Title	Policy Planning and Environmental Burden Estimation for Passenger Vehicle Ownership in Malaysia using System Dynamics Modeling Method
Author(s)	Bin Azmi, Muhammad
Citation	大阪大学, 2017, 博士論文
Version Type	VoR
URL	https://doi.org/10.18910/61777
rights	
Note	

Doctoral Dissertation

Policy Planning and Environmental Burden Estimation for Passenger Vehicle Ownership in Malaysia using System Dynamics Modeling Method

システムダイナミクスモデリングを利用したマレーシアにおける

乗用車保有に関する環境影響評価と将来計画立案

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January 2017

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Osaka University

Acknowledgement

Most thankful to Allah S.W.T for allowing me an opportunity to complete my research successfully through health and providence.

Foremost, I would like to express my deepest and sincerest gratitude to my PhD supervisor, mentor and guide; Professor Tokai Akihiro for the endless guidance, advices and support throughout the completion of this study. I truly appreciate your concern, assistance and comments throughout my study. Also, mountain of appreciation for all the help provided when my baby decided to see the world much earlier than expected.

Special appreciation to Special Professor Tadashi Itoh for his goodwill in introducing me to honourable Tokai Laboratory, and Deputy Vice Chancellor of USM Malaysia Professor Abdul Rahman Mohamed for his massive help.

Thank you also to my PhD referees, Professor Akira Kondo, and Associate Professor Takashi Machimura for all the honest criticism, idea and impressive interest given throughout my PhD defence and dissertation preparation.

Also, many thanks for Dr Kojima, Dr Ming Xiang, and Dr Narila for the ideas and critics on my work. It all helped to complete this study. A special thanks for Dr Ibnu Susanto for forcing me to learn System Dynamics Modeling the hard way, and all the positive discussions. Not forgetting, thanks to all students in Tokai Lab for being a supporting friend.

To my beloved mother Datin Norhayati and father Dato' Azmi Mohamad, thank you very much for the support as well as the endless motivation given. I love you both.

Last but not least, special thanks for my wife for taking care of all my needs and being on my side all the way. I could have never able to finish this study without your support.

Abstract

Malaysia is aspired to reduce national greenhouse gas emission intensity against GDP to 45% of 2005 emission by 2030. Much effort has been spent on increasing utilization of renewable energy. However, transportation sector, which are the second biggest source of GHG emission and pollution is not being improved as much as it should have been. Leading to this is the concern that prioritizing environmental friendly transportation will have unwanted consequences on the economy. Consequently, quantitative and comparative analysis is required in order to provide rigorous and comprehensive insight of any policy impact designed to govern transportation sector. Passenger vehicle make up the majority of this sector. Hence, finding a better policy solution in managing passenger vehicle is most desirable.

To clarify this problem, a dynamic quantitative tool has been designed using System Dynamic (SD) Modeling approach on environmental policy analysis and environmental impact assessment. A dynamic system is characterized by the mutual interaction, interdependence, and information feedback aided to the better understanding of the problem being studied. This serves as one of the most suitable system for transportation policy analysis.

In the second chapter, a causal loop between population, existing number of vehicles, income capability and vehicle pricing was analysed. The result shows that personal vehicle ownership is nearly reaching the saturation point. Unless amended, this situation will cause passenger vehicle industry to suffer. Present managing policy allows vehicles being used extensively regardless of the tailpipe emissions. Understandably, better replacement vehicles are somewhat beyond the owner affordability. This was also contributed by the steep vehicle tax that are in effect. SD analysis shows that reduction of vehicle taxation coupled with high efficiency vehicles such as Electric Vehicle (EV) and Hybrid Electric Vehicles (HEV) promotion has high potential to increase vehicle replacement with average vehicle age reduced from 15 years to 12 years.

The third chapter extends this result into vehicle tail-pipe emission estimation. An analysis of vehicle fuel consumption and measured carbon dioxide relationship have also reveals that current emission regulation which equals to EURO 2 was insufficient. The model estimated that improvement of tailpipe regulation to at least EURO 4 will reduce overall tailpipe Hydrocarbon (HC) emissions by nearly 70%. However, if no action is taken, tailpipe HC will be increased by 45% in 20 years' period.

In Chapter 4, this research focus on the environmental as well as human health impact caused from vehicle production using Life Cycle Inventory (LCI) Analysis. It is learnt that production of the latest generation EV have the least overall impact on health, which are measured in DALY. Integration of LCI analysis result in the SD model in Chapter 5 reveals that overall, policies which are supportive towards EV have the lowest environmental emission, impact, health and damage potential.

This dissertation proposed a way for environmental policy analysis in order to assist decision makers for better transportation fleet management as Malaysia aims to reduce national overall greenhouse gas (GHG) emissions, as well as environmental impact. However, mismanagement and wrong policy implementation creates lag for technology adaptation leading to negative impact on the economy as well as environment. The execution of SD modeling has higher potential to provide better insight to guide policymakers and stakeholders with quantitative proof and feedback on improvement of transportation related policies for a better sustainable environment, economy and society in the future.

For my lovely Sheila, Azmi Hafiy, and humanity.

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List of abbreviation

SD	:	System Dynamic
CV	:	Conventional Internal Combustion Engine Vehicles
HEV	:	Hybrid Electric Vehicle
EV	:	Pure Battery Electric Vehicles
CNG	:	Compressed Natural Gas Vehicles
MYR	:	Malaysian Ringgit (100 ¥ = MYR 4)
JPY	:	Japanese Yen (100 ¥ = MYR 4)
GHG	:	Greenhouse Gas
CO_2	:	Carbon Dioxide
CH_4	:	Methane
NOx	:	Nitrogen Oxides
SOx	:	Sulphur Oxides
HC	:	Hydrocarbon
CTG	:	Cradle-to-Gate
WTT	:	Well-to-Tank
LCI	:	Life Cycle Inventory
DALY	:	Disability-Adjusted Life Year
NMC	:	Nickel Magnesium Cobalt. One type of Lithium Ion Battery chemistry.
NiMH Battery	:	Nickel-Magnesium Hydride Battery
Li-Ion Battery	:	Lithium Ion Battery

Chapter 1. Introduction

1.1 Background

Climate change caused by increasing levels of carbon dioxide emissions has emerged as one of the most challenging environmental problems in recent decades. It is a global issue that directly or indirectly affects every country on Earth. Further, more anthropogenic greenhouse gases will be emitted as nations continue to develop, rapidly urbanize, and industrialize, thus adding impact to climate change (Kasipillai and Chan, 2008). In fact, the total annual carbon dioxide equivalent emissions have increased by about 2.4% per year, from 22.5 billion tons in 1990 to 35.67 billion tons in 2014 (Olivier et al., 2015), nearly double the total emissions from 1980.

Greenhouse gas (GHG) emissions from transportation sectors have been a popular discussion topic among scientific environmental communities and activists. Emissions include carbon dioxide (CO2), methane (CH4), and nitrogen oxides (NOx). The majority of the transportation sector's GHG is CO2 released from the combustion of petroleum-based products such as gasoline. Waning global oil prices are also unfavourable to global sustainability as they lead to greater oil production and consumption and the CO2 emissions that follows (Balaguer and Cantavella, 2016).

Malaysia has announced reduction of GHG emission intensity based on its gross domestic product (GDP) in the 2009 Copenhagen United Nations Climate Change Conference. There, Malaysia pledged a 40% reduction of carbon dioxide intensity in terms of GDP in 2020, compared to 2005 emissions. As a result, Malaysia managed to reduce carbon intensity per GDP to 44%, six years earlier than planned (European Comissions, 2015), thus prompting the country to increase the target to 45% in 2030 during the Paris 2015 UN Climate Conference (UNCCC, 2015). However, emissions per capita increased by 13% over the same period, forcing Malaysia to rethink its environmental footprint strategy. Therefore, the country needs to take prudent measures for climate-friendly development of transportation to fulfil national aspirations for sustainability (Shahid, Minhans and Puan, 2014).

Some are also concerned that CO2 reduction efforts will inherently create a trade-off with economic growth (Joyosemito, Tokai and Nakakubo, 2013), not excluding the transportation sector. Nevertheless, vehicle technology advancement continues to improve, and this could decelerate CO2 emission growth and enable the country to offset its CO2 emissions (Rahim, 2014), especially with the introduction of higher-efficiency vehicles and lower-emission technologies. Unfortunately, current Malaysian vehicle management and recycling policies have the potential to hamper this technology from seeing mass application (Azmi et al., 2013).

1.1.1 Transportation Sector: Malaysia and The World

The transportation sector plays a vital role in driving the national economy and improving the livelihood of society. In developed nations, cities, and most nations' capitals, modern transportation systems, such as mass transit subways and commuter railways, reduce commuting time *and* environmental impact. However, in underdeveloped, developing nations and rural areas, most people rely heavily on traditional modes of transportation such as passenger cars, motorcycles, taxis, and buses (Timilsina and Shrestha, 2009). Moreover, personal car ownership generates billions of direct revenue to the government through taxation and excise duties. These, mostly internal-combustion-engine vehicles, consume natural resources while contributing to environmental deterioration because they are responsible for a large and growing proportion of GHG emissions.

Global anthropogenic carbon dioxide are increasing alarmingly in since the past decade with forecasted to pass 400ppm in 2016 (Betts *et al.*, 2016) caused from fossil fuel burning and human need for energy and mobility. This is made worse by transformation of carbon sunk forest into residential and food production area. This situation will most likely bring catastrophic consequences if it remains increasing.

The US Environmental Protection Agency estimated that over half of the transportation GHG released in the United States is contributed by personal passenger cars and light-duty trucks. Also in the United States, the transportation sector serves as the second largest single contributor of national GHG—26% of the total in 2014 (US Department of State, 2014). This is slightly lower than the total emissions from the production of the electricity sector at 30%, highlighting the importance of properly managing this problem. Unfortunately, emissions from the transportation sector are more challenging to manage and estimate due to the high number of vehicles and multiple variables involved.

However, increasing environmental awareness and desire to reduce our reliance on fossil fuel give rise to the introduction of Hybrid Electric Vehicle (HEV) and pure battery driven Electric Vehicles (EV) to reduce the impact from transportation sector. These new generation vehicles tend to have higher fuel efficiency and lower emissions compared to current mass produced conventional internal combustion engine vehicles (CV).

Hosting the largest fleet of electric and hybrid vehicles, passenger car transportation sector in European Union only consist of 12% of the total CO_2 gas emissions. However, this does not stop the EU from introducing newer policies to reduce this sector's impact even further. Main targets include legislation requiring new cars to emit less than 130g of CO_2 for each kilometre travelled by 2015 and less than 95g of CO_2 per kilometre by 2021 (Haq and Weiss, 2016). A penalty payment system for excess emissions, focused on vehicle manufacturers, is also being implemented. Finally, the EU provides incentives for manufacturers of highly efficient vehicles via its super credits incentives system.

Several other countries also proven to be the leader in New Generation Vehicle production and adoption. Japan for instance is seeing registered New Generation Vehicle to be exceeding five million units in 2015 (Japan Automobile Manufacturers Association Inc., 2016) which was driven by government policy towards clean emission vehicle. Norway on the other hand sees 22% of total vehicle sales in 2015 contributed by EV (Jeff Cobb, 2016). Increasing trend of New Generation Vehicle ownership can be seen across European Union countries due to various EV and HEV friendly policies and incentives(International Energy Agency Organization, 2015).

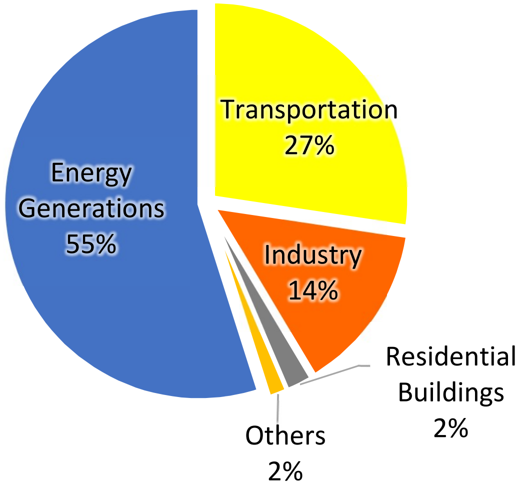

Figure 1.1 Main Sources of GHG in Malaysia, 2013,.

As shown in Figure 1.1, transportation sector is the second largest producer of greenhouse gas in Malaysia next to energy sector. It contributes to nearly 28% of annual national carbon emissions (Shahid, Minhans and Puan, 2014; International Energy Agency, 2015; The World Bank, 2016) due to its heavy dependency of hydrocarbons such as gasoline (Azmi and Tokai, 2016). Like the United States, the road transportation sector is the second largest source of GHG, following electricity generation. Shahid, Minhas and Puan (2014) also stated that 82% of total transport related emissions is contributed to road transport which is more than aviation, maritime and rail. Furthermore, without amendments to current policies, the demand for personal transportation is expected to grow by 45% by 2030 (Ong, Mahlia and Masjuki, 2012). Based on the compilation of Malaysia's Transportation Statistics (Ministry of Transportation Malaysia, 2016), 70% of land transport sector are private passenger vehicles (cars & motorcycles), which have the potential of generating the most GHG, thus indicating the need for better management of the group. If not properly managed, carbon dioxide emissions per capita is expected to nearly double in the next five years. Lack of interdisciplinary study on this sector has caused proper mitigation initiatives to be delayed, compounding the damage to the ecosystem.

According to Ministry of Transportation (2014b), the majority of motorcycles in Malaysia is under 150cc (Figure 1.2) while 2-stroke motorcycle offerings are becoming less. Comparative studies between motorcycle emissions with similar engine size and cars emissions reveals that motorcycle GHG emissions per KM is much less compared to GHG emissions of cars. Measured findings by Chan (1995) reveals that 4-stroke motorcycle produces on average 55g CO_2 per KM as opposed to 187g CO_2 per KM in passenger car and 0.2g NO_x per KM as opposed to 1.9g NO_x per KM in passenger cars. Moreover, study by Vasic and Weilenmann (2006) reveals the CO_2 emission of motorcycle of similar engine size to be in range of 34-44g per KM and NO_x at 0.1-0.22g per km. This emission per KM ratio of 1:3.4 to 1:6 shows another need to control emissions from the bigger polluter which is passenger cars.

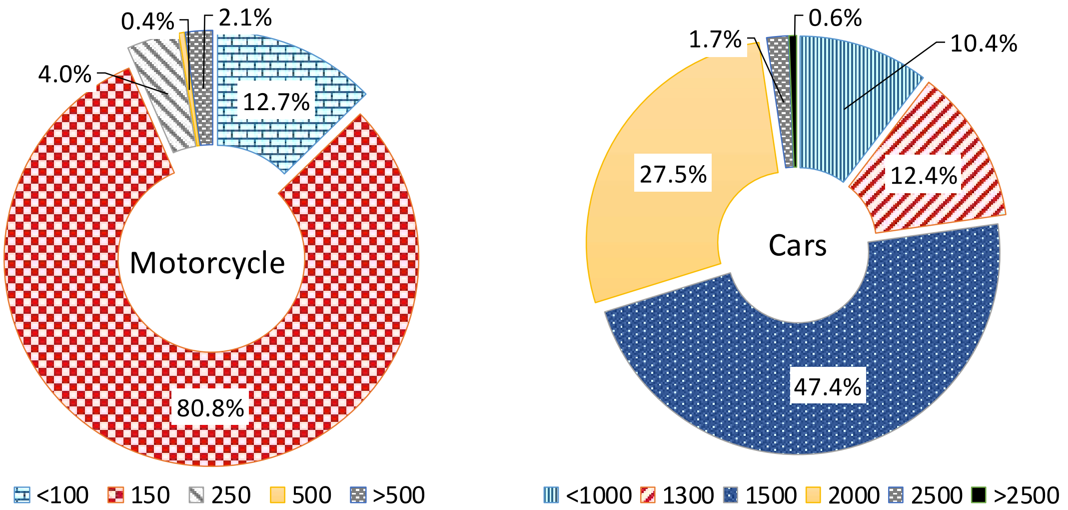

Figure 1.2 New Vehicle Registration Composition by Engine Size, Malaysia (2014). Source: (Ministry of Transportation Malaysia, 2015)

The Malaysian government is constantly trying to introduce regulations to manage the country increasing passenger car quantity. It is also related to recent government plan to target a registration of 1 million new passenger vehicles in 2020 (Ministry of International Trade and Industry, 2014). However, to ensure a sustainable future for the general population, economy, and environment new transportation management policies and regulations need to be addressed. Previously, impact of such regulations mainly prioritize economic benefit under excuse of a developing nation, and it needs to change soon.

Old vehicles are a common sight in Malaysia. Vehicles still being used after 15 years here, regardless of their condition with cars having obsolete engines with high emission level and low fuel efficiency (Ong, Mahlia and Masjuki, 2011). Owners risk their life, as well as the lives of other road users, by extending the usage of the vehicles with their acquired skills of self-diagnosis and repair of their own vehicles, motivated by the high cost of obtaining a replacement vehicle. Owners are not to blame. Even under the prosperous economic prosperity, cars are very expensive for purchase not because of low income, rather due to the taxation system.

The steep non-value added tax structure at 75% to 105% excise duty depending on engine size (Malaysia Automotive Association, 2016) are charged for each vehicle sold in Malaysia. Another tax system introduced in 1st April 2015 added another 6% for government service tax on top of this exorbitant charges. Malaysian government recorded collecting MYR 8 billion (JPY 200 billion) in 2014 from car sales and duties alone (Ministry of Finance Malaysia, 2015) making this lucrative sector as one of the government key income.

Although newer regulations for transportation emissions have become slightly stricter, it still failed to encourage owners to upgrade their transportation. Moreover, older cars are often badly maintained, having higher emissions compared with newer ones, regardless of the technological level. This condition slows down new vehicle registration ownership in the past years (Ministry of Transportation Malaysia, 2016) and new policies are laid to re-excite the transportation market under National Automotive Plan.

Ever since the successful introduction of mass production of New Generation Vehicle, Toyota and Honda leap far ahead in HEV technology compared to other manufacturers, and Nissan turns to be the main producer of EV. The new technology helps Japan to be the global leader of New Generation Vehicle production and export while having manufacturing facilities in foreign nation. In recent years, United States also shown great interest in embracing cleaner emission vehicles. Tesla is starting to dominate the electric cars market. However, arguments arise whether this kind of New Generation Vehicle is truly clean compared to the existing system, especially in developing country such as Malaysia. Out of 11 million active passenger cars here, only 50,000 units is consisting of new generation vehicles (Ministry of Transportation Malaysia, 2016). This trend is unlikely to change as the policies being implemented here still favours the previous generation vehicles, further degenerating the environment. Worse, Malaysia ended support for New Generation Vehicle in December 2013 (Monical, 2014) through disposition of tax incentive after only 2 years of application. This decision leads to a plummeting number of New Generation Vehicles being sold in the market while reducing public confidence on future of New Generation Vehicle.

From a regulations perspective, the last time any vehicle emission ruling was modified was in 1996, covering emissions regulations to 2010, yet remaining unchanged to this day (2016). However, the ruling covers only carbon monoxide (CO) and hydrocarbon (HC) emissions. While the European Union adopted the EURO 6 emission standard in 2014, the Malaysian emissions standard is equivalent to the EURO 2 emission standard, making it inefficient for managing climate change. It is crucial that this regulation be updated at regular intervals and best if updates are supported by quantitative data.

1.1.2 National Automotive Policy

The last policy adjustment involving passenger vehicle and commercial vehicles is the National Automotive Policy, Update 2014 (NAP) under Ministry of International Trade and Industry (MITI). This policy introduced the new regulation regarding fuel economy of new vehicles being sold in the market under the Energy Efficient Vehicle (EEV) programme. NAP provided aim for EEV promotion, which was fuel consumption based on kerb weigh bracketing. It aims to entice foreign investors to expand its production and R&D in Malaysia by providing certain tax breaks, although unknown to public. MITI aims to see 85% of EEV being produced in 2020. EEV vehicles includes vehicles using conventional fuel, as well as alternative fuel such as CNG, LPG, Biodiesel, Ethanol, Hydrogen, Petrol-Hybrid, Electric, and Fuel Cells. NAP categorized the vehicle under 8 categories listed in Table 1.1. However, the regulation has several weaknesses such as; the target fuel consumption is too high, for an example Audi Q3 (1610kg) which have fuel consumption of 7.9L/100km[1] under JC08 fuel consumption test can clearly be identified as EEV. Moreover, this policy only benefit manufacturer with cost saving, often not benefiting end-user. Fuel consumption testing and rating methodology is also unavailable (Mahlia, Tohno and Tezuka, 2012) since the first discussion until today. Vehicle manufacturer is given leverage to use their own testing method. Most importantly, it does not cover vehicle tailpipe CO_2 emission and the EEV status award is given subjectively based on other grey merit. Surprisingly, vehicles such as Nissan Leaf, Toyota Prius and Tesla Model S is not even considered as EEV (Lin Say,

[1] Information obtained from fuel consumption tracking website “e-nenpi.com” at September 11, 2016.

2014). This hidden and often subjective tax reduction method in turn leads to unpredictable vehicle price and policy impact estimation. Making thing worse, this regulation reduces the available options of high-efficient vehicles for Malaysian.

Table 1.1 EEV Program for Malaysian Transportation Sector.

Segment	Description	Kerb Weight (Kg)	Fuel Consumption (L/100 Km)
A	Micro Car	<800	4.5
A	City Car	801 – 1000	5.0
B	Super Mini Car	1001 – 1250	6.0
C	Small Family Car	1251 – 1400	6.5
D	Large Family Car	1401 – 1550	7.0
D	Compact Executive	1401 – 1550	7.0
E	Executive Car	1550 – 1800	9.5
F	Luxury Car	1801 – 2050	11.0
J	Large 4x4	2051 – 2350	11.5
Others	Others	2351 - 2500	12.0

Like the United States, the road transportation sector for Malaysia is the second largest source of GHG, following electricity generation. Based on the compilation of Malaysia's Transportation Statistics (Ministry of Transportation Malaysia, 2016), a large portion of passenger vehicles are passenger cars, which have the potential of generating the most GHG, thus indicating the need for better management for the group.

1.1.3 System Dynamics Modeling

System Dynamics is a methodology for studying and managing complex systems that change over time (Ford, 2010), a rigorous modeling method that enables complex systems to be built for effective policies and organizations (Sterman, 2000). 'System' is a set of interaction or interdependent components which forms an integrated whole. Modeling of a system us the usage of model or simulation in order to conceptualize and construction of the system. Mainly it is based on Systems Thinking which are the ability to understand the world as a complex system (Sterman, 2000). This System Thinking functions as a view of the system in a holistic manner which are obtained by the viewing and considering something as part of an overall system, rather than individual part.

Modeling is a method to substitute real equipment, beings or system into something else which have certain level of similar criteria. It is a simplification or approximation of a real equipment, beings or system. Usage of a model have help the explanation of scientific phenomena of the real system and prediction outcomes in certain settings where empirical observations are limited, unavailable or too expensive to be constructed. A model can be divided into two distinctive group which is static model and dynamic model (Ford, 2010).

Static model can be used to understand a system behaviour at rest, which does not involve time related changes. For instance, the calculation of forces need to keep an object at rest. A dynamic model on the other hand, is build more towards the understanding of a system behaviour over time. As an example, dynamic model helps explanation of economic forces required to cause economic growth over time, or how much force required to accelerate a rocket in order to reach orbit and returns back on specific location in certain amount of time. A dynamic model can also help an ecologist to study the effect of livestock overgrazing on survivability of certain type of grass.

System Dynamics (SD) is a computer-aided approach for policy design and analysis, which involves the study of time-behaviour of a system. It is often used to solve dynamic problems which derived from complex social, economic, managerial, ecological or integrated systems, or more accurately described as any dynamic system which are characterized by interdependence, mutual interaction, information feedback and circular causality. A distinct concept of a SD is involvement of stock and flow (also known as level and rates) that have the potential to affect final outcome.

A SD Modeling is distinguishable by four main criteria. The first one System Definition is a boundary of a system, with input and output variables being put in place. Such input can also utilize multiple type of distributions, such as presented in this study.

Second, the System Modeling, which is usually represented in mathematical or graphic relationship. It can either be determined empirically or analytically. Third criteria are the determination of the system behaviour or also known as the feedback thinking, which can be through simulation or analytic. Diagrams of loops of information feedback and circular causality are tools for conceptualizing the structure of a complex system and also for communication of model based insights. It controls the effect of any system input to change the output of the system.

Last criteria are the recommendation formulation. Under this last criteria, system performance improvement is done through system structure or parameter values to study any cause-effect relationship of any input modification.

1.1.4 List of previous studies

GHG estimation from transportation sector have been intensified over this past half-a-decade. Various studies specifically on this topic have been done in other countries (Malcolm A. Weiss, John B. Heywood and Andreas Schafer, 2000; Ipcc, 2006; Schafer, Heywood and Weiss, 2006; Yang *et al.*, 2009; Ross Morrow *et al.*, 2010; Hao, Wang and Yi, 2011; Higuchi *et al.*, 2012; Huo, Wang, *et al.*, 2012; He and Chen, 2013; Akashi *et al.*, 2014; Lewis, Kelly and Keoleian, 2014; U.S. Environmental Protection Agency, 2016). However, only two previous time-based estimations have been found on GHG emissions from transportation sector. Such studies are from Safaai *et al.* (2011) and (Shahid, Minhans and Puan, 2014).

The first study (Safaai *et al.*, 2011) is related to time based estimation from 2000 to 2020 utilizing existing LEAP model which covers the immediate vehicle usage emissions from estimated vehicle quantity demand. This demand was estimated based on the extrapolated historical data, and does not consider the limitation of such increase. Moreover, transportation related emissions was also not considering other part of the vehicle lifecycle phase. It also covers only the generation of Carbon Dioxide emissions and no other type of greenhouse gas. Utilization of LEAP model is also limited, as this black-box model in 2011 was incapable to be optimized, non-modifiable through the use of macro, and requires on the limited build-in national data sets.

Second study (Shahid, Minhans and Puan, 2014) on the other hand focus more on historical data estimation which covers a period of 1971 to 2010. Although this study has improved the understanding on historical point of view, it did not deliver the more required future estimation, and intervention actions required to avoid catastrophic global calamity.

This thesis attempts to expand the scope covered by (Safaai *et al.*, (2011) with better estimation of vehicle demand, bigger scope of GHG emissions, longer timeline and strategy options to reduce the impact from transportation sector.

1.2 Problem Definition

Malaysian Greenhouse Gas emission is increasing at steady rate since 2000 and does not seem to stop anytime soon. Transportation sector is identified as the second biggest contributor to this problem. Several methods have been implemented everywhere in the world, yet Malaysia seems to be lagging in combating transportation caused Climate Change. Proper action and planning needed to be done if we intend to continue living in this balance environment.

1.2.1 Study Reference Mode

A "Study Reference Mode" is the initial step in generation of a System Dynamic (SD) Modeling. It represents the problem which the model will represent. Reference mode is based on historical information which often described in graphical form. Usually, it is based on historical data which may be a starting point for model construction, and may contain concrete variables as well as abstract variables summarizing qualitative information.

According to Figure 1.3, annual GHG emissions for Malaysia continues in increasing trend since it is being recorded in year 2000. Seeing this negative contribution and towards global climate change and better understanding of its effects, the Malaysian government announced to the world of their willingness to change in order to avoid climate change.

The increased annual GHG emission is in tandem with the total number of vehicles over the time period. Although it shows a bad relationship, vehicle industry is one of the primary income for this nation's economy with many job depends on it. This being said, it is empirical to reduce annual GHG emissions without reducing the annual new vehicle quantity. Controlling this balance required new policy introduction as well as changes of existing vehicle related policies. This situation created the basis for this study to provide quantitative estimation analysis of Malaysian vehicle emissions until the year 2040, via comparative analysis of multiple vehicle management policies' application. To achieve the estimates, we constructed a prototype model for deterministic estimation using the system dynamic modeling method and input data from multiple existing data sources related to passenger vehicles.

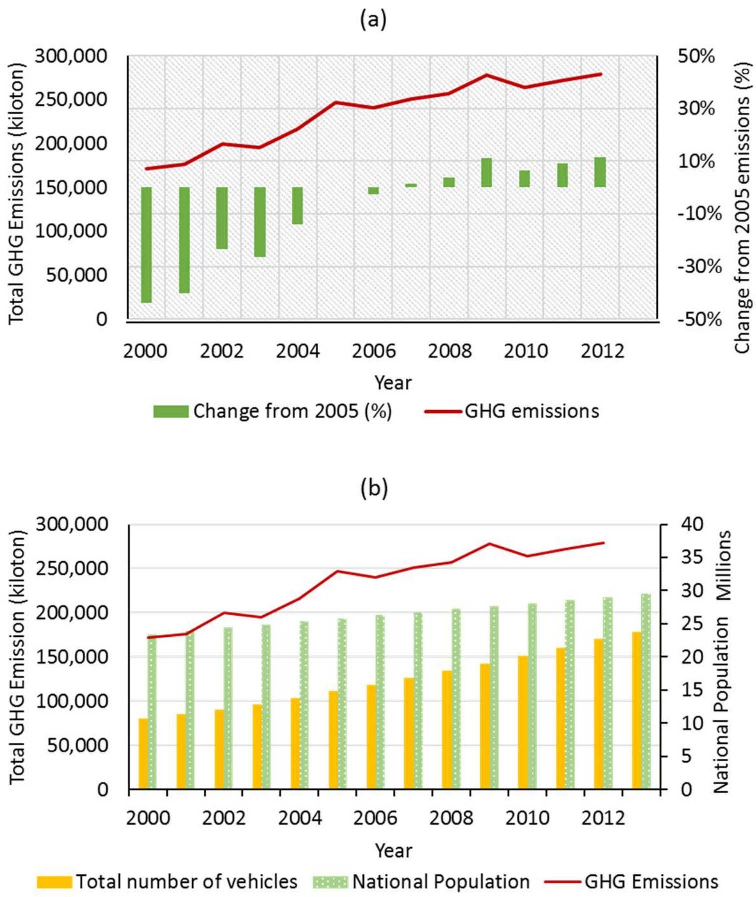

Figure 1.3 (a) Annual National GHG Emission and changes compared to 2005 emissions, (b) National Population, vehicle quantity and total GHG Emission, Malaysia. Adapted from The World Bank (2016).

1.2.2 Research objective

Objective for this study is to generate a dynamic model for a more accurate analysis of potential environmental impact and its reduction from passenger vehicles through the use of policy control measure.

Application of this model is expected to:

1) Estimate the adoption of Hybrid Electric Vehicles and Full Electric Vehicles adoption in 2040, and Estimate the generation of end-of-life vehicles for each year,

2) Determine the environmental impact of vehicle usage for each year,

3) Estimate the environmental impact from manufacturing of the vehicles,

4) Gauge the electrical power requirement to support Full Electric Vehicle, and assess the overall impact on passenger vehicle under different policy scenarios.

5) Propose the solution of vehicle management.

1.2.3 Research question

"How to reduce overall GHG emissions and environmental impact from passenger cars without affecting people mobility"

1.2.4 Scope

This study will cover passenger vehicle utilization in Malaysia of four different type; Conventional Internal Combustion Engine Vehicle, Conventional Vehicle using Compressed Natural Gas as fuel, Hybrid Electric Vehicle and Full Battery Electric Vehicle. We will look at the impact from material production, until the vehicle reached its end-of-live, which are the retirement time. The term "vehicles" from now on will refer to passenger cars of the four different type mentioned above.

1.2.5 System Dynamics Model Parameter Settings

Any modeling is required to set its own individual parameter. This is important in order to keep result consistency throughout the estimation options. Model parameter applied in this study is as follows;

1) The study will utilize an analytical tool by *Lumina Decision System, Inc*. named *Analytica*. The Version used is *64Bit Educational Professional Edition*, release 4.5.3.31 dated February 4th 2014.

2) The model will utilize Simple Monte-Carlo Random Sampling Method with sample size, N = 1000, and randomization method is set as minimal standard.

3) As for Probability Band Result settings, the model will utilize median at 50%, mid-upper and mid-lower bound at 75% and 25%, and ultimate upper bound and lower bound at 95% and 5%.

4) Probability density uncertainty setup will be using smoothing function which is applied on all input distribution at maximum smoothing setting. Reason for this is we tried to avoid any jagged and unrealistic distribution especially in generating income distribution in 0 which might alter the end estimation result. However, activating this function will increase calculation time for each input alteration.

5) Time setting is set as sequence from 1 to 29, representing the time period intended for this study which is 2012 to 2040. Historical vehicle data of 30 years is also applied for input data of 2012.

