PREDICTIVE ANALYSIS OF ICE, HYBRID AND ELECTRIC VEHICLE: SELECTED CASE STUDIES

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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LIST OF ABBREVIATIONS

ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
PHEV	Plug-in hybrid electric vehicle
BEV	Battery electric vehicle
EV	Electric vehicle
CO2	Carbon dioxide
LCA	Life cycle analysis
GHG	Greenhouse gas
US	United States
UK	United Kingdom

LIST OF APPENDICES

ANALISIS RAMALAN BAGI KENDERAAN ENJIN PEMBAKARAN DALAM, HIBRID DAN ELEKTRIK: KAJIAN KES TERPILIH

ABSTRAK

Pemanasan global adalah salah satu isu yang paling banyak diperkatakan di seluruh dunia hari ini. Ini kerana pemanasan global memberi kesan yang besar kepada manusia dan alam sekitar. Salah satu faktor terbesar yang menyebabkan pemanasan global ialah sektor pengangkutan. Kenderaan enjin pembakaran dalam yang menggunakan petrol mengeluarkan karbon dioksida, seterusnya menyumbang kepada pelepasan gas rumah hijau. Oleh itu, langkah-langkah balas perlu diambil untuk mengurangkan kesan enjin pembakaran dalam melalui penggunaan penjana kuasa hibrid dan elektrik. Dalam kajian ini, jejak karbon untuk ICEV, PHEV dan BEV akan ditentukan melalui analisis kitaran hayat. Model yang akan digunakan dalam kajian kes terpilih ini ialah BMW 3-Series kerana ia mempunyai rangkaian kuasa yang luas daripada ICE hingga elektrik. Memandangkan semua kenderaan mempunyai saiz yang sama, reka bentuk yang sama dan dikeluarkan oleh syarikat yang sama di kilang yang sama, oleh itu perbezaan antara setiap kenderaan boleh diabaikan. Seterusnya, ramalan trend jualan kereta bagi setiap jenis kenderaan boleh dibuat melalui simulasi dalam MATLAB Simulink. Dengan mengaitkan kedua-dua data untuk pelepasan karbon dan data jualan kereta, ramalan jejak karbon untuk setiap jenis kenderaan pada masa hadapan boleh dibuat. Antara 3 senario yang dibuat, didapati senario 1 mengeluarkan pelepasan CO2 tertinggi iaitu 1.80688 X 10^12 kgCO2, diikuti dengan senario 3 pada 1.58632 X 10^12 kgCO2 dan penyumbang paling sedikit untuk pelepasan CO2 adalah senario 2 dengan 4.6252 X 10^11 kgCO2.

PREDICTIVE ANALYSIS OF ICE, HYBRID AND ELECTRIC VEHICLE: SELECTED CASE STUDIES

ABSTRACT

Global warming is one of the most spoken issues around the world today. This is because the global warming has a significant impact on the human and environment. One of the biggest factors that causes global warming is the transportation sector. Internal combustion engine vehicle that runs on gasoline emits carbon dioxide, hence contributing to the greenhouse gas emission. Therefore, a counter measure needs to be taken to lessen the impact of internal combustion engine through the use of hybrid and electric powertrain. In this study, the carbon footprint for ICEV, PHEV and BEV will be determined through the life-cycle analysis. The models that will be used in this selected case study is BMW 3-Series as it has a wide range of powertrain from ICE to electric. Since all of the vehicles has the same size, same design and manufactured by the same company in the same factory, therefore the difference between each vehicle is negligible. Next, the forecasting of car sales trend for each powertrain can be made through the simulation in MATLAB Simulink. By correlating both of the data for carbon emission and car sales data, the forecasting of carbon footprint for each powertrain in the future can be made. Among 3 scenarios that is made, it is found out that scenario 1 emits the highest CO2 emission at 1.80688 X 10^12 kgCO2, followed by scenario 3 at 1.58632 X 10^12 kgCO2 and the least contributor for CO2 emission is scenario 2 at 4.6252 X 10^11 kgCO2.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Carbon footprint is one of scientific method used by professionals to assess the environmental impact of an activity or process. The amount of carbon footprint accumulated for that particular year will be evaluated in order to determine the severity of an activity or process has to the environment. If the carbon footprint of that particular year shows a bad impact on the environment, then a countermeasure action needs to be taken as soon as possible.

Carbon footprint of a product is defined as the sum of greenhouse gas (GHG) emissions and removals in a product system, given in carbon dioxide equivalents based on a life cycle assessment utilizing the single impact category of climate change. There are many sectors that contributes to the carbon emission such as transportation, electricity generation, industrial sector and agriculture sector. It is reported that in 2020, the greenhouse gas emission from transportation is one of the biggest contributors to this problem with almost a quarter of the total greenhouse gas emission in that particular year is being produced by the transportation sector [1]. This is concerning as the transportation sector is one of the most rapidly expanding sectors, thus contributing to more pollution in the future. Each year shows an uptrend in the greenhouse gas emission as a result of more and more vehicles on the road. The addition of vehicles on the road is due to the fact that many people use it as a form of commuting from one place to another for working and many more. In fact, some individual may have more than one vehicle for each household because they may use it as a sign of luxury status instead of needs. This is alarming as the number of vehicles on the road increases, so do the traffic jams and the carbon emission. Many traffic jams translate to more time spend on the road to travel even for a short distance. This can cause fatigue to the drivers, and hence causing stress to them and resulting their life quality to drops. The high rate of traffic jams also means more fuel is burned as many vehicles are idling when stuck in traffic jam, thus contributing to higher carbon emission.

