COMPARISON OF CARBON FOOTPRINTS BETWEEN INTERNAL COMBUSTION ENGINE, HYBRID AND ELECTRIC VEHICLES: SELECTED CASE STUDY

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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.

Signed  (Muhammad Syazwan Bin Kamarul Adzman)

Date (02/07/2021)

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.
Other sources are acknowledged by giving explicit references.
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LIST OF ABBREVIATIONS

BEV	Battery electric vehicle
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
PHEV	Plug-in hybrid vehicle
HEV	Hybrid electric vehicle
EV	Electric vehicle
WTW	Well-to-wheel
CO2	Carbon dioxide
LCA	Life-cycle analysis
GHG	Greenhouse gas
US	United States
UK	United Kingdom
BAU	Business-as-usual
ISO	International Standardization Organization
USM	Universiti Sains Malaysia

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PERBANDINGAN PELEPASAN KARBON DARIPADA ENJIN PEMBAKARAN DALAM, HIBRID DAN ELEKTRIK: KAJIAN KES TERPILIH

ABSTRAK

Pemanasan global adalah masalah yang sangat membimbangkan terutamanya penggunaan pengangkutan meningkat setiap hari. Sektor pengangkutan dipercayai antara penyumbang tertinggi untuk pelepasan karbon dioksida global sebanyak 28% pada tahun 2017 seperti yang diumum EPA AS. Ini masalah yang membimbangkan kerana lebih banyak kereta digunakan untuk berulang-alik setiap hari, ini akan meningkatkan pelepasan. Oleh itu, alternatif dan penyelesaian harus dilaksanakan untuk mengatasi masalah alam sekitar ini dan salah satunya adalah menggunakan enjin alternatif seperti kenderaan hibrid dan elektrik. Dalam jurnal ini, jejak karbon akan dikaji untuk tiga enjin termasuk dua yang disebut sebelumnya dan enjin pembakaran dalaman, dari kajian kes Volvo XC40 yang memiliki semua varian ini. Kajian sebelumnya telah mengkaji secara eksperimen jenis kenderaan terhadap alam sekitar, tetapi perbandingannya tidak jelas antara semua. Dalam kajian ini, perbandingan antara epal ke epal dibuat kerana kenderaan ini dibuat dari pengeluar yang sama, sesuai dan terbaru pada tahun 2021, dan mempunyai minimum perbezaan lain di antara mereka. Kaedah yang digunakan adalah analisis kitaran hidup (LCA) untuk setiap kenderaan untuk menentukan jejak karbon dalam setiap kitaran hidup agar perbandingannya adil. Kemudian, unjuran jejak karbon dibuat sehingga tahun 2040. Hasil utamanya adalah; ICEV menghasilkan pelepasan tertinggi, diikuti oleh BEV dan PHEV dengan 8558, 5818 dan 5056 kgCO2/tahun. Dari senario yang dibuat untuk unjuran; pelepasan CO2 dalam Senario 2 (30% BEV) adalah 1.5353x10^12 kgCO2, terendah berbanding dengan Senario 1 (BAU) dan 3 (30% ICE) yang masing-masing menghasilkan 1.42488 x 10 ^ 13 kgCO2 dan 9.70414 x 10 ^ 13 kgCO2.

COMPARISON OF CARBON FOOTPRINTS BETWEEN INTERNAL COMBUSTION ENGINE, HYBRID AND ELECTRIC VEHICLES: SELECTED CASE STUDY

ABSTRACT

The global warming is a very concerning issue right now especially when the use of transportation is increasing day by day. Transportation sector is believed to be one of the highest contributor to the world's global carbon dioxide emission at 28% in 2017 as claimed by US EPA. This is a worrying issue as more cars are being used by every people to commute every day, this will increase the emission. Therefore, alternatives and solutions should be implemented to tackle this environmental issue and one of the solutions is using alternative powertrain such as hybrid and electric vehicles. In this paper, the carbon footprint will be studied for three powertrains including the two mentioned before and internal combustion engine, from a case study of Volvo XC40 that has all these variants. Prior work had studied experimentally the effect of the powertrains to the environment, but the comparison is not clear between those three. In this paper, an apple to apple comparison was made as all the three vehicles are made from the same manufacturer, is ideal and latest in 2021, and has minimum other differences between them. The method used is life-cycle-analysis (LCA) for each vehicles to determine carbon footprint in each life cycle to make the comparison fair and square. Then, a projection of the carbon footprint are made until 2040. The key results are; ICEV produce the highest emission, followed by BEV and PHEV with 8558, 5818 and 5056 kgCO2/year respectively. From each scenario made for projections; total CO2 emissions in Scenario 2 (30% BEV) is 1.5353x10^12 kgCO2, lowest compared to Scenario 1 (BAU) and 3 (30% ICE) that produce 1.42488 x 10^13 kgCO2 and 9.70414 x 10^13 kgCO2 respectively.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Carbon footprint is a broadly used indicator to measure the threat an activity or process has to the environment. According to ISO 14067:2018, carbon footprint of a product is defined as the summation of greenhouse gases (GHG) emissions and removals in a product system, expressed in carbon dioxide equivalents based on a life cycle assessment using the single impact category of climate change. Carbon emissions can be from many activities such as mining, petroleum refining, electricity generation and transportation. Carbon emission from vehicles is one of main contributor to global warming and other pollutions. In the United States (US), transportation is the largest source of carbon emissions. From US transportation sector, half carbon dioxide emissions comes from passenger cars and light-duty trucks [1]. Besides, as reported by United States Environmental Protection Agency (EPA), transportation contributed 28.2% of 2018 greenhouse emissions that mainly comes from usage of fossil fuels in the vehicles [2]. This is a worrying situation because transportations sector is growing significantly nowadays, therefore will contribute more towards pollution in the future. More cars on the road as people are in need of commuting from one place to another for working and other purposes. Besides, a household may also have more than a single vehicle as it has become a form of luxury instead of just needs. This is just a single sector in the world, not taking into account other sectors such as electricity production, manufacturing and many more that also contribute a lot to the environmental pollution.