However, the tool being used (Luminar Analytica 4.5) is not without its limitation. For instance, the communication diagram used in this document needed to be constructed using other software (such as Vensim from Ventana Systems) which resulted in oversimplification of the real model. Regardless, this limitation does not have the potential to change the main model result outcomes.

1.3 Model Framework

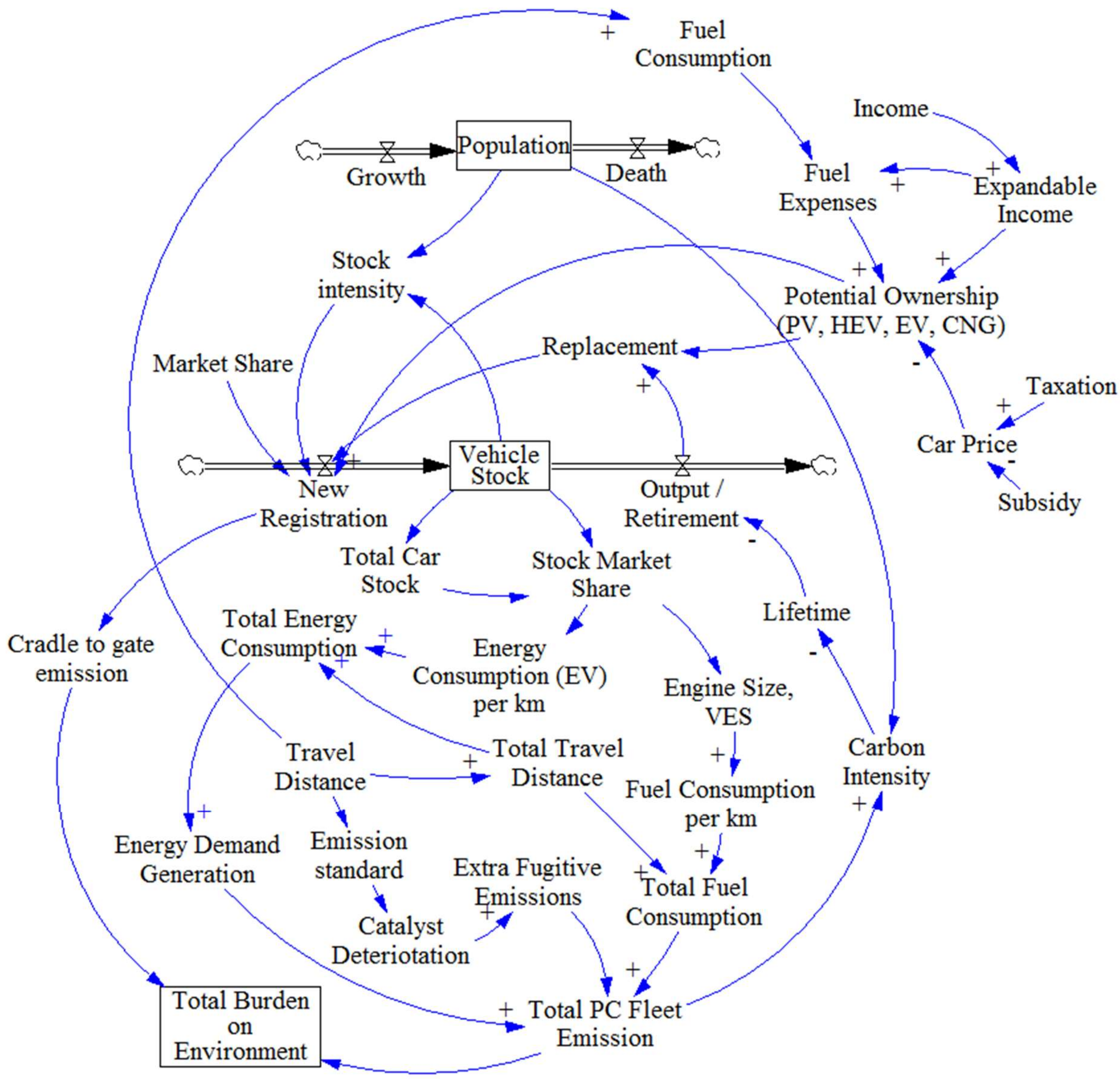

Figure 1.4 Model Framework for this study.

This study model framework is depicted in Figure 1.4 1.4. This figure will be used throughout the thesis chapters with slight modification in order to differentiate the different focus on respective chapter. It will be marked with different indication for better understanding.

Generally, this model framework can be summarized as in Figure 1.5 in its main modules. The first part is Vehicle Quantity Module representing Estimation of Future Passenger Vehicle Quantity (0), second part is Usage Module representing Environmental Burden of Vehicle Management Policies (0), while the third LCI Module representing Analysis of Environmental Risk Trade-off for New Generation Vehicle Production (0). The result is compiled under Estimation/Scenario Policies Module (Chapter 5), which covers all the methods and lifecycle stage covered in previous chapters.

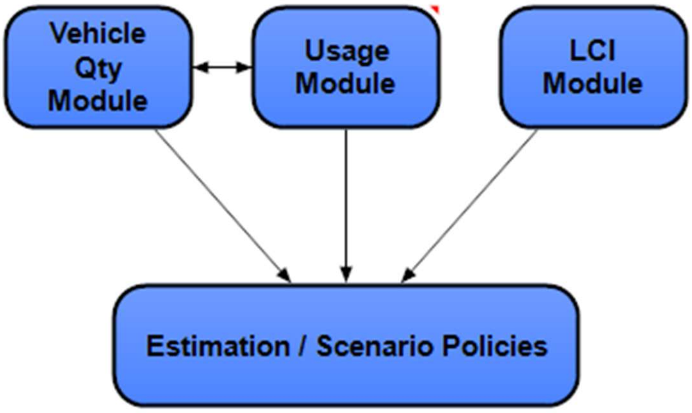

Figure 1.5 Modular View of the conceptual diagram.

1.4 Dissertation outline

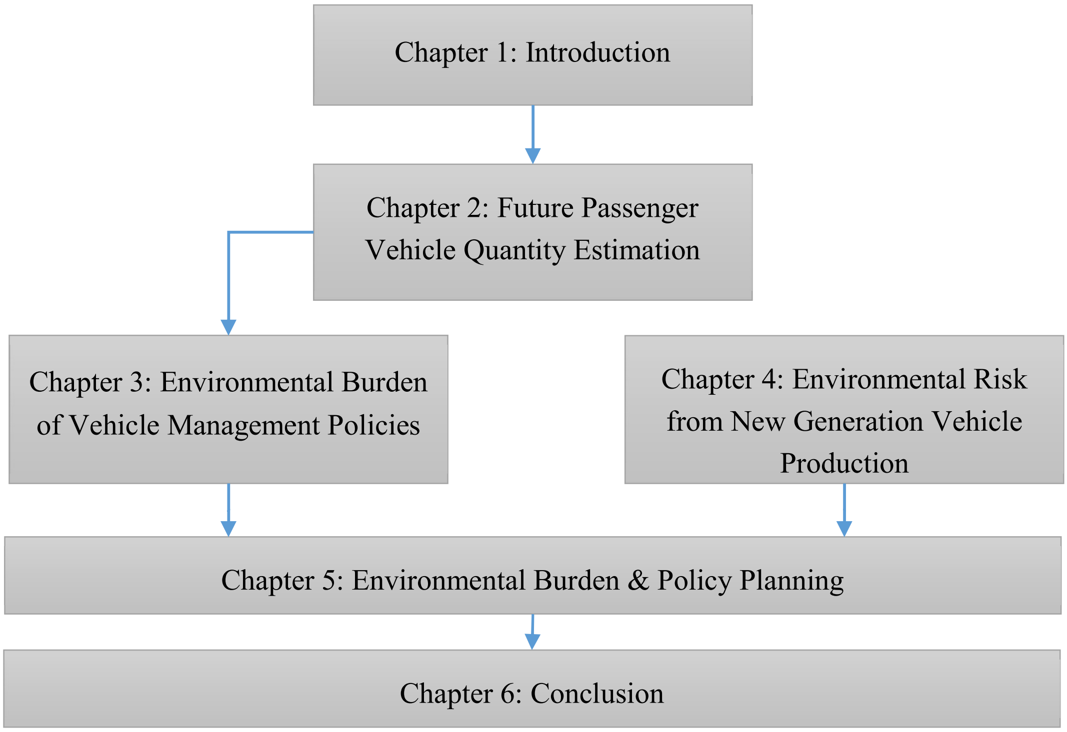

Figure 1.6 Outline of Dissertation Chapters.

This dissertation is being sorted into 6 chapters as shown in Figure 1.6. The first chapter; Introduction explains the research background, research statement and objectives, research questions, scope, and framework used in this research.

It then followed by the second chapter, the stock estimation of passenger vehicles until year 2040. The objective of this chapter is to evaluate the current policies on the generation of passenger vehicles type. Furthermore, this chapter also aims to estimate the quantity of end-of-life vehicles generated over the years. System Dynamics modeling method have been used with integrated population expandable income and vehicle price reduction. We also include various other variables such as vehicle pricing, technology adaptation rate theory, and emission regulation improvement as control variable. It is estimated that passenger vehicle market will be nearing saturation point in 2030 at 12 million active vehicles while half million ELVs is also being generated in that year. In 2040, HEV is estimated to be 1.43 million units while EV at 43,000 units. Research also concludes that adapting mandatory inspection and improving emission regulation, HEV & EV can be increased by additional 70%.

The third chapter is the evaluation of environmental burden of vehicle management policies. It uses the output result from Chapter 2 as main driver variable. This third chapter will be the platform for emission estimation that are generated from vehicle usage. Utilizing mainly existing mobile combustion knowledge from International Protocol of Climate Change (IPCC) and various usage related variable, this chapter takes the first effort of estimating GHG emissions under several vehicle management policies which was based on governmental, industrial and stakeholder's intervention.

Fourth chapter; Environmental Risk from New Generation Vehicle Production is an attempt to provide better understanding of the environmental consequences of the vehicle production activities based on 5 impact classifications which is Greenhouse Gas (GHG) generation, Acidification, Eutrophication, Carcinogenic Effect, and Human Health measured in DALY using Life Cycle Inventory (LCI) Analysis. The higher efficiency of New Generation Vehicles has lower carbon emission potential during usage. However, it is a different story is compared on production alone.

The fifth chapter purposes as to provide the final analysis integrating all the method and significant policies and results presented in the previous chapters. Results found in this chapter corresponds to the whole vehicle lifecycle from material procurement until the vehicle reached its end of life.

The last chapter summarizes main contributions of the thesis, concludes this research with policy suggestions in order to manage passenger vehicle fleet without having negative impact on environment, social wellness, or the economy. This chapter also points out limitations and relevant future works on this issue.

Chapter 2. Future Passenger Vehicle Quantity Estimation.

2.1 Chapter Overview

This chapter aims to estimate the number of potential HEV, EV and End-of-life Vehicles, as well as the different impacts of vehicle management policies on the future mix of vehicle types using a system dynamic. This chapter covers the first part of the research indicated in Figure 2.1.

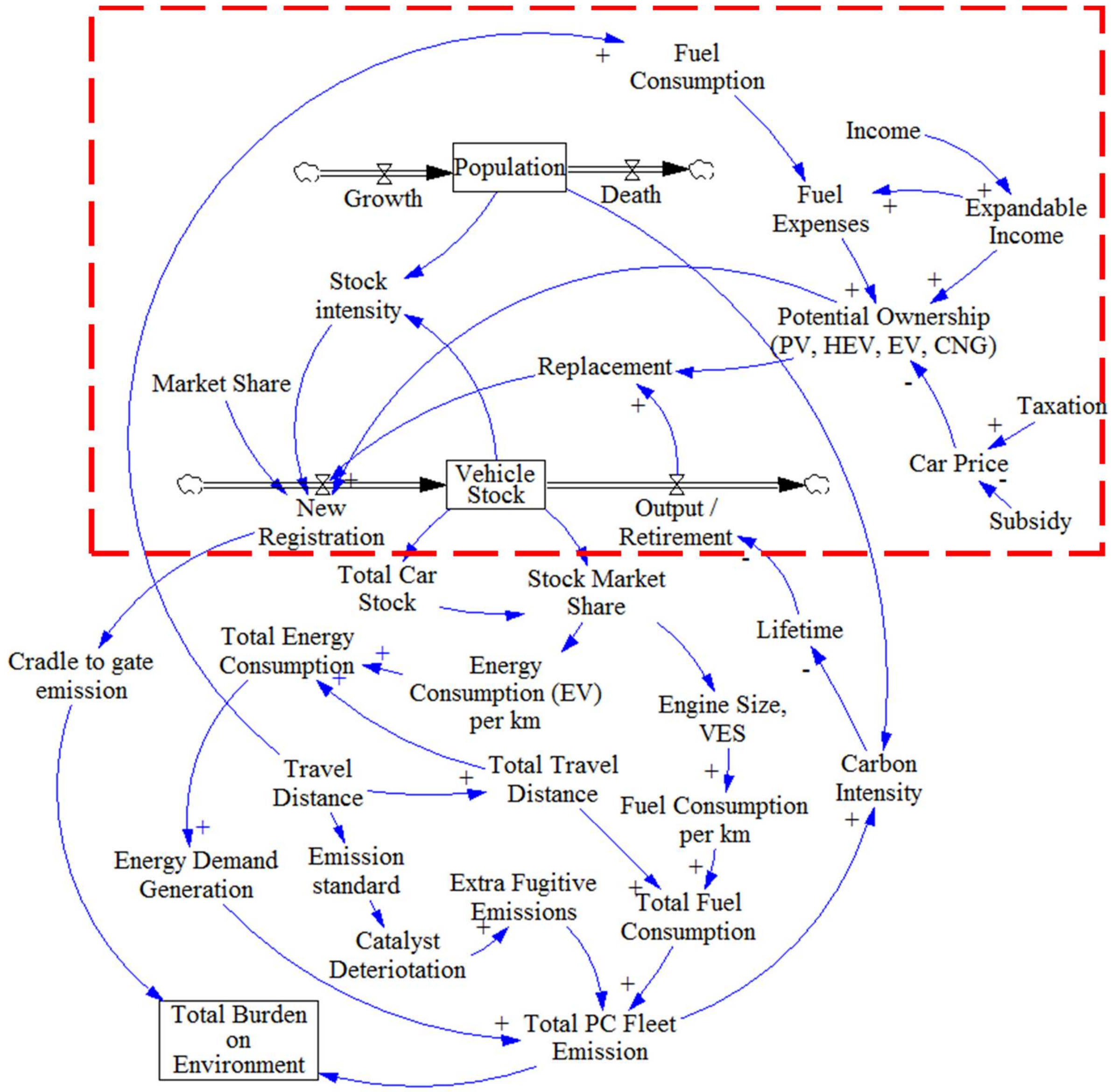

Figure 2.1 Thesis main conceptual diagram with studied variables. The red rectangle indicates the area being focused in this chapter.

Section 2.3 provides the assumption used, method, data used and modeling process which are created and implemented for vehicle stock estimation. It is done via five driving parameters: Consumer Factor, which represents the vehicle type choice; Vehicle Survival Estimation, which represents the average age of a vehicle; Population Growth; Saturation Limit, which serves as a limiter for passenger vehicle (PC) ownership sustainability; and most importantly, Vehicle Management Policy Choice. The result is being presented in Section 2.4 which shows estimated vehicle stock, expected quantity of scrap vehicles generated, and number of expected new vehicle being registered. Result from this study is expected to better estimation of future greenhouse gas generation and emissions from personal transportation of future studies.

2.2 Introduction

Newer hybrid-electric technology was introduced to the personal-vehicle market in Malaysia in 2009. However, acceptance of this technology is lacking, with only 322 units out of 1 million units registered in the following year. By 2014, Hybrid and electric vehicles only managed to be added by about 7000 units (Ministry of Transportation Malaysia, 2016). This is due to the high cost of ownership and because the existing relatively old vehicle owners do not consider owning a new vehicle as an important expense. Japan, on the other hand, recorded 11% sales of hybrid electric vehicles (HEVs) in 2009, and reaches 20% market shares at 940,000 units in 2014 (Dan Rutherford, 2015). This number is expected to reach 43% in 2030, as estimated by Higuchi et al. (2012). However, this study needed improvement as the same estimation methodology does not consider the increase in population that commonly exists in Malaysia and other developing nations. By implementing a population change variable, this model can be used to estimate vehicle quantities in any developing nation. Other studies, such as Zachariadis *et al.* (1995), also implemented population as an input variable; however, they did not consider the population age distribution, which may lead to slight overestimates.

In the period from 2009 to 2013, the average increase in the number of vehicles in Malaysia was 594,242 annually, and it is expected to increase every year. As more and more vehicles are being produced, the stress on the environment has become overwhelming. The existence of a directive will force automotive manufacturers to deal with environmental problems and to develop ELV recovery programs specifically for reuse, remanufacturing, and recycling. This program also serves as an opportunity to phase out internal combustion engine vehicles (CV) in the long run.

China controls vehicle age indirectly through vehicle emissions inspection. Non-commercial vehicles are required to be tested every year after the age of 7, and twice annually after the age of 16. Commercial vehicles are required to be tested twice annually after the age of 5 (Yang *et al.*, 2015). This intervention based control shown to be an effective measure for early vehicle retirement. Similar regulation implemented in Japan for decades which average age of vehicles is kept below 10 years. Singapore on the other hand took a bolder approach by leasing entitlement certificate for vehicles with 10 years term (Land Transport Authority Singapore, 2016).

Japan has one of the world's best track records for environmental regulation adherence. Passenger vehicles in Japan had an average age of 8.13 years and 12.64 years of average lifetime in 2014 (Japan Automobile Manufacturers Association Incorporated, 2015), as opposed to 18 or 19 years in the United States (Jacobsen and van Benthem, 2013). Newer vehicles emit less GHG. Furthermore, the Japanese have one of the toughest vehicle emissions testing methods in the world, requiring every vehicle to be tested every 1 or 2 years (apart from new vehicles that must be tested after 2 or 3 years, depending on their type). Vehicles that fail this test are not allowed on the road and require more testing.

This often leads owners to scrap or recycle their vehicles, although they sometimes export these vehicles to developing countries. Additionally, Japanese emission tests provide much needed information in estimating gross emissions from the national transportation sector.

2.3 Method and Modeling Process

Due to the existence of multiple variables, we choose to utilize a system dynamic approach for this problem. System dynamics have been proven to produce results in such cases as exampled by Sterman (2000) and Ford (2010). Figure 2.2 depicts the framework of this study that consists of the input, process, output, and feedback diagrams of the modeling process, including the model structure.

Evaluation for this study is based on the adaptation of Hybrid Electric Vehicles (HEV) and Battery Electric Vehicles (EV) in the future. Also included in this study is the number of potential ELV generation. HEV and EV is the best replacement as it has lower GHG emission throughout its use (Thiel, Perujo and Mercier, 2010; Pasaoglu, Honselaar and Thiel, 2012; Wu *et al.*, 2012). Vehicle management policy depends on a mix of small regulation changes. The first step was the identification of required data often used in similar studies. Huo et al. (2012b) provided the groundwork for future vehicle estimation in China 2050.

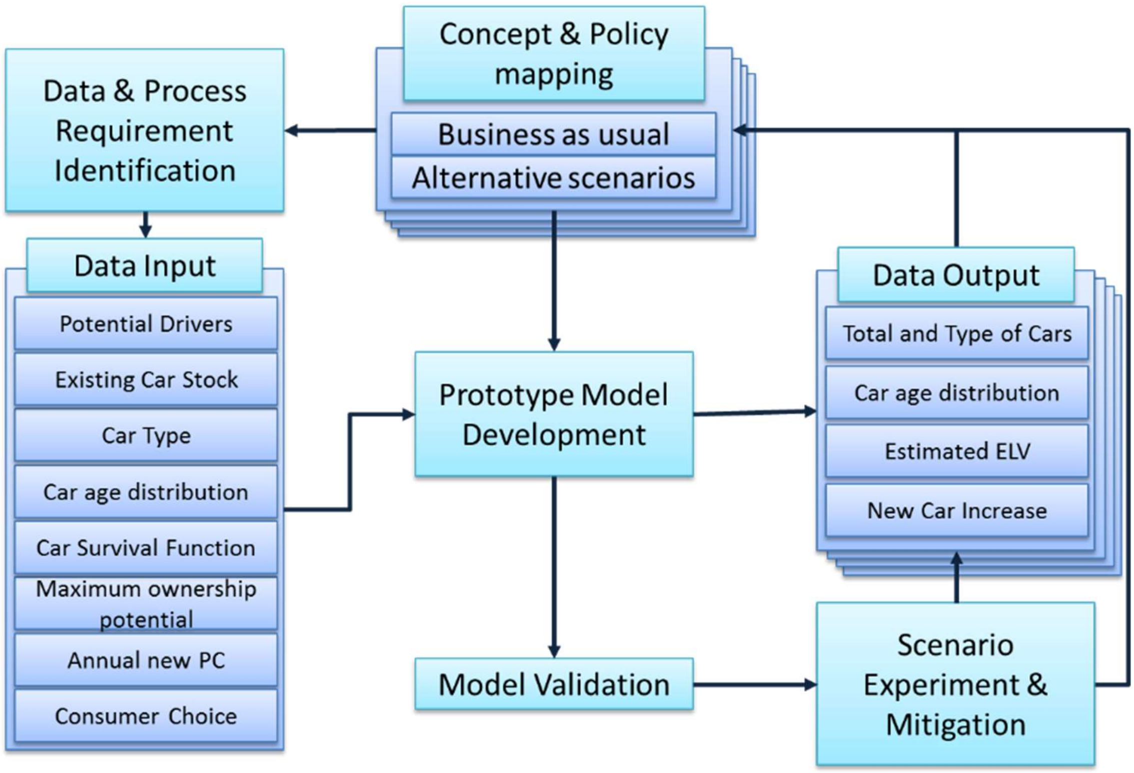

Figure 2.2 Research Framework for Future Passenger Vehicle Quantity Estimation.

National population, existing vehicle stock, vehicle age distribution, vehicle type distribution, historical annual increase and saturation limit was identified as key importance in previous study. Later, this information is used to develop a prototype model under existing policy.

Output data targeted in this study is the total number of vehicles and its type, the distribution of age of vehicles, estimated number of ELV generated, and annual registration of new vehicles. This information is later used to generate alternative scenario policies before being used in the process loop.

The whole modeling process is done using simulation software Analytica. Although this tool is not designed specifically for System Dynamics, it can be customized to fit the same purpose. Model Parameters and Feedback Structures used in the model is as follows;

1. *National Population* : The projected population of Malaysia based on World Bank Population Prospects (United Nations Population Division, 2012). The estimation uses Bayesian Probabilistic Statistic method which was based on complete county based information (or variables). This increases the reliability of the population estimates compared to recreating it in the model.

2. *Time, t*: Simulation starts on 2012 and ends on 2040. The simulation time ended in 2040 as it covers the average usable age of nearly all vehicles. Meaning, all vehicles stock in 2040 is a result of vehicle replacement starting from the policy change starting time which are 2017 and 2030.

3. *Policy starting time*: Policy is modeled to start being implemented at year 2017, while secondary policy will start in 2030. This will not be applicable for Business-As-Usual (BAU) scenario.

4. *Potential Drivers*: Population aged 20 to 80 which have the capacity to drive. The allowed age to drive in Malaysia is after the person reach 17 years of age and will only receive full driving permit at the age of 19. Moreover, 20 years old are the average of the population to finish studies and assumingly started to earn by themselves (Abdullah, 2016).

5. *Maximum Potential Ownership*: Theoretical limit of vehicle ownership per *Potential Driver*, which is assumed to be at 50%. This limit is considered as vehicle ownership is one vehicle per family. This is related with parameter 4 which translates to one vehicle being shared by two adults. Huo, Zhang, *et al.*, (2012) determined this value to be 40% at lower value, and 50% at higher value for his study. However, Huo consider this values out of total number of people regardless of age.

6. *Existing Vehicle Stock* : Number of vehicles in 2012 based on report of (Ministry of Transportation Malaysia, 2016). This parameter was chosen because at the time of study, the oldest official data provided by this report series only started from 2012. Regardless, this limitation should not change the final model output towards the later year.

7. *Vehicle age distribution*: Since there is no published reliable source that methodically tracks the historical vehicle age distribution in Malaysia, we end up using age distribution data from a much smaller sample size. This information is collected from an anonymous insurance agency providing insurance coverage on local vehicle.

8. *Vehicle survival function*: Average vehicle age is estimated at 15 years old (Hoh, 2013; Ahmed *et al.*, 2014).

Interrelationship theories and assumptions used in the model is as follow;

1. *Demand*: Demand is assumed to be fully fulfilled.
2. *Income of individual*: Income is kept at constant.
3. *Vehicle Price*: Vehicle Price is kept at constant.

In the real world, demand fulfilment is usually being done following some time delay due to the manufacturing process involved from the time of vehicle booking which usually takes up to several months. This is true especially for low demand vehicles which are only affordable to the few high income individuals. Another example are vehicles which are in high demand, but under manufacturing constrains. However, in this study it is decided that this demand & demand fulfilment delay is negligible as the time interval is measured in year. Regardless, if the time interval is reduced to month, the delay needs to be addressed.

The second and third assumptions are interrelated. Although individual income distribution increases over time, inflation is often follows suit. For an example, the income in 2014 (MYR 6141)[2] seems higher compared to income distribution in 2002 (MYR3011)[3]. However, the value of money also reduced as effect of inflation and the quantity of goods available for purchase is either remains but prices higher, or same price but less quality.

This study also assumes vehicle pricing to remains as effect of inflation. Actual vehicle prices in 2015 (MYR35,000) is higher compared to 2002 (RM26,000)[4] regardless of industrial automation, lean production, and all other manufacturing improvement done throughout the decade. Cost savings is expected to be retained by manufacturers as the market is currently being carefully protected. Moreover, the problem with Malaysian automotive sector is the unrealistic amount of taxation being implemented since 1985 which are going to be showcased throughout this dissertation.

Method and Data used as input for this study is explained from the following subtopic.

2.3.1 Population

Population controls the demand of any consumer product including passenger vehicles. The population growth datasets in Table 2.1 are collected from (United Nations Population Division, 2012) reveals that future population growth is seeing reduction, a similar trend to the rest of the world. This Growth values (*g*) is being used to estimate future population for Malaysia. The same report also

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[2] Department of Statistics Malaysia (2015), Household Income/Basic Amenities Survey 2014. https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=120&bul_id=aHhtTHVWNVYzTFBua2dSUlBRL1Rjdz09&menu_id=amVoWU54UTl0a21NWmdhMjFMMWcyZz09. Accessed 30th December 2016.

[3] Department of Statistics Malaysia (2010), Household Income/Basic Amenities Survey 2009. https://www.dosm.gov.my/v1/images/stories/files/LatestReleases/household/Press_Release_household2009_BI.pdf. Accessed 30th December 2016.

[4] Personal Experience

provided age bracket for each year, which are utilized in this study. Vehicle owners is assumed to be of population aged 20 to 80 years old. In dynamic diagram, population can be represented in Figure 2.3.

Table 2.1 Annual Malaysian Population Growth,g (%).

Year	Growth	Year	Growth
2013	1.63	**2027**	1.10
2014	1.58	**2028**	1.06
2015	1.53	**2029**	1.02
2016	1.48	**2030**	0.98
2017	1.43	**2031**	0.94
2018	1.39	**2032**	0.90
2019	1.36	**2033**	0.87
2020	1.33	**2034**	0.83
2021	1.31	**2035**	0.80
2022	1.28	**2036**	0.76
2023	1.25	**2037**	0.73
2024	1.21	**2038**	0.70
2025	1.18	**2039**	0.68
2026	1.14	**2040**	0.66

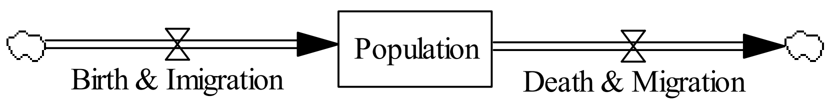

Figure 2.3 Diagram of Population Dynamic.

Since the data used for population is from secondary type of data, the population is acting as input variable instead of process variable.

2.3.2 Market Saturation

Malaysia has seen steady growth in the annual registration of new PCs. Over the period of 12 years, Malaysia has been seeing an average growth of 4.6% in PCs. This equals to an average of 3.7 vehicles for every 10 persons in 2014 based on official transportation ministry report (Ministry of Transportation Malaysia, 2016). Moreover, official statistics from the same report indicated that there are only 13,844,234 licensed drivers in Malaysia as of 2013, including 506,034 new probationary drivers (Ministry of Transportation Malaysia, 2016). This translates to 7.5 vehicles for every 10 drivers. As comparison, Japan has 79.79 million licensed drivers (National Police Agency, 2013), while the total number of passenger vehicles is 59.43 million (Sakai *et al.*, 2013) which equals to a ratio of 7.44 vehicles per 10 drivers. Initial information indicates that Malaysian vehicle quantity might have nearly reached its saturation point.

Eventually, the number of vehicles in each class will be limited to the number of potential owners; thus, a saturated market is being created. It simply means that people will only purchase vehicles due to the premature retirement of their vehicles, also known as *premature ELV*. The impact of this can be devastating to auto manufacturers in the country, and will soon follow what happened to The Big Three in the United States—Ford, General Motors, and Chrysler—in 2009. Japan had anticipated this problem much earlier and made amendments to vehicle ownership rules by enforcing a law that settles the problems of raw material insufficiency, environmental pollution, and demand sustainability.

Although at a glance the growth seems unlimited, it will eventually find its limit, as described by Aoki and Yoshikawa (2002) and Osenton (2004). Considering this situation, eventually growth of PC ownership will stabilize at close to 0%. Following the same idea, Huo *et al.* (2012b) utilized a saturation limit of 400–500 vehicles for every 1000 persons in China, which indicates higher economic urban development potential. The World Bank indicates some developed market specifically Japan and UK have reached the saturation point (The World Bank, 2014).

The saturation indicated above is slightly unsuitable to be used in a growing market such as Malaysia. Our equation is slightly different compared to the reported above as we exclude the population of incapable owners such as people below the age of 20 and people above the age of 80. This assumption is used to reduce the error for bottom-heavy population demographic country such as Malaysia. Therefore, saturation values are assumed at 0.5 in Equation 2-1, which is used for the estimation of new vehicle sales in a certain year.

$$max\ New\ Vehicle_T = Sat \cdot \sum (P - p)_T - \sum Stock_{T-1}$$ *Equation 2-1*

$$max\ New\ Vehicle_T = Sat \cdot \sum (Pot)_T - \sum Stock_{T-1}$$

Sat = Saturation Values
P = Total Population
p = Population Below Age of 20 and Above 80

2.3.3 Income Distribution & Potential Owner

Monthly Household Income distribution is represented by Lognormal with Mean of 6141 and median 5000 (Department of Statistics Malaysia, 2015a). Figure 2.4 is the adaptation of this finding translated into annual income per person in order to maintain modeling dimension. In average, 14% to 16% of income is used for transportation (Department of Statistics Malaysia, 2015b), while monthly loan repayment is allowed to maximum of 30% of income. Certain vehicle owners also combined their spouse income in order to acquire vehicles with higher price although this is only small minority.

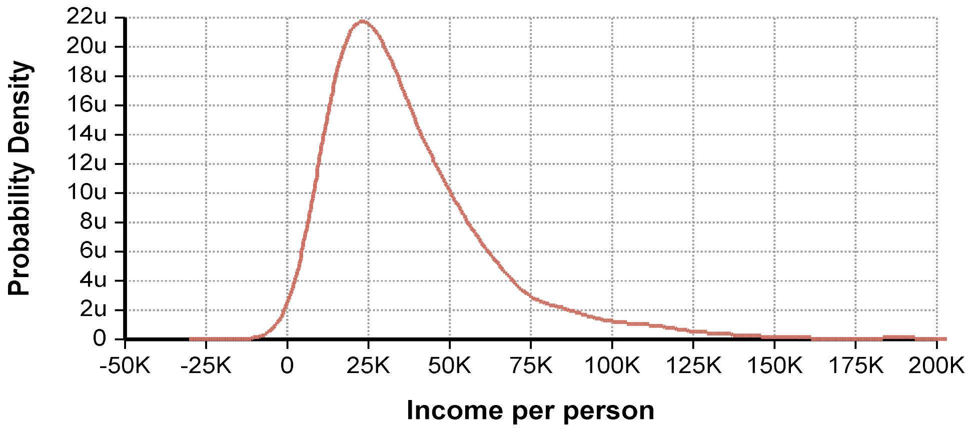

Figure 2.4 National Personal Income Distribution, Adapted from Department of Statistics Malaysia, 2015.