Therefore, countermeasure action needs to be taken to reduce the carbon emission caused by the usage of fossil fuels in the vehicles. Some of them are hybrid and electric vehicle. The sole purpose of hybrid and electric vehicle is to reduce the carbon emission as well the dependence on the fossil fuel alone. The powertrain used in electric vehicle are powered by electric motor, while hybrid vehicle uses the combination of internal combustion engine and electric motor. Although it seems as hybrid and EV are more environmentally friendly since hybrid will produce lower carbon emission and no carbon emission for the electric vehicle, however the manufacturing and real-life cycle process for both type of vehicles may result in the opposite way.

In this paper, the carbon footprint of internal combustion engine, hybrid and electric vehicle will be evaluated and compared in selected case studies. For each category, a conclusion will be drawn as well as their future prospects. The data used for this research was collected from literature reviews of some relevant journals, articles, books, reports, and other sources. Carbon footprint, carbon dioxide emissions, transportation emissions, and many other keywords are utilised in search engines. To produce a conclusion at the end of the article, all of the data or information obtained is evaluated, analysed, and explored in depth.

1.2 Objectives

i. To analyze the carbon footprint of internal combustion engine vehicle, hybrid and electric vehicle.

ii. To investigate the carbon emission emitted with the type of powertrain.

iii. To make a projection of carbon emission with the type of powertrain in the future.

1.3 Problem Statement

The climate change has become a significant issue in our life as it has become more vulnerable due to the pollution occur in our world. This climate change occurs due to the global warming that is caused by the greenhouse gas emitted. This greenhouse gas will trap heat inside the atmosphere and cause the world temperature to increase. The carbon footprint produce by the production and the use of ICE, hybrid and electric vehicle also contributes to global warming. Therefore, a projection of carbon emission in the future needs to be done in order to propose a solution to reduce the global warming effect to the world.

1.4 Scope of Project

The main scope of this paper is about the carbon footprint or carbon emission of internal combustion vehicle, hybrid and electric vehicle. The type of vehicle that is analyzed in this research is passenger car and no other vehicle such as bus, trucks and motorcycle will be taken into account. The data that is collected is taken from online sources and not through experimental activities. For the type of powertrain used in this paper, it will only be taken from gasoline internal combustion engine, hybrid and battery electric vehicles. Other powertrain such as diesel powered and hydrogen powered will not be taken into account.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions of ICEV, PHEV and EV

Internal combustion engines operate by using gasoline and diesel as their main power source. Due to its durability and simplicity, they are commonly used as the propulsion system in the passenger car nowadays [2]. It is estimated that until this present day, there are approximately 2 billion internal combustion engine vehicle is being used around the world [3]. Within the engine, combustion takes place to produce energy from a mixture of air and fuel. The work then spins the piston and rotates the crankshaft, which drives the wheels through a series of more complex systems and operations. The main problem with internal combustion engine vehicle is the dependency toward unrenewable fossil fuel. Gasoline and diesel that is use to powered the vehicle will eventually run out as the resource is limited. This will create a series of problem if the world keep depends on it and does not shift towards other alternatives such as renewable energy. The second problem with ICEV are the carbon dioxide emitted by the vehicle during combustion process that takes place in the engine chamber. The amount of carbon dioxide emitted every year keep showing an uptrend and this is a very concerning situation as it also affects the greenhouse gas emission. This shows that ICEV is a very huge threat that can result in a very significant result to the environment. Therefore, countermeasure action that can be taken as alternatives to reduce the carbon emission is through the use of electric and hybrid vehicle.

Electric vehicle is a vehicle that uses electric motor to move and it is powered by battery. EV is more efficient than ICEV as it can reuse the energy from regenerative braking and store it back into the battery. EV also does not waste energy when idling in traffic jams because the electric energy is only used to power electrical appliances in the car such as radio and air-conditioning system, while ICEV burn fuel in order to power all these electrical devices. This makes EV more efficient than ICEV in town driving where stop and go traffic occurred due to its regenerative braking and smart energy saving. Since EV uses electric motor to power the vehicle, therefore there is no carbon dioxide emitted by the vehicle, making it a good alternative to reduce the carbon emission around the globe. However, the electricity generation does contribute to the carbon emission, depending on the sources used [4]. The downside of EV is its driving range is not as far as ICEVs per charge. The limited number of charging infrastructure in our country also cause problem as the EV owner might suffer range anxiety and need to plan their journey properly.

Lastly, hybrid vehicles use the combination of internal combustion engine and batteries. As a result, it offers the advantages of both ICE and battery electric vehicle, but at a lesser cost. Mild hybrid uses the battery to power the electrical appliances in the car when the vehicle stops such as in the traffic jams. However, it cannot use the electricity to power and move the vehicle. Full hybrids, on the other hand, have more powerful motors and larger batteries, allowing them to produce more power in a shorter distance. It can also save more energy through regenerative braking due to its larger battery pack. Plug-in hybrid electric vehicle (PHEV) uses the same concept such as full hybrid, however the only difference that makes them apart is the fact that PHEV has the ability to charge the battery pack from the chargers as well from the regenerative braking. It also features larger battery packs than full hybrid vehicles, allowing it to drive further on electricity alone. ICE can come to work and operate when the battery is low, in accelerating, high heating, or high air conditioning loads [5].