Minimizing cars in the world is nearly an impossible idea as the sector is growing rapidly, and having a car is a convenient method for people as well as its affordability nowadays. Besides, in Malaysia, most of public transport is quite inefficient and too packed with people in this pandemic. The global automotive motor market size is expected to grow from 20321 million USD now to 25719 million USD in 2025 [3]. It is clear to say that vehicle is still a need for every people. Therefore, there had been some alternatives for traditional industrial combustion engine vehicles to reduce carbon footprints. Some of them are electric and hybrid vehicle.

Some purposes of introduction of electric and hybrid vehicles are to cut cost, changing from reliability of ICE and fossil fuel that is now having depletion as well as reducing the carbon footprints emitted from the vehicle. But, the truth and efficiency of these alternatives are still a question mark. In this research, its purpose is to compare the carbon emission from internal combustion engine, electric and hybrid vehicles in selected case studies and a conclusion will be drawn for each type as well as their prospect in the future.

This study is very important because the greenhouse gas emissions from passenger vehicles are majorly contributing to the global carbon emission. Besides, with the rising of new type of vehicles such as electric (EV) and hybrid vehicle (HV), their carbon footprint must be determined and compared with the conventional internal combustion engine vehicles (ICE). In this paper, the models from Volvo XC40 variants including all those three engines are being used to make an apple-to-apple comparison. A conclusion can be made after the assessment to determine which type of vehicle is the best to reduce the carbon emissions from passenger vehicles. Some studies had been made on carbon footprint from passenger vehicles, but in this paper, a comparison between the most used and popular vehicles at least in Malaysia that are ICEV, EV and HV are made for a better understanding and comparison. There are a few ways in determining the carbon footprint in a vehicle and one of it is life-cycle assessment (LCA). Besides, all the methods of analysis have their own advantages and disadvantages. Each of them can be used in different purposes or objectives of the experiment. Therefore, a lot of data can be obtained from the published sources to make the comparison.

The first significance of this research work is to provide a clearer comparison between the most popular vehicle types in Malaysia. By doing so, everyone can know the better choice of vehicle to choose from when buying their new car, in terms of performance and their contribution to some major environmental problems. The highest contributor to carbon emission from these type of cars should be improved, or avoided by buyers for the sake of their health and air they breathe in.

In this paper, it is represented by data collected from literature reviews of some relevant journals, articles, books, reports, and other sources. The sources can be found from some webpage or open sources such as Google Scholars, Taylor & Francis,

Scopus and Science Direct. The accessibility from open Athens in USM Engineering Library Off-Campus log in. Keywords used in search engines are like carbon footprint, carbon dioxide emissions, emissions from transportation, and many more. All the data or information collected are reviewed, analyzed and studied in detail to provide a conclusion at the end of the paper. Software such as MATLAB Simulink and SPSS are used for data analysis in this research. After the in-depth-reviews made at the end of this paper, a clear conclusion will be drawn to determine which type of vehicle is the best to minimize the carbon emission to the environment.

1.2 Objectives

The objectives of this research are:

i. To compare the carbon footprints of internal combustion engine, electric and hybrid vehicle in a fairly basis based of real life example.

ii. To make a projection based on each vehicle's carbon footprints and their prospect in the future until 2040.

1.3 Problem Statement

Global warming is a major problem in today's world, and transportation is one of its main contributor. For the past few decades, carbon dioxide emitted from passenger vehicles are about 4.6 metric tons per year [3]. So, decarbonization of internal combustion engine cars using alternatives such as hybrid and electric vehicles had been used lately. Therefore, studies are made to compare the carbon footprints of these type of vehicles to validate which type is the best to tackle this issue. Most journals published just shows the carbon footprints of each separate type. Hence, the objective of this paper is to compare these three types of vehicles related to few real examples as case studies.

1.4 Scope of Project

In this experiment, it will focus on carbon footprint or carbon emission only. Other greenhouse gas emissions such as methane will not be considered. The data is only taken from online sources and not through experimental activities. Besides, vehicle type considered in this experiment are only passenger cars available in the market. Bus, van, motorcycle and other vehicles are not taken into account. In addition, only three type of passenger car engine are considered which are gasoline internal combustion engine (ICEV), battery electric (BEV) and plug in hybrid (PHV) vehicles only from Volvo XC40 variants for purpose of selected case study. Other type such as hydrogen and diesel are not considered. Lastly, the life cycle analysis (LCA) of the vehicles only consider fuel production, distribution, vehicle production, vehicle operation and emissions for ICEV. For BEV, it considers electricity production, transportation, vehicle production, vehicle operation and emissions. Both consists of Well-to-Tank and Tank-to Wheel analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions and Terms

2.1.1 Definition of Carbon Footprints

Based on what had been discussed in the introduction above, carbon footprints is defined as the summation of greenhouse gases (GHG) emissions and removals in a product system, expressed in carbon dioxide equivalents based on a life cycle assessment using the single impact category of climate change [4]. It can also be defined as a calculation of the total amount of CO2 emitted either directly or indirectly from a series of activities [5] such as electricity usage, mining activities, paper and plastic usage, the process of food and beverage production, construction activities, vehicle traffic, and other actions associated with daily life. GHGs trap heat in the atmosphere. There are four main greenhouse gases, namely carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and fluorinated gases. The major contributor of CO2 emissions is urbanization and transportation because transportation is essential for carrying out daily activities, such as commuting to and from work and school or traveling.