The vehicle models being used in this study is as represented in Table 2.2. Proton Saga is currently the cheapest decent family vehicle being offered in the market at MYR35,000. Honda Jazz Hybrid represents HEV at price of MYR90,000 while Nissan Leaf is used to represents Electric Vehicle at MYR180,000. According to Malaysia Automotive Association (2016a), vehicles in Malaysia is subjected to 75% to 105% Excise Duty and no other source can provide a clearer information on this matter. Therefore, this study will assume the claim is correct and utilize the lower value as minimum tax implementation. Under this assumption, vehicles will only prices MYR20,000 for CV, MYR51,430 for HEV, and MYR102,900 for EV respectively without this extra non-value added fee. CNG Conversion kit is added on existing CV which increase the cost by MYR8000[5] including installation services cost.

[5] Based on personal experience

Table 2.2 Modeled Passenger Vehicles Pricing in Malaysia.

Vehicle Type	CV	HEV	EV	CNG
Introduction year	-	2009	2011	1997
Make/Model	Proton Saga	Honda Jazz Hybrid	Nissan Leaf	Proton Saga with CNG modification kit
Selling Price (MYR)	35,000	90,000	180,000	40,000
Basic Price pre-tax (MYR)	20,000	51,430	102,900	28,000

Income Distribution and Vehicle Price is then used to estimate the affordability for each vehicle class under income capability.

Prospective vehicle owners in Malaysia is allowed to extend the purchase loan by up to 9 years, and maximum monthly commitment for all loans is allowed to up to 30% of income. This study assumes loans is being serviced with maximum 20% of individual income for a 9-year loan as it provides a more realistic condition. Figure 2.5 is an illustrative image of this situation. Area to the right of line represents the level of choice of respective vehicle type. Vehicle pricing under 9 years' payments equals to MYR3,889 for CV, MYR10,000 for HEV, and MYR20,000 for EV. Under this condition, 75.8% of income earners affords to purchase only CV, 21.4% have the choice between CV or HEV, while 3.6% of income earners can afford to choose between CV, HEV or EV.

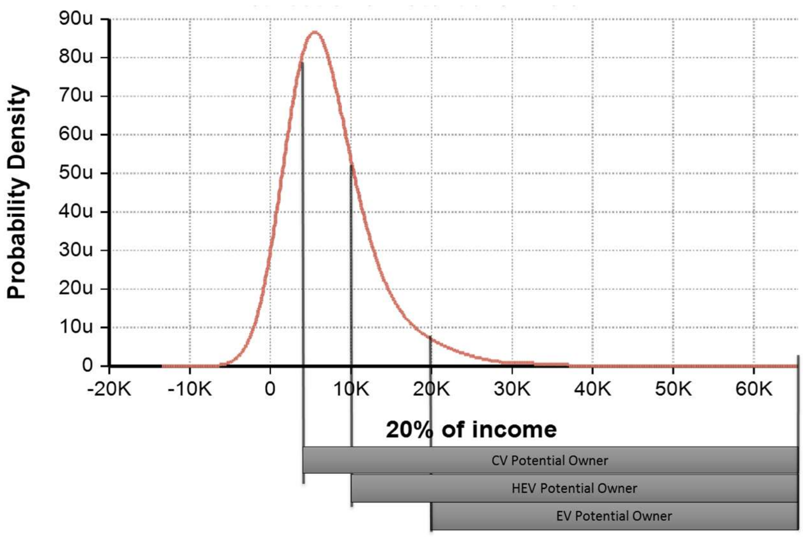

Figure 2.5 Distribution of Potential Owners of respective vehicle types based on income.

Potential owners are used as the maximum potential, or limit value in Gompertz function. This function introduced by Benjamin Gompertz can be used to estimate the market penetration under s-curve profile (Trappey and Wu, 2007). The Gompertz function is a simple formula to explain S-curve that can be used to match growth or market adoption, and upper limit or saturation limit illustrated in Figure 2.6. The S-curve pattern is typical observation for consumer product market penetration which the growth rate (indicated orange) increase exponentially after some lag from introduction time before gradually slows down. The Gompertz Function is represented from the equation;

$$y(t) = ae^{-be^{-ct}}$$ *Equation 2-2*

where *a* = maximum potential, while *b* and *c* dictates the curve and growth. Under Gompertz function, b and c modification enables the adoption rate to be fitted according to real data. This allows the function to be used to estimate future conditions under limited data availability. Result of data fitting enables the annual growth rate to be determined based on market adoption in Year *t*+1 against Year *t*.

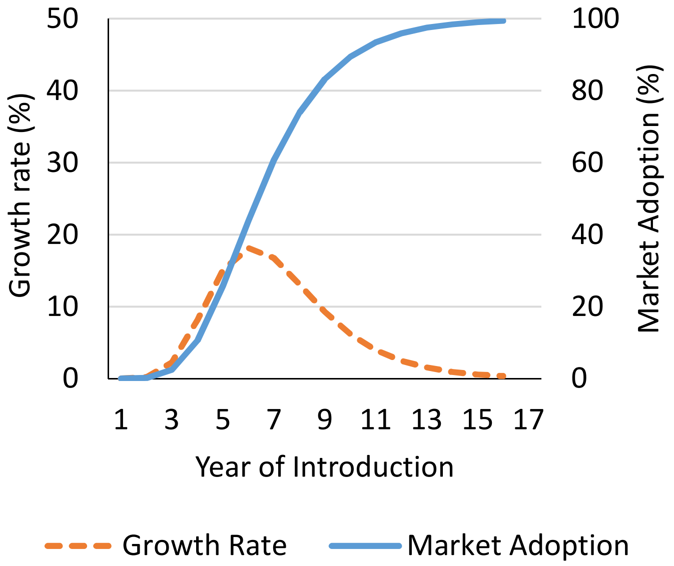

Figure 2.6 Example of S-curve pattern (Market Adoption) from Gompertz Function.

The functions described above however is not applicable to Compressed Natural Gas (CNG) vehicles. Vehicles commonly used this type of vehicles are from commercial transportation such as taxis. Historic data also shows that only 4% to 7% of vehicles registered as CNG every year.

Income Distribution and Vehicle Price is then used to estimate the affordability for each vehicle class under income capability further discussed in 2.3.5.

2.3.4 Historical Vehicle Purchase

Several organization and paper reported that passenger vehicles exceeds 10 million units in 2012 (Ministry of Transportation Malaysia, 2013; Ministry of Works Malaysia, 2013; International Organization of Motor Vehicle Manufacturers, 2014). However, this quantity is debatable as the latest Road Transport report by Ministry of Transportation Malaysia (2015a) indicated that about 28% out of 25.1 million vehicle (combination of all type of vehicle including bus, taxi, motorcycle, and lorry) being reported is inactive vehicles, which either have been scrapped or the owner failed to renew the vehicle licence. Based on this information, active passenger vehicles are assumed to be 7.64 million units in 2012.

Monthly new vehicle sales statistics collected from Malaysia Automotive Association (2016) report reveals that 52% of passenger vehicle registered is consist of entry-level vehicles priced less then RM 50,000 after taxation (JPY1,250,000) (Figure 2.7). The other 48% is represented by vehicles of higher price range. The information justified that the mean vehicle prices being sold is under RM50,000.

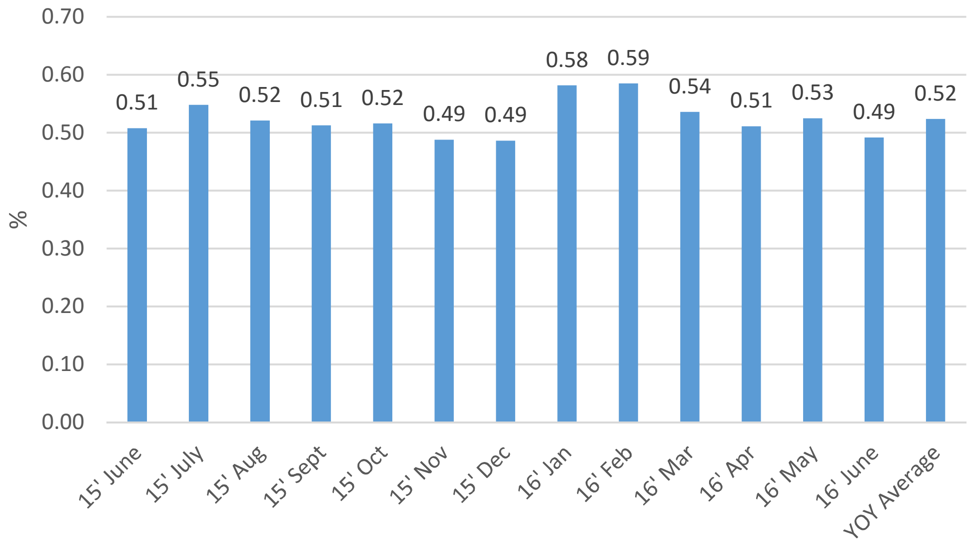

Figure 2.7 Composition of Low Cost Vehicles from total new passenger vehicle registration (monthly). Data adapted from Malaysia Automotive Association, July 2015 to June 2016.

2.3.5 Passenger Vehicle Purchase Decision

Ownership of new passenger vehicles type is one of the most important variable in the model. We used income distribution and passenger vehicle prices to estimate the upper bound of potential ownership for each vehicle type.

Estimating future stock of CV, HEV, EV and CNG depends of Year-on-Year input and output of each vehicle type. Output usually occurs when vehicle reached its end-of-life either by intention or by accidental. On the other hand, stock input is fed by new purchase by new eligible owners and replacement of the previously retired vehicles. This stock and flow is represented by Figure 2.8. The tricky part is to estimate the rate of output and replacement, as well as rate of input of different type of vehicle.

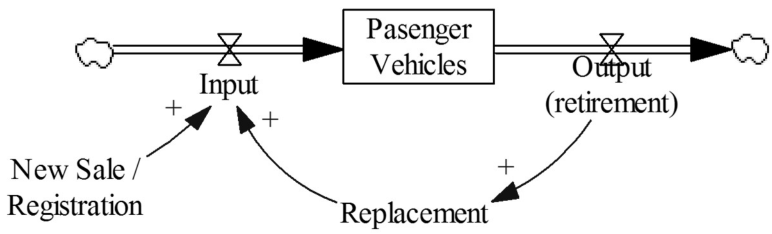

Figure 2.8 Basis Stock-flow diagram of passenger vehicles.

Using income capability as affordability and capacity to choose, we can solve half of this problem. People with higher income have wider option of different type of vehicle compared to people with lower income. Identifying offered price is usually the first step of product acquiring process. People with higher choice also have the option to weight in the total cost of ownership such as fuel consumption cost as another option.

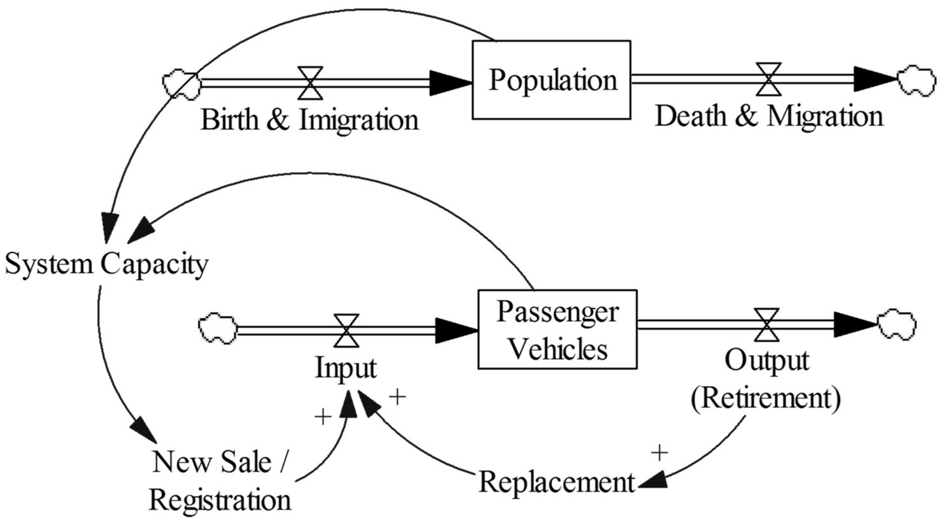

Figure 2.9 Passenger vehicle relationship with population.

Passenger vehicle relationship with population is described in Figure 2.9. Total number of existing vehicle will control the number of new vehicle being sold or registered the next time slice, according to the saturation limitation (see Market Saturation) while new registration will be influenced by the capacity of the system to absorb the new registration.

There is also other external variable which have impact on the passenger choice such as purchase price, expendable income, taxation and fuel consumption. These additional variables have the highest potential to control vehicle type purchasing decision.

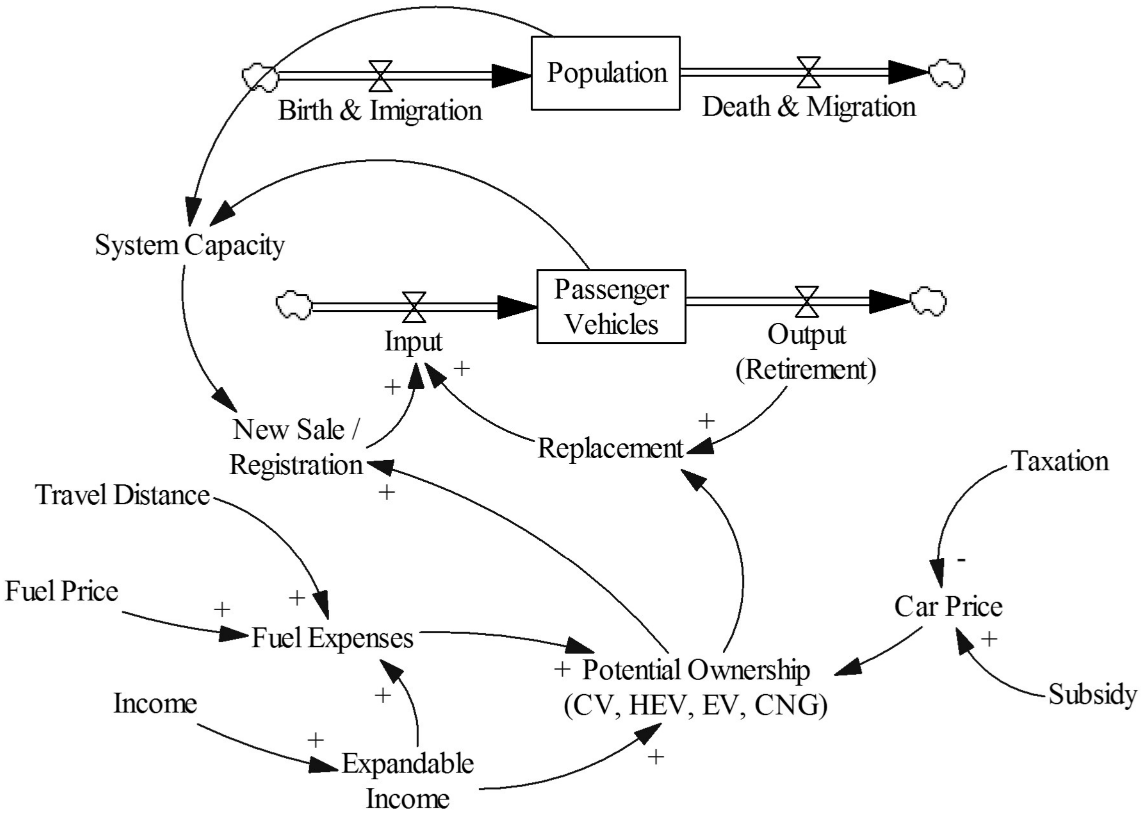

Figure 2.10 Influence diagram of income, taxation, subsidy and distance on vehicle choice.

Figure 2.10 represents the overall influence relationship for variables in this Chapter. Input is identified as Income, Tax level, Subsidy for vehicle purchases, Travel Distance, Fuel Prices which are cost related, population, and existing vehicles. Dotted line represents information sharing.

Purchasing of new and replaced vehicles depends mainly on income, final price and additional operational cost of the vehicles. Growth of different type of vehicles on another invisible variable 'technology adaptation curve' which was covered under the Gompertz curve function. EV and HEV is considered as new technology and suitable to be paired with Gompertz function while CV and CNG responds to this change of adaptation. Estimated vehicle sales for EV and HEV is represented by Equation 2.3.

$$EVS_{i,t} = Adoption\ Rate_{i,t} \times Max\ Potential_{i,t} \times TES_t \qquad \textit{Equation 2-3}$$

Where *EVS* is Estimated vehicle sales by type and time, *Adoption Rate* is individual result of S-curve Gompertz function on each vehicle type (HEV and EV) over time, *Max Potential* is maximum potential number of vehicles which was based in national income distribution for each vehicle type at current time, *TES* is the *Total estimated vehicle sales* which was estimated from the population-vehicle saturation at the current time.

Developers of new technologies generally face challenges in motivating consumers to purchase their products (Mohr, Sengupta and Slater, 2009). Traditional consumer-adoption models estimate diffusion of new innovations through society (Rogers, 2003; Moore, 2014). Main factors identified are Cost[6] and Society[7] (Rogers, 2003; Ford, 2010; Eppstein *et al.*, 2011; Parasuman and Colby, 2011; Moore, 2014; Wilmink, 2015; Choi, 2016; Hagman *et al.*, 2016). Survey based study was also done in order to develop other factor relationship for EV and HEV adoption (Hidrue *et al.*, 2011; Kurani, 2013; Sang and Bekhet, 2015). However, there is strong evidence that actual purchases are much lower than consumer's stated preferences derived from such survey (Coffman, Bernstein and Wee, 2017). This situation leads to utilization of historical data regression and fitting in most modeling study (Higuchi *et al.*, 2012; Huo and Wang, 2012; Nagata *et al.*, 2012; Coffman, Bernstein and Wee, 2015).

Vehicle Choice for vehicle ownership is being modeled in *Potential Ownership* module. Here, vehicle choice needs to go through two level of decision process. The first one involves affordability (*Cost*) which are directly related from Car Price, Expendable Income, and Fuel Expenses (as operating cost). Following this is *choice* level. This are the part where Equation 2.2 is again being used. The maximum potential, a for each vehicle type is equals to the distribution of population residing in the price bracket while the values of b and c is modified to seek the closest fitting according to historical data. The growth rate generated from this activity is being used as *Adoption Rate* in Equation 2-3.

2.3.6 Vehicle Survival Estimation

Vehicle survival functions as controller for passenger vehicle retirement as older vehicle leaves the system in a different rate compared to newer vehicles.

Survival estimation of vehicles mainly utilizes a Weibull distribution, as demonstrated by Nagata et al. (2012). He estimated that the average usable age of PCs in Japan is 12.6 years, on the basis of historical data from 1995 to 2010. The Japanese Automobile Inspection and Registration Information Association (AIRIA) reiterates this finding, and published a detailed average age of vehicles-in-use annually (Japanese Automobile Inspection and Registration Information Association (AIRIA)).

A similar study has also been conducted by Huo et al. (2012a), in which selected countries were compared: US, Japan, Europe, and China. This calculation utilized the *vehicle survival function* developed by Zachariadis, Samaras and Zierock (1995), who used a modified Weibull distribution to estimate the survival rates of automobiles (Sano, 2008; Hao, Wang and Yi, 2011; Huo, Zhang, *et al.*, 2012) in Equation 2-4;

$$f(age) = exp\left[-\left(\frac{age + b}{T}\right)^{b}\right] \qquad \textit{Equation 2-4}$$

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[6] "Cost" refers to initial purchasing cost of the vehicle.

[7] "Society" in layman term represents the condition of word-of-mouth, or peer-to-peer promotion.

where parameter T is the maximum vehicle service life, b is the failure steepness parameter for the vehicle type (which increases with age), and k is the present probability of a vehicle having age k. With this, he suggested that vehicles in Greece have a natural maximum usable age of 30 years, which represents the value of the Weibull function at the 99th percentile. Under this survival function, the older the age of the vehicle, the less its chance of surviving that year.

Table 2.3 Vehicle Survival Function, Selected Countries (Modified from Sano (2008)).

			Percentile	
	b	*T*	*50th*	*99th*
			(Vehicle age)	
US	3.4	21.6	16	31
UK	3.48	18.1	14	26
Japan	3.5	17	12	24

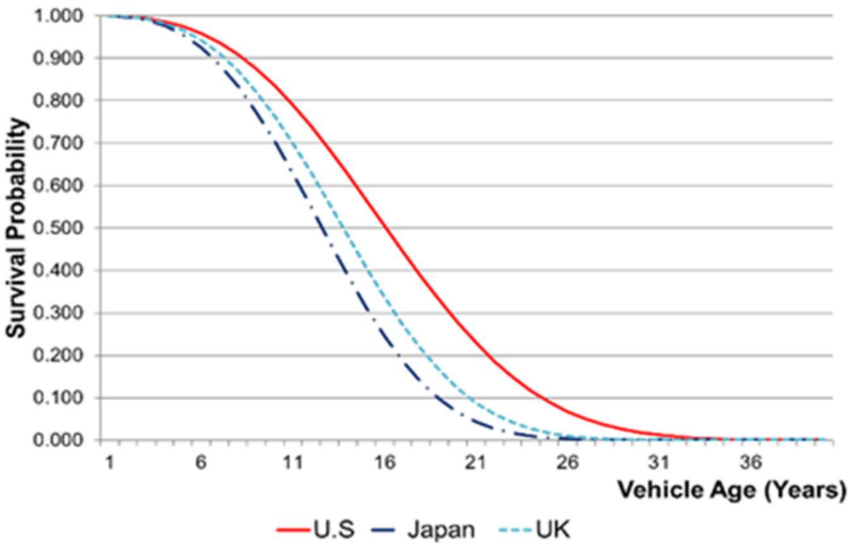


Figure 2.11 Example of vehicle survival function according to age; Japan, U.S.A, and United Kingdom modified from Sano (2008).

Utilizing this formula on the 2006 vehicle database, we obtained b and T for several countries, which are given in Table 2.3, as well as the average age of the vehicles and the longest estimated lifespan of the vehicles in the year as shown in Figure 2.11. The Malaysian vehicle age characteristic is estimated at 15 years old (Hoh, 2013; Ahmed *et al.*, 2014). This study assumes MA14 vehicle survival function will move the estimated age to 14 years old, while MA12 is expected to move the estimated age to 12 years' old which was based on success of vehicle scrapping policies in Japan and China which are going to be discussed in the next section. All data assumption used in this chapter are available in Table 2.5 while the rest of the equations are available in Table 2.6 of the following section.

2.3.7 Policy Scenario

Two alternative scenario is being investigated during this stage. The model is being build according to current scenario which called Business-as-Usual, BaU. The alternative scenarios MA14 and MA12 each represents the desire to increase the adoption of newer generation vehicles such as HEV and EV, and at the same time reducing the desire on fossil fuel consumptions.

Table 2.4 Study Policy Scenario Settings.

Policies	**Vehicle Age Policy**		**Promotion**			
	Inspection Regulation	*Emission Regulation*	*Base tax per vehicle (only for new vehicles)*		*Additional tax per vehicle*	*Subsidy (MYR)*
BAU	No inspection regulation	Euro 2 (no change)	CV :	75%	0%	
			HEV :	75%	0%	
			EV :	75%	0%	
			CNG :	75%	0%	
MA14	Annual inspection for vehicles above 12 years	Euro 6	CV :	40%	10%	
			HEV :	40%	5%	
			EV :	40%	0%	
			CNG :	40%	10%	
MA12	Twice annual inspection for vehicles above 10 years	Euro 6	CV :	15%	15%	
			HEV :	15%	0%	
			EV :	15%	0%	5000
			CNG :	15%	15%	

Scenario settings for this model is listed in Table 2.4. Under current condition, non-commercial vehicle inspection is not required for passenger vehicles except in the case of ownership transfer while emission regulation have not been changed since 1994. On top of that, each vehicle sold in Malaysia is being priced including non-value-added 75% to 105% excise duty (Malaysia Automotive Association, 2016) imposed by government. Still, vehicle ownership reached 370 vehicles per 1000 people in 2013 (The World Bank, 2014) or 57.6% of potential drivers population. The vehicle age policy indirectly serves as ELV management policy, which allows only vehicles that can pass the emission based inspection to be continuously used. Vehicles which fail this inspection is either required to be wholly exchanged, or repaired before re-tested. This condition follows the method used by Japan to control vehicle emissions and safety adherence.

First alternative MA14 is expected to reduce average vehicle age to 14 years via indirect government intervention by introducing annual inspection for vehicles aged 12 and above with implementation of Euro 6 emission regulation. At the same time, vehicle taxation is reduced to lower overall vehicle prices. This reduction couple with new regulation is expected to boost demand for new vehicles. Additional taxation for CV is needed to create a comparable pricing of HEV.

Second alternative MA12 aims to reduce average vehicle age to at least 12 years by requiring vehicle to be inspected twice annually after age of 10. Such aggressive emission regulation started implementation in China in January 2016 (Innovation Center for Energy and Transportation, 2015). Emission regulation is also upgraded to Euro 6 standard and base tax per vehicle is limited to 15%.

Table 2.5 Input Data Used for This Chapter

Item	**Variable**	**Value**	**Source**
1	National Population 2012	29.2 Million	(United Nations Population Division, 2012)
2	Potential Owner 2012 (population aged between 20 and 80)	63.5%	(United Nations Population Division, 2012)
3	Passenger Vehicle 2012, PV2012	10.5 Million	(Ministry of Transportation Malaysia, 2013)
4	Active vehicle in 2012	PV_{2012}*0.73	(Ministry of Transportation Malaysia, 2013)
5	New Vehicle Registration, Nr	633,231	(Ministry of Transportation Malaysia, 2013)
6	Sales Growth, h	Mean 0.0403, SD 0.1053	(Ministry of Transportation Malaysia, 2016)
7	Saturation Value, Sat	50%	(Huo and Wang, 2012)
8	Taxation, Tax	Refer Table 2.4	(Malaysia Automotive Association, 2016)
9	Average Vehicle Age, Age	15	(Zainal Abidin *et al.*, 2009; Hoh, 2013)
10	Vehicle Prices without tax, vp	CV = 20,000 CNG = 28,000 HEV = 90,000 EV = 180,000	Refer Table 2.2
11	Annual Income	Mean 73,932, SD 53,189	Adapted from (Department of Statistics Malaysia, 2015a)
12	Expendable Income	20%	(Department of Statistics Malaysia, 2015b)
13	Maximum Vehicle Loan Tenure, Loan	9 years	(Bbazaar.my, 2016; Ministry of Finance Malaysia, 2016b), bbazaar.my
14	Travel Distance (km)	24,280	(Shabadin, Johari and Jamil, 2014)
15	Vehicle Type, i	CV, CNG, HEV, EV	
16	BaU survival function	b=3.4 T=20.5	
17	MA14 survival function	b=3.48 T=18.1	
18	MA12 survival function	b=3.5 T=17	

Table 2.6 Equations used for this Chapter

Item	**Variable**	**Equation**
1	National Population , *Pop(t)*	$Pop(t) = Pop_{(t-1)} \times g_t$
2	Potential Owner, *Po (t)*	$Po_t \times 0.63$
3	Vehicle Stock, *S(t)*	$PV_t + \sum Tes_t - \sum Scrap_t$
4	Maximum Potential Vehicle Stock, *MaxS(t)*	$\left(Sat \times \sum Pot_t\right) - \sum Stock_t$
5	Stock Intensity, *Sp(t)*	$\sum Pop_t \div S_t$
6	Allowable annual sale, *MaxN(t)*	$MaxS_t - S_t$
7	Total Estimated Vehicle Sales, *Tes(t)*	$Nr_{(t-1)} + Nr_{(t-1)} \times g$
8	Annual Vehicle Price, P_i	$\frac{vp_i \times Tax_{Tax\ Policy} + Subsidy_{Subsidy\ Policy}}{Loan}$
9	Annual Income Distribution, *Income(x)*	$f(x) = \frac{1}{73932\sqrt{2\pi}x} e^{-\frac{(\ln x - 53189)^2}{2(53189)^2}}$
10	Population with ability to choose, *Affordability*	$\int_{P_i}^{\infty} f(x)\, dx$
11	Affordability Ratio, *Ar*	$If\ Income \times 0.2 \geq P_i\ then\ 1\ else\ 0$
12	Coefficient Affordability, *Cr*	$\sum Ar_{CV,\,EV,\,HEV,CNG}$
13	Maximum Potential Vehicle of Type *i*,$MaxT_i$	$\frac{Ar_i}{Cr} \times Tes$
14	Growth EV, *gEV*	$e^{-10.7e^{-0.023t}}$
15	Growth HEV, *gHEV*	$e^{-4e^{-0.147t}}$

Table 2.6 Equations used for this Chapter (Continued)

Item	**Variable**	**Equation**
16	Estimated Vehicle by Type, $EVS_i(t)$	$\frac{MaxT_i \times g_{i_t} \times 100}{Tes}$
17	Vehicle Survival Function , *f(age)*	$\exp\left[-\left(\frac{age+b}{T}\right)^b\right]$
18	Scrap Rate, *ScrapR (t)*	$f(age-1) - \frac{f(age)}{f(age-1)}$
19	Scrap, *Scrap (t)*	$\sum_{i,age} Stock_{t-1} \times ScrapR_t$

2.3.8 Model Testing

Sterman (2000) points out that a model cannot be "validated" nor "verified" as all model are wrong as they differ from the reality. This statement echoes Forrester (1961), Greenberger, Crenson, and Crissey (1976), and Oreskes, Shrader-Frechette, and Belitz (1994) which concluded that no model has ever been or ever be thoroughly validated. However, a model can only be tested if it has the capability to conform to the actual situation.

A model is required to undertook model testing in order to improve the trustworthy, robustness and sensitivity of the model results to assumptions about the model boundary and feedback structure. The sensitivity analysis was required to assist replication or expansion of the model itself for future works (Sterman, 2000). It also functions as an evidence for making any related decisions. A model testing is also done in order to uncover any error, understand model limitation, and to find out any improvement opportunities so that the model can be useful.

In this topic, two testing is done in order to understand the weakness of the model. The testing are Historical Data Testing and Uncertainty analysis.

2.3.8.1 Historical Data Testing

This testing method involves a technical comparison between the actual measured or quantified values against the simulated values. The testing was done on two main variables which are the Total Number of Vehicles, and Annual New Vehicle Registration based on statistical data availability which was done from 2012 to 2015.

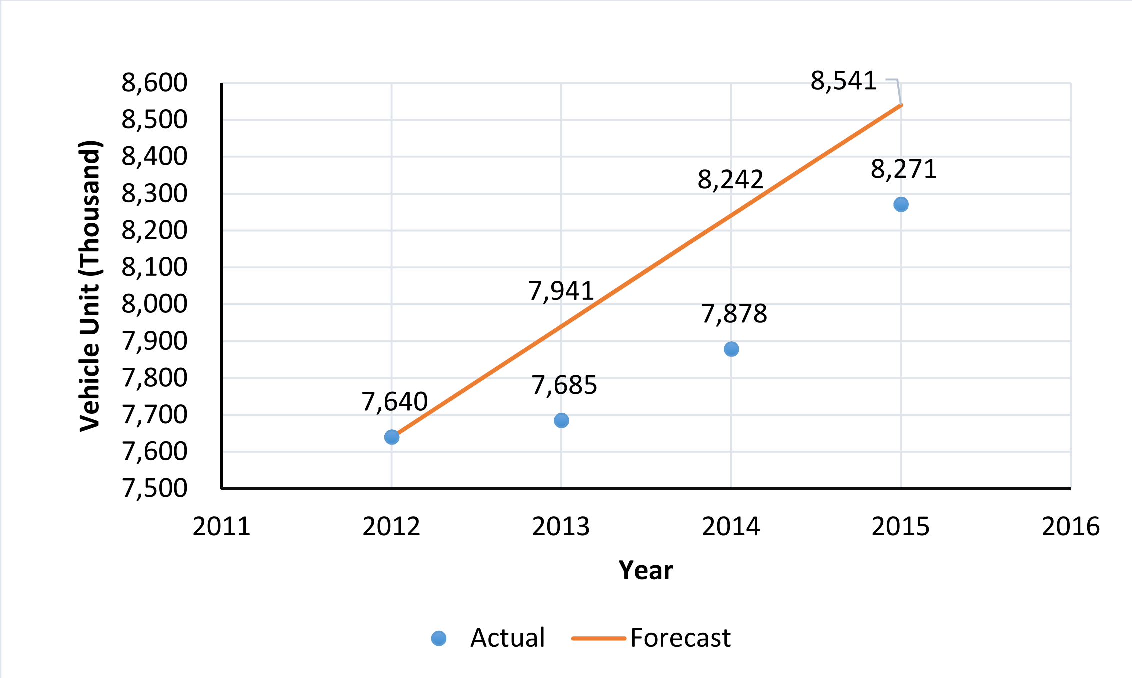


Figure 2.12 Data Testing for Total Number of Vehicles (2012 - 2015).