2.2 Effect of Internal Combustion Engine towards Environment

The effect of internal combustion engine towards environment can be seen when there are too many pollutions happening around the globe. Combustion from ICE produce exhaust gas which emits a wide range of gases and solid matter to the environment [6]. Meanwhile, noise generated when operating the engine also contributes to noise pollution. The exhaust gas produced consist of nitrogen, carbon dioxides and water vapor. These are the major components in the exhaust gas emitted. However, there also toxic gas component that are emitted such as carbon monoxides (C0), nitrogen dioxides (NOx), hydrocarbons (HC), particulate matter (PM) and polycyclic aromatic hydrocarbons (PAH) [8].

Carbon monoxides is produced when a fuel is not burnt completely. When exposed to a high concentration of carbon monoxides, it can cause headaches and visual impairment. This is because, carbon monoxides affect the oxygen delivery to human's vital organ. When exposed to a high concentration of CO at a very long time, it can even lead to death. Nitrogen dioxides however, is produced when fuels burn at high temperatures, high pressures and excess oxygen in the engine combustion chamber. The effects of NOx are it can increase the risk of total mortality, cardiovascular death and infant mortality. Next, is the hydrocarbons. It is produced in the same way such as carbon monoxides. When exposed to high concentration of hydrocarbons, it can lead to cancer and other harmful effect on human tissue. Lastly is particulate matter and polycyclic aromatic hydrocarbons. Upon exposure of these two chemicals can cause asthma, chronic bronchitis, respiratory problem and heart disease [9].

Exhaust gas also affect the atmosphere as it can cause global warming. Greenhouse gas emission such as carbon dioxides has become the main contributor to this problem. This greenhouse gas traps heat in the atmosphere, hence causing the world temperature to rise. This will then cause other problems that affect wildlife, sea levels and natural landscapes. The greenhouse gas emission can also affect air, water and soil quality. The emission of these harmful gases can cause the air quality to drop and make visibility become poor. Meanwhile, for the water and soil quality, the mixture of sulphur dioxide and nitrogen dioxide with rain water can cause acid rain. This can then lead to damaged crops, forest, as well as the death of marine wildlife [8].

2.3 Carbon emission of ICE, hybrid and EV

ICEV contributes to the largest CO2 emission in the transportation sector around the globe. This is due to the fact that every combustion that occur in the engine chamber produces exhaust gas such as nitrogen, water vapor and carbon dioxide. At the end of its life cycle, internal combustion engine car is reported to produce an average specific CO2 equivalent emission of 187g/km which is 40% higher than the expected emission of 133.5g/km that came from the fuel consumption [10]. This is by taking consideration of the tailpipe CO2 emission as well as the vehicle production phase that leads to higher emission.

Meanwhile, for hybrid vehicle is characterized by having lower impact of CO2 emission compared to ICE. Hybrid car is reported to produce an average specific CO2 equivalent emission of 160g/km which is 52% higher than the expected road emission of 105.7g/km [10]. The increase in CO2 emission is also by taking consideration of the vehicle production phase.

Lastly, for the electric vehicle, it is reported to produce CO2 equivalent emission of 109.6g/km. Although electric vehicle does not produce tailpipe CO2 emission, the production phase of the vehicle and the battery pack as well as electricity generation does produce carbon dioxide emission [10].

2.4 Energy consumption of ICE, hybrid and EV in the future

Energy consumption for each of the vehicle is different due to different powertrain system used. For the energy consumption of ICE vehicles, it can be calculated using the tailpipe CO2 emission. For the ICE vehicles, it is expected to decrease from 130g CO2 per km in 2018 to only 91g CO2 per km in 2030 and onwards. The assumption is made by following the regulations set by the New European Driving Cycle (NEDC). The decrease in the tailpipe emission is due to the improvement that can be made such as engine downsizing, aerodynamic improvement, reduction in engine friction, smaller transmission loss to the wheels and other potential improvement [7].

Meanwhile, for electric vehicle, it is expected to use lesser energy consumption up to 10% less in 2030. The energy consumption is expected to drop from 223Wh per km in 2020 to 201Wh per km in 2030 and onwards. This energy efficiency is achieved by making some improvement in the system such as weight reduction, smaller reduction in transmission loss, aerodynamic improvement and reduction in rolling resistance [7].

For the hybrid vehicle, it is assumed to use the ICE for 50% of each driven kilometer in 2020, where this results in an electric engine utility factor of 0.5. However, this figure is expected to increase linearly to 0.8 by following the Worldwide harmonized Light vehicles Test Procedure. This is due to stronger incentive such as higher availability and use of fast chargers and also increasing benefits of electricity where the cost of electricity is lower than the price of fossil fuel [7].

2.5 Carbon Footprint effect of Banning ICE vehicle

By introducing a ban towards latest ICE vehicle, the annual carbon footprint is expected to decrease from 14 million tons of CO2 (MtCO2) in 2020 to between 1.5 and 5.1 MtCO2 by 2060. This assumption is made depending on the decarbonization of background system such as tailpipe CO2 emission, fuel cycle emission and vehicle cycle emission. Without a ban on ICE, the annual carbon footprint is expected to be at 5.8 and 9.1 MtCO2 in 2060 due to much stricter emission policy and the use of biofuel which has lower carbon intensity [7]. This shows that a ban on ICE is something that we might need in the future in order to lower the annual carbon emission.

For the tailpipe CO2 emission, it is expected to drop significantly from 9.1 MtCO2 in 2020 towards zero between 2045 and 2050 if a ban was introduced. Without a ban, the tailpipe CO2 emission is expected to decrease a lot until 2030, and it continues to decrease slightly in 2042, only to increase back to a level of 3.6MtCO2 in 2060. This situation occurs due to the biofuel policy that is introduced in 2030 that causes the tailpipe emission to decrease. For year 2042, the slight decrease is due to the assumed energy efficiency improvement and for 2060, the increase in tailpipe CO2 emission occurs due to increased travel demand [7].