2.1.2 Definitions of ICE, EV and PHEV

Internal combustion engine vehicles are the most popular and most used type of vehicles in the world. In the US alone, it is estimated exceeding 250 million of highway vehicles use internal combustion engine [6]. It is approximately 1.332 people per ICEVs in the country. ICEVs had been around since 1885 when first built by Karl Benz and had been transporting people around for hundreds of years because of its reliability. It can operate using gasoline, diesel as well as renewable alternatives such as natural gas and biodiesel. To produce energy, combustion takes place from the mixture of air and fuel within the engine. The work produced then turns the piston and rotates the crankshaft which in turns drives the wheels through some more sophisticated systems and processes. Besides, ICEVs can also be divided and grouped into their own characteristics such as the number of cylinders, cycle of combustion, cylinder arrangement, method of ignitions and many other ways. The problems with ICEVs are the reliability towards

unrenewable fossil fuels, inefficiency of alternative fuels relative to fossil fuels and the worst is the emissions towards the atmosphere. The tailpipe emissions of the ICEVs are one of the major contributor of GHGs in the world, so the impact towards the environment is in a huge threat. Therefore, some of alternatives such as lower emission fuels and battery as well as hybrid engines had been produced and manufactured recently.

On the other hand, all electric vehicles or EVs or BEVs are a vehicle that uses battery to store electrical energy to power the motor. Besides, EVs also can reuse the energy from regenerative braking and do not waste energy idling. Therefore, it is more efficient in city driving that can utilizes more regenerative braking as more stops in city compared to the highways. Although it is comparatively more expensive than hybrid and ICEVs, but it is very good in reducing the emissions as no tailpipe emissions released by BEVs, even the generation of electricity produced emissions depending on the sources used [7]. The disadvantage of EVs is its driving range is not as far as ICEVs per charge. In addition, the less number of charging points also especially in Malaysia creates problem and anxiety to users to buy BEVs as the facilities are still in development state.

Lastly, hybrid electric vehicles HEVs utilizes the combination of ICE and batteries. Therefore, it has the benefits of both ICE and BEV discussed earlier, but at lower rate as trade-offs. Mild hybrid can turn off the engine when the car stops at the congestion or traffic lights. But, it cannot uses electricity only to power the vehicle. On the other hand, full hybrids have more powerful motors and bigger batteries that can produce more power in short range. Parallel hybrids uses mechanical coupling to connect the motor and engine to the wheels and both of them drives the wheel directly. While series hybrids that commonly used in PHEVs use inly the electric motor to drive the wheels [8]. PHEVs has the ability to charge the batteries from the chargers and regenerative braking as well, when the motor act as generator. It is also typically has larger battery packs than hybrid vehicles, so it can travel further just by using electric. When the battery low, in accelerating, high heating or high air conditioning loads, ICE can come to work and operate [9].

2.2 Brief Data of Carbon Emissions

2.2.1 Global Data of Carbon Emissions

China and India as well as United States are the biggest contributor to the greenhouse gas emission. The transportation sector in US was the second largest source of carbon dioxide (CO2) emissions globally. It directly emitted approximately 27% of total U.S. greenhouse gas (GHG) emissions in 2003. Latin American carbon emissions from transport, mostly from cars, are predicted to grow threefold by 2030 as both automobile ownership and vehicle use expand [10]. The United States Environmental Protection Agency stated that, in 2017, the transportation sector contributed the largest percentage of CO2 emissions (28.9%), followed by electricity (27.5%), industry (22.2%), commercial and residential buildings (11.6%), agriculture (9%) and land use and forestry (0.8%) [11].

2.2.2 Local Data of Carbon Emissions

Malaysia is second largest per capita greenhouse gas emitter among the group of ASEAN countries [12]. Besides, we already surpassed many developed countries in terms of GHG emission [13]. For car ownership, Malaysian had one vehicle for 3 people in 1995 and in 2010, 1.4 people had one car [14]. Therefore, the GHG gas emission will be more as vehicle on the road is increasing significantly. Plus, most vehicles in Malaysia is using fossil fuels as development of battery and other alternative cars are still not popular. Transport sector of Malaysia produced 42.43 million metric tons CO2 which shares 22.9% of total CO2 emission in Malaysia. Increased number of registered motor vehicles is expected in years to come which will certainly increase the emission further. Cars are the major emitter of CO2 which stake about 59% of total emission from road transportation. This indicates that private transportation is the major sources of CO2 emission from road transportation [10]. Besides, the number of used cars that is increasing in Malaysia will also contribute more carbon emission to the atmosphere [15].

2.3 Factors Affecting Carbon and GHG Emissions

Some aspects that directly affect GHG emissions based on study from [16] includes fuel efficiency, distance travelled and type of fuel used. In addition, driving condition also plays an important role in determining the emissions. Almost 53% higher carbon dioxide released into the environment when a vehicle is in congested traffic [17]. There are some issues in calculating GHG emissions using number of vehicles as the number of vehicles are larger than licenses issued which is 25 million compared to only 14.3 million licenses issued [18]. This will be a difference in calculation. So, vehicle kilometer travel (VKT) is used to match the numbers. Based on results obtained in [16], car has biggest VKT compared to other vehicles and contribute the most to GHG emissions. In fact, petrol based car emits 189.63 gCo2eq while electric car emits 129.43 gCo2eq [19]. A study shown that fuel-switching option can reduce GHG emission in a relatively shorter time and energy efficiency option can work in a longer term [20]. Therefore, it is a good option to use alternative fuels such as biodiesel and use more advanced technologies such as battery and hybrid vehicles. In addition, in electric car, the source of electric generation also becomes a huge factor in determining the WTW emissions for the vehicle. That is why it is important to know the source of generation mix for electricity in a certain region or country. The use of renewable energy such as hydro or solar to generate electricity is more sustainable and environmental friendly than the use of coal and fossil fuels.

2.4 Methods to Calculate and Collecting Carbon Emissions Data

Carbon dioxide released or emitted to the atmosphere increased when the harmful pollutants derived from fossil fuels form a reaction with chemical substances in combustion process. The type of fuels used and condition of vehicles play important role in determining the amount of carbon dioxide released [21]. Besides, larger displacement engine produce more fuel consumption and emissions. So, the size of vehicle and the engine also will lead to different amount of emission [22]. Therefore, comparisons of same type of vehicles with almost the same size and weight is used in this research to conduct a fair and accurate comparison.