A comparative in term of Mean Absolute Percentage Error (MAPE) was chosen as a criterion for comparing the deviation value of forecasted value based on simulation against the actual quantified data. MAPE is often used to compare the fits obtained by using different calculation method, which expresses accuracy as a percentage of error. The forecasted or simulated MAPE value of less than 10% is considered as acceptable (Joyosemito, Tokai and Nakakubo, 2014). A high MAPE values also indicates the high degree of fit between measured or actual data and simulated or calculated data (Coleman and Steele, 2009). Mean Absolute Deviation (MAD) is the expression of accuracy in the same unit as the data itself, which can help the conceptualization of the amount of error, while Root Mean Square Error (RMSE) serves to aggregate the magnitudes of errors in estimation for multiple times into a single measure of predictive power. However, MAPE provided a most understandable value which in term of percentage. The simplicity of MAPE provided better understanding for majority of people.

Based on the values of actual against forecast in Figure 2.12, MAPE value for Total Number of Vehicles is 2.79% which indicates the reliability of the forecasted value. MAD is calculated at 222,037 while RMSE is calculated to be 259,726. Value of MAPE is considerably lower, which strengthen the model output.

However as discussed in Section 2.3.4, the values of actual result itself have certain degree of uncertainty as the accurate number of active vehicle is unknown. Therefore, this study tested the second available statistical value, which are the Annual New Vehicle Registration, shown in Figure 2.13.

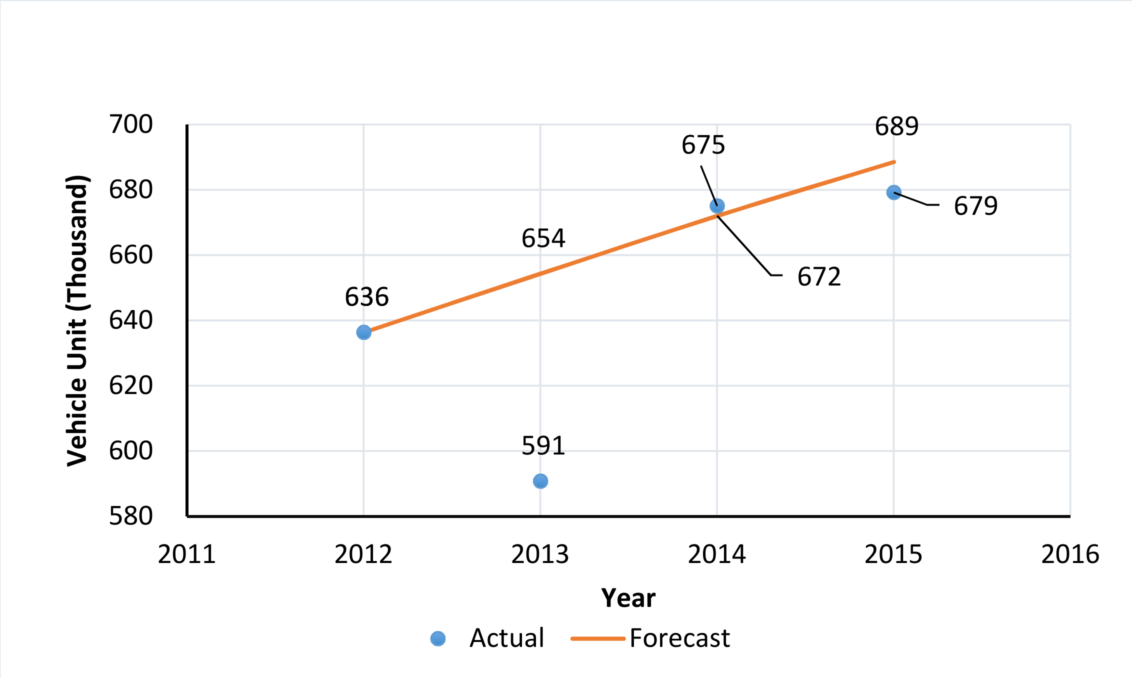


Figure 2.13 Data Testing for Annual New Vehicle Registration (2012 - 2015).

The actual quantified number of new vehicle registration is gathered directly from New Vehicle Registration statistics provided by Ministry of Transportation Malaysia (2015a). Result from MAPE calculation for Annual New Vehicle Registration reveals the error percentage at 3.14%, MAD value is at 32,139 while RMSE stands at 32,139. The low value of MAPE indicates the reliability of this simulation result.

Historical Data Testing shows a high reliability of model to estimate vehicle demand. This in turn can be used for policy planning under key variable adjustment.

2.3.8.2 Uncertainty Analysis

This analysis is the second scrutiny done in order to locate the source of incoherence in a misbehaving simulation. As a model is only a replication of a real system, users need to be provided the probability of the probabilistic values of the model to fit to the real values of the real system. Uncertainty analysis was done on the New Vehicle Registration as this variable have better data representation in the real system.

In Analytica, the Uncertainty Analysis is being represented by Probability Bands functions, which uses median as opposed to mean of the distribution as data representation. This resulted in slight difference compared to the values shown in MAPE.

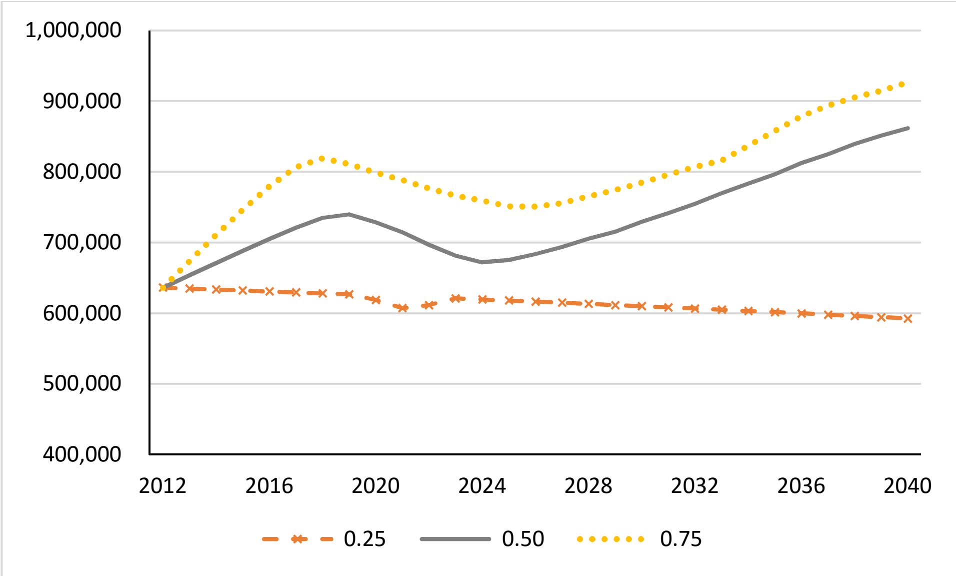


Figure 2.14 Probability Bands of New Vehicle Registration at 75% prediction interval (2012 – 2040).

Utilization of the model reveals the probabilities of New Vehicle Registration in every year until 2040 indicated in Figure 2.14. The array of percentiles was estimated from the random sample at 25th percentiles (0.25) and 75th percentiles (0.75), also known as % prediction interval throughout the simulation results. The estimated New Vehicle Registration are based on the probabilistic projections of, among others, population, income, existing vehicle survival, and vehicle-population intensity.

Result shown in Figure 2.14 also shown to have probability since 2012, rather than 2016. This was due to Time=1 of the model (2013) is also an estimation, and not actual value in the real system. The lower probability at 25th percentile was also the result of direct feedback from stock-population intensity. The broad difference in the high and low probability band against the mean shown in in Figure 2.14 also reveals the limitation of the model to establish a higher accuracy estimation.

2.4 Result & Discussion

2.4.1 Stock Estimation

Malaysia reported to have 11.19 million vehicle registration at the end of 2014[8]. The same report also mentions that nearly 28% of total vehicle is inactive, an increase of 1% compared to 2012. Under this assumption, we estimate the number of active passenger vehicles is at 7.64 million in 2012. We found that the relevant authority does not keep track of the statistics of vehicle being de-registered

[8] 11,192,921 vehicle including Car, Taxi and Rental Cars, Malaysia Road Transport Department Transport Statistics, 2015.

or scrapped. Moreover, they do not keep the data of individual vehicle age, making estimate of average vehicle age and vehicle age distribution less accurate.

In a nutshell, the model is constructed so that it will respond to any given changes at any one of the variable to predict future environmental impact of passenger vehicle quantity. Main variable for hybrid and electric vehicle promotion responds to input of income and vehicle price. In this study, we keep income in constant, while vehicle pricing is controlled with taxation and subsidy. The maximum number of passenger vehicles in a year is being limited to the number of potential owners, one part of the total national population.

Based on this information, current policy application is modelled under Business-as-usual, BaU and expected to continue unchanged until 2040. It is estimated that in 2020, number of passenger vehicles is expected to reach 9.71 million, 12.1 million in 2030 and 13.09 million in 2040, as depicted in Figure 2.15. Number of ultra-efficient vehicles such as HEV and EV will also increase to approximately 169,000 units in 2020, with 1000 unit of EV. In the year 2040, number of this vehicles will be increased to 1.54 million and the number of EV will exceed 49,000 units. This number however is relatively small, as HEV will only consist of about 10.9% while EV is only 0.3% out of the total number of passenger vehicles.

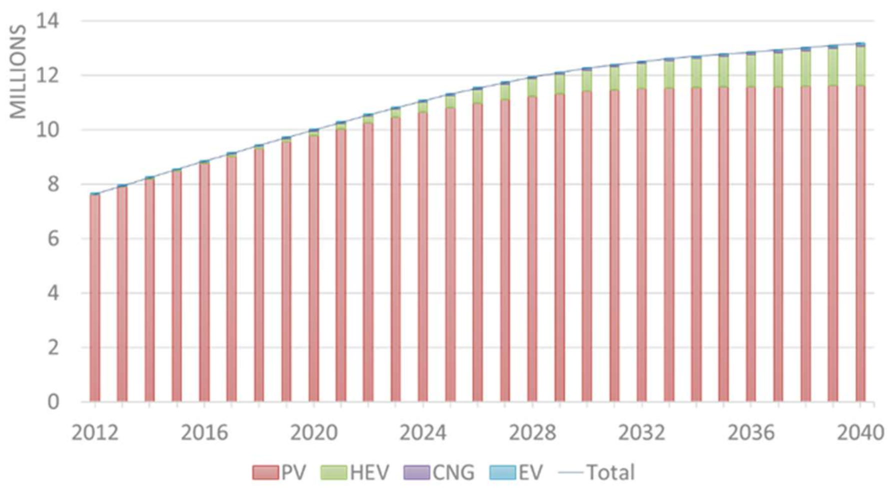


Figure 2.15 Annual PC stock level estimated according to vehicle type under Business-as-usual.

Further detail can be seen in Table 2.7. This situation will have a less desirable environmental impact with rather small reduction of total emissions. Under this condition, the nation will continuously increase its contribution towards global carbon stock.

Table 2.7 Detailed estimation of Passenger Vehicle Stock according to type.

	CV	HEV	CNG	EV	Total Stock
2012	7,605,318	23,607	10,925	31	7,639,881
2013	7,898,310	28,271	13,947	77	7,940,605
2014	8,189,390	35,404	16,998	137	8,241,928
2015	8,474,629	45,757	20,061	214	8,540,660
2016	8,753,924	60,062	23,127	311	8,837,423
2017	9,026,484	78,988	26,182	435	9,132,089
2018	9,290,121	103,101	29,213	589	9,423,023
2019	9,545,227	132,816	32,203	783	9,711,028
2020	9,789,632	168,383	35,138	1,022	9,994,175
2021	10,022,681	209,859	38,003	1,316	10,271,860
2022	10,243,803	257,116	40,780	1,676	10,543,376
2023	10,451,408	309,841	43,452	2,113	10,806,814
2024	10,644,053	367,559	46,001	2,641	11,060,254
2025	10,820,173	429,654	48,411	3,272	11,301,510
2026	10,978,527	495,407	50,664	4,024	11,528,623
2027	11,115,425	563,974	52,745	4,914	11,737,058
2028	11,233,327	634,473	54,640	5,958	11,928,398
2029	11,331,132	706,042	56,338	7,177	12,100,690
2030	11,409,296	777,923	57,838	8,595	12,253,651
2031	11,468,735	849,520	59,138	10,238	12,387,630
2032	11,510,934	920,315	60,271	12,139	12,503,659
2033	11,540,001	989,949	61,232	14,337	12,605,519
2034	11,558,922	1,058,181	62,059	16,880	12,696,042
2035	11,570,744	1,124,849	62,768	19,820	12,778,182

Table 2.7 Detailed estimation of Passenger Vehicle Stock according to type (continued).

	CV	HEV	CNG	EV	Total Stock
2036	11,578,811	1,189,851	63,392	23,221	12,855,274
2037	11,587,425	1,253,078	63,947	27,148	12,931,597
2038	11,597,975	1,314,475	64,443	31,682	13,008,575
2039	11,612,454	1,374,039	64,952	36,907	13,088,352
2040	11,633,798	1,431,812	65,451	42,918	13,173,980

Under this condition, vehicle age is unrestricted while the are no effort to control vehicle characteristics. The high taxation also leads to low number of HEV and EVs, and high number of conventional vehicles as CV pricing is considerably lower. Another observation from this result is the slowing down of growth which are noticeable after 2028. Under this condition, vehicle sales are only driven by replacement of retired vehicles. However, looking at the composition in Table 2.7 and 2.8, most of the replacement will still consist of CV.

Table 2.8 CV, HEV, CNG, EV composition under different policy application.

Policy	**BAU (%)**				**MA14 (%)**				**MA12 (%)**			
Year	***CV***	***HEV***	***CNG***	***EV***	***CV***	***HEV***	***CNG***	***EV***	***CV***	***HEV***	***CNG***	***EV***
2012	99.5	0.3	0.1	0.0	99.5	0.3	0.1	0.0	99.5	0.3	0.1	0.0
2020	98.0	1.7	0.4	0.0	97.5	2.1	0.4	0.0	97.0	2.6	0.4	0.0
2030	93.1	6.3	0.5	0.1	91.0	8.4	0.5	0.1	88.4	10.9	0.5	0.2
2040	88.3	10.9	0.5	0.3	85.1	13.7	0.5	0.7	80.9	17.5	0.5	1.1

Reduction of vehicle price under the new tax regime MA14 and MA12 caused more people to afford passenger vehicles. This will increase people's mobility, and downstream industry creating more demand for the industry. Also, the nation inspired to reduce their overall vehicle emissions and HEV/EV have the most efficient system per engine size. Vehicles with big engines such as BMW 325I with 2.5L engine have substantially high fuel consumption thus high CO_2 emissions, compared to the same vehicle class such as Lexus IS Hybrid system with 30-40% less fuel consumption. Providing more tax cut on EV/HEV provide better desire to own this new technology system.

Increasing demand on EV/HEV will create economy-of-scale while at the same time creating new area of industry; the environmentally friendly technology development and manufacturing, as well as improvement of current combustion technology to match HEV and EV emissions. The delay on this "promotion" will make the local producers having loosing opportunity due to weak demand, and further investment is put on hold. For an example, California have placed this regulation and directly benefit companies such as Tesla and Nissan. This situation provides the motivation for this kind of companies to increase its R&D investments. As demand picks up, more and more companies started the EV revolution. This cyclical situation made the EV/HEV industry to be sustainable, at the same time reducing the overall tailpipe emissions.

2.4.2 End-of-Life Vehicles (ELV) Generation

Generation of end-of-life vehicle however responded rather extremely following the policy changes. Different life expectancy was modified following artificial intervention from new regulation of requiring annual and bi-annual vehicle inspection, and requiring all vehicles emission system to be upgraded to higher standard of EURO 6. This shock generated a spike of ELVs in both cases of MA14 and MA12 as shown in Figure 2.16 (b) and (c).

The high number of retired vehicles is currently being processed by small-medium scale material recycling businesses. On average, about 418,000 vehicles scrap or end-of-life vehicles (ELV) is expected to be generated annually from 2012 to 2020. The number continues to rise until it reached 764,000 units in 2040 alone. Table 2.9 listed ELV generated at 5-year interval from 2016. Approximately 2.2 million ELV is generated until 2020. The high number of units is enough to create concern regarding the management of this waste. As Malaysia does not have vehicle age limitation, average age of scrapped vehicle is estimated to be 15 to 16 years old, reducing the value and reliability of harvested parts. This situation leads to low part reusability and remanufacturing which are higher value, and high number of material recycling and energy recovery. Moreover, the only small number of ELV contains the valuable and highly recyclable NiMH or Lithium ion batteries.

Table 2.9 End-of-life Vehicle Generation per 5 year period.

	CV	HEV	CNG	EV	Total
2016-2020	2,257,228	5,164	3,599	20	2,266,011
2021-2025	2,653,454	22,670	6,985	124	2,683,233
2026-2030	3,013,149	67,384	11,274	473	3,092,280
2031-2035	3,308,635	148,388	15,430	1,367	3,473,820
2036-2040	3,470,319	256,300	18,176	3,377	3,748,172

Alternatively, shorter lifespan of vehicles in MA14 and MA12 condition have higher potential to generate more reusable parts as the vehicles being retired have less service age.

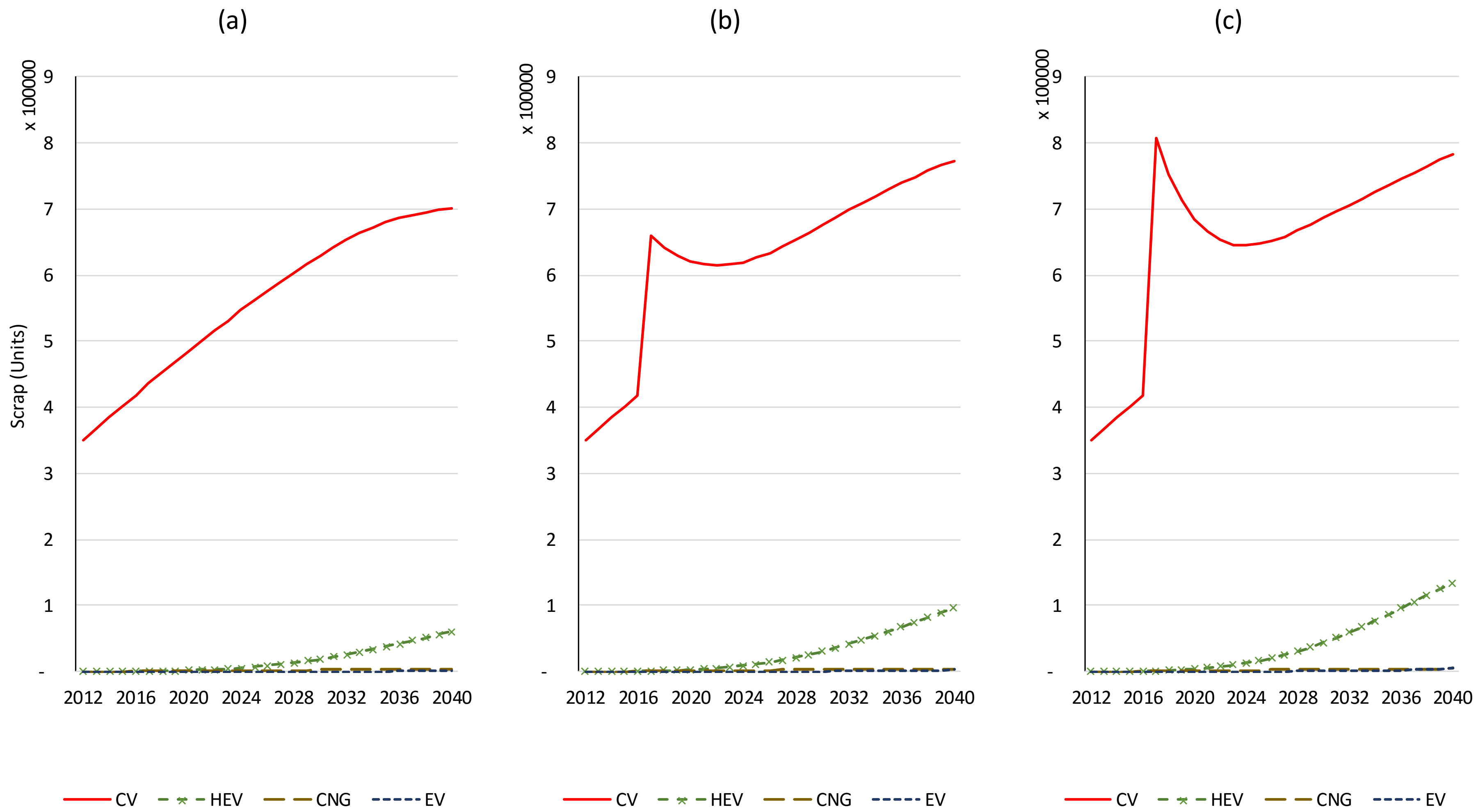


Figure 2.16 End-of-Life vehicle generated from (a) Business-as-usual, (b)MA14 policy, and (c) MA12 policy.

As expected, ELV generation is higher in MA12 policy, which have the potential to reduce overall vehicle age. The spoke at $Time_6$ is caused by the policy implementation which we set at 2017, 6 years after the model. Although the sudden implementation is unlikely, the we cannot rule out the possibility of its implementation. Result shows that proper ELV management system is required in order to quickly absorb the spike created by any regulation changes.

Implementation of controlled vehicle age also created a condition where a more sustainable market can be achieved, and any technological improvement adaptation can be done quickly.

2.4.3 New Vehicle Sales/Registration

New vehicle sales under BaU will be stagnated in 2024 at roughly 800,000 units annually while the effect of saturation can be delayed under the alternative policies as shown in Figure 2.17. This situation created a less appealing condition for new investors as the current market capacity is nearing its saturation in about 10 years while other neighbouring countries have better outlook. As a result, economic sustainability for efficient vehicles is unable to be reached.

Under the alternative policy, new vehicle sales saturation is reached much later and at higher values, giving confidence for investors for additional capacity building and R&D, under assumption of profitable investment.

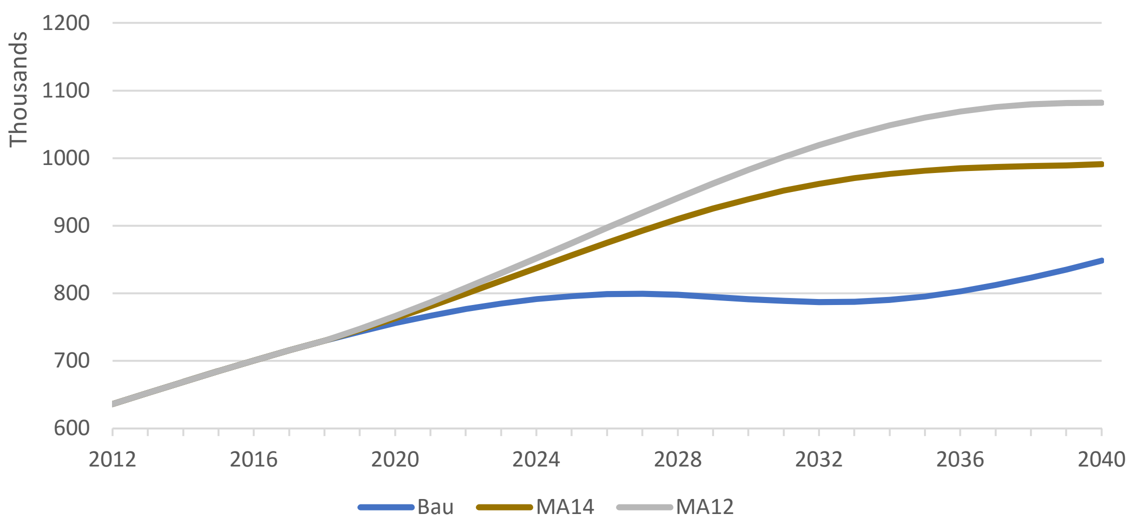


Figure 2.17 Estimated New Vehicle Sales.

2.5 Conclusion

Based on the methodology of Higuchi *et al*. (2012), we have constructed a stock and flow model of Malaysian PC quantity using all available data from 2000 to 2014 to establish a pattern of customer preferences and their effect on future passenger vehicle stock, considering the implementation of two alternative policies. We also utilized income distribution, expendable income, vehicle pricing, tax, subsidy and emission regulation as variable to make the model more representative of the real world situation.

High efficiency vehicles such as HEV and EV is estimated to reach 2.5 million vehicles of total existing vehicle in 2040 under MA12 policy as opposed to 1.4 million under business-as-usual policy, described in 2.4.1.

Passenger vehicle market will reach its saturation in 2024, where new purchases is only filled by vehicle replacement while end-of-life vehicles will continually increase. At the end of 2014, more than 400,000 units of ELV is generated as reported in Section 2.4.2. Parts from these scrapped vehicles can only use for material recycling and energy recovery, rather than reuse or remanufacture due to extended wear and tear under the long survival age. Under alternative scenarios, ELV generated age is reduced providing options for this activities.

New registration of vehicles has the potential to reach 800,000 units in 2024 but the growth is unlikely to be sustained. As result, vehicle market will stagnate from 2024 onwards as discussed in Section 2.4.3.

This study uses the average vehicle age database, which is based on existing vehicles and includes all types of vehicles: internal combustion engine, hybrid, electric, and compressed natural gas vehicles. In relation to environmental tests, hybrid and electric vehicles rarely fail emission tests, hence allowing them to have a longer life. In future studies, researchers may also need to address this issue.

Chapter 3. Environmental Burden of Vehicle Management Policies for Future Malaysia.

3.1 Chapter Overview

This chapter is the expansion of model covered in previous chapter. It will have in-depth focus on the greenhouse gas emissions from passenger vehicle usage variables highlighted in Figure 3.1. Study motivation and scope is explained in subsection 3.2.1 and 3.2.2.

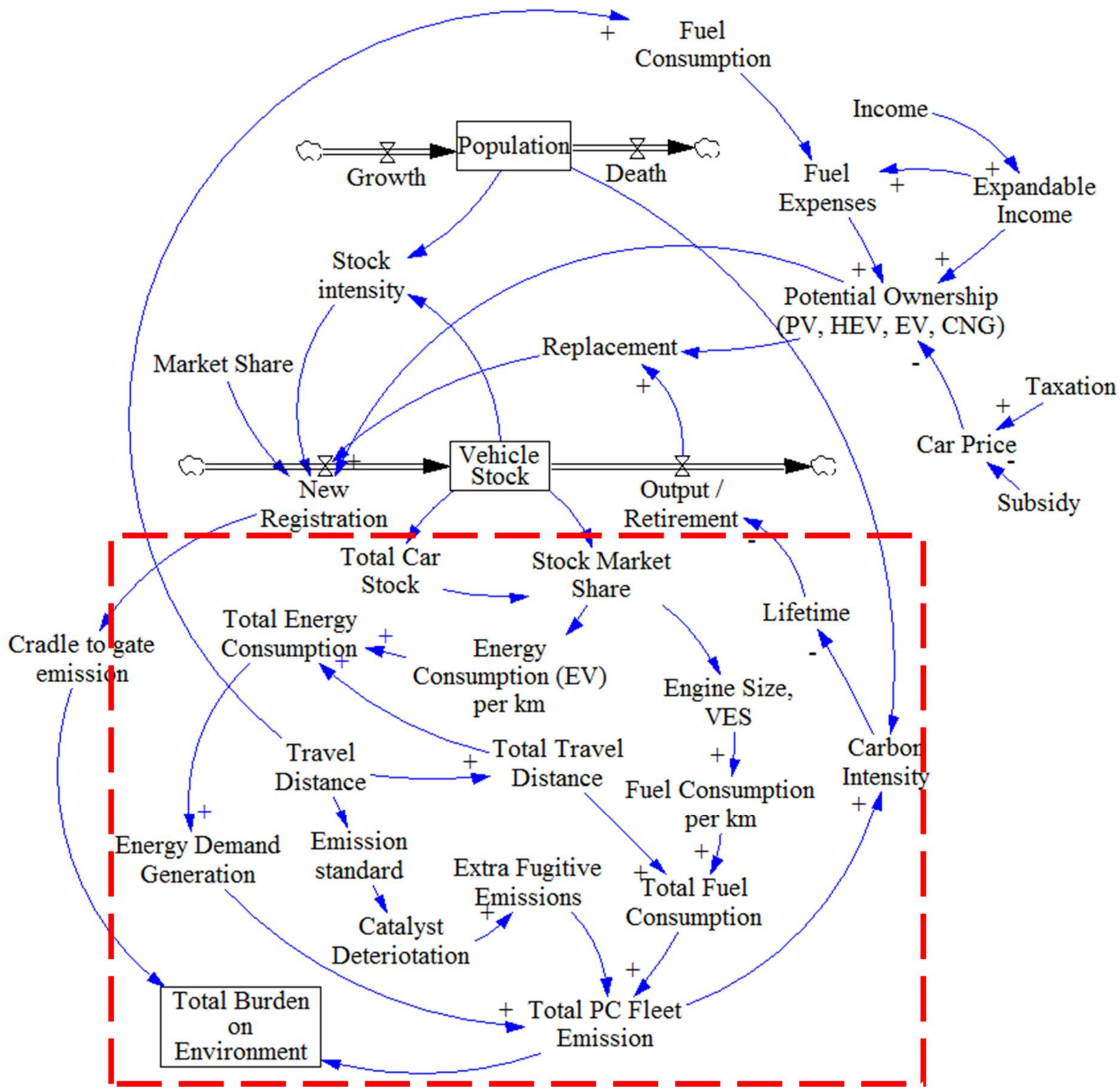


Figure 3.1 Thesis main conceptual diagram with studied variables. The red rectangle indicates the area being focused in this chapter.

The method used and modeling process can be found in Section 3.3 which also describes the calculation, data sources used, emission model formula, model testing and policy formulation method.

Section 3.3.5 provided the results of estimated energy requirement to support electric vehicle usage. Greenhouse gas emissions and pollutions generated from vehicle usage is explained in Section 3.4.

3.2 Introduction

3.2.1 Need for study

Measurement of CO_2 emissions is often complex and nonlinearly interacted due to its dynamic nature. Application of modern computing techniques and sophisticated system dynamics should be used for more reliable simulation of vehicle emissions. Information collected over the years can improve the overall emission estimation. Modeling environmental impact from transportation has previously been done using time series analysis, optimization, regression analysis, and system dynamic modeling. Very few study have estimated CO_2 release from the transportation sector in Malaysia, with many relevant issues being ignored (Shahid, Minhans and Puan, 2014).

Other countries have developed time series models for transportation emissions with a focus on local information, for instance,Sweden (Börjesson and Ahlgren, 2012), Japan (Kojima *et al.*, 2016), the United States (Lakshmanan and Han, 1997), China (Huo, Wang, *et al.*, 2012), and Ghana (Ackah and Adu, 2014).

As for Malaysia, a plethora of review papers have addressed this matter (Ong, Mahlia and Masjuki, 2011; Salem, Atiq and Jaafar, 2011; Mohd Jawi *et al.*, 2012; Hosseini, Wahid and Aghili, 2013). However, quantitative transportation environmental modeling and policy modeling and analysis are scarce. Kamarudin et al. (2009) constructed an optimization model to conclude minimum cost–maximum benefit for a delivery network of hydrogen fuel. Mustapa and Bekhet (2015) performed multiple regression analysis to discover the root cause of Malaysian transportation emissions, while Ang (2008) used time series analysis, and Azam et al. (2015) used time series with the compounding effect from historical increases for all vehicle types. Regardless, policy studies have been conducted elsewhere, for instance, in China (Chen, 2005; Wang, Teter and Sperling, 2011; Huo and Wang, 2012), the United States (Jacobsen and van Benthem, 2013), Japan (Higuchi *et al.*, 2012; Kojima *et al.*, 2016), and the European Union (Thiel, Perujo and Mercier, 2010; Pasaoglu, Honselaar and Thiel, 2012).

3.2.2 Scope

Dynamic problems in environmental concerns and other activities can be tackled using the system dynamics modeling approach (Joyosemito, Tokai and Nakakubo, 2013), which this study advances for transportation, energy, and related emissions. Due to the immense quantity of passenger vehicles (PCs) in the Malaysian transportation mix, historical PC quantities according to fuel type have been collected, and the trend has been analysed to estimate future energy demand and related GHG emissions. Distribution of engine sizes, travel distances, fuel types, consumption details, and emission data have also been processed.

Various realistic policy applications have been included in the model and their impact analysed to determine the advantages of application. Furthermore, easy input modification can help us study the effect of adopting EURO 5 and 6 emissions should the measured database become available, as well as application for all vehicle types in the near future.