For the fuel cycle annual emission, it is expected to be at 3 MtCO2 in 2020 and decrease significantly if a ban was introduced where it is expected between 0.43 to 0.55 MtCO2 in 2060. By introducing a ban on the ICE, the usage of fossil fuel into commercial vehicle will soon be replaced by electrification and this contributes to the lower emission. If the ban is not introduced, the fuel cycle annual emission is expected at a level of 1.2 MtCO2 in 2060 [7].

For the vehicle cycle annual emission, the emission is estimated at 2.3 MtCO2 in 2020 and increase rapidly if a ban is introduced. This is the effect of the increased manufacturing process for the battery pack where the ban in ICE will result in the high demand of hybrid and electric vehicle. The emission is expected to rise until 4.6 MtCO2 in 2060. In a scenario without a ban on ICE, the annual emission in 2030 is expected to be between 2.1 and 2.5 MtCO2, while the annual emission for the same year is expected to be between 3.1 and 3.7 MtCO2 if the ban is introduced [7]. The difference is due to the high demand of the battery pack which causes the manufacturing process of the battery pack to increase significantly.

2.6 Carbon Emission of ICEV and BEV using Life Cycle Analysis

For the life cycle analysis, the amount of CO2 emission produced by both the ICEVs and BEVs are calculated in 4 different phases. Phase 1 is the vehicle production where the raw material extraction, vehicle component production and vehicle assembly are done. For phase 2, it is the fuel production for ICEVs and generation of electric power for BEVs. For phase 3 and 4, it is maintenance and end-of-life (EOL) respectively. [11]

For phase 1, the vehicle production process, the CO2 emission produced is calculated by splitting it into 4 parts which are chassis parts, engine and transmission parts, motor and inverter parts and lastly is the battery parts. For the chassis parts which is the body, tires and interiors of the car, the CO2 emission for both ICEVs and BEVs are assumed to be identical [11]. This is because both of this vehicle uses the same chassis and interior design regardless of its powertrain. According to the database of Life-Cycle Assessment Society of Japan (JLCA), CO2 emission from material extraction alone is calculated at 5494 kg of CO2. Since chassis parts take accounts of 76.8% from the weight, therefore, the production of chassis parts contributes to 4219 kg of CO2 emission [11]. Meanwhile, for engine and transmission parts is only taken account for ICEVs since it still uses conventional ICE. For this part, the CO2 emission is calculated at 1274 kg of CO2 based on the JLCA. For the motor and inverter parts, it is only taken account for BEVs since it uses electric motor to move. The CO2 emission is calculated at 1070 kg of CO2 and 641 kg of CO2 emission respectively [11]. Lastly is the battery part, where the emission is calculated at 177 kg of C02.

For phase 2, the fuel production for ICEVs also contributes to CO2 emission. Based on LCA database collected, the emission factors of the fuel are calculated by considering the amount of CO2 emission by 1 kg fuel. It was specified that the density values of gasoline are 0.727 kg/L, meanwhile for diesel is 0.828 kg/L [11]. By taking account of these energy density, we will get the CO2 emission of gasoline which is 2.28 kg-CO_2/L and 2.62 kg-CO_2/L for diesel [11]. This means for every liter of fuel burned, it will produce 2.28 kg and 2.62 kg of CO2 emission respectively.

Next is phase 3 which is the maintenance phase. For the maintenance phase, it depends on the type of powertrain used in the vehicle. ICEVs has more maintenance part compared to BEVs. This is because ICEVs has more component such as engine and radiator. This means maintenance is needed to change the engine oil and the radiator coolant [11]. On the other hand, BEVs does not have many components that needs to be maintain as it only runs using electric motor powered by the battery. The only similarities that BEVs share with ICEVs is the maintenance of tires, lead-acid-battery and also brake disc and brake pad maintenance.

Lastly is phase 4 which is the end-of-life phase. This phase includes the disassembly process, shredding and sorting process as well as transporting and landfilling process. This process is done in order to destroy the car as it has become a liable to the owner.

For the CO_2 emission of this phase, the ICEVs and BEVs share the same amount as the process is the same [11].

2.7 Carbon Footprint of Battery Pack in Electric Vehicle

For the carbon footprint of battery pack, it can be divided into two parts which are the production of the battery pack and also the charging of the battery pack. Both of these two processes contribute to the carbon emission and the greenhouse gas emission. For the production of the battery pack, it can be categorized into four sections which are the terrestrial acidification, particulate matter formation, mineral resource deployment and fossil resource deployment. [12]

For the first section which is terrestrial acidification, this is mainly contributed by the atmospheric deposition of acidity, or in other terms called as acid rains. The production of the battery pack causes chemical substances being emitted to the atmosphere such as nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxides (SO_2). It is clear that the production phase of BEV leads to a very high level of acid rains, giving an overall final result of 661 mg/km which is 78% significantly higher than that for ICEV [12]. Next is the particulate matter formation where it occurs due to the extraction and refining of materials in the production phase of the battery pack. This is also contributed by the outdoor storage of mineral during the production phase too [12]. The third section is the mineral resource deployment. The production of the lithium-ion battery pack requires rare mineral elements such as lithium, nickel, cobalt and copper being extracted from the Earth. This results in the mineral resources deployment of BEV being four times higher than ICEV due to the production of the battery pack [12]. Lastly is the fossil resource deployment. Even though BEV does not use fossil fuel, however it does contribute to the usage of fossil fuel. While ICEV and hybrid vehicle uses fossil fuel in the use phase of the vehicle, BEV uses fossil fuel in the production phase of the vehicle. Overall, the fossil fuel consumption for ICEV, hybrid vehicle and BEV are 57.8 g/km, 48.4 g/km and 26.6 g/km respectively. [12]