Approved by the US government, a method from Asian Development Bank is used considering distance travelled, fuel consumptions, type of vehicles and speed traveled to measure the carbon footprint. The CO2 emissions factor of the travel mode is multiplied with the individual travel distance. The formula or equation can be seen in Eq (1) [23].

$$Mi = Di \times Ei \quad \text{..... eq.(1)}$$

Mi: individual commuting CO2 emissions,
Di: the individual commuting distance and
Ei: the CO2 emissions factor of the travel mode

Next, CO2 emitted increase in proportion as fuel consumed is increased [24]. The methods can be used using the formula in Eq (2) below.

$$XUsedFuel = D * Caverage * Y \quad \text{..... eq.(2)}$$

XUsedFuel: the energy consumption for road transportation (kWh),
D: the route distance (km),
Caverage: the average fuel consumption (liters/km)
Y: the conversion factor for each fuel (kWh/liters), where Y = 9.2 for gasoline and Y = 10 for Diesel.

Besides, the fuel consumption model can be expanded by including the weight of vehicles, its technical data, and distance travelled. The Eq (3) below shows the formula to calculate the CO2 emitted considering these data [25]

$$C = FC * f \text{ …….. eq.(3)}$$

C is CO2 emissions from transportation (kg CO2),
FC is the fuel consumption of the vehicle (L/100 km),
f is the fuel-based emission factor (kg CO2/L).

In addition, Gharineiat and Khalfan [26] calculated CO2 emissions based on Eq (4) below. The constants include inertia, drag, and grade on fuel consumptions.

$$f(x) = fi\ vs + cK \text{ …….. eq.(4)}$$

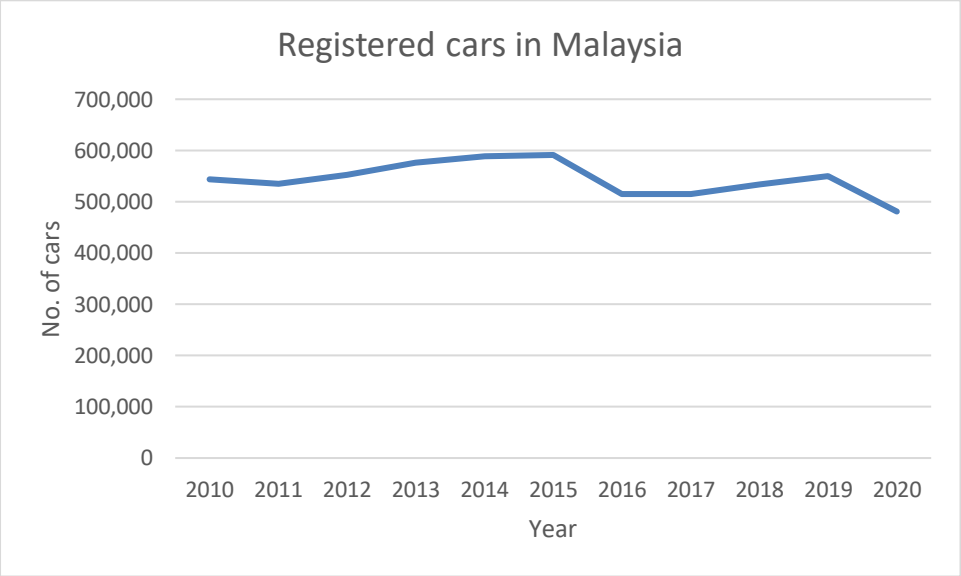
where;
fx is fuel consumption per unit distance in ml/km,
vs is mean network sped in km/h,
fi is idle fuel consumption rate in ml/h,
c is regression coefficient,
K is adjustment factor.

Nowadays, a promising recent approach used air quality monitoring instruments or equipment and the green-transportation sector. Several parameters are taken into account for example vehicle and fuel type as well as distance travelled. A hand held device can be used to measure the air quality [23]. The major benefits of using this device and approach is it can save time and cost, accurate for all chemicals in GHGs including methane, nitrogen oxides, ozone and other gases. Therefore, with the other gases calculated too, it can facilitate future research from upgrading exisiting research without having to go to the site for observation. In conclusion, a lot of methods can be used to calculate CO2 emissions, depending on our data in hand and objectives.

2.5 Car Sales of ICEVs, BEVs and HEVs

According to Malaysia Automotive Association (MAA), registered cars in Malaysia in 2020 had seen a significant drop from the increasing trend from the past few years. For last year, Malaysia had recorded a total of 480965 new cars all together. It is below than in 2019 when its recorded around 550179 [27]. The trend can be seen in the chart below.

Figure 2.1 New cars trend in Malaysia



It is believed that the trend drops because of the pandemic that hit the country and all over the world. The pandemic had created fear among users to spend money on cars as a lot of people lose their job due to lockdown and economic problems.

From data of US, car sales in the country reach up to 14.5 million cars in 2020. It also recorded a significant drop in sales from the previous year which is 17.1 million cars in 2019. On the other hand, the world electric car stock increased around 40% in 2019 from 2018. But, the stock rose at a slower increment than in 2018 and 2017 which rocketed by 63% and 58% respectively. The total number of electric cars almost half can be found in China that was around 47%, a quarter in Europe and 20% in the US. In addition, global EV car sales exceeded 2 million in 2019 after passing the 1 million benchmark in 2017. Around the globe, BEV sales increased in 2019 by 14% compared to the previous year. But, the sales of PHEV decreased by 10%. The rapid growth shows that the EVs are getting places in the market especially in the developed

countries. To conclude, the sales of EVs is still showing major progress, but the overall growth is quite slow compared to 2018. This is believed to be because of a few factors such as cutting of purchase subsidies, expectations from buyers about more technology advancement in EVs and contracting vehicle markets. In 2020 and above, the market may be experiencing slower growth as the pandemic hit the world that forced some productions to be delayed and the purchasing power is low due to economical factor.