3.3 Method and Modeling Process

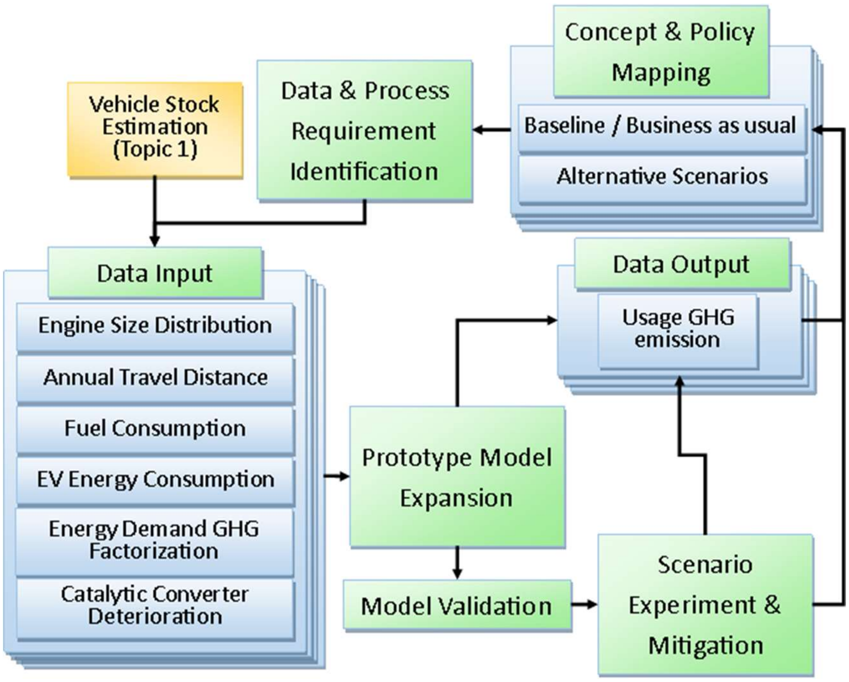


Figure 3.2 Research Framework for Environmental Burden of Vehicle Management Policies for Future Malaysia.

Data and process requirements were identified from previous, similar system dynamic studies. Historical data is primarily used for generating statistical data. Input data used in this section is mainly from vehicle stock quantity and fuel-type distribution, collected from annual reports of Malaysian Transport Statistics from 2000 to the most recent publication. Based on this, we extrapolated historical data to estimate each variable's growth and trend.

The next phase, construction of a prototype model, was accomplished with two separate modules. The first module functioned as determination of stock while the second module, which is further discussed in the following section, housed variables for estimating vehicle emissions based on the first module's results. The model was later tested using tornado analysis to determine each variable's importance and sensitivity. After the business-as-usual (BaU or *Baseline*) iteration has been completed, sets of policy scenarios are constructed through manipulation of these values, and the data generated can help select the best policy. Results from these scenarios are compared to provide recommendations for the most effective policy and combinations of policies for actual application.

Transportation modeling software, for example, MOBILE, COPERT, and LEAP, have previously been developed. However, the advantage of using a system dynamic tool such as Analytica, means that distribution can be used as input data, application of the Monte Carlo uncertainty method and logic functions is made possible, thus providing results in terms of mean values of the lowest and highest probabilities.

3.3.1 Calculations and Data Sources

Various papers have addressed emission information for vehicles. However, country-specific information for Malaysia is unavailable, so other data sources were required. Thus, utilization of raw data from the United Kingdom's Vehicle Certification Agency (VCA) was chosen to represent basic emissions data from vehicles; PCs, HEVs, EVs, and Compressed Natural Gas Vehicles (CNG)s. The VCA is the agency responsible for collecting, testing, and issuing emissions certification for every UK vehicle registered, in order to meet minimum EU emission standards. The VCA is also responsible for producing the "New Vehicle Fuel Consumption and Emissions" booklet and data, which is available free to the public. Table 3.1 lists related input data and their sources used in this model. Other localized data sources include annual PC travel distance, commonly referred to as "Vehicle Kilometre Travel" (VKT) and engine-size quantity distribution. Electric generation sources are gathered from the Malaysia Energy Commission, which does long-term energy planning and is responsible for analysis, planning, and procurement for energy-related activities in Malaysia.

Table 3.1 Input Data and Formula Table for System Dynamic Model to Estimate Malaysian Transport.

No	***Variable***	***Values***		***Source***
1	Vehicle Stock	Refer Chapter 2, Section 2.4.1		
2	Travel Distance (km)	Mean (24129) Standard Deviation (3001)		Existing survey result (Shabadin, Johari and Jamil, 2014)
3	Vehicle Engine Size distribution, *VES*	Refer Appendix 2.		Transport Statistic Malaysia (Ministry of Transportation Malaysia, 2016)
6	Fuel Density Factor (TJ/L)	Gasoline CNG	3.42×10^{-5} 2.50×10^{-5}	Hafemeister et al. (2008)
7	Initial Nitrous Oxides (NO_x) Emission (kg/km)	CV HEV CNG	2.43×10^{-5} 1.13×10^{-5} 1.08×10^{-5}	Adapted from Vehicle Certification Agency, UK (UK Vehicle Certification Agency, 2016)
8	Initial Carbon Monoxide (CO) Emission (kg/km)	CV HEV CNG	3.87×10^{-4} 1.81×10^{-4} 1.69×10^{-4}	Adapted from Vehicle Certification Agency, UK (UK Vehicle Certification Agency, 2016)
9	Initial Hydrocarbon (HC) Emission (kg/km)	CV HEV CNG	4.58×10^{-5} 2.66×10^{-5} 4.61×10^{-5}	Adapted from Vehicle Certification Agency, UK (UK Vehicle Certification Agency, 2016)
4	Methane emission (kg / TJ of fuel)	Gasoline Natural Gas	LogNormal, Median = 33, Std Deviation = 34 92	2006 IPCC* Guidelines for National Greenhouse Gas Inventories; mobile combustion (IPCC, 2006)
10	Fuel Consumption, *FC* (L/km for CV, HEV, CNG)	CV : (4.021+(2.119m × *VES*))/100 HEV : (2.87+(1.552m × *VES*))/100 CNG : (6.067+(1.432m × *VES*))/100		Adapted from Vehicle Certification Agency, UK (UK Vehicle Certification Agency, 2016)

Table 3.1 Input Data and Formula Table for System Dynamic Model to Estimate Malaysian Transport (continued).

No	***Variable***	***Values***	***Source***
11	Energy Consumption, *EC* (TJ/km for EV)	EV: Mean (5.184×10^{-7}), Standard Deviation 7.56×10^{-8}	Adapted from Vehicle Certification Agency, UK (UK Vehicle Certification Agency, 2016)
12	Carbon Dioxide emission (kg / TJ of fuel)	CV : 1.27+(2369 × FC[CV]) HEV : -1.414+(2350 × FC[HEV]) CNG : 2.546+(1761 × FC[CNG])	IPCC* Mobile combustion, Vehicle Certification Agency, UK (UK Vehicle Certification Agency, 2016)
17	Electricity Generation Plan	Refer Figure 3.3	Malaysia Energy Statistics Handbook 2015 (Energy Commission, 2015) KeTTHA Annual Report 2013 (Ministry of Energy Green Technology and Water, 2013)
18	Electricity generation GHG Emission (kg)	Refer Appendix 4	2006 IPCC Guidelines for National Greenhouse Gas Inventories; Stationary combustion (IPCC 2006)

*Intergovernmental Panel on Climate Change

Future Greenhouse Gas emissions from power generation is calculated from IPCC recommendation on stationary combustion with planned electrical generation mix by Ministry of Energy Green Technology and Water, (2013) and Energy Commission (2015) as depicted in Figure 3.3. Malaysia also plans to source much larger amount of renewable electricity from hydropower dams starting in 2023 as well as embarking to nuclear energy generation starting from 2025 to boost energy security this was necessary as part of national GHG reduction framework previously discussed in Section 3.1.

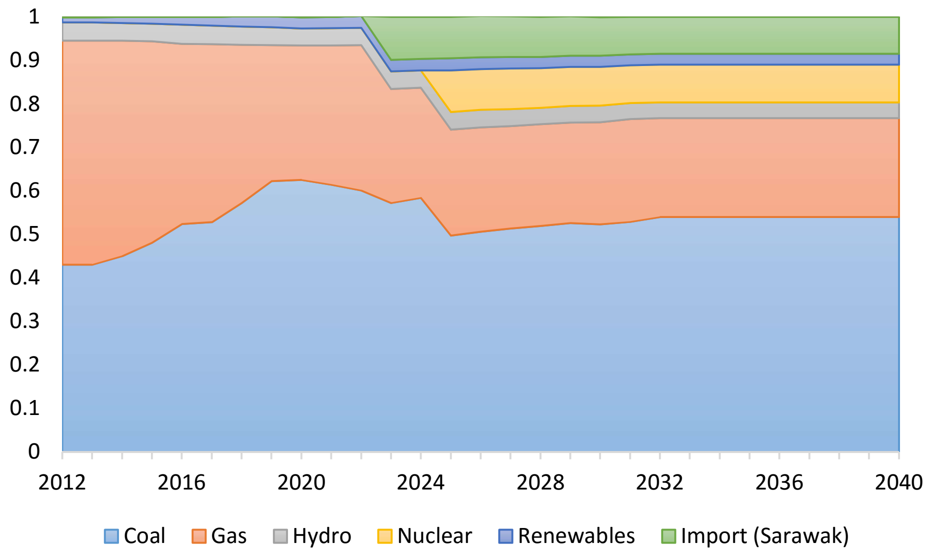


Figure 3.3 Electricity Generation Historical and Plan, 2012 to 2040. Sources from Malaysia Energy Statistics Handbook [74] and Energy Commissions of Malaysia [75]. (see Appendix 3 for further details).

3.3.2 Emission Model

The model was constructed based on the ideas illustrated in Figure 3.1. Passenger vehicle data for various fuel types are used to estimate fuel consumption and, later, catalyst deterioration rate. Travel distance data were also collected from vehicle owners to estimate fuel requirements and emissions. As for EVs, a separate path was introduced; this path goes through an electrical generation module that uses Intergovernmental Panel on Climate Change (IPCC) electrical generation emission guidelines. At the heart of it all is PC fleet management policy that dictates what and how many changes are required to achieve reduction of GHG and pollutant emissions from the Malaysian transportation sector.

One of this model's most important variables is the catalytic converter deterioration rate. The catalytic converter, which exists on all vehicles, functions as a simultaneous converter for release of nitrous oxides, carbon monoxide, and hydrocarbon, which are by-products of combustion. Application of catalytic converters reduces NO_x into more natural N_x and O_x, CO into CO_2, and hydrocarbons into CO_2 and water. The converter's nature, which relies on chemical conversion, means that, literally, sometime down the road, it will fail (Borken-Kleefeld and Chen, 2015).

An estimation method for the catalytic converter was first proposed in 2008, by Choudrie et al. (2008) Later, Boulter (2009) suggested using the estimation method for the UK Department of Transport. The European Union accepted the method and adopted it under Regulation No. 103 of the Economic Commission for Europe and the United Nations.

However, another calculation methodology exists for the EU. The "EMEP/EEA Air Pollutant Emission Inventory Guidebook" (Ntziachristos *et al.*, 2014) provided a more detailed method for calculating exhaust deterioration rate. However, Borken-Kleefeld and Chen (2015) recommended an improvement for the methodology based on data collection of roughly 100,000 vehicles from Switzerland over 13 years. He suggested that deterioration began as soon as the vehicle was used for NO_x and CO, but agreed that the current practice of measuring HC conforms to their findings. This confirms that such emissions have no correlation with engine capacity or fuel consumption rates, but with deterioration rates according to usage.

Related variables utilized modification of recommended formulas from an Borken-Kleefeld and Chen (2015) to estimate the rate of catalytic converter deterioration. More specifically, the converter deterioration rate is represented by Equation 3-1 to Equation 3-6:

$$CD\ Rate_{NOx,Euro2} = 1.0057e^{(6E-6)\times Vkt}$$ *Equation 3-1*

$$CDR_{NOx,Euro4} = 0.9948e^{(3E-6)\times Vkt}$$ *Equation 3-2*

$$CDR_{CO,Euro2} = 1.018e^{(4E-6)\times Vkt}$$ *Equation 3-3*

$$CDR_{CO,Euro4} = 1.082e^{(4E-6)\times Vkt}$$ *Equation 3-4*

$$CDR_{HC,Euro2} = 1 + e^{(2E-5)\times Vkt}$$ *Equation 3-5*

$$CDR_{HC,Euro4} = 1$$ *Equation 3-6*

where "CDR" is the Converter Deterioration Rate, "NO_x" is nitrous oxide emissions, "*CO"* is carbon monoxide, and "*HC"* is hydrocarbon element converters. "*Vkt"* is vehicle cumulative travel distance in kilometers. Interestingly, there is no proof of converter deterioration for HC on Euro 4 vehicles, while fugitive emissions (*Fe*) from vehicle fuel combustion is measured using Equation 3-7 to Equation 3-9.

$$Fe_{NOx}(\text{kg/km}) = \int_{2014}^{t} CDR_{NOx,Euro\ N} \times Initial\ NOx\ \text{dt}$$ *Equation 3-7*

$$Fe_{CO}(kg/km) = \int_{2014}^{t} CDR_{CO,Euro\ N} \times Initial\ CO\ dt$$ *Equation 3-8*

$$Fe_{HC}(\text{kg/km}) = \int_{2014}^{t} CDR_{HC,Euro\ N} \times Initial\ HC\ dt$$ *Equation 3-9*

Here, "*Fe"* is the total fugitive emissions of the entire PC fleet, measured in Kg per Km. Values for initial NO_x, CO, and HC are gathered from statistical results of the UK Vehicle Certification Agency's data analysis (Table 1). Initial values were derived from each new vehicle. This calculation's objective is to give emission values to each vehicle according to its age and converter technologies.

Total annual fuel consumptions for PCs, HEVs, and CNGs were calculated using Equation 3-10.

$$Total\ Fuel_{PV,HEV,CNG}\left(\frac{L}{Year}\right) = \int_{2014}^{t} Vehicle\ Stock_{PV,HEV,CNG} \times\ FC \times Vkt\ dt \qquad \text{Equation 3-10}$$

Vehicles that exclusively use electricity (EVs) require a different pathway to estimate related emissions, with the first step of estimating energy requirements to meet travel demands represented in Equation 3-11.

$$EV\ Electricity\ Requirement\ (TJ) = EV\ Stock\ \times Vkt\ \times Energy\ Consumption\ \times 3.6^{-9} \times (Electricity\ Plan/100) \qquad \text{Equation 3-11}$$

The Electricity Plan is the long-term energy generation sources set by the Energy Commissions of Malaysia. This equation is further used to estimate GHG emissions until the target year, represented by Equation 3-12 with Electricity Generation GHG emissions information gathered from 2006 IPCC guidelines. Lastly, the total anthropogenic GHG release from personal vehicles is calculated using Equation 3-13.

$$GHG\ Release_{EV} = \int_{2014}^{t} EV\ Electricity\ Requirement \times Electricity\ Generation\ GHG\ Emissions\ dt \qquad \text{Equation 3-12}$$

$$Total\ Fleet\ Emissions = \int_{2014}^{t} Total\ Fuel_{PV,HEV,CNG} \times GHG\ Release_{Gasoline,CNG} + GHG\ Release_{EV}\ dt \qquad \text{Equation 3-13}$$

Main point of this study is to estimate the total, crude GHG emissions from transportation usage and therefor does not incorporate GHG absorption or dissipation under transportation-only policy adjustment. CO_2 have a lifetime of 50 to 200 years (U.S. Environmental Protection Agency, 2016) with 20% will only be removed in thousands of years (Archer, 2009) that CO_2 emissions is needed to be minimized. Forest GHG absorption, carbon capture technology and agriculture based industry which is beyond this study scope all have the potential to offset transportation GHG emissions, but it will not improve vehicle management nor help the creation of better vehicle policies.

3.3.3 Model Testing

The model testing procedures are intended to uncover flaws build confidence that the model is useful in order to enhance our insight and understanding relative to the themes being studied. A Sensitivity Analysis was done for this purpose, using tornado diagram as reporting method. Tornado diagram is a bar chart, that is, a graphical output of comparative sensitivity of a result to changes in selected variables. It aims to give readers an idea of the most important and influential factors for quantifiable problems, to provide insight for decision makers of uncertainties and possible impacts through analytical results by showing the effect on output of varying each input variable, while maintaining other input variables at their nominal values.

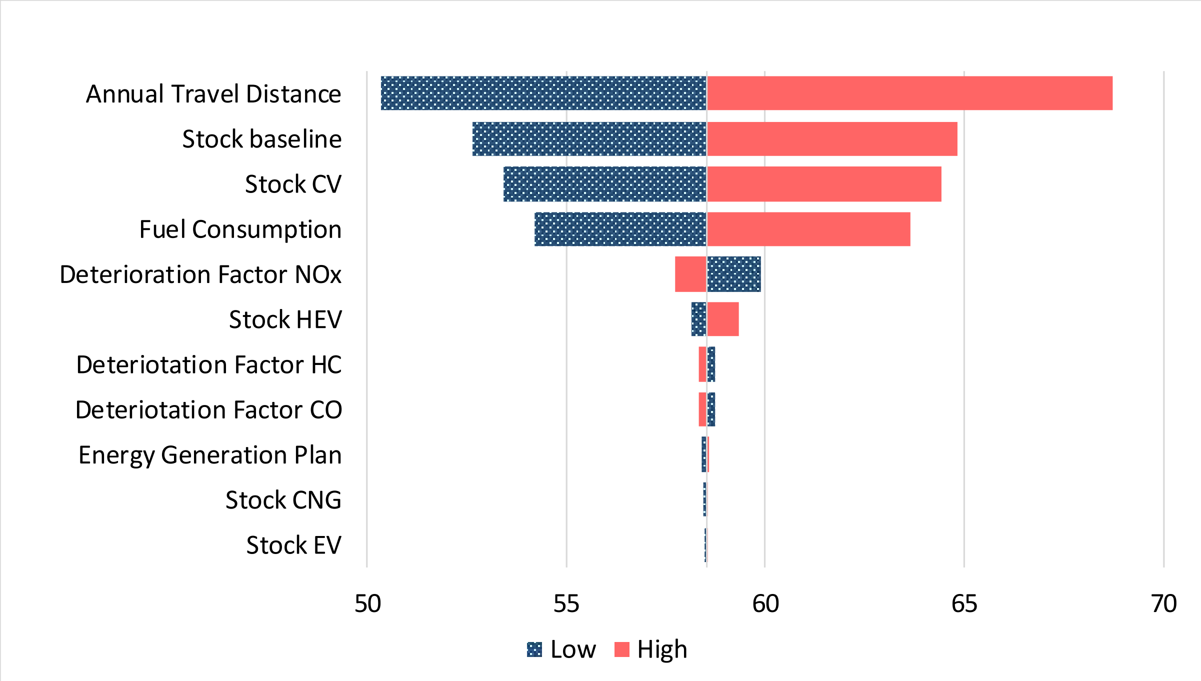


Figure 3.4 Tornado Chart of Euro 4 GHG release at Time = 2040.

Tornado analysis introduction, as shown in Figure 3.4, into the Baseline model suggested that the most influential variables are annual travel distance, overall vehicle stock, and fuel consumption. Further dissection of vehicle stock reveals that internal combustion vehicles have the greatest environmental effect among the four groups. Also worth mentioning is that Euro 2 and Euro 4 showed a definitive difference in emission base. Thus, we derived eight different policies with the objective of achieving the lowest release of GHG while having the least impact on vehicle demand.

3.3.4 Policy Formulation

The policies developed in this section is an extension of policies generated in Chapter 2. As MA14 and MA12 policies targeted on general reduction of vehicle age, and promotion of HEV/EV, policies in this chapter extends it with specific changes targeting to intervene with three main group.

Policy tested, above and beyond the *Baseline*, is shown in Table 3.2. Three main groups have been identified to be responsible for leading the change: mainly the *government*, which is responsible for passing any related legislation; *industry*, which is required to improve their vehicles' efficiency; and *drivers*, as stakeholders who can lead the change from the demand area. This study's model also analyses by using combinations of the first seven discrete policies. The main reason for policy analysis is to apply the highest impact with least effort, based on the results obtained. This means trying to find the path with the least anthropogenic environmental emissions. Having a flexible, dynamic model provides the much-needed customization to achieve this objective.

Table 3.2 Policy application for emissions reduction in Malaysia's transportation sector.

Responsibility	Policy Number	Policy names
	Baseline, 0	Business-as-usual
Government	1	Euro 4 Adaptation (Emission Standard)
	2	Engine-Size Reduction
	3	Eco Labelling and Carbon Premium
Government & Driver Attitude	4	Travel Distance Reduction of 10%
Industry	5	Fuel Efficiency Improvement of 10%
Government & Industry	6	Vehicle End-of-Life Implementations
	7	Hybrid Vehicle Promotion
	8	Mandatory EV from 2030
Government, Industry & Driver	9	Combination of 1,2,3,4,5,6

Policy 1 involves "Euro 4 adaptation" equivalent emission regulations. In this situation, emission standard is being improved with vehicle converters must be upgraded to at least the equivalent of Euro 4 technology. The adaptation value is limited to 75%, in order to provide a safer, more realistic estimation. *Policy 2* involves the higher number of vehicles of 1.3L compared to the current mean of 1.5L, by which we move mean of engine-size distribution toward 1.3L. This policy focuses more on manufacturers and industry players, driven by governmental support and legislation targets, such as have been successfully applied in the EU.

Policy 3 involves the introduction of Eco-Labeling into passenger vehicle sales. Previously implemented in the EU, such policy provides the potential buyer information regarding a vehicle's carbon emission level. Moreover, vehicles that emit higher CO_2 than the set limit will require payment of a premium, thus pushing polluting vehicle prices higher and their demand lower. Modeling this behaviour involves increasing the price of polluting vehicle while increasing growth of HEV and EV by 1% annually.

As for *Policy 4*, average vehicle travel distance is reduced by 10%. This can be done by increasing pump fuel prices for personal passenger vehicles (Jong and Gunn, 2001; van Wee, Rietveld and Meurs, 2006), providing alternative transportation systems, from ride-sharing services to improvement of existing rail services and all the way to construction of a more intricate network of rail transportation. Driver attitude can also be influenced through media and education.

Policy 5 represents national regulation, advocating that industrial players improve vehicle fuel efficiency by 10%. Previously, manufacturers primarily addressed fuel efficiency without any regulation by governing bodies. Protection of local manufacturers, introduced since 1985, also did not help this situation and led to less competition and fewer improvements. In such situations, manufacturers have placed low priority on efficiency R&D. The introduction of EEV incentive (Chapter 1.1) is on track with this aim. However, it required further reduction and liberation to meet this change.

Policy 6 aims to reduce the CV stock that contributes to the immense volume of GHG emissions with implementation of an end-of-life vehicle (ELV) policy. Basically, vehicle age is limited to 14 years, with older vehicles requiring more frequent safety and emissions testing. Additionally, manufacturers are required to play a more active role in designing vehicle parts for ease of recovery and recycling. Automotive recyclers also need to be clearer in their recovery and recycling methods. Moreover, application of ELV policy can increase technological acceptance with a shorter vehicle lifecycle. A more detailed explanation of this variable is provided in 0.

In *Policy 7*, NGVs such as HEVs and EVs receive better promotion. Under this policy, HEV and EV taxation is reduced to 45% and 40% while taxation for CV and CNG vehicles reduced only to 50%.

The model used the HEV growth rate before application of the normal taxation method from historical data and doubled the growth. This growth rate follows the technology adoption curve commonly seen in other product consumerism.

We also tested modeling the extreme case of carbon reduction in *Policy 8*, in which all vehicles sold need to be fully electric, beginning in 2030, with gradual application of emission regulation to Euro 4 as early as 2017. This policy represents a shift in which all manufacturers and stakeholders are required to do away with the previous generation of vehicles for new sales. This technological shift can be seen in Norway, where in just 3 years, composition of NGVs for new vehicles exceeded 50% of total vehicles sold, with the target of 100% NGV annual sales from 2025 (Cobb, 2016). This shift is impossible without the support of industry, needed to provide options for potential owners in terms of models, functions, and pricing.

However, *Policy 9* spots a difference compared to other policies. In the 9^{th} policy option, a combination of *Policies 1* to *6* is applied. The reason for this decision was due to the government objective of making transportation market as one of key driving source for the national income, which means the taxation on vehicle needs to stay as is. However, in the further chapter, this thesis will highlight the importance of taxation reduction for HEV and EV on the overall impact of vehicle usage. Another previous policy not being implemented in this integration was the extreme regulation of only allowing EV for new registration starting in 2030 which is being implemented in Policy 8. This policy was omitted from being integrated in Policy 9 due to the highest potential to reduce GHG alone by itself, and thus the potential to overshadow the effects of the other policy combination which are being showcased in this topic. Regardless, Mandatory EV is expected to only show GHG reduction from 2030 onwards but not before.

3.4 Results and Discussion

3.4.1 Electrical Energy Requirement for EV

Energy requirement for electric vehicles mobility increases together with EV quantity. We estimated the amount of electricity required to support electric vehicles usage to be only 4 GWh in 2020 before increasing exponentially to 153 GWh in 2040 as shown in Figure 3.5. The electricity generated for EV use can also be fully harvested from solar, creating much less environmental burden.

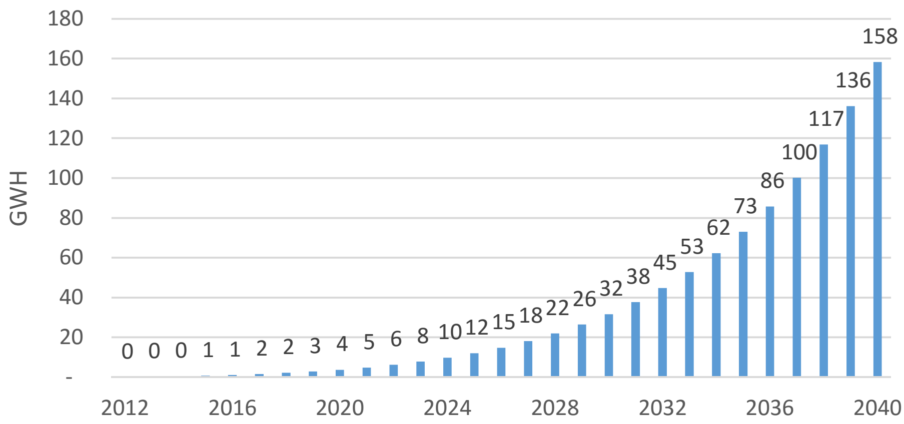


Figure 3.5 Electric Vehicle Mobility Energy Requirement.

3.4.2 Passenger Vehicle Greenhouse Gas and Pollution Generation

Due to the ever-increasing population, the quantity of PCs also increases to meet the population's demand. This study modelled GHG in CO_2 equivalent, carbon monoxide, and hydrocarbon release to 2040, based on several policies listed in Table 3. The diagram in Figure 3.6 shows the output of carbon dioxide emissions in kilotons, Figure 3.7 shows the same for carbon monoxide, and Figure 3.8 is the result of hydrocarbon emissions from the total number of passenger vehicles in a respective year.

Clearly, without intervention efforts, vehicle emissions will increase by nearly 35% by 2040, as represented in the *Baseline*, due to increasing demand for personal mobility. However, if stricter emissions regulations were introduced, GHG release would show a slight reduction over time, as demonstrated in these results.

Implementation of regulations demanding smaller engine capacity does not provide as much improvement in total emissions as we had hoped and neither does improvement of fuel efficiency as shown in the results of *Policy 2* and *Policy 5*. This situation is caused by slow technology adaptation due to the slow increase in the quantity of newer, more efficient vehicles and fairly long vehicle age.

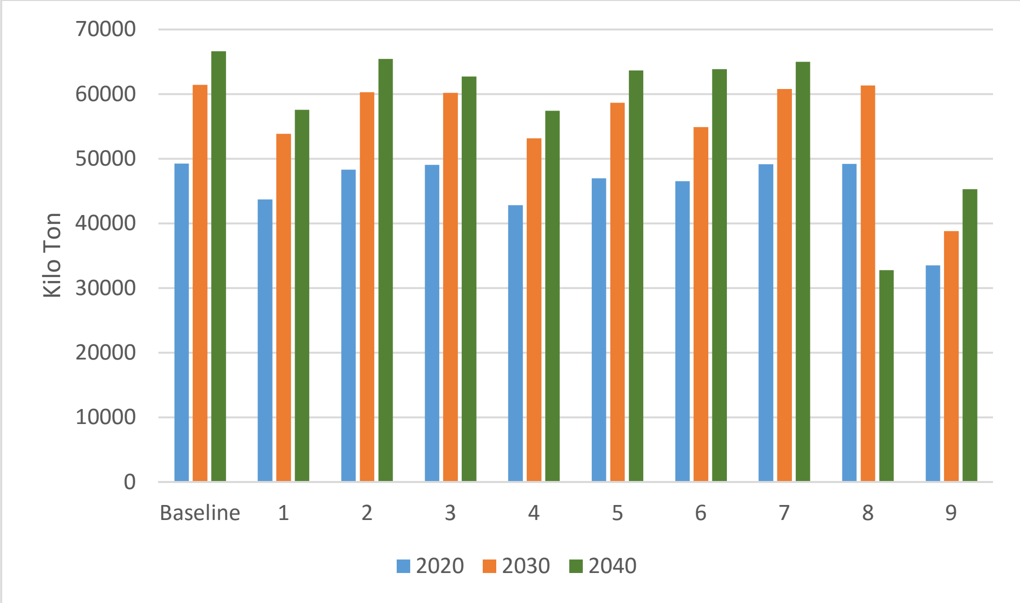


Figure 3.6 GHG release of different policies against Baseline, factorized to CO_2.

In *Policy 3*, consumer education was included in vehicle purchasing decisions which may be altered by Eco Labels and premiums. This policy provides facts and education (Thomas, 2003) that lead to certain attitudes and motivations for purchase (Coada, Haan and Woersdorfera, 2009). This method also provides the government with extra income since new vehicles not meeting the emissions limit must pay extra in terms of taxation. Carbon premium taxation has been introduced in several European countries with great success. Unexpectedly, the current method of taxation by engine size is unproductive because it also punishes big high-efficiency engines vehicles of low GHG emissions such as Hybrid vehicles. Regardless, the policy can only reduce 5% emissions level compared to the Baseline condition. Further analysis reveals that even under extra charges on high CO_2 emission vehicles, the final price of HEV and EV remains out of reach for majority of consumer.

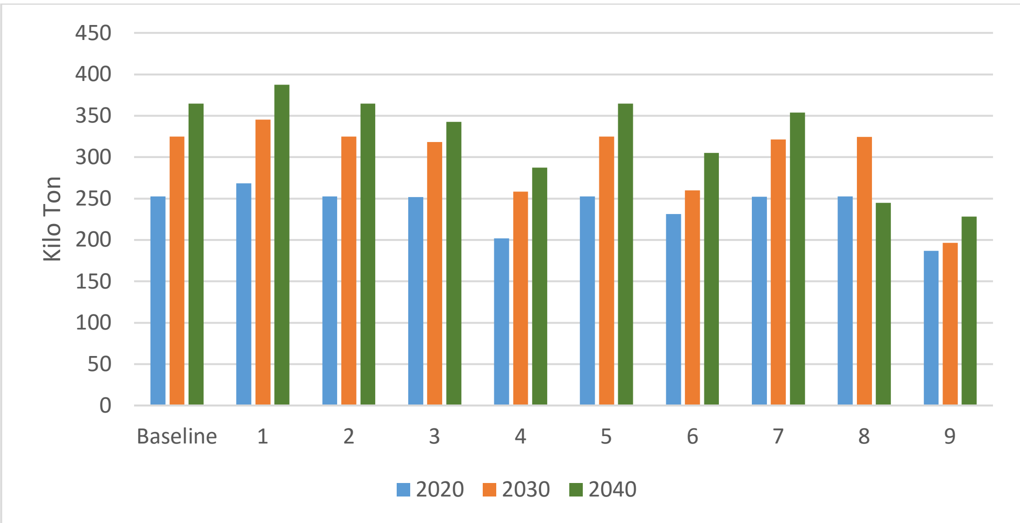


Figure 3.7 Carbon monoxide release of different policies against Baseline.