For the charging phase of the battery pack, it is highly dependent on the type of electricity generated. For non-renewable energy sources that is used to generate electricity such as oil, coal and natural gas, it does contribute to the carbon emission of the production of battery pack. The greenhouse gas emitted such as carbon dioxides and nitrogen can then lead to global warming as it traps heat inside the atmosphere. However, for renewable energy sources such as hydropower, nuclear power, wind energy and solar energy, it does not contribute to greenhouse gas emission as it does not produce any harmful gases. [13]

CHAPTER 3

METHODOLOGY

3.1 Overview

This study contains several important steps that needs to be done in order to finish the analysis and making projection in the future. The first step that needs to be done is through literature research. In literature research, a lot of data and information was extracted from the related journals, articles, websites and reports. The literature research is done in order to help to understand more about the analysis that needs to be done. Next, the data is collected and sorted out accordingly to its type such as the type of powertrain. After getting all the necessary data, a simulation is conducted in order to make the projection of the sale according to powertrain and the carbon emission according to the chosen scenario in this paper. From the simulation, the results were analysed and discussed to provide a conclusion of the projections made. The car manufacturer that is selected in this case study is BMW as it has a wide variety of car model that uses ICE, hybrid and electric powertrain. The model that is chose is BMW G20 3-Series. For the ICE, it will be represented by BMW 330i, meanwhile for the hybrid and electric vehicle will be represented by BMW 330e and BMW i3 Sedan respectively. All of this vehicle is manufactured by the same manufacturer in the same factory, by the same company, therefore the differences is minimum and will make this comparison even more accurate. The sedan category is selected due to fact that it is the most common car sold in the world and are produced in mass production, therefore the selection of this category is considered appropriate as it has the greatest number of vehicles sold.

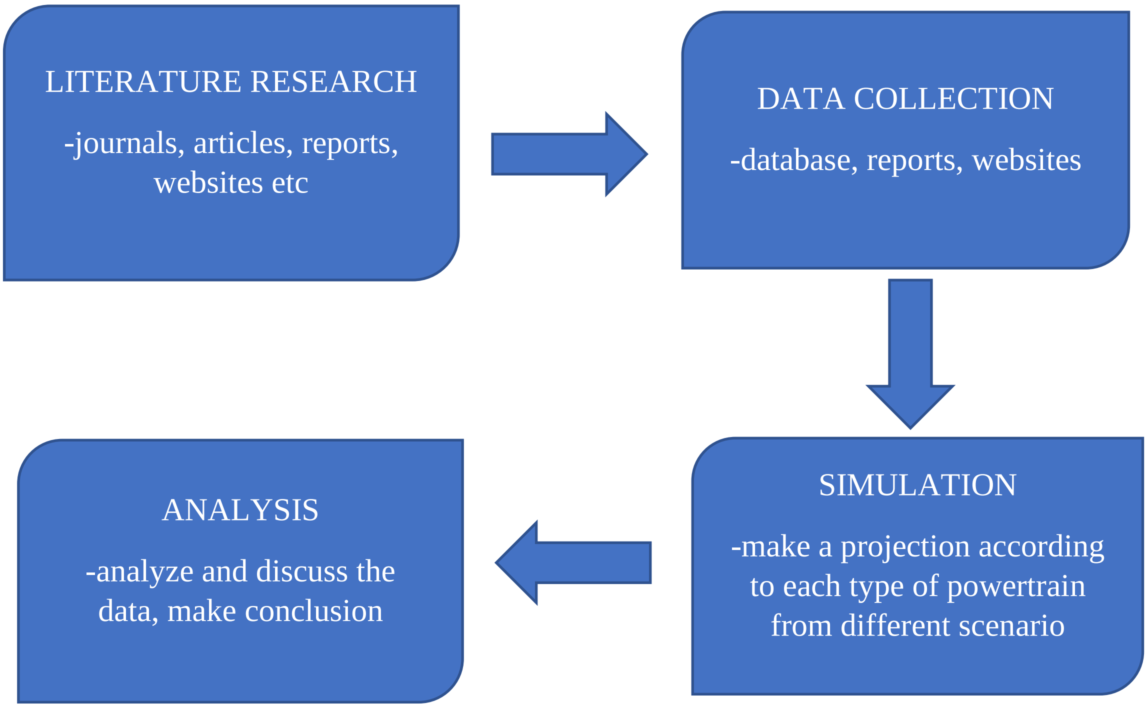

Figure 3.1 Flow chart of methodology overview

3.2 Literature Research

In order to understand about the analysis that needs to be done, literature research needs to be conducted in order to understand the overall purpose of this paper. In literature research, a lot of reading is needed in order to collect the data and fully understand the problem. The data is collected through the review of many journals, articles, reports and websites taken from online sources. Important keywords such as carbon footprint, carbon dioxide emissions, electric cars, hybrid cars, emission from ICE and many more are used to find related articles from the online sources.