2.6 Policies

Several international accords had been agreed by Malaysia to commit with the increasing climate issues such as 1997 Kyoto Protocol and 1987 Montreal Protocol. In addition, a climate summit in Copenhagen had also been conducted to reduce the emissions. Internally, the government of Malaysia in 2009 had developed the National Green Technology Policy (NGTP) that includes initiative to implement environmental friendly technologies that can reduce GHGs released to the environment [28].

In addition, under the United Nations (UN), Malaysia had agreed to commit in Paris Agreement under UN Framework Convention on Climate Change (UNFCCC). This agreement consider different countries to have different responsibilities to encounter climate change to give fairness to developing countries. Reports on efforts to tackle the issues must be submitted to UNFCCC from every countries involved. For Malaysia, by 2030, we had committed to reduce the GHGs emissions by 45% as related to Malaysia's GDP in 2005. The proportion is set as 35% unconditional target and 10% conditional after receiving funding, technological transfer and helps from developed countries. Half of forest and tree also had been agreed to be preserved and maintained by the government. Besides, Malaysia also had conducted initiatives with some plans. First and foremost is Energy Efficiency Action Plan . The goal of the plan is to reduce 13.113 million tonnes of carbon dioxide by 2030. Besides, development of Mass Rapid Transit MRT had also made a huge success by reducing almost 10 million cars in 2017 and estimated to reduce more in 2020 until 2030 by almost 89 million cars [29].

Besides, in automotive sector, Malaysia had also developed National Automotive Policy (NAP). In NAP 2014, it focused on transforming our country into an Energy Efficient Vehicle (EEV) hub. Mainly in green and sustainability. o In 2020 until 2030, connected mobility had become the main target that will enhance country's auto industry in the era of digital industrial transformation. o NxGv or Next Generation Vehicles is environmentally friendly and fuel efficient with low emissions vehicles including EV, HV, PHEV and FCV. NxGV standards for all vehicles will be developed by year 2021 to ensure NxGV market penetration by year 2025. Malaysia also had established National Emissions Test Centre (NETC) from NAP 2014. NETC provides testing facilities in measuring vehicle emission pollutants and fuel consumption. NETC is the most advanced emission testing facility in the ASEAN region (measures up to Euro 6d Emission Standard - WLTP). Besides, EEV penetration has been successfully increased from 14% (93975 units to 62% (339978 units). The green vehicle sales in ASEAN, meanwhile, achieved 32% penetration in 2018. In 2018, global total green vehicles sales are 4067460 from 91906886 global vehicle sales which accounts to 4%. Increase from 2% in 2014.

The first objective of NAP 2020 is to develop the NxGV technology ecosystem to make Malaysia as a Regional Hub for the production of NxGV. The last but not least objective of NAP 2020 is to reduce carbon emission from vehicles by improving fuel economy level in Malaysia by 2025 in line with the ASEAN Fuel Economy Roadmap of 5.3 Lge / 100km. The direction of NAP 2020 in technology and engineering is to expand the EEV tech and engineering to NxGV, MaaS and Ir4.0 in unison. The strategy of NAP 2020 is to promote the adaptation of new, more environmentally friendly elements of techs that will address the pollution issues. Critical components & systems to be developed including hybrid, EV and FCV in direction1 of NAP2020. Specific measures also conducted in EV including Develop EV Smart Grid Interoperability Centre, and Promote manufacturing and application of local battery and battery pack together with development of Battery Management System (BMS) and Thermal Management System (TMS) in Phase 1 (2020-2024). In Phase 3 (2028-2030), mass deployment of ultra-fast charging is going to take place. In investment (Direction 2), the issuance of EEV manufacturing license will be continued as one of the measures. A customized incentives also given for certain criteria including fuel consumption and carbon

emissions. For Market Expansion (Direction 3), measures taken including expanding soft loan scheme to promote new export areas such as NxGV, MaaS and IR4.0 related services [30].

2.7 Mitigating Measures

Development and usage of EEVs has a great potential to lower the CO2 emissions in our country. It is one of the content in NAP already and can be achieved an immediate result and already shared 52% of new car sales in 2017. Besides, EVs promotion can also lead to reduction in CO2 emissions given some criteria been taken by the government for example the electricity generation, more charging stations and lower the cost of vehicles. Thirdly, usage and expanding of public transports especially in city area is a good initiative to reduce cars, traffic congestion and further reducing carbon emissions. Besides, government should make a more efficient connectivity for public transport to boost the usage and ridership. The last but not least, biofuels usage in vehicles is also believed to lower the emissions if more research and development can be done in the future to increase the efficiency of the biofuels, given that our country has the sources [31].

To increase the usage and buyers' confidence in buying EVs Tenaga National Berhad (TNB) and Malaysia Green Technology Corporation (MGTC) had planned to add more charging stations in Malaysia. Up to 100 stations worth RM1.5 million are going to be installed to add on to 14 ChargeEV stations so far in October 2019 [32].

Some countries had made their voice heard loud in their effort to promote EVs and ban ICEs. The UK has made a commitment to halt the sale of conventional petrol and diesel-powered cars and vans by 2040 and reduce by 2050, national vehicle emissions reduced to zero. Besides, Taiwan has committed to banning the production of non-electric motorcycles and four-wheel drive vehicles by 2035 and 2040, respectively. Norway that sold 52% of their total car sales in 2017 also had given a lot of subsidies to the buyers. In Germany, they are considering to ban all ICEs by 2040, same goes to UK. France and Ireland pledges to stop selling of ICE cars by 2030 and Belgium also impose diesel ban in its capital. By looking at all these measures taken by the governments around the world, it is believed that EVs promotion is slowly taking place and will replace ICEs in the future. But, it is still unknown whether this process will be successful or not as no country has really passed a law prohibiting ICEs yet. It means in regulation, no law is enforceable yet, just commitments from governments and politicians [33]. Therefore, hopefully these effort will be taken seriously and enforced in the law books to make a

more drastic change towards carbon emissions into the environment. Also, by these efforts taken by the developed countries, hopefully the developing countries can also have the ability to follow this meaningful step in tackling the issue.