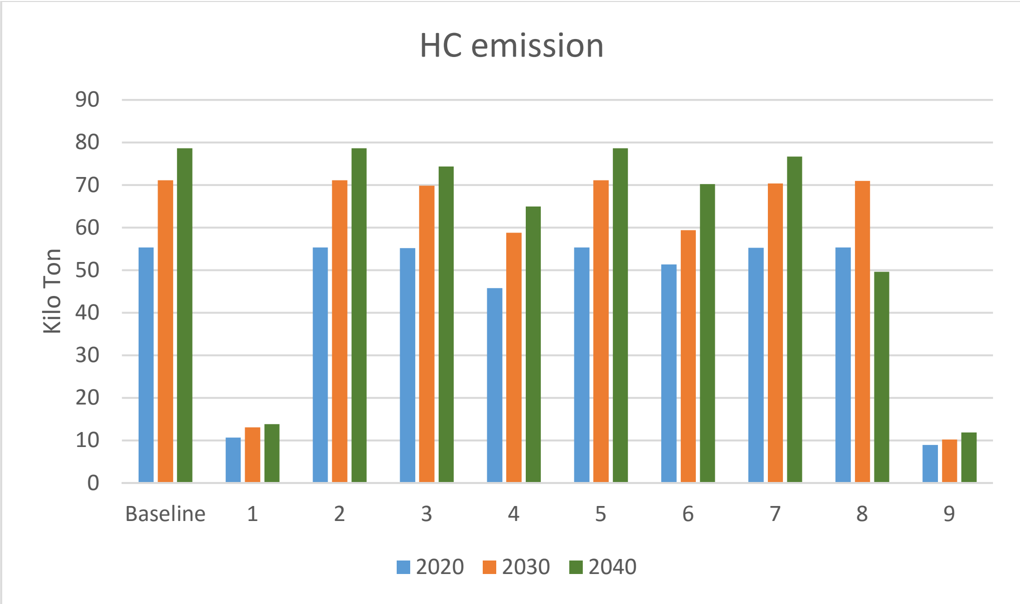


Figure 3.8 Hydrocarbon release of different policies against Baseline.

Policy 6—Sole implementation of ELV policy—gave a surprising result because even with shorter vehicle life and every vehicle being scrapped, they will nearly always be replaced with the same type of EV demand. It is common to hear consumers complain about resale value, unreliability of newer technologies such as HEVs and EVs, and non-scientific claims that discourage HEV and EV ownership. Without additional governmental and industrial support, this resistance to change leads to nearly the same total emission as the *Baseline*.

Application of *Policy 7*—promotion of HEV and EVs only leads to slight decrease compared to BAU condition. This is highly expected, since number of HEV and EV is limited to income distribution. Under this assumption. Only 2.3million vehicles are of HEV and EV, while 10.8 million still is CV.

Experimental *Policy 1* to *Policy 6* was achieved by changing just one variable in each situation. *Policy 9* is the combination of several policies discussed earlier, mainly adaptation of better Euro emission regulation, reduction of vehicle engine capacity and annual traveling distance, improvement of fuel efficiency, application of ELV policy, provision of Eco-Labels for all new vehicles, and a carbon taxation system. This situation leads to a 30% reduction of passenger vehicle GHG emission in 2040, compared to 2020. This activity requires changes to government, industries, and stakeholders' ways of thinking. Under this condition, CO_2 emission in 2040 is 8% less than 2020 CO_2 emission under BAU.

Policy 8, however, shows the lowest emission level, with over half of emissions at 2020 *Baseline* eliminated with the same volume of transportation and travel distance. The main contributor is the increased number of EVs starting in 2030 and reduction of the number of nonelectric vehicles, thus accelerating the transition to renewable energy. Although this situation is currently only theoretical, it is not impossible. A sudden mass change of mind-set is often caused by certain catastrophic events that transcend our cognitive beliefs.

Biggest improvement can be seen with improvement of emission regulation under hydrocarbon pollution. Application of this regulation will help clearing air pollution from hydrocarbon by 5 times current level. This simple solution involves requirement for catalytic converter replacement of all passenger vehicles. However, the effect of Euro 6 application is unable to be modeled. This relatively new technology deterioration factor is still unknown, causing the model to only be satisfied with Euro 4 application.

3.5 Conclusions

Fulfilling Malaysia's aspiration to a long-term, sustainable future requires addressing a substantial threat to the environment. As the second largest producer of greenhouse gas in Malaysia, the transportation sector holds a key element for resolving this threat. Statistics show that the number of passenger vehicles is the largest single group from this sector, making it logical to approach better vehicle management. Malaysia has long intended to improve its vehicle transportation policies, but the fear of economic slowdown postponed this decision until a proper study could be completed.

This study offers quantitative insight and improved accuracy of passenger vehicle emissions from transportation activity for Malaysia, with expansion of the previous model for estimating vehicle quantity. Input data such as population, vehicle quantity, purchasing preferences, and current policy application have been used in constructing this study's model. Moreover, the model can be further expanded to include other vehicle classes and their emissions throughout the lifecycle.

Several vehicle management policies have been estimated and tested at the national level through 2040, involving several assumptions gathered from literature reviews. Although a single policy can yield a good result, a combination of policies has also been generated to estimate outcomes and proven to be more efficient. This combination policy consists of adoption of Euro 4 and higher emission regulation, reduction of travel distance, reduction of vehicle engine size, improvement of fuel efficiency, reduction of vehicle age by end-of-life regulation implementation, and mandatory new generation vehicles for new vehicles. This analysis found that greenhouse gas emissions and pollutants in 2040 can be reduced by up to 30%, compared to emissions of 2020, without affecting the economy and vehicle demand, and a 10% reduction can be achieved if catalytic converter upgrades were performed on all vehicles. Hydrocarbon pollution can also be reduced to 18% the original value with implementation of only this one policy. However, if current policy continues to be implemented, business as usual will generate emissions like those estimated in the Baseline situation described in Section 3.4.

Chapter 4. Environmental Risk Trade-off for New Generation Vehicle Production

4.1 Chapter Overview

Chapter 4 provides the estimated emission from vehicle production processes, specifically in cradle-to-gate, or Lifecycle Inventory impact analysis indicated in Figure 4.1. The research modeling and method is explained in Section 4.3 which covers research framework, research scope, and vehicle inventory used while Section 4.4 provided the results and discussions. Chapter conclusion is presented in Section 4.5.

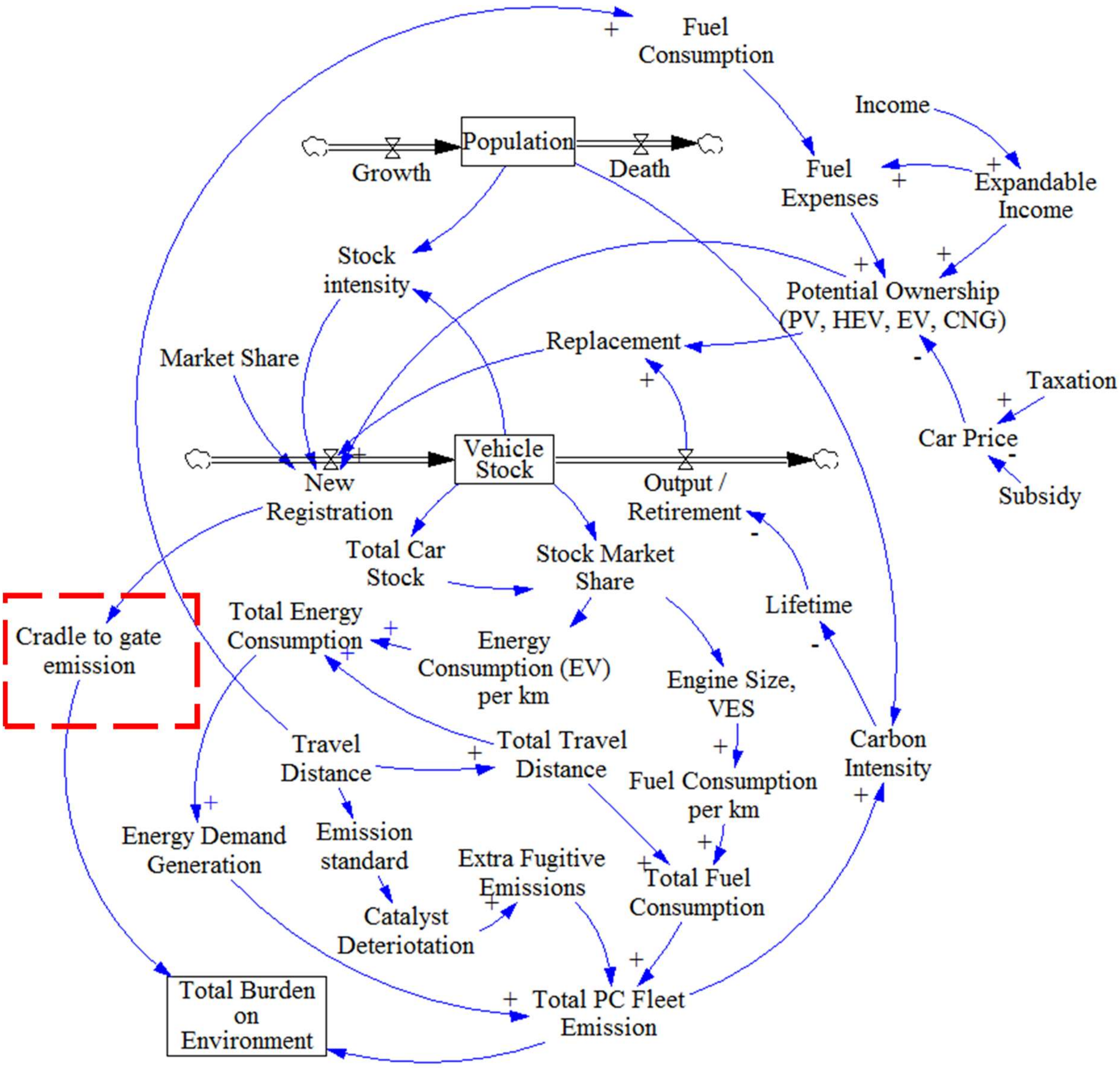


Figure 4.1 Thesis main conceptual diagram with studied variables. The red rectangle indicates the area being focused in this chapter.

4.2 Introduction, Purpose & Present State of Research

One of the strong point of New Generation Vehicle is having higher fuel efficiency compared to conventional vehicles, and therefore having less carbon emissions. However, policy makers continue to dispute whether this kind of New Generation Vehicle is truly clean especially if embodied emissions is being factored in. Several studies have been done in order to study this through life cycle assessment of New Generation Vehicle. Brinkman et al. (2005) uses probability based distribution function to measure the energy use and emission for individual vehicle. However, he focuses more on the fuel system variable than vehicle production inventory. Hawkins uses the whole lifecycle of a vehicle as basis of study, including usage, fuel type used, mileage, and based on European condition. Additionally, Hawkins et al. (2013) uses the Eco-Invent database for inventory with ReCiPe for impact calculation method. Higuchi et al. (2012) uses data from existing material from Japanese literature to manually calculate the Disability Adjusted Life Year (DALY) and Expected Increase in Number of Extinct Species (EINES) based on Japanese specific case while Zackrisson et.al (2010) on the other hand uses Eco-Invent database as information source to estimate the impact of Lithium Ion Battery for EVs. This database serves as tools in order to quantify the impact of each product being studied.

Another related study is from Messagie et al. (2010) which assess the vehicle technologies based on Belgium inventory context, also using information from Eco-Invent database. Hawkins et al. (2012) also stated that out of 51 LCA studies being reviewed, none of it provides a complete assessment of a single vehicle which may lead to a significant error due to insufficient representation of production phase. Similarly, Nordelöf et al. (2014) presents a conclusion based on 79 research papers of the same area. Main problems are related to intention of study application and proper reason of carrying out the study. Correspondingly, this study aims to answer the question related to quantitative and comparative environmental impact of various type of vehicle production stage. Also, results of this study is expected to provide supporting information for manufacturers and policy makers to improve related environmental management policies especially in national level.

This chapter aims to quantify the amount of environmental impact of vehicle production activities from material mining until final production of compact passenger vehicles in Malaysia using IDEA database and LIME factorization method. This article will provide 5 impact classifications which is Greenhouse Gas (GHG) generation, Acidification, Eutrophication, Carcinogenic Effect, and overall Human Health Impact – DALY for a comparative analysis. An integration calculation is done via Life-cycle Impact Assessment Method Endpoint Modeling (LIME2) methodology by (Itsubo and Inaba, 2010) based on the information generated. This method uses material and weight based calculation in order to determine the impact for each product and process. Result of impact calculation carry the purpose as evaluation information between the vehicle technologies. It also serves as calculation basis for modeling of vehicle management policy for the determination of best case scenario to assist policy development of future regulation adaption and environmental improvements.

Study will also limit on the simulation of production to Malaysia context, with implementation of localized data information. Power generation mix for national grid is used as one of the primary variable. Electricity production is divided into five major categories; fossil fuels, hydro, nuclear, and renewables.

4.3 Method and Modeling Process

4.3.1 Research Framework

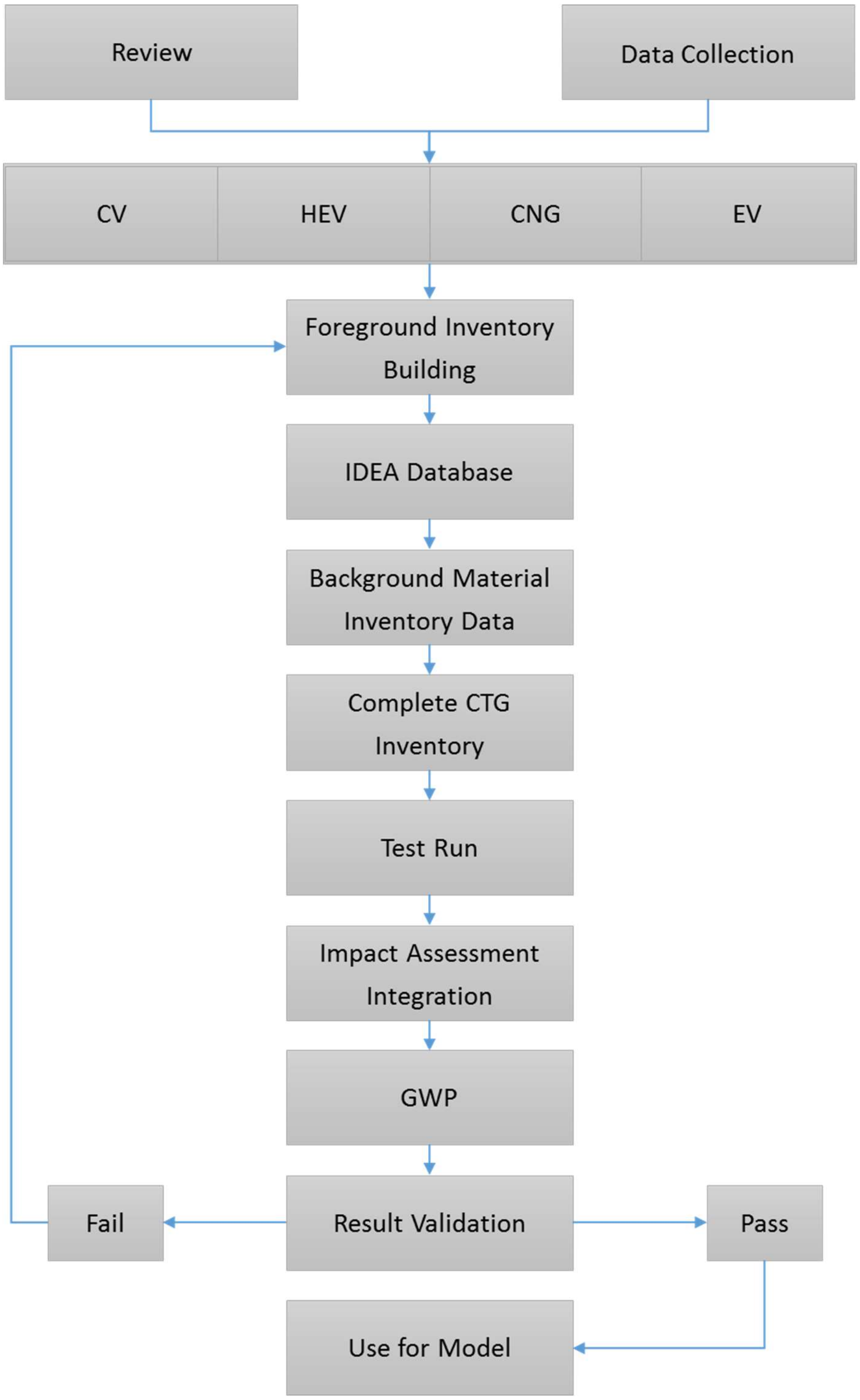


Figure 4.2 Lifecycle Inventory Assessment Method applied in this chapter.

The assessment method used to evaluate certain stage of vehicle lifecycle is known as life cycle assessment (LCA). It includes all life stage including production, usage and post-usage thus also known as "cradle-to-grave". Each life cycle stage has plenty of variables which have the potential to modify the outcome of lifecycle study. Hence, some study focus only on certain stage of vehicle lifecycle which is known as Life Cycle Inventory (LCI) or "cradle-to-gate". There are plenty of reason for focusing on certain life stage. One of it is to increase the transparency and improving existing understanding and estimation (Hawkins *et al.*, 2013). However nearly all studies found focused on vehicle cradle-to-grave analysis. Moreover, in order to create an LCA analysis, researchers often left out the details of material inventories with minor attention given in cradle-to-gate stage.

Previous LCI study for CV ranges from 4500 to 10,000 kg of CO_2 being released during the whole process of production (Schweimer, 2000; Heather L. Maclean and Lave, 2003; Volkswagen AG, 2012; Gbegbaje-Das, 2013). Hawkins (2013) offered an factorization of 5kg CO_2 per 5kg of the vehicle weight. Most studies indicated using heavier passenger vehicles compared to our study. Nearly all of the current LCA & LCI studies utilize inventory database form either GREET from US or Eco-Invent from Europe. Absence of studies utilizing tools from Asia provided the motivation for this chapter.

4.3.2 Scope & System Description

This chapter evaluates the risk of environmental impact of all vehicle classes from the viewpoint of Life Cycle Inventory (LCI). Studies of environmental impact of vehicle lifecycle has been done by various researchers focusing on whole vehicle lifecycle (Majeau-Bettez, Hawkins and Stromman, 2011; Hawkins *et al.*, 2013). Due to the complexity of Lifecycle assessments calculations, researchers opted to use commercially available software using many available inventory data.

This situation had lead this study into constructing own vehicle model in LCA software. It is decided to utilize MiLCA software tool as to provide an alternative analysis compared to other existing articles. Clues for the inventory database had been collected from various existing sources (Althaus, Gauch and Empa, 2010; Majeau-Bettez, Hawkins and Stromman, 2011; Babu and Ashok, 2014). Unlike previous studies, vehicle LCI in this research uses Inventory Database for Environmental Analysis (IDEA database) which was developed and maintained by Japanese Environmental Management Association for Industry. This LCI research focus is exclusively from material extraction from mines until the finished product is ready for delivery (Cradle-to-gate) analysis without consideration of the usage and end-of life stage. LCI was originally only one part of LCA studies. The reason for focusing on production stage is to provide a clear and unbiased assessment between the technologies. Environmental assessment used in this study is based on "Lifecycle Impact Assessment Method Based On Endpoint" (LIME and LIME2) methodology. LIME method basically covers the evaluation of common environmental impact such as Global Warming Potential, Acidification Potential (AP), Eutrophication Potential (EP) and Carcinogenic Potential. LIME2 on the other hand offers to integrate the inventories in order to provide damage on human health and damage on ecosystem index. The vehicle types being studied is CV, HEV with Nickel-Metal Hydride (Ni-MH) and Nickel Manganese Cobalt Oxide (NMC) based Lithium Ion (Li-Ion) batteries, and EV with NMC Li-ion batteries. It is modelled according to IDEA inventory database which are based from statistical and industry input of Japan.

In order to estimate the associated risk from vehicle production, it is decided to construct a vehicle inventory model from past researches for most components before any analysis can be done. As for base model, we chose to model a Conventional Internal Combustion Engine Vehicle based on a locally manufactured vehicle as the ‘glider’ – a vehicle with all necessary components and equipment, minus the addition of the vehicle power plant and its immediate components. Furthermore, a modified version of the vehicle is also being modeled with additional parts suited for Hybrid Electric Vehicle and Battery Electric Vehicles. Model build is based on material type and weight for each component. This information is used as input on IDEA database to calculate all the necessary upstream processes involved either directly (foreground) or indirectly (background). Our estimation uses global average values from IDEA database as basis of calculation for this study with modification to suit Malaysian case.

4.3.2.1 Time period

We chose to model the vehicle using energy mix of 2017 and 2030 to test whether the planned energy mix have any substantial difference on overall environmental impact. Energy Commissions of Malaysia provided local historical and future plan of electricity generation (Ministry of Energy Green Technology and Water, 2013). The country plans to generate 53% of electricity from Coal, 41% from national gas, while 4% from hydroelectric dam and 2% from other renewables in 2017. However, in 2030, 52% of electricity will be generated from coal, 24% from natural gas, 9% from the planned nuclear power plant, 13% from hydroelectric plant and 3% from other renewable sources.

4.3.2.2 Target Area

Aiming at quantifying the impact of vehicle produced in Malaysia, the target area is Malaysia. Boundary for the lifecycle study will be from cradle-to-gate, which starts from prime material extraction until the vehicle is ready to be delivered. Complimenting this is geographic boundaries which limits to Malaysia. Most inventory data for vehicle production and material mining was using the supplied data from IDEA on Malaysia. However, the vehicle model, parts and component weight was modified to reflect the target vehicle models. Malaysian power generation characteristics was also integrated into the modified data.

4.3.3 Inventory and Analysis

This study limits the LCA scope until the production process of a completed compact passenger vehicle, which evaluation can be done responsibly. Functional unit for this study will be on per vehicle basis. For the sake of modeling, we excluded the logistical part of each inventory for the immediate inventories as we consider main components as being manufactured in-house (foreground). Transportation of inventories further up the production stream (background) has been integrated within each production steps. The compact vehicle is selected as model due to the very high ownership of compact vehicles in Malaysia.

Table 4.1 Vehicle Model Component Parameter (in kilogram weight).

Component modules	CV	HEV (NiMH)	HEV (Li-Ion)	EV
Curb weight 980kg Glider	830	830	830	830
Internal Engine	150	150	150	-
NiMH battery (55.3aH per KG)	-	28	-	-
Li-Ion battery (112aH per KG)	-	-	13.8	200
Power Distribution Unit	-	2.9	3.9	3.9
Inverter	-	9.5	9.5	9.5
Electric Motor	-	26.5	26.5	42.4

Vehicle used as model for this study only weighted 980k which falls under "City car" category. It was used due to the large portion of personal vehicles in Malaysia is from this type of vehicle (Ministry of Transportation Malaysia, 2015). The model used in this study was based on one glider shell which consists of all the necessary parts to be distinguished as a complete vehicle which includes all the interior and exterior parts & panels, tires and its spare, windows, cables and instrument, lead-acid type battery, minus the engine and power generation unit with its auxiliary items. Main difference between vehicle models can be seen in Table 4.1. As for Electric motor, we used value of 50kW for HEV, and 80kW for EV. Power distribution and inverter remains the same for both units. All foreground inventories for electric motor and its directly related components is gathered from Habermacher (2011).

Previously New Generation Vehicle was often modeled with weight reduction compared to existing vehicles. However, in recent years the manufacturers started to implement the hybridization of current vehicle models without the weight reduction as battery size continues to shrink with technology. Therefore, this study will use the same CV models as basic model and retrofit with New Generation Vehicle System respectively.

There are plenty of high capacity batteries deemed suitable for electric vehicle usage. Majeau-Bettez et.al. (2011) provided the inventories for Nickel-Metal Hydride and Li-Ion battery used in this study. Two types of batteries being used in the HEV model – Nickel Magnesium Hydride (NiMH) and Nickel-Manganese-Cobalt Oxide (Li-Ion NMC) which have higher energy density per kilogram compared to NiMH as a comparative assessment. The battery energy capacity for HEV is fixed to 1550 wH and 44000 wH for EV model based on currently available vehicle in the market. The EV being modeled in this study is expected to be able to reach 270 km per full charge. This travel distance represents the average of one week of commute for residents in Kuala Lumpur for day-to-day activities.

Impact categories being considered for this study in order to quantify the environmental impact of vehicle construction is shown in Table 4.2. Global warming potential (GWP) which calculated at per kilogram of carbon dioxide is commonly used as indicator for climate change. Acidification calculated using LIME represents the potential of transforming air and ground in becoming more acidic, which technically including acid rain potential (Itsubo and Inaba, 2012a). Eutrophication is the potential of causing algae bloom as direct result from increase of nutrient salts such as phosphorus and nitrogen. This have the potential to increase biochemical oxygen demand and causing suffocation of aquatic lives. Carcinogen being measured in LIME target on toxic chemicals which may endanger human health. It is characterized as Human Toxicity Potential (Carcinogen) and being factorized as 1 kg of benzene equivalent exposure. The values also accompanied with 1 main indicator; DALY.

Table 4.2 Impact Assessment Parameter.

Impact Category	***Method***	***Unit***
Global Warming Potential	IPCC, 2007	kg-CO_2 eq.
Acidification	LIME, 2006	kg-SO_2 eq.
Eutrophication	LIME, 2006	kg-phosphate eq.
Human Toxicity Potential (Carcinogen)	LIME, 2006	kg-benzene eq.
Human Health	LIME2, 2006	DALY

DALY is the characterization of the ability loss of health due to loss of life expectancy. Murray (1994,1996) developed the groundworks for DALY characterization together with World Health Organization for research on the Global Burden of Disease. Itsubo and Inaba (2012b) modified this in order to compute the impact of each substance used in LCI for LIME2 to make calculation easier. In our case, DALY is being calculated for the passenger vehicle production sector. The damage factors are initially calculated by product inventory's DALY per kg for each substance before integrating all of the substance. This gave the result of total DALY expressed in number of year loss. This is expressed in Equation 4-1. Substance impact have been pre-calculated in the LCI tool.

$$\text{DALY Index}_{Year} = \sum_{Impact} \sum_{Substance} \{Damage\ Factor^{Impact}(Human\ Health, Substance) \times Inventory(Substance)\} \qquad \text{Equation 4-1}$$

4.4 Result and Discussions: Factorized Environmental Impact

Evaluation results in Figure 4.3 to Figure 4.6 is the LCI comparison between four vehicle technologies in question. It represents current conventional internal combustion engine vehicle (CV), Hybrid electric vehicle with Nickel Metal Hydride (HEV-NiMH) batteries, Hybrid electric vehicles with batteries of Lithium Nickel-Magnesium-Cobalt Oxide type (HEV-NMC) and pure battery driven electric vehicle (EV). It was modelled by power generation mix of Malaysia in 2017.

Environmental impact in interest are Global Warming Potential (GWP) measured from greenhouse gas emissions, Acidification, Eutrophication, Carcinogen Emission, and indexed in

Disability-Adjusted-Life-Year (DALY). Calculation and factorization was done using LIME2 library and methodology apart from GWP which uses IPCC factoring method.

The global warming potential of passenger vehicle production in Malaysia is shown in Figure 4.3. The values portrayed is results of factorization based on IPCC 2007 method for each emitted gas. Production of electric vehicles based on the same platform have the potential to increase 39% extra CO_2 equivalent gas per vehicle. This increase was due to the production of the electrical drive components which contributes 960kg of CO_2 equivalent GHG whilst the 200kg Lithium NMC carries 1860kg of GHG. HEV with NiMH battery also releases a noticeable increase of GHG compared to Lithium NMC due to higher mass required to carry the same energy capacity. NiMH batteries carries CO_2 intensity of 14.96kg CO_2 for each kg as oppose to 13.41kg in Lithium NMC. Changing of power generation mix to include nuclear, solar, and more hydroelectric energy as planned is likely to reduce the total GHG by a slight margin.

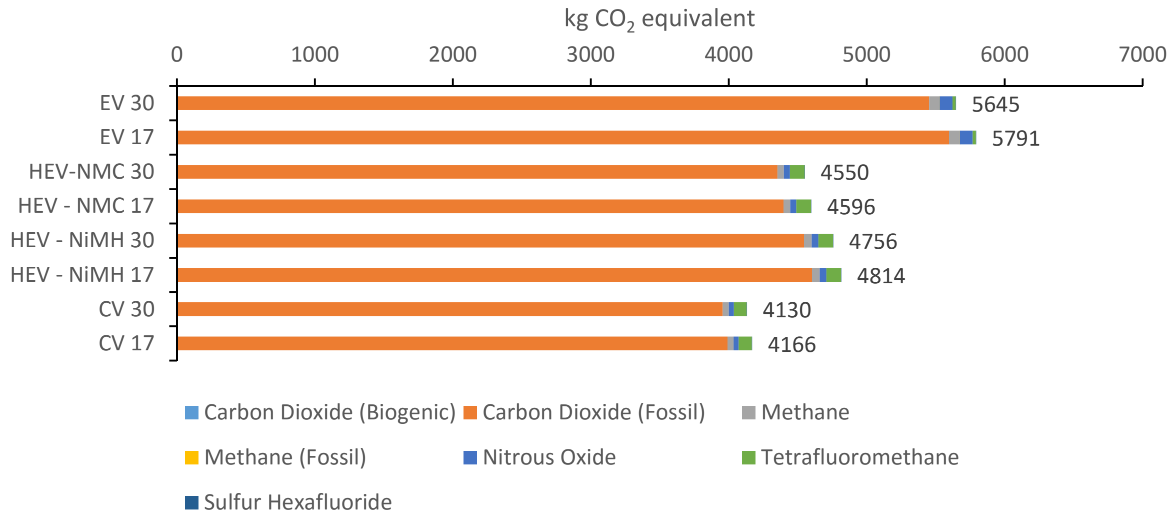


Figure 4.3 Global Warming Potential of passenger vehicle production in Malaysia. Note: Electric Vehicle (EV), Hybrid Electric Vehicle with Lithium Ion battery (HEV-NMC), Hybrid Electric Vehicle with Nickel Metal Hydride battery (HEV-NiMH), conventional vehicles (CV). 16 = modelled with 2016 power mix, 30 = modelled with 2030 power mix.

Global Warming Potential is often used as common measurement for vehicle technology comparison. This provide an opportunity for a comparative analysis with previous studies. Table 4.3 lists the GHG comparison between result of LCI between previous studies and this study, under vehicle expected lifetime of 150,000 km. GHG emission is lowest compared to other existing studies at 4,166 kg per CV. Reason for this is the compact vehicle model being modeled for the study, as well as inventory data uncertainty caused by different database used, and power generation mix used in vehicle production.

Table 4.3 Comparative GHG emissions of CV with other studies.

	Total GHG Emission (kg)	**GHG emission per distance (g/km)**
This Study	4,166	27.77
(Schweimer, 2000)	4,402	29.35
(Heather L. Maclean and Lave, 2003)	10,000	66.67
(Notter et al., 2010)	6,000	40.00
(Dunn et al., 2015)	7,000	46.67
(Volkswagen AG, 2012)	5,000	33.33
(Hawkins, Gausen and Strømman, 2012)	6,450	43.00
(Kim et al., 2016)	7,700	51.33
(Onat, Kucukvar and Tatari, 2015)	4,445	29.63

Cradle-to-gate GWP for Battery Electric Vehicles on the other hand, is done by Del Duce et al. (2014) suggested 74.6g/km while Hawkins et al. (2013) suggests 87 to 95g/km and Onat et al. (2015) 43.83g/km for 150,000km estimated life. Other finding also suggested (Notter *et al.*, 2010; Argonne National Laboratory (ANL), 2015; Dunn *et al.*, 2015; Kim *et al.*, 2016) 66g to 70g/km on the same estimated vehicle life. Comparatively, this study only calculated 38.6g/km for the same case. This might be due to the different Lithium Ion battery technology being applied in the model, or different process input being used. The lower output from utilizing IDEA database can provide an alternate understanding regarding environmental emissions.

The human toxicity potential of passenger vehicle production in Malaysia is shown in Figure 4.4. Production of EV have the highest potential of carcinogenic material emission with each of electric vehicles emitted about 1.27 kg of benzene equivalent throughout its supply chain under 2017 energy profile. However, changing to 2030 energy profile does not yield any change as we have hoped for. LIME calculated the emissions by integrating all chemicals involved according to its weight emission and later factoring it to equals to a kilogram of benzene. Under this analysis, CV have much less potential for toxicity compared to both HEV and EV.