3.3 Data Collection

For the data collection, it is done by browsing through many websites, journals and articles from all over the world. However, the data in Malaysia is difficult to obtain as most of it is not allowed to be publish to public. Therefore, the data was collected also from published journals that do the calculations on this matter. On the other hand, the data from US and Europe are easily accessible due to the publishment in certain websites such as in International Energy Agency websites and reports. This makes data collection from US and Europe easier compared to from Malaysia. However, the data from Malaysia can still be obtained such as from Malaysia Energy Statistics Handbook from Energy Commission. Data about the information of the vehicle that is used in the research such as the tailpipe carbon emission, weight and fuel consumption will be collected from the BMW official website. In this paper, comparison of Life-Cycle Analysis will be done to compare the carbon emission from each powertrain. Figure below shows the complete LCA details that needs to be done.

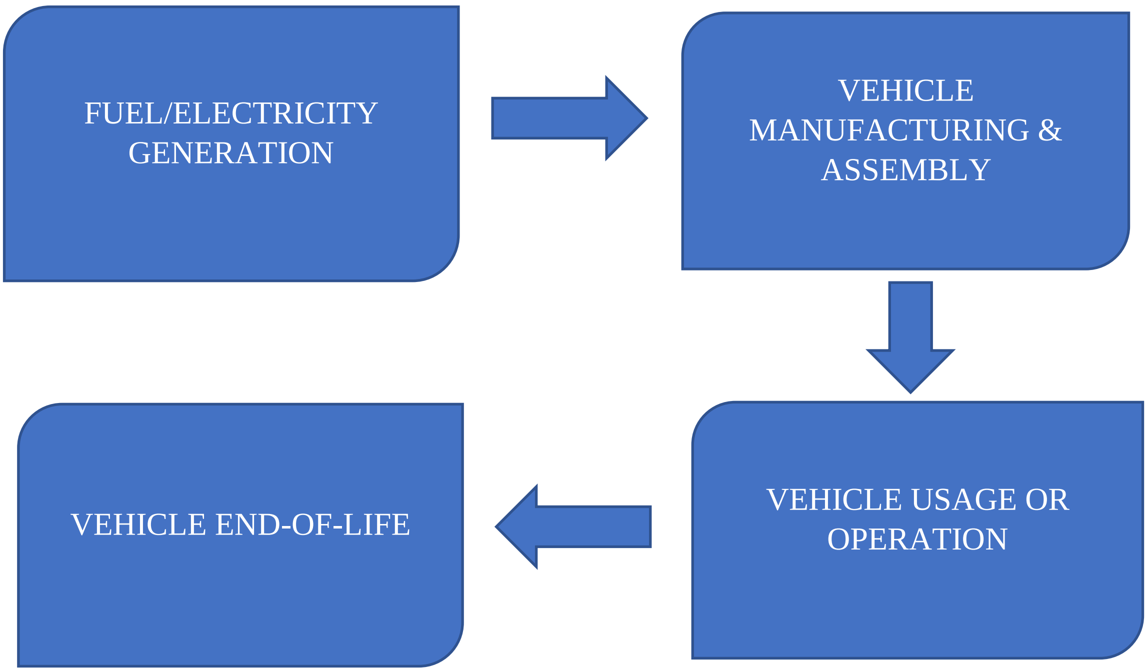

Figure 3.2 System Boundary for LCA cycle

3.3.1 Fuel or Electricity Generation

The production of fuel for ICE and electricity generation for BEV and PHEV is the first step in the LCA. For ICE, fuel production contributes carbon emission in the overall process such as extraction, refining, transportation and distribution of fuel. These are the several process in the fuel production that contributes to the carbon emission around the globe. Meanwhile, for electricity generation, it takes into account Malaysia's generational mix or grid mix, which consists of coal, natural gas, hydro, diesel, and other sources in their respective proportions. This approach is taken because it is believed that different sources emit different amount of GHG to the atmosphere. In modern country that uses most of renewable energy to generate electricity such as in Norway, it shows that the electricity generation from renewable energy produces less GHG emission compared to countries that uses unrenewable energy to generate electricity [13]. In Malaysia, the electricity generation was sourced from 4 primary sources which are coal, natural gas, oil and renewable energy.

Table 3.1 Percentage of grid mix in Malaysia and its carbon emission factor. [14]

Power plant	**Coal**	**Natural Gas**	**Oil**	**Hydro**
Percentage Grid Mix (%)	43	40.4	0.5	16.1
Carbon Emission Factor (kg/kWh)	0.921	0.404	0.269	0.024

3.3.2 Vehicle Manufacturing & Assembly Process

For vehicle manufacturing process, it can be divided into several steps such as raw material extraction, material and component production as well as vehicle assembly. Each different process contributes to different amount of carbon emission, as it requires chemical and mechanical process in order to obtain the finish product. In order to calculate the carbon emission produced by the vehicle manufacturing process, a general equation needs to be obtained. All cars are believed to have the same components, proportions of material compositions, distribution, and transformation processes. However, for BEV the carbon emission might be impacted more due to the manufacturing of battery pack. Since the data to calculate the carbon emission in the vehicle manufacturing process is not available, hence a special linear case equation in Equation (1) can be used [15].

$$VMP = [K]W + M \ldots\ldots\ldots(1)$$

Where VMP is the amount of carbon emission in the vehicle manufacturing process,

K is 0.74kgCO2/kg of car,

M is 890kg,

W is the weight of the vehicle

By using this equation, the carbon emission in the vehicle manufacturing process for all vehicle can be obtained.