2.8 Conclusions

In short, carbon emissions from transportation is one of the major contributor towards climate problems. This need to be tackled seriously as we need to preserve the nature and environment for our future generation. But, we also need to make sure not to sacrifice the present needs such as easy mobility. Therefore, sustainability development and advanced technologies need to be used wisely, for example BEVs and HEVs or efficiency improvement of ICEs. Several steps can be used to calculate GHGs emissions. This paper will utilize the method of collecting data from published reports, journals or articles from reliable sources to make a comparison between the three power trains. A lot of journals had been published in relevance to this topic but in most of journals I researched, most of them just shows the emissions from individual powertrains such as in EVs only. In paper such as in [34], all three vehicles are compared using experimental method in Italy. This paper will fill the gap with the use of one of most recent cars in 2020, from same manufacturer, under same model which is Volvo XC40. Therefore, a better comparison can be made as the specs are mostly the same. In addition, power generation mix covered in this paper is also from Malaysia. As electricity mix is an important factor in affecting GHGs emission for BEVs in WTW analysis, this paper will paint a better picture about the usage and comparison in Malaysia. Lastly, a projection will also be made to predict or forecast the trend of those three type of vehicles in the future.

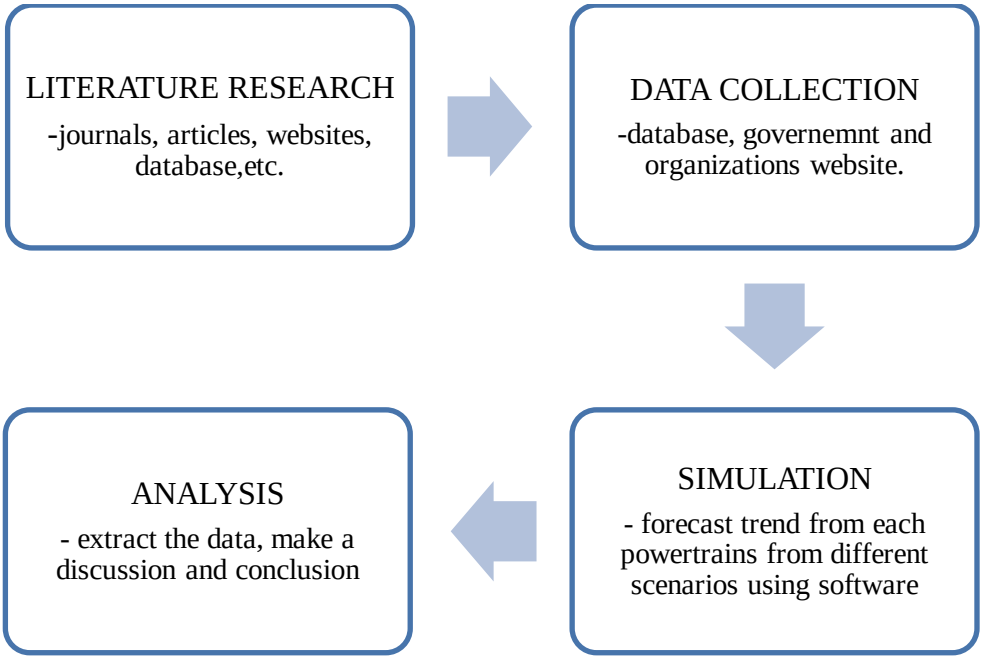
CHAPTER 3

METHODOLOGY

3.1 Overview

This research paper contains several important steps or procedures to be completed. It firstly includes literature research from related journals, websites, reports and other reliable sources. Next, a lot of data and information were extracted from those sources or other government or organizations websites and annual reports. After getting all the necessary data, a simulation is conducted based on some scenarios chosen in this paper. The results were divided into carbon emissions from different type of vehicles including ICEV, EV as well as PHEV as well as carbon emissions prediction from transportion sector in the next few years to come. The research is related to a case study chosen from Volvo XC40 variants that include ICE, battery and plug in hybrid. From the simulation, the results were analysed and discussed to provide a conclusion of the projections made. The overview of the steps and overall methodology of the research are shown in Figure 3.1 below. In this paper, Volvo XC4O was used in comparing the different powertrains as it offered all variants ranging from ICE, BEV and PHEV. The 1.5L, 3 cylinders turbo is an ideal standard mostly used by modern car manufacturer nowadays. Besides, the differences between each powertrains in other aspects is minimum as they are manufactured in the same factory, by the same company. Therefore, this justifies the reason why Volvo XC40s are used as the comparison in this paper.