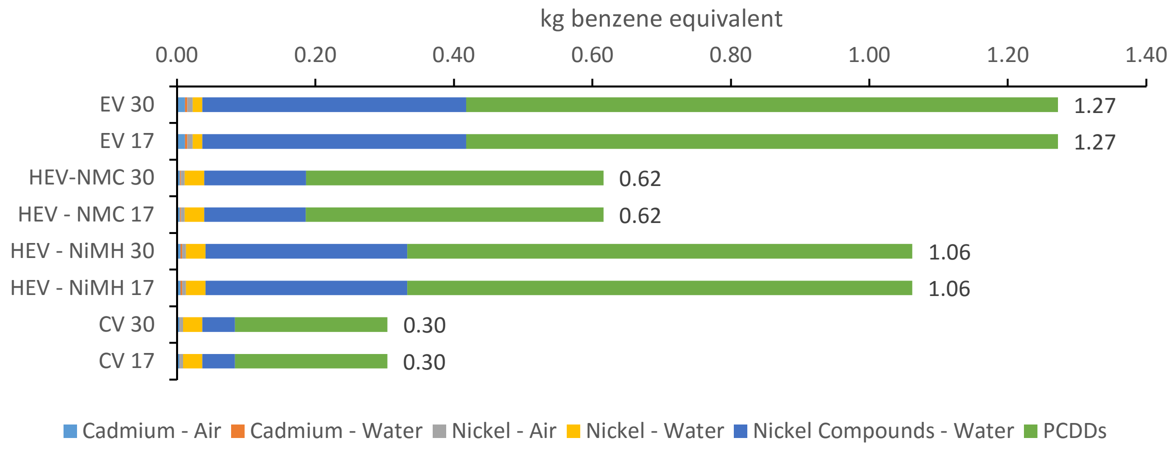


Figure 4.4 Human Toxicity Potential of passenger vehicle production in Malaysia.

However, the same situation is not applicable to Acidification Potential (AP), which is factorized in kg SO_2 equivalent. LCI under IDEA database shown that highest potential of producing acid rain is generated from production of HEV with NiMH batteries as shown in Figure 4.5. The lowest score was EV production which was likely due to reduced utilization of copper and sulphuric acid during smelting of mineral ores (aluminium, copper, zinc, lead, and iron) for the engines. This is consistent with results from Boureima et al. (2012). This is not always the case nevertheless when compared to another related study by Hawkins et al. (2013) which indicates higher AP of 10% compared to base model. Highest emissions are from release of nitrogen dioxide as by-product from electric power generation. In another sense, EV have lower Acidification potential, but resulted in higher CO_2 emission during production. This created trade-off between AP and HTP, as well as AP and GWP.

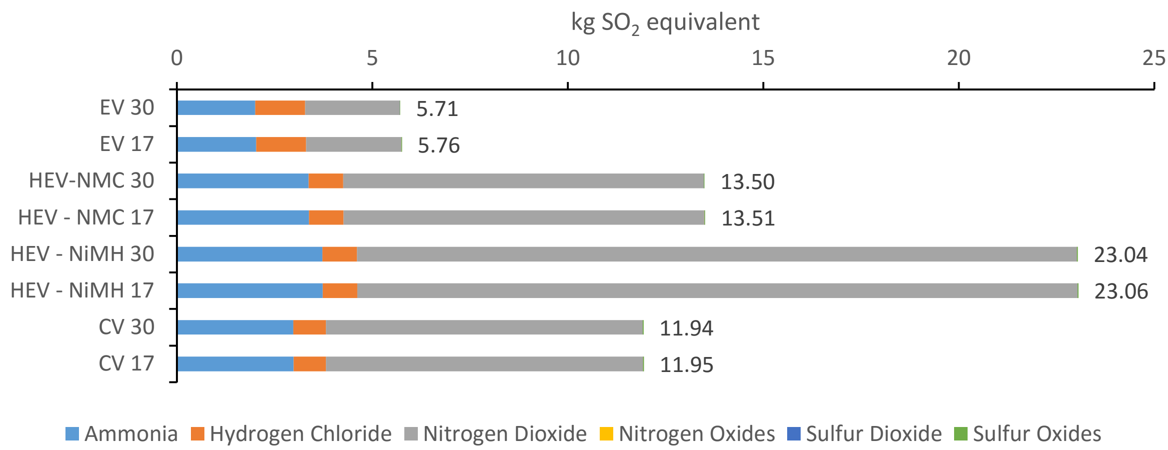


Figure 4.5 Factorized Acidification Potential for different type of passenger vehicle production in Malaysia.

Similarly, Eutrophication Potential for EV is lowest among the vehicle in question while HEV with NiMH batteries have nearly four times the amount of phosphate equivalent emission compared to CV as shown in Figure 4.6. This increase of eutrophication potential is caused by increased use of nickel and copper in its batteries and electronic motor.

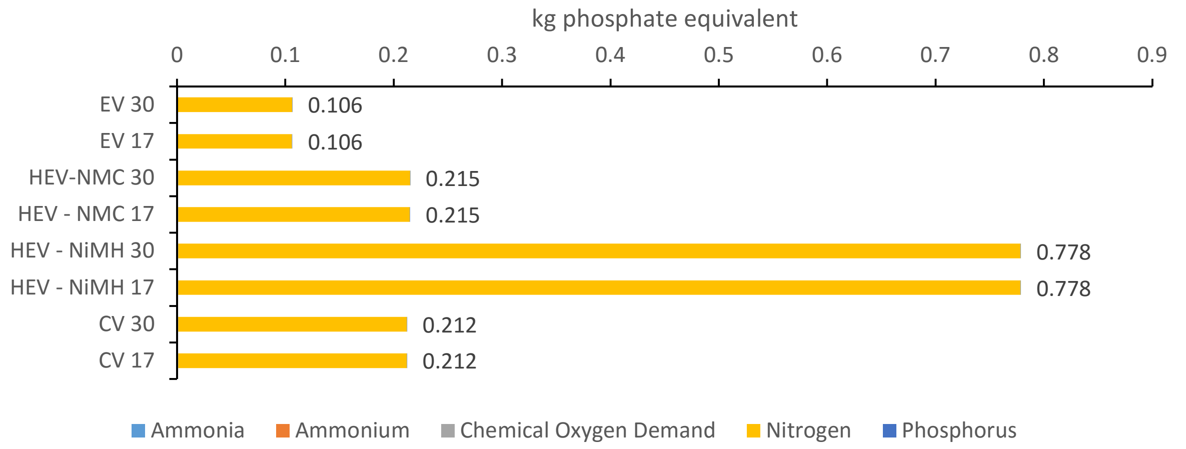


Figure 4.6 Factorized Eutrophication Potential for different type of passenger vehicle production in Malaysia.

Previous studies such as listed in Table 4.3 focus on the impact of GHG from vehicle production. This creates a situation where production of EV seems to have worse environmental impact compared to CV. DALY is often used as quantitative measurement of overall impact on human health endpoints. It is expressed as the number of years lost due to ill-health, disability or early death. Table 4.4 list the factorized DALY related materials used throughout the process of vehicle production for CV, both HEV, and EV. Factorize DALY on NiMH equipped HEV is highest at 0.0036 represented from the essential elementary flow while NMC equipped HEV scores 0.0022 DALYs. This is followed with CV and EV at 0.0019 and 0.0014 respectively.

LCI analysis found that highest DALY impact is brought by key GWP components methane and carbon dioxide. However, cumulative impact from non-GHG related have the potential to change the total DALY of each vehicle. Further analysis shown that majority of the damage is from production of engine and vehicle shell. HEV with NiMH batteries scored the most regardless of the two application of energy mix. On top of having an engine, it also equipped with 28kg of NiMH batteries which contributes 32% of total HEV production DALY.

Table 4.4 Factorized DALY impact for each vehicle type with its respective material based on 2017 and 2030 power generation.

		2017				2030			
Elementary flow	**DALY Factori-zation**	**CV**	**HEV-NiMH**	**HEV - NMC**	**EV**	**CV**	**HEV-NiMH**	**HEV - NMC**	**EV**
2,3,7,8-Tetrachlorodibenzo-P-Dioxin - Air	1.3E+02	1.6E-07	5.2E-07	3.1E-07	6.1E-07	1.6E-07	5.2E-07	3.1E-07	6.1E-07
Arsenic – Air	7.9E-03	5.1E-06	5.8E-06	5.4E-06	3.6E-06	5.1E-06	5.8E-06	5.4E-06	3.7E-06
Arsenic - Water	7.9E-03	8.1E-08	4.3E-07	2.2E-07	5.5E-07	8.1E-08	4.3E-07	2.2E-07	5.5E-07
C6 Alkylbenzene - Water	2.0E-06	3.7E-17	6.3E-17	4.0E-14	5.8E-13	5.1E-17	8.5E-17	4.0E-14	5.8E-13
Cadmium - Air	2.2E-02	2.1E-08	2.9E-08	2.6E-08	6.8E-08	2.1E-08	2.9E-08	2.6E-08	6.9E-08
Cadmium - Water	2.2E-02	1.2E-09	7.4E-09	3.7E-09	9.6E-09	1.2E-09	7.4E-09	3.7E-09	9.6E-09
Carbon Dioxide (Fossil) - Air	1.3E-07	5.2E-04	6.0E-04	5.8E-04	7.3E-04	5.2E-04	6.0E-04	5.7E-04	7.2E-04
Lead - Air	2.0E-02	1.3E-06	3.0E-06	2.1E-06	5.5E-06	1.3E-06	3.0E-06	2.1E-06	5.5E-06
Lead - Water	4.8E-02	4.9E-06	5.4E-06	5.2E-06	3.1E-06	4.9E-06	5.4E-06	5.2E-06	3.1E-06
Mercury - Air	4.8E-02	1.6E-06	1.9E-06	1.8E-06	2.6E-06	1.6E-06	1.9E-06	1.8E-06	2.6E-06
Mercury - Water	4.5E-02	1.1E-09	1.1E-09	1.1E-09	5.5E-10	1.1E-09	1.1E-09	1.1E-09	5.5E-10
Methane - Air	3.3E-06	7.0E-06	8.9E-06	7.6E-06	1.2E-05	6.9E-06	8.6E-06	7.4E-06	1.2E-05
Methane (Fossil) - Air	3.3E-06	8.2E-20	4.4E-13	1.0E-11	1.4E-10	9.1E-20	4.4E-13	1.0E-11	1.4E-10
Nickel - Air	9.1E-05	5.4E-09	6.2E-09	5.9E-09	8.5E-09	5.4E-09	6.2E-09	5.9E-09	8.6E-09
Nickel - Water	9.1E-05	1.4E-08	1.4E-08	1.4E-08	7.0E-09	1.4E-08	1.4E-08	1.4E-08	7.0E-09

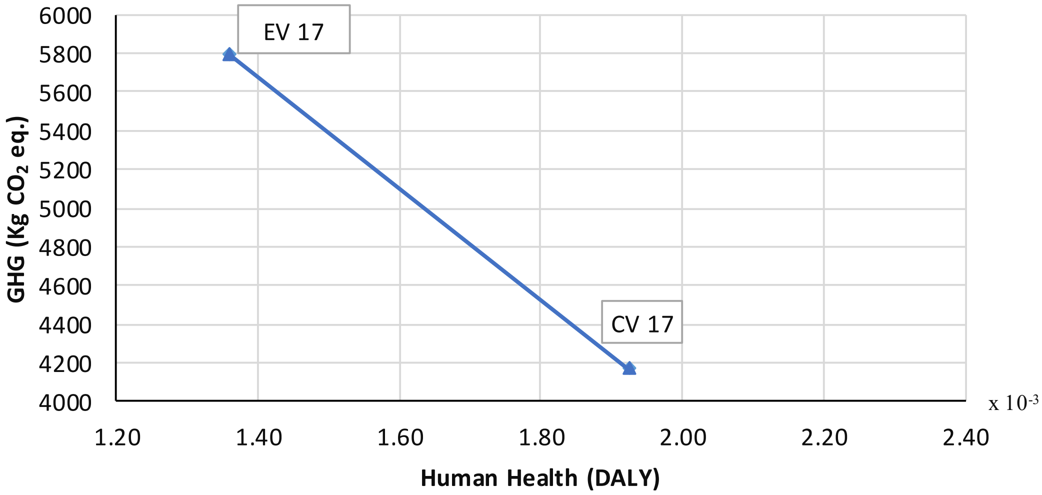
Table 4.4 Factorized DALY impact for each vehicle type with its respective material based on 2017 and 2030 power generation (continued).

		2017				2030			
Elementary flow	**DALY Factori-zation**	**CV**	**HEV-NiMH**	**HEV - NMC**	**EV**	**CV**	**HEV-NiMH**	**HEV - NMC**	**EV**
Nitrogen Dioxide - Air (NO_2)	2.1E-05	8.4E-10	1.2E-09	2.3E-08	3.2E-07	8.4E-10	1.2E-09	2.3E-08	3.2E-07
Nitrogen Oxides - Air (NO)	1.2E-05	5.0E-05	6.2E-05	5.6E-05	3.4E-05	5.0E-05	6.2E-05	5.6E-05	3.4E-05
Nitrous Oxide - Air (N_2O)	3.9E-05	4.6E-06	6.2E-06	5.4E-06	1.2E-05	4.6E-06	6.2E-06	5.4E-06	1.2E-05
Non-Methane Volatile Organic Compounds - Air	6.9E-06	2.5E-07	3.2E-07	3.0E-07	7.3E-07	2.3E-07	3.0E-07	2.8E-07	6.7E-07
Particles (Pm10) - Air	7.1E-04	7.4E-17	2.8E-05	9.1E-09	1.3E-07	8.2E-17	2.8E-05	9.1E-09	1.3E-07
Phenol - Water	6.0E-07	4.0E-17	5.2E-17	4.9E-17	1.2E-16	5.9E-17	8.3E-17	7.3E-17	2.0E-16
Sulfur Dioxide - Air	1.5E-04	1.2E-04	1.3E-04	1.3E-04	1.9E-04	1.2E-04	1.3E-04	1.3E-04	1.9E-04
Sulfur Hexafluoride - Air	3.0E-03	6.8E-10	7.0E-10	6.9E-10	7.6E-10	6.8E-10	7.0E-10	6.9E-10	7.7E-10
Sulfur Oxides - Air	1.5E-04	1.2E-03	2.7E-03	1.4E-03	3.6E-04	1.2E-03	2.7E-03	1.4E-03	3.6E-04
TOTAL DALY		**0.0019**	**0.0036**	**0.0022**	**0.0014**	**0.0019**	**0.0036**	**0.0022**	**0.0013**

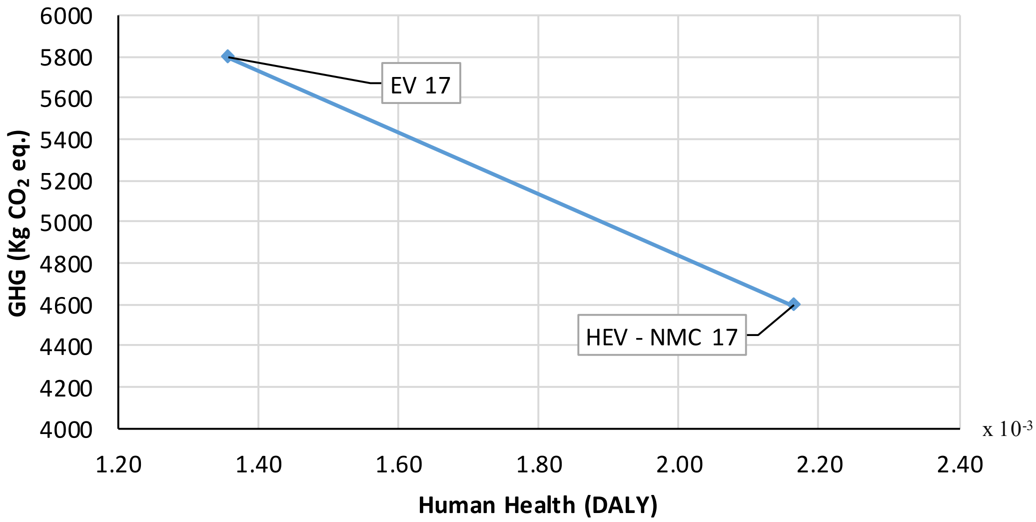
Absence of an engine which requires casting process and constant melting of metal for enables cradle-to-gate of an EV to be reduced over half total DALY as appose to current CV. An engine block is the largest single piece of metal in a vehicle housing components such as pistons and cylinders. It needed to be cast from molten metal in order to retain its strength and heat resistance. This process utilizes most of the energy for vehicle production. This situation overturns the CO_2 emission disadvantage in the initial assessment. Consistent with other impact assessment, the 2030 power mix does not carry any substantial difference for each vehicle's DALY.

National vehicle transformation from CV to EV will also create trade-off especially between GHG generation as specific impact against overall human health impact which was depicted in Figure

4.7. As the production of EV increases, so will total GHG emission from higher EV potential. On the other hand, overall Human Health will be reduced creating a trade-off. Current policy analysis method relies heavily only on GHG emissions while giving less care on the overall impact. This shows that producers, policy makers and governmental agencies need to thread more carefully in order to take measure to control the environmental impact of transportation sector.



(a) CV against EV



(b) HEV against EV

Figure 4.7 Vehicle transformation trade-off between (a) Conventional Vehicle (CV) against Electric Vehicle (EV), and (b) Hybrid Vehicles (HEV) against Electric Vehicle(EV) for human health component.

Environmental impact from vehicle production also have the potential to be reduced. This can be achievable through weight reduction, as well as introduction of newer production processes. Moreover, less impact can also be gained by using renewable energy in much larger scale such as demonstrated in the result between 2017 and 2030. Emission reduction is a direct result from the increase of renewable energy from 2% to 2.6% and increase of hydroelectric energy production from 4.3% to 12.6 %.

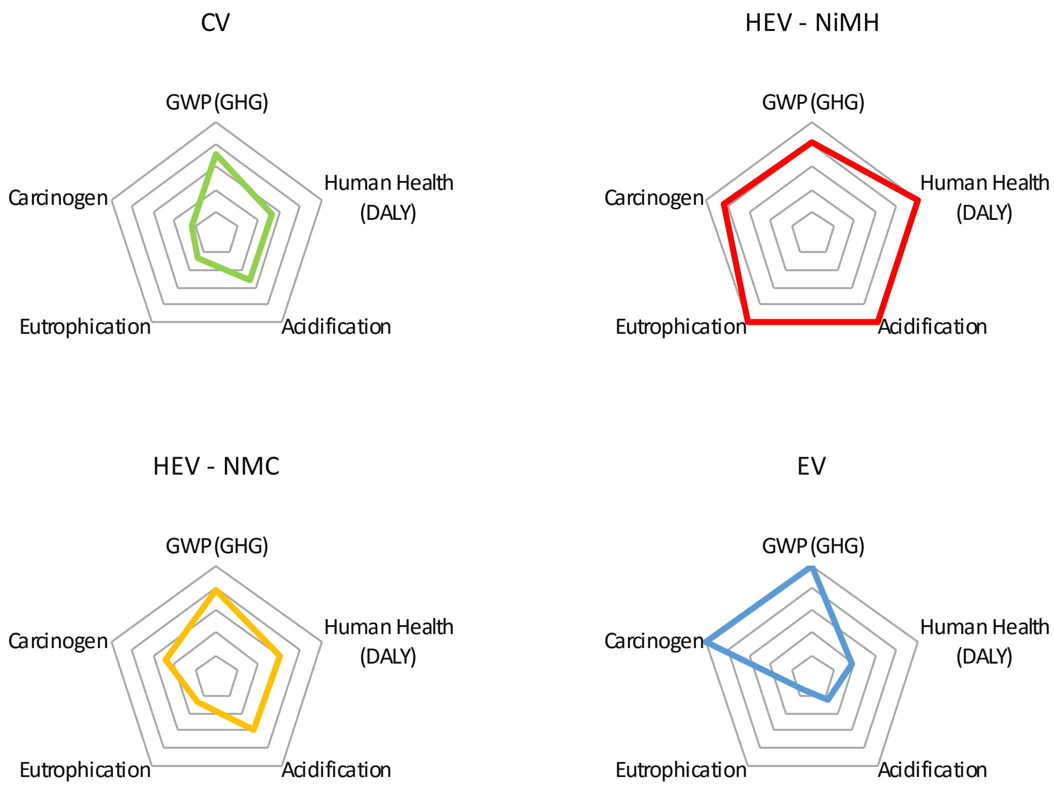


Figure 4.8 Factorized Compact Vehicle Production Environmental Impact.

Summary of environmental impact from compact passenger vehicle is depicted in Figure 4.8. HEV-NIMH is shown to have the largest impact in all the impact category studied. The impact is being normalized according to impact category and vehicle type. The most outer ream represents 100%. As an example, GWP for EV is the highest among the vehicle technology being studied, thus having GWP point at the most outer ream. GWP for HEV-NMC is measured lower compared to GWP of EV, at about 80% of its value. Thus, the point is situated at the second most outer ream.

Newer battery technology such as lithium ion on HEV NMC have managed to reduce this impact substantially making vehicle transformation towards this technology needs to also weight the impact of vehicle usage, fuel consumption, and distance travelled. Trade-off of vehicle transition to EV can also be observed here.

GHG emission increase between manufacturing of CV to EV is also consistent with prior studies such as from Baptista, Tomás and Silva (2010), Notter *et al.* (2010), and Girardi, Gargiulo and Brambilla (2015). Similarly, higher emission resulted from production of Hybrid Vehicles (HEV) as compared to CV is also consistent with previous study from Samaras and Meisterling (2008), Baptista, Tomás and Silva (2010) Burnham (2012), and Hawkins *et al.* (2013). However, this is the first time a study was done using IDEA database and LIME methodology on estimation of compact vehicle production impact.

The information generated from this study can be used to estimate the damage potential of using vehicles older than 12 years old (C12+) as opposed to replacing it with new vehicle as shown in Table 4.5. This estimation is generated by multiplication with vehicles quantity of age 12 and above (see 0). However, constant vehicle engine size variable is used (2000cc) in order to simplify the results.

Table 4.5 Damage Potential of vehicle extended use against replacement.

	Total vehicles age 12 & up usage.	Total vehicle replacement production + New vehicle use impact	New vehicle usage + new vehicle replacement (if all replacement is hybrid)
GWP (Kiloton)	12,137	12,664	9,315
DALY	37,327	10,761	7,525

The result shown that replacement of all vehicle with new ones of the same type is expected to increase Global Warming Potential but reduces the impact of DALY. Although CV replacement production releases 5094 kiloton GHG, it is being offset by the efficiency of new engine combustion. Comparatively, GHG released from C_{12+} is considerably higher per KM caused by efficiency loss through deterioration, and wear & tear.

Reduction in DALY was primarily contributed from the lower fuel consumption, and lower release of fugitive toxic chemicals from new catalytic converters (Borken-Kleefeld and Chen, 2015). Further reduction of GWP and DALY can be observed if all C_{12+} is replaced with more efficient system such as Hybrid vehicles.

4.5 Conclusions

Present work is an expansion of LIME2 methodology into the assessment of compact vehicle production in Malaysia. The environmental impact of compact passenger vehicle based on 5 impact classifications; Greenhouse Gas (GHG) generation, Acidification, Eutrophication, Carcinogenic Effect, and Disability-Adjusted-Life-in-Year (DALY). Vehicle models is inventoried by using IDEA inventory database, and analysed using LIME2 method. Main methods for the integration of environmental impacts weighting is better represented with data of Asian under LIME2 method, especially in term of body weight and size. Under this premise, its use is more suitable to Malaysia.

This study examines three types of compact passenger vehicle production in Malaysia which are Conventional Internal Combustion Engine Vehicle (CV), Battery Electric Vehicle (EV), and Hybrid Electric (HEV) vehicles with two types of batteries; Nickel Magnesium Hydride (HEV-NiMH), and Lithium Nickel-Magnesium-Cobalt (HEV-NMC).

Main conclusion from this study is as follows;

First, production of EV have slightly high potential to cause a global warming, follow by HEV and CV. Even without the traditional components, EV consumes higher energy for the production of the 200 kg battery and its components. The 5,791 kg CO_2 emissions is 39% increase compared to the existing CV. The values generated in this study are significantly low compared to other existing studies mainly due to reduction of the total vehicle weight. Overall impact; DALY is much lower compared to other vehicle being analysed.

Second, HEV-NiMH production release 4,814 kg CO_2 while HEV-NMC production emitted 4,596 kg CO_2 during its production process. HEV-NiMH also have highest acidification potential at 23.06 kg SO_2 and eutrophication potential at 0.78 kg phosphate equivalent for each unit production. Utilization of this two different battery technologies have notable difference especially in Carcinogen, Eutrophication, and Acidification impact categories. Swapping the NiMH batteries to lithium ion batteries can provide less impact to the environment.

Third, cradle-to-gate of CV is better in term of GHG emission and Carcinogenic impact compared to all the studied subjects. CV production process added 4,166 kg of GHG and 0.30 kg of benzene equivalent into the environment for every unit produced, posing the least impact among all the vehicles being studied. However, if vehicle usage emission is being considered, the total emissions from CV will become the worst as it consumes much more fuel compared to the other vehicle type.

Lastly, the various impact is being summarized in term of DALY. Although GHG emissions from EV is the highest during production, the overall index in human health is the least among the vehicles being studied. Lowest DALY from production is exhibited by EV at 0.0014, followed by CV at 0.0019, HEV-NMC at 0.0022 and finally by HEV-NIMH at 0.0036. This shows that EV production still is the best solution for the global sustainability. Under this premise, national vehicle manufacturers should invest more on creation and production of EVs, while governing bodies should develop more active policies towards increasing the ownership of Electric Vehicles.

This study also provided the trade-off between GHG and DALY in vehicle transition from CV to HEV. Although GHG emission from EV is higher, overall impact towards human health is effectively 35% lower compared to conventional vehicles production.

Moreover, as EV technology is considerably new, the improvement potential is much more compared to conventional vehicles. Current state-of-knowledge regarding fuel consumption HEV and EV also have the capability to reduce the overall vehicle lifecycle impact much lower compared to CV. Upcoming battery technologies may have the potential to reduce it further down and helps to create a more sustainable future.

Chapter 5. Environmental Burden & Policy Planning

5.1 Chapter Overview

Chapter 5 offers to combine all the scattered results in previous chapters. Total Environmental Impact calculation method from passenger vehicle fleet is reported in Section 5.3.1 while policy generation method is available in Section 5.3.2. Results of the overall impact and policy comparative analysis is reported in Section 5.4.

5.2 Introduction

Passenger vehicle is identified as the second biggest contributor of Greenhouse Gas emissions. It also the second biggest polluter behind power generation due to the sheer number of vehicles. Although pollution from single vehicle is small compared to a single power plant, the pollution source is mobile and thus making many small amount of pollutions everywhere. Moreover, the vast selections of vehicle model and technology made controlling emissions from this sector more challenging. In contrast, grid power generation control is easier to be managed due to less number of variable, making stationary combustion emissions from grid power generation is also easier to control.

This chapter provides the results from overall methodologies being implemented, and using results generated in the earlier chapters, which completes the passenger vehicle lifecycle from material mining until it reached the end-life stage. Environmental Burden and Policy Planning Chapter focused on combining the fragmented methodology and results generated in the previous chapters into main impact for policy combination assessments.

5.3 Methodology

5.3.1 Environmental Impact from Passenger Vehicles Fleet

This study reports four most significant environmental impact related to passenger vehicle manufacturing and usage which are GHG Emission, Acidification Potential, Eutrophication Potential, and Carcinogenic Potential. The Cradle-to-Waste (CTW) GHG emissions is calculated by summation of existing results from Chapter 3 indicated by ‘GHG Usage (Ch3)’, Cradle-to-gate emissions (CTG) from vehicle productions ‘CTG Cars’, and Well-to-tank (WTT) of fuel usage ‘WTT Fuel’ as depicted in Figure 5.1. Compared to other impacts, CTG from electricity generation is not included in GHG emissions, as the component was covered in Section 3.3.2 calculation.

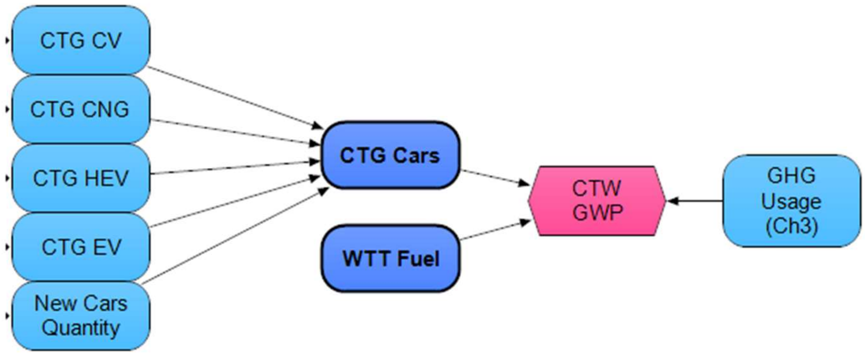


Figure 5.1 Variables involved in estimation of Total GHG Emissions for passenger vehicle fleet in Malaysia

'WTT Fuel' values were generated from IDEA database which enable the calculation of the environmental impact per litre of fuel used based on material and elements used throughout the process of fuel production, until it reached individual vehicle tanks. This value is multiplied by fuel usage which was the result from Chapter 3. 'CTG Cars' is calculated by the multiplication of CTG from CV, CNG, HEV, and EV from Chapter 4 with New Vehicle Registration values from Section 2.4.3.

Acidification Potential Impact was calculated with slight difference, where electricity production impact need to be added separately. This was because the Acidification Potential Impact during vehicle usage is not being covered in the previous chapters. The impact of electrical production is direct multiplication of 'Total Electric Demand' which can be found in Section 3.4.1 with the environmental impact from electric production depicted in Figure 5.2. However, this only covers vehicle production, and vehicle fuel combustion impact. Values for 'Acidification from Usage' was gathered from results in Section 3.4.2, specifically Nitrogen Oxides, Carbon Monoxide and Hydrocarbon fugitive emissions from vehicle tailpipe. This values then multiplied according to its respective impact factorization previously discussed in Chapter 4. The rest of the model formula can be found in Appendix 10.

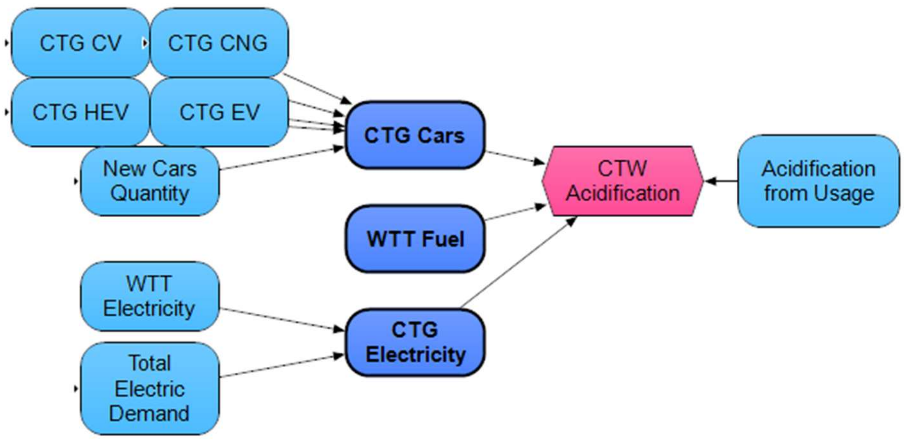


Figure 5.2 Variables involved in estimation of Total Acidification Potential.

All of the impacts mentioned above serves as mid-point impact. Another point worth to mention is the end-point impact which was measured in DALY. LIME methodology enables the direct calculation from material and elements used into DALY without having to go through the mid-point estimation process, as discussed in Chapter 4. Under this premise, DALY calculation method was done in similar fashion with Total Acidification Potential Estimation in Figure 5.2.

5.3.2 Policy Option

Chapters 3 indicates that the Environmental Impact results is highly sensitive to 4 main variable drivers; Tailpipe Emission Regulation, Mandatory EV, Vehicle End of Life Age, and HEV and EV pricing factor. Understandingly, 35 policy combination was done in order to explore all possible combination which are shown in Figure 5.3.

The current policy applied is named Baseline, other policy combination is listed in numerical order. For instance, Under P3, 'Euro 2 Tailpipe Emission Regulation' was adopted, but sales and registration of other vehicles apart from EV is allowed. At the same time, MA14 based vehicle emission testing frequency was applied but vehicle taxation and pricing strategy remains the same.