Table 3.2 Data of CO2 emissions for part manufacturing and assembly of the model

Vehicle Type	**BMW 330i**	**BMW 330e**	**BMW i3 Sedan**
Weight (kg)	1545	1815	2029
CO2 emission (kg)	2033	2233	2391

3.3.3 Vehicle Usage or Operation

For the vehicle usage, the carbon emission takes place when the vehicle operates and move from one place to another using its designed powertrain. For ICEV, the carbon emission takes place at the tailpipe where the product of fuel that is burned is emitted. The fuel is burned as a result of combustion that takes place in the engine chamber that is used to power and move the vehicle. Meanwhile, for hybrid vehicle, the tailpipe emission only occurred when the vehicle switch to ICE to move. Upon using electric motor, there will be no tailpipe emission. The same case can be said to BEV as it also moves using electric motor, hence no carbon dioxide is emitted. Fuel consumption and CO2 emissions in g/litre of fuel or g/km from the vehicle can be used to compute direct emissions. The distance travelled per annum is also important in order to determine the carbon dioxide emitted in the vehicle operation. Cars in Malaysia is believed to travel at an average of 28 000 km per annum [16].

Table 3.3 Vehicle operation data for each powertrain [17] [18] [19]

Vehicle Type	**BMW 330i**	**BMW 330e**	**BMW i3 Sedan**
Weight (kg)	1545	1815	2029
CO2 emission (g/km)	150	50	0
Fuel consumption (l/km)	15.15 (6.6l/100km)	45.45 (2.2l/100km)	134 Wh/km
Range (km)	894	56 (pure electric)	526
Battery size (kWh)	-	12	70.3

3.3.4 Vehicle End-Of-Life

End-of-life cycle is the process where the vehicle will be disassembled and get rid of. This process consists of several steps which are disassembly, shredding and sorting, transportation and landfilling. For the EOL process, each vehicle is assumed to emitted the same carbon dioxide emission as all vehicles has the same design, size, and are from the same car manufacturer. In the life cycle analysis, the EOL process contributes to the least amount of carbon emission as it is much simpler compared to other process. Even though the EOL process only contributes small amount of carbon dioxide, however, it is still worth considering.

Table 3.4 Data for carbon emissions from each step in the EOL process [10]

Process	CO2 emission (kg)
Disassembly	-
Shredding & Sorting	24
Transportation	4
Landfilling	38
Total	**65**

3.4 Simulation

For the simulation part, the projection is done based on the carbon footprint produces by each type of powertrain. The projection is done by analysing two important parameters in this study which are the carbon emission data by each powertrain and also the car sale data for each powertrain. The carbon emission data for each powertrain that is calculated using LCA will then be collected and sorted out accordingly. The data car sale for each powertrain will be collected from the journals, articles and reports that has been reviewed. Next, both of these data are being corelated with each other by multiplying it. The carbon emission data for ICEV will be multiply with the car sale data for the ICE powertrain. Meanwhile, the carbon emission data for hybrid and EV will be multiply with car sale data for the hybrid and electric powertrain respectively. The data obtained is then collected and sorted out accordingly. By using the data obtained, it will then be keyed in into the simulation. The desired year will serve as the input, while carbon footprint for each powertrain will serve as the output.

Three scenarios will be created in order to justify the increment or decrement of the carbon footprint for each powertrain. These scenarios will be used as parameters to forecast the emission of each vehicle in the future. The first scenario is the increment of 13% for each powertrain for every year. Scenario 2 is one in which BEV sales increase by 25% each year while ICE sales decline by 25% each year. Scenario 3 shows a 25% decline in BEV sales and a 25% increase in ICE sales. From the obtained forecasting trend, the best powertrain that can help to overcome GHG emission in the future can be anticipated.

The overall simulation will be done in the MATLAB Simulink. The data collected from the previous calculation will be imported in Simulink. Four main items will be used in order to develop the simulation which are Constant, 1-D Lookup Table, Gain and Display. The Constant will be used to keyed in the input, which in this case is the desired year. Meanwhile, the 1-D Lookup Table will serve as the processor where the carbon emission data and the year data will be input in. The year data will be keyed into the breakpoint column while the carbon emission data will be keyed into the table data column. Then, a multiplier which in this case is the Gain, will be assigned according to our scenarios created. The multiplier is responsible for the increment or reduction of the desired data. This will then affect the overall graph that is displayed to show the trendline of the data. For the rise of 25% and reduction of 25%, gain factor of 1.25 and 0.75 will be used respectively. Lastly, the Display will show the desired output which is the carbon emission for each powertrain. All of these items will be linked to each other in order to make the simulation operates well as can be seen in Figure 3.3

