taiwan's grid emissions factor will make the Tesla Model 3 equally clean as the Ford Kuga in its life cycle emissions.

## CONCLUSION

The results of this study reinforce that choosing between an ICEV and an EV is not as straightforward as it may seem. The multiple stages of an automobile's life cycle have various effects on the vehicle's total carbon emissions. It is important to consider variables such as the grid emissions factor of where the vehicle is operating and the lifespan of the vehicle. For EVs to be beneficial to Taiwan, Taiwan must focus on shifting the source of electricity generation to renewables. The Taiwanese government has passed the Greenhouse Gas Reduction and Management Act, which aims for 20% of Taiwan's energy to come from renewables, and 50% to come from low-carbon natural gas by 2025. As a result, the proportion of electricity derived from coal and ignite will be lowered to 30%. Assuming this translates to a 15% improvement in Taiwan's grid emissions factor, EVs will finally become a more environmentally friendly option in Taiwan.