Figure 3.1 Flow chart of methodology overview



3.2 Literature Research

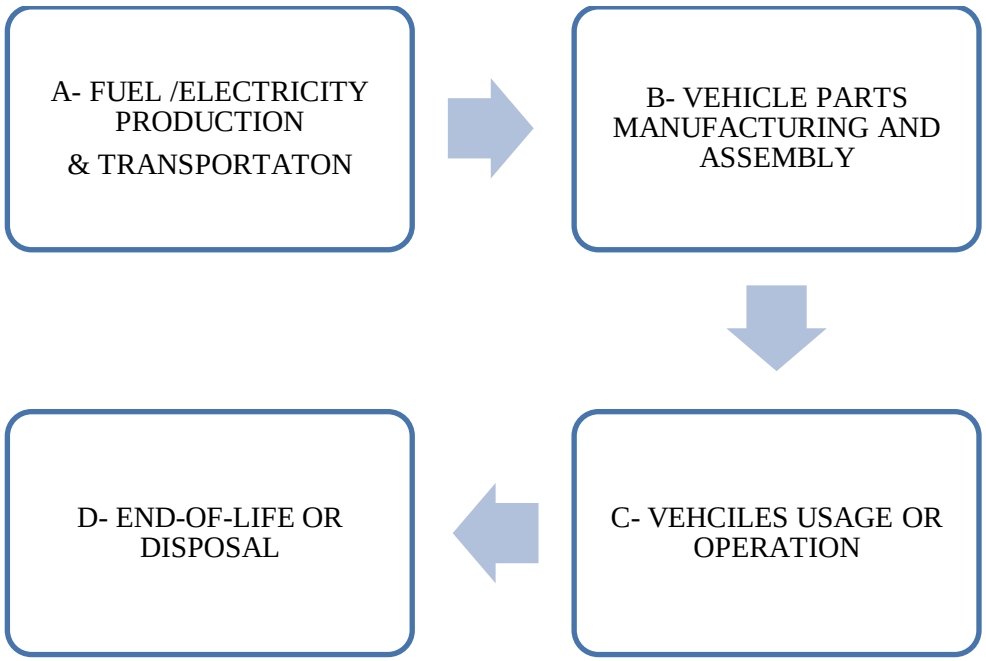
Before conducting the research, a lot of literature reviews had been made. As this paper is about data analysis and nothing experimental involved, a lot of information were collected through review and research of past papers. Plenty of sources involved especially electronic sources from USM off-campus login including articles, journals and e-books. The sources were searched from Google Scholar, SCOPUS, Science Direct, Springer as well as Taylor and Francis. Keywords used to find relevant articles are like carbon footprint, carbon dioxide emissions, electric cars, hybrid cars, emissions from transportation, and many more. Besides, research was also made in policies from countries around the world especially Malaysia in reducing emissions from transportation sector.

3.3 Data Collection

The data collected are from different sources in Malaysia and around the world. A lot of data are very hard and difficult to get in Malaysia as some of them are not published to the public, for example the emissions from electricity generation in Malaysia. It was a non-disclosure data and not accessible to the public. Therefore, the data was collected also from published journals that do the calculations on this matter. In addition, the data from US are easily accessible due to the publishment in certain websites such as in US Department of Energy (USDOE), United States Environmental Protection Agency (EPA) and International Energy Agency (IEA) websites and reports. From Malaysia, the data can also be found from annual reports from Malaysia Green Technology Corporation (Green Tech Malaysia) and Malaysia Energy Statistics Handbook from Energy Commission.

For all three types of vehicles, life-cycle analysis (LCA) will be conducted. From ISO, LCA is defined as compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle including raw material acquisition , power or fuel generation to disposal of the vehicle. The details of the LCA determined in this paper is shown in Figure 3.3 below.

Figure 3.2 System Boundary for LCA study in this paper



As can be seen in Figure 3.2 above, there are four main phases in the calculation of LCA in this paper. Maintenance phase is not considered as it is believed to have just a little contribution to GHGs emissions from the vehicle.

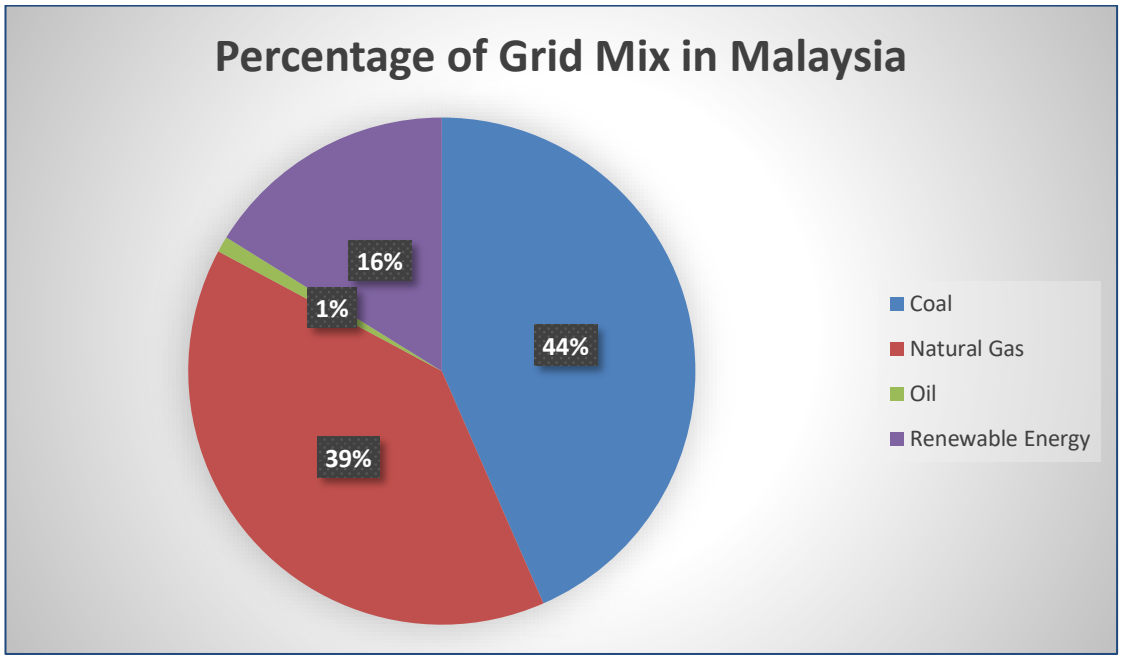
3.3.1 Fuel or Electricity Production and Transportation

The first phase of phase A is from the production of fuel for ICE and electricity generation for BEV and PHEV. The electricity generation includes tank-to-wheel (TTW) analysis in Well-to-tank (WTW) analysis such as extraction, refining, transportation, production and distribution of fuel. In electricity generation for BEV, it considers the generational mix or grid mix used in Malaysia that composed of coal, natural gas, hydro, diesel and other sources in their own unique proportion. It is believed that this consideration is important because different generation source emit different amount of GHGs to the atmosphere. In countries that use renewable energies as the main source of their electricity generation, they amount of GHGs emissions from usage of power in BEV is considerably lower than regions or countries that use non-renewable energy such as coal. Figure 3.3 below shows the proportion of sources used in electricity generation in Malaysia power grid and Figure 3.4 shows process in petroleum production. The table 3.1 below shows emissions from different primary source for electricity generation [35].