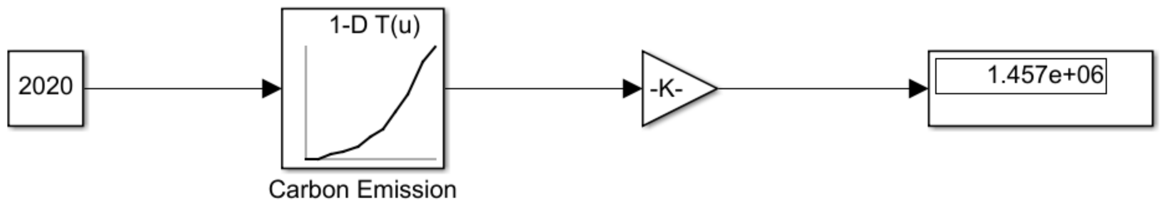

Figure 3.3 Setup for the Simulation

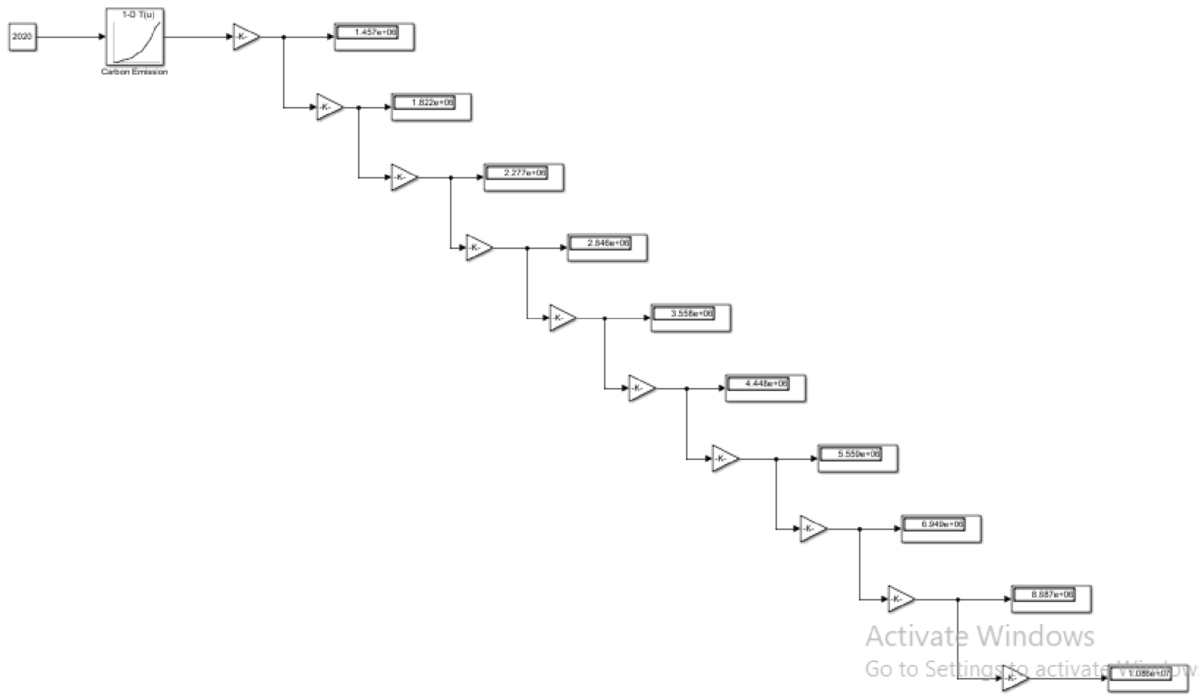

Figure 3.4 Full Setup for the Simulation

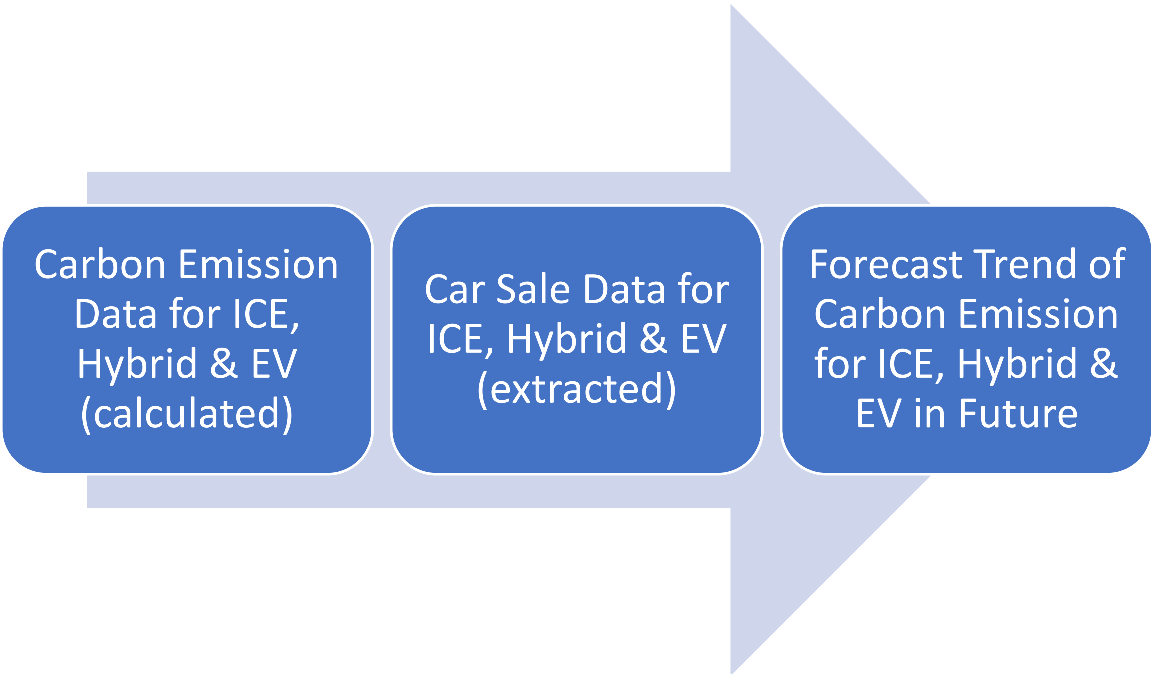

Figure 3.5 Calculation and Simulation workflow process

3.5 Analysis

A conclusion regarding the projection can be drawn from the calculations and simulations performed in accordance with the procedure outlined above. Based on the projection done, the most eco-friendly vehicle powertrain in the future can be anticipated. The type of vehicle powertrain that is safe for the environment will emits the least amount of carbon dioxide emission around the world. By forecasting the carbon emission trend, it can help consumers to choose the most environmental-friendly car based on this BMW G20 3-Series case study. In addition, certain enhancements that can be done to improve vehicle quality and reduce emissions will also be highlighted. Last but not least, subsequent advancements from this study will be identified in order to improve future research and findings.