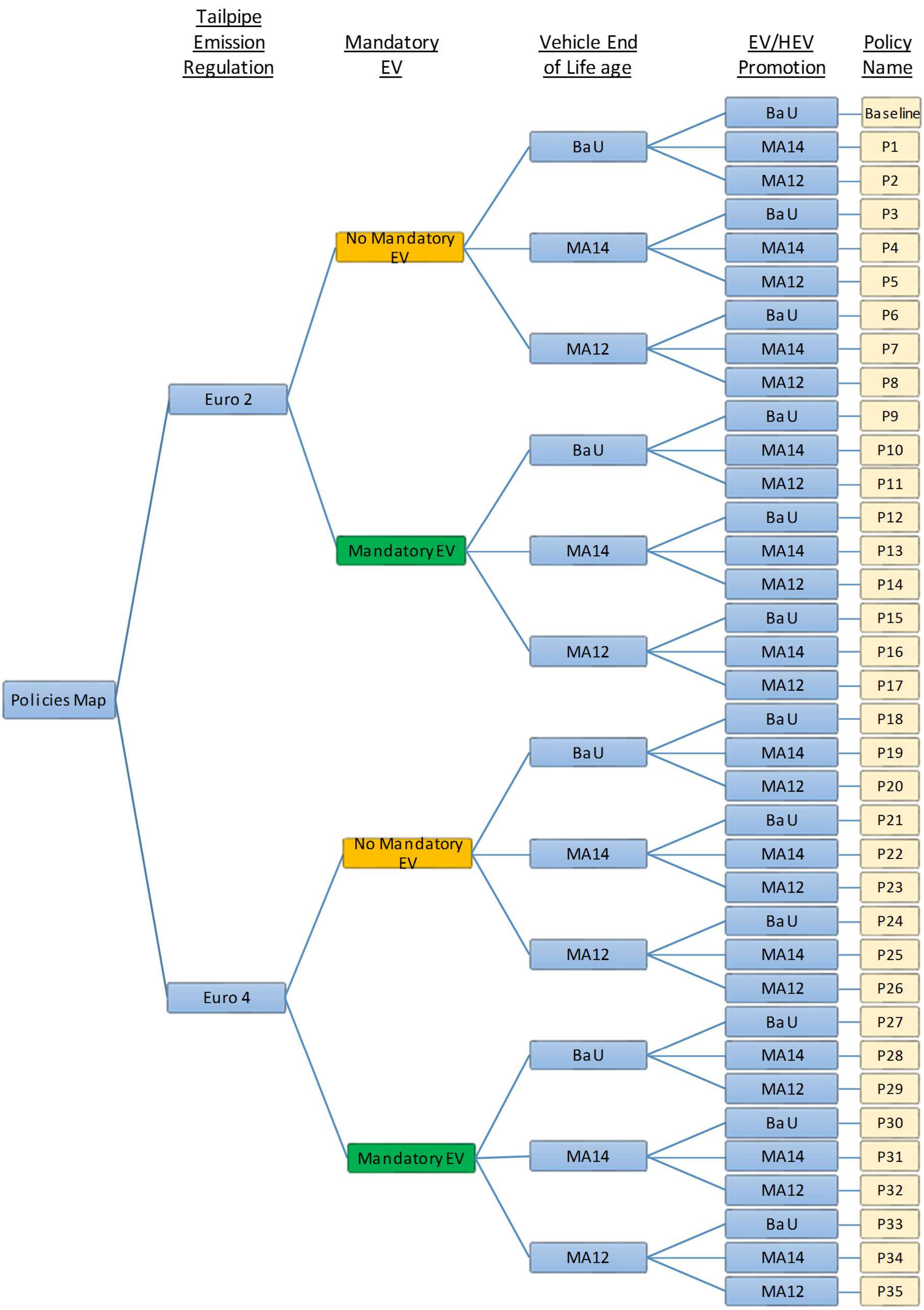


Figure 5.3 Policy Name Diagram

5.3.3 Model Testing

This thesis opted for four type of model testing namely historical data testing, and sensitivity analysis. Historical Data Testing

Historical data testing is a method to estimate the likeliness of key variables simulated results to follow the actual values in the real world. This type of data testing was done in Section 2.3.8 which covers the actual number of new vehicle registration against the simulated value, and total active vehicle stock against the values generated from this model.

5.3.3.1 Tornado Chart Sensitivity Analysis

Tornado Chart is another common test to study the sensitivity of data input on the output the model. It involves increasing and decreasing a variable by 10% to know the results on the final output for both high and low condition. Although combination of all assumption testing is desirable, selection of only a few scenario of special interest for examination is sufficient (Morgan and Henrion, 1990).

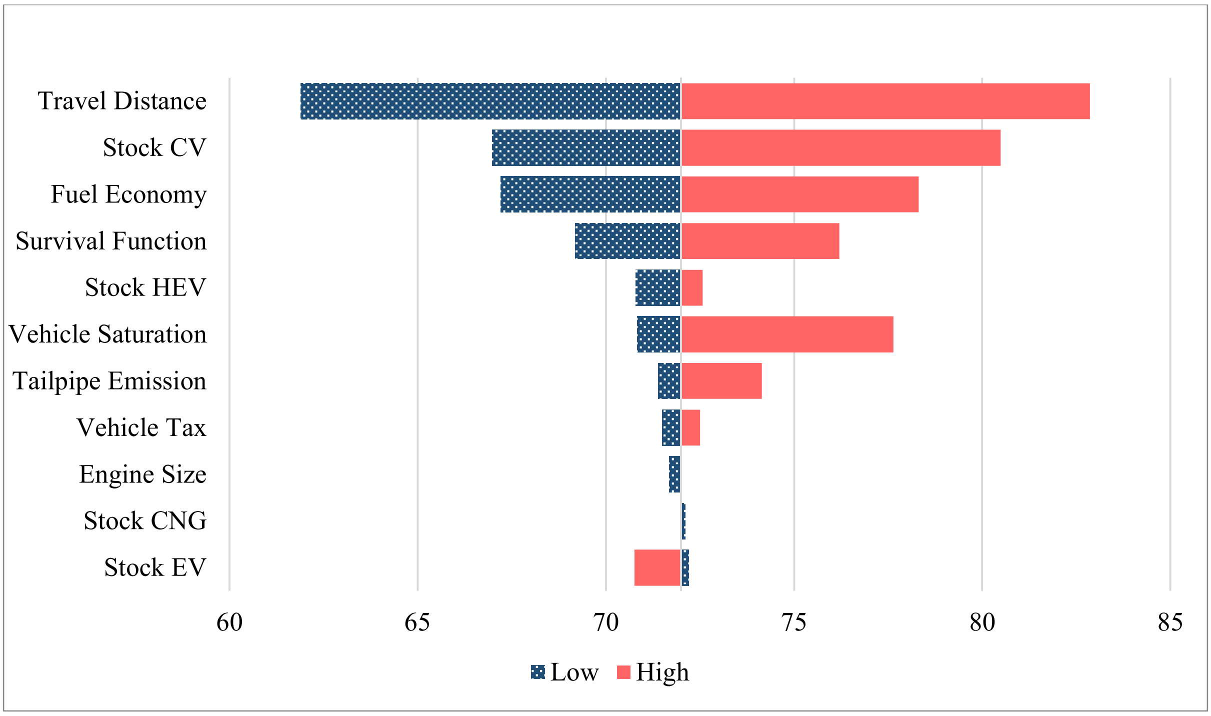


Figure 5.4 Tornado Chart based on sensitivity analysis.

Sensitivity analysis was done towards the focus of the generation of GHG in year 2040 as shown in Figure 5.4. From this analysis, Travel Distance, stock of conventional vehicle, fuel economy, and survival function have a great influence on the final GHG emission model output. It also reveals that the higher number of HEV actually have the potential to increase vehicle lifecycle GHG emission. Vehicle Taxation reduction of a mere 10% only have marginal impact on the final output.

The implementation of input sensitivity is not without weakness, especially in the comparison between Stock of CV changes of 10% compared to Stock EV changes of 10%.

The CV actual input is at 9.81million. Increasing this value by 10% will lead to 10.79 million vehicles which are a huge difference. Comparatively, Stock EV in 2040 is only 42,000 units which increased by 10% only lead to 44,200 units. Alas, model users should understand the implication of using this kind of sensitivity. This being said, increase of EV stock by 10% have the potential to reduce GHG by huge difference if the basic stock of EV is comparable to CV.

5.4 Results and Discussions

As in 2016 alone at 8.8 million active vehicles with mostly internal combustion engine vehicles, the amount of GHG emission is expected to reach 44,382 kilotons from fuel combustion during usage. At the same time 2,909.31 kiloton GHG is also being released from manufacturing sector to support demand for new passenger vehicles and 7,480.88 kiloton GHG from fuel production. EV uses 100% electricity which was counted separately. Supporting EVs in 2016 involves adding 317.97 kiloton GHG to the atmosphere. This brings the total GHG generation in 2016 to 55,885 kiloton. Table 5.1 lists the GHG emissions generated from total number of passenger vehicles for 5 year interval from vehicle production stage, fuel production and fuel combustion during usage. The first period 2016 to 2020, total new GHG emissions is expected to be 295,950 kilotons. New emission for the next period will increase by 9.9%, before the growth slows to 4.2%, 2% and 1.7% for the last observed period.

Table 5.1 GHG Emissions generated from passenger vehicles, 2016 – 2040 (see Appendix 5 for detailed data).

Time Period	Vehicle Production	Fuel & Electric Production	Fuel Combustion (vehicle usage)	Total
2016-2020	14,615.87	39,765.02	243,109.80	297,490.70
2021-2025	13,664.56	43,502.67	269,997.53	327,164.75
2026-2030	13,586.73	44,887.27	283,072.34	341,546.33
2031-2035	14,321.43	45,398.12	289,659.55	349,379.10
2036-2040	15,195.52	46,057.31	294,630.87	355,883.70

Acidification Potential Impact is shown in Table 5.2 measured kiloton Sulfur dioxide equivalent. The concentration of SO_2 have are influential to habitat suitability especially for plants. Main acidification potential is generated from fuel production and fuel combustion while vehicle production and electricity generation only produces relatively minute quantity of acid rain generation elements. The high quantity of Acidification components during mobile combustion further increase the need for increased quantity of EV. Electricity generation have easier process of controlling acidification components emission altogether using flue-gas desulfurization, or the Claus Process due to focused source of emission rather than speeded emissions in case of vehicle use.

Table 5.2 Estimated Acidification Potential generated from passenger vehicles, 2016 - 2040, normalized to SO_2 kiloton equivalent. (see Appendix 6 for detailed data).

Time Period	Vehicle Production	Fuel Production	Electricity Generation (EV Usage)	Fuel Combustion	Total
2016-2020	41.95	48.48	0.00	33,957.27	34,047.70
2021-2025	39.25	53.03	0.00	39,982.89	40,075.18
2026-2030	39.02	54.72	0.01	44,468.31	44,562.06
2031-2035	41.09	55.34	0.03	47,429.47	47,525.93
2036-2040	43.48	56.15	0.07	48,726.30	48,825.99

Impact of passenger vehicle on water pollution is also being studied. This Eutrophication Potential impact is being normalized in kilotons of Phosphate equivalent, and reported in Table 5.3.

Table 5.3 Estimated Eutrophication Potential generated from passenger vehicles, 2016 - 2040, normalized to Phosphate kiloton equivalent. (see Appendix 7 for detailed data).

Time Period	Vehicle Production	Fuel Production	Electricity Production	Usage	Total
2016 -2020	0.74	0.00	0.00	518.79	519.53
2021 -2025	0.69	0.00	0.00	610.85	611.54
2026 -2030	0.68	0.00	0.00	679.38	680.06
2031 -2035	0.72	0.00	0.00	724.62	725.33
2036-2040	0.76	0.00	0.00	744.43	745.19

The fourth impact being studied is the carcinogen potential on human being. It is being factorized by the effect of 1 kiloton benzene exposure. Table 5.4 represents the amount of Carcinogenic potential emissions resulted from vehicle manufacturing, fuel and electricity production, as well as vehicle usage. It is clear that vehicle usage contributes to the largest impact of cancerous related health issues from fuel combustion in individual vehicles.

Table 5.4 Estimated Carcinogenic Potential generated from passenger vehicles, 2016 - 2040, normalized to kiloton Benzene equivalent. (see Appendix 8 for detailed data).

Time Period	Vehicle Production	Fuel Production	Electricity Production	Usage	Total
2016-2020	1.09	0.00	0.00	1,120.55	1,121.64
2021-2025	1.05	0.00	0.00	1,211.95	1,213.00
2026-2030	1.07	0.00	0.00	1,230.10	1,231.17
2031-2035	1.16	0.00	0.00	1,220.28	1,221.44
2036-2040	1.25	0.00	0.00	1,215.18	1,216.43

Overall impact on human health based on environmental emissions is measured in Disability-Adjusted Life Year (DALY). This overall measurement of disease burden is expressed as the number of years lost due to ill-health, disability or premature death. LIME2 calculates this index from amount of factorized related materials. Method for calculating overall DALY have been provided in Table 4.4 of Chapter 4.

Table 5.5 Total Disability-Adjusted Life Year (DALY) generated from passenger vehicles, 2016 – 2040. (See Appendix 9 for further details).

Time Period	Vehicle Production	Fuel Production	Electricity Production	Usage	Total
2016-2020	6,676.94	9,437.14	0.53	1,025,269.44	1,041,384.06
2021-2025	6,252.71	10,324.16	1.71	1,204,311.81	1,220,890.39
2026-2030	6,223.41	10,652.76	4.45	1,336,361.30	1,353,241.92
2031-2035	6,558.77	10,773.99	10.73	1,423,171.82	1,440,515.31
2036-2040	6,947.81	10,930.44	24.23	1,461,549.24	1,479,451.71

Estimated a total of 144 policy options are possible for the best policy mix. Based on the sensitivity analysis, six dimension of variable is found to be highly sensitive to the final change in 2040. The first two is ELV age policy and HEV/EV promotion discussed in 0 Table 2.4. Another 4 variables derived from Table 3.2 are 'Euro 4 emission adaptation', 'Mandatory EV from 2030', 'Fuel Efficiency Improvement of 10%', and 'Engine-Size Reduction' with GHG emission reduction of 13.6%, 52%, 7.6% and 1.5% respectively compared to Baseline situation in 2040. Implementing the alternative individual variable change also have the potential to reduce overall DALY by 66%, 24%, 0.4% and 0.1% respectively in the same time period as shown in Table 5.6. Fuel efficiency improvement only managed to reduce overall emission of GHG by less than 8, and only small fraction of DALY. This result shows that fuel efficiency has less priority compared to other variable modification.

Table 5.6 Potential reduction of GHG emission and DALY in 2040 for individual variable changes against 'Baseline' situation.

	GHG (Mt)	Change	DALY	Change
Baseline	71.72		296,742.06	
Euro 4 Emission Adaptation	61.95	13.63%	100,825	66.02%
Mandatory EV 2030	34.42	52.01%	225,049	24.16%
Fuel Efficiency Improvement	66.24	7.64%	295,711	0.35%
Engine Size reduction	70.68	1.45%	296,546	0.07%

Base on this information in Table 5.6, a list of policies estimating each policy change have been done exploring each impact on future emissions (Refer Table 5.3 for detailed view) with its result presented in **Error! Reference source not found.** for Total GHG emissions in 2040, and **Error! Reference source not found.** for total DALY in 2040. Under this policies, only number of vehicle mix is different, and the total number of vehicles remains the same. Policy application is also set to start at 2017 for all variable, except for *mandatory EV* regulation policy, which starts implementation in 2030.

Results from Baseline to Policy 8 represents the effect of non-improvement of the vehicle emission standard, which are being shown in Figure 5.5. It is estimated that implementing vehicle end-of-life policy and promotion of new generation vehicles alone is not enough for a significant reduction of GHG emissions as seen in Policy 1 to 8 and 18 to 26.

Reduction of vehicle prices to the extreme MA12 level can only create 2 Megaton reduction in GHG emissions in 2040 compared to Baseline situation, which represents a 3% change as seen in Policy 2. This situation might be due to the still-high HEV and EV prices compared to CV. However, with implementation of price reduction and vehicle age control, a reduction of 15% can be seen compared to Baseline situation, as seen on Policy 8 impact.

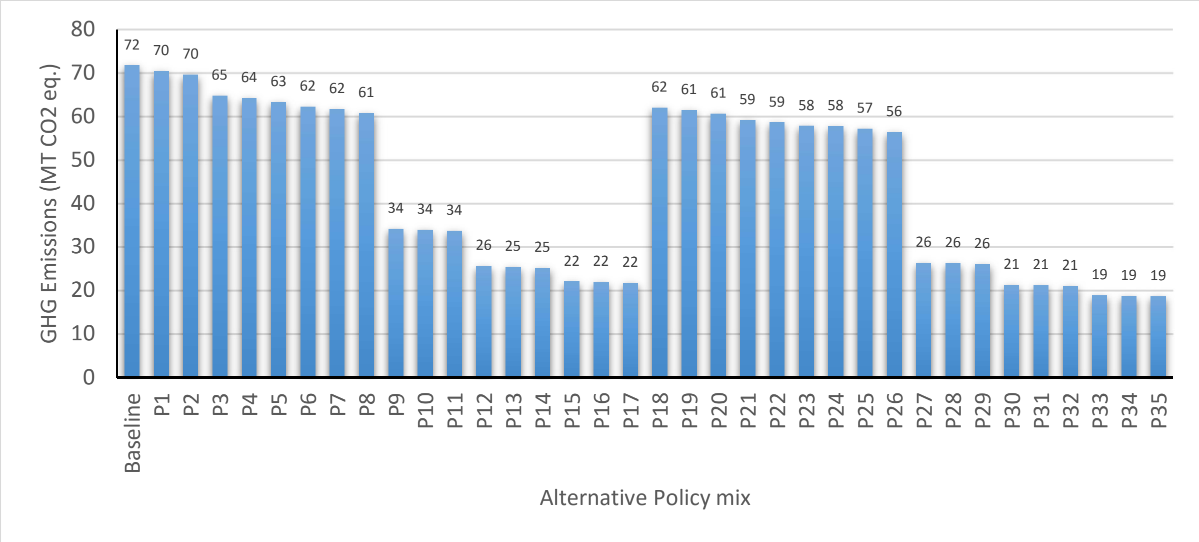


Figure 5.5 Passenger Vehicles GHG emissions across 35 alternative policies, 2040.

Emissions in only one measure taken; vehicle age control based on current Baseline situation can be seen in Policy 3 and Policy 6. Under this control measures alone, GHG emissions can be reduced by 9.7% and 13.3%.

However, a stark difference is seen in Policies 9 to 17 and Policy 27 to 35. These policies have mandatory EV registration in place in 2030 which means, all new registered vehicles are Electric vehicles. Over the period of 10 years, the number of CV, HEV and CNG is phased out according to its surviving factor leaving the majority of vehicles left is from EV type.

Result of keeping all other variable apart from this mandatory EV regulation as constant have the potential of reducing overall GHG by 52.5% after 10 years of implementation. This regulation implementation is possible as the production cost of EV is expected to reduce significantly on top of lower availability of fuel.

At the most extreme case of Policy 35, all non-EVs is also governed by higher tailpipe emissions standard. It shows the potential of 74% GHG emissions reduction compared to Baseline, further reducing the gap to become carbon-negative sector.

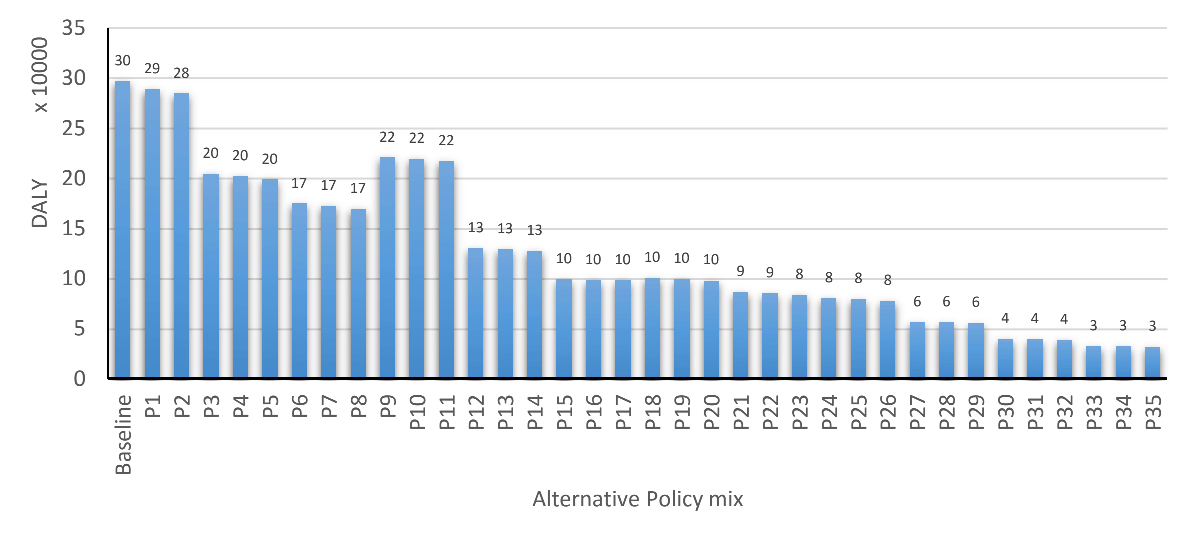


Figure 5.6 Estimated total DALY from passenger vehicles across 5 alternative policies, 2040.

Impact on DALY also have a significant change compared to Baseline situation presented in Figure 5.6. Application of single variable change; reduction of vehicle taxation is shown in the results of Policy 1 and Policy 2. The policy will directly reduce HEV and EV prices which provides more options and opportunity for vehicle owners to purchase HEV and EVs. This higher number of HEV and EV have direct impact on overall health of the population with reduction of 3% DALY in moderate EV and HEV promotion MA14, and 4% in higher tax cut in MA12.

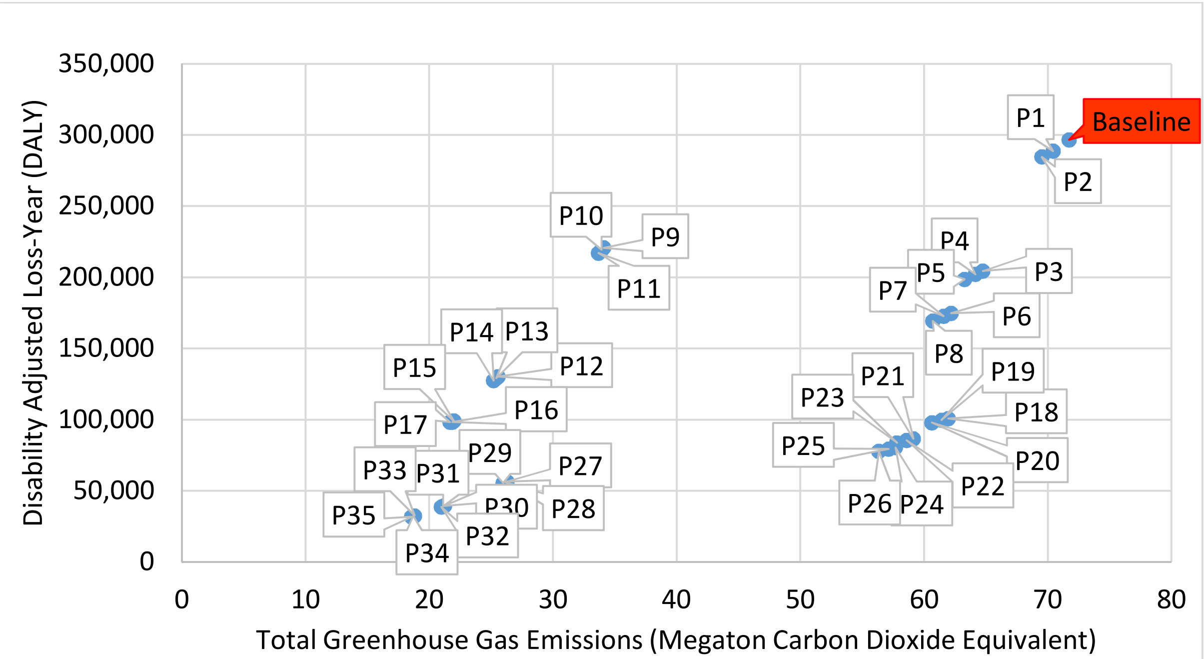


Figure 5.7 x-y Graphic Interpretation of Passenger Vehicles GHG Emissions Against Total DALY Across 35 Alternative Policies, 2040.

Impact on the measures of controlling vehicle usable age can be seen in Policy 3 and Policy 6 with DALY reduction of 31% and 41% compared to Baseline. This condition represents the situation where shorter vehicle age have the higher potential for new technology adoption by new vehicle purchases. Effect of this is the higher uptake of HEV and EV for vehicle replacement.

Another point worth to mention is the effect of applying mandatory EV regulation on Baseline set of rule. The application of this regulation alone will not a very high change on overall DALY as seen in Policy 9 to Policy 11 compared to other regulation mix. Even the improvement of tailpipe emission standard to Euro 4 also have the potential to reduce DALY by 66% compared to baseline, with overall reduction of DALY can be seen throughout Policy 18 to Policy 35. This shows that tailpipe emission regulation has a very high sensitivity on overall health standard on the population.

Combination of the results from Figure 5.5 and Figure 5.6 is shown in Figure 5.7 in term of x-y graph. This graphical representation shows a distinct change in GHG emissions and DALY at year 2040 across the policy options. The group results on *top-right* areas have common traits which have no mandatory EV regulation application, and the emission standard is not being updated. The *top-left* areas common regulation traits are the Mandatory EV regulation application, and being done under BAU vehicle end-of-life condition. The *bottom-right* areas represent the results of non-application of Mandatory ELV regulation, but emission regulation is updated to later version. Last, the *bottom-left* areas common regulation trait involves the application of Mandatory EV regulation.

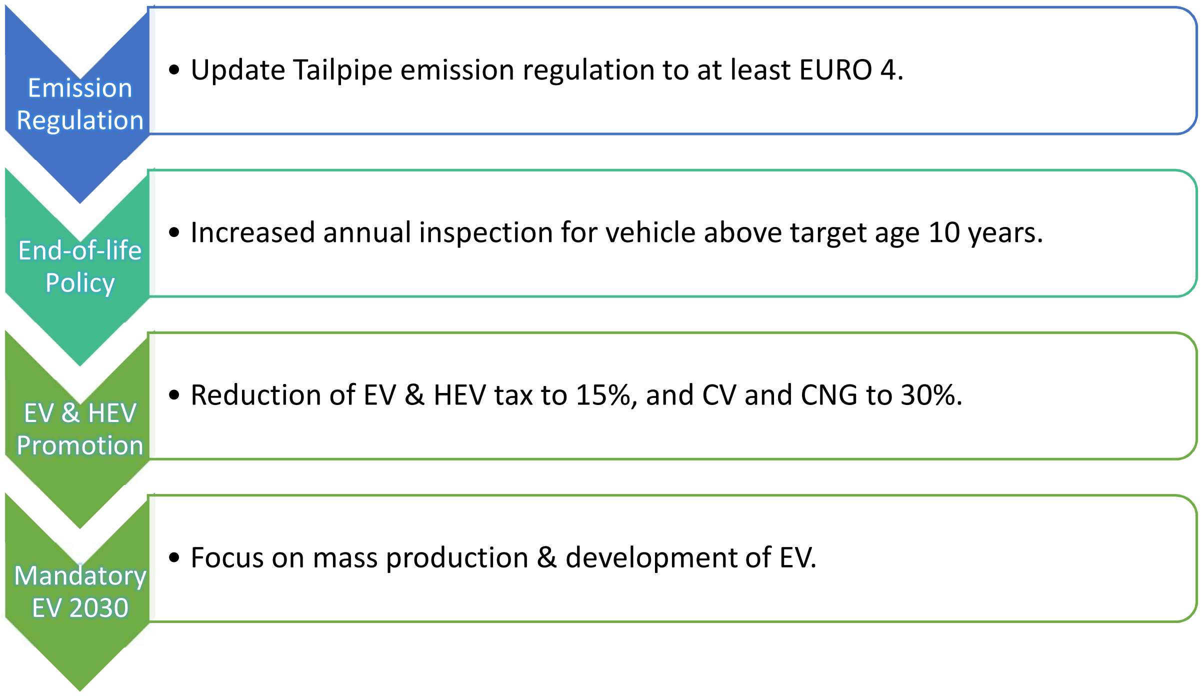


Figure 5.8 Key Activity Application in the Extreme Scenario based on Policy 35.

Figure 5.8 shown the changes being applied for Policy 35 which generated the least amount of GHG emission and DALY in 2040. It involves the update of tailpipe emission regulation, increased vehicle testing for all vehicles after it reaches the age of 10 years, reduction of vehicle tax to 30% for CV, and 15% for HEV and EV, and application of regulation that required all new vehicle registration needed to be free from internal combustion engine from 2030 onwards.

The application of this policy regulation gave results to lower overall cumulated GHG emission over time, shown in Figure 5.9. The extreme scenario manages to reduce overall GHG emission by 26% to 1375 million tons by the year 2040. This condition is generated after the application of new regulation in 2017, and gradual phasing out of CV during the 10-year period leading to 2040.

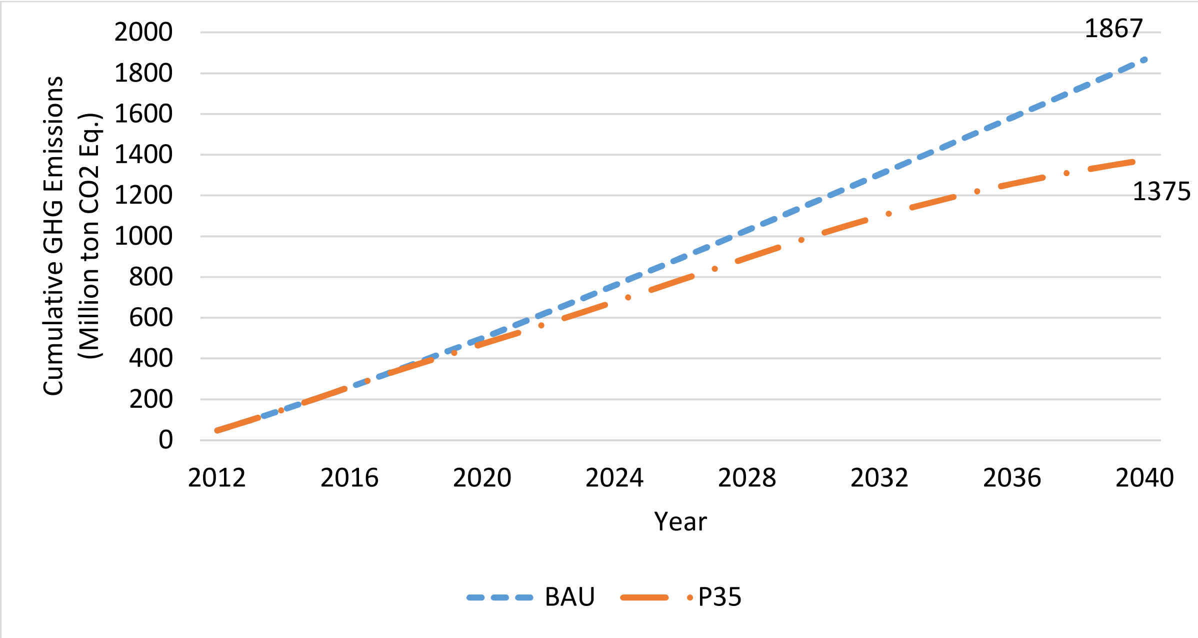


Figure 5.9 Cumulative GHG Emission from passenger vehicle lifecycle from 2012 to 2040 under Business-as-usual and Extreme Scenario (Policy 35).

5.4.1 Trade-Offs Between Impacts.

As the Extreme Scenario (Policy 35) have the potential for a significant reduction of GHG emission, other impact also needed to be addressed. Moreover, it is empirical to understand that such 'extreme' policy might not be preferred to decision makers. Such condition gave rise to a more moderate or optimist policy application. It is identified that Policy 22 the potential to fit in this description. Policy 22 involves the vehicle Tailpipe Emission Regulation improvement, moderate Vehicle End-of-Life policy, and moderate EV/HEV Promotion, but without the regulation of EV-only registration for new vehicle registration.

Figure 5.10 represents the correlation between selected Final Environmental Burdens which are being measured as percentage of change compared to values in 2020. The output provides a unique results for this study compared to the previous similar study by Higuchi (2012) which was done on Japan case. In his study, future vehicle impact for GHG emissions, Total Material Requirement[9] (TMR), Material Consumption per Material Production ratio, and Material Consumption per Reserve ratio was all reduces as time progress.

Compared to this study which focus on Malaysia case, the GHG emissions, Carcinogenic Impact, Acidification Impact and DALY impact all shown to be increased under BAU scenario. Increase can also be seen in GHG emission and Carcinogenic Impact for Optimist Scenario. In Extreme scenario however, all impact indicated a reduction.

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[9] Another method to estimate the material required for production of new vehicles.