Table 3.1 CO2 emissions from different energy source

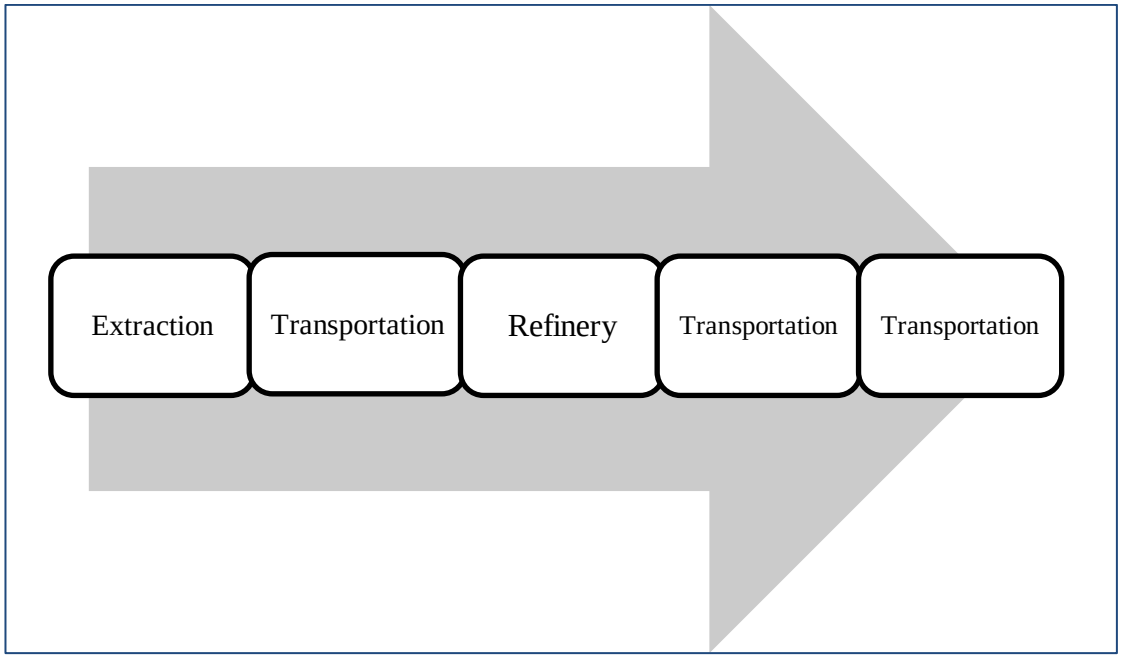
Source	Coal	Natural Gas	Co-gen	Oil	Biomass
Co2 (kg/kWh)	0.918	0.595	0.440	0.739	0.055

Figure 3.3 Percentage of electricity grid mix in Malaysia



Source: Malaysia Energy Commission (2018)

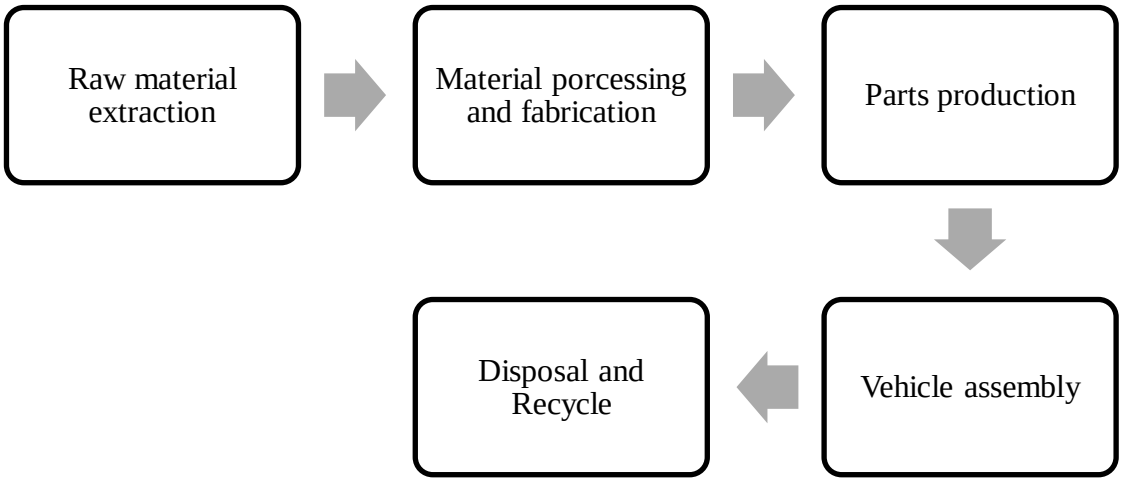
Figure 3.4 Process in petroleum production



3.3.2 Vehicle Parts and Manufacturing Assembly

Next, in phase B of vehicle parts manufacturing and assembly, it includes raw materials exploration and extraction, material and components production as well as vehicle assembly. Besides, it can be simplified into process types such as part fabrication, subassembly manufacture and vehicle assembly. The process in this stage includes stages as can be seen from Figure 3.5 below.

Figure 3.5 Phase B stages



Every different process and materials will emit different amount of CO2. In addition, electric batteries will have a significant impact in weight for BEVs, so it will increase the emission of CO2. In the manufacturing of battery itself will emit an amount of CO2 into atmosphere including in lithium exploration. The data for this phase is get from [36]. It is assumed that all cars have the same components and proportion of material compositions, material distribution and transformation processes. From the data, a lot of individual processes can be calculated to determine the carbon emissions but the data of processes related to production of Volvo XC40 is not publicly available. Therefore, a special case linear equation in Equation (5) below can be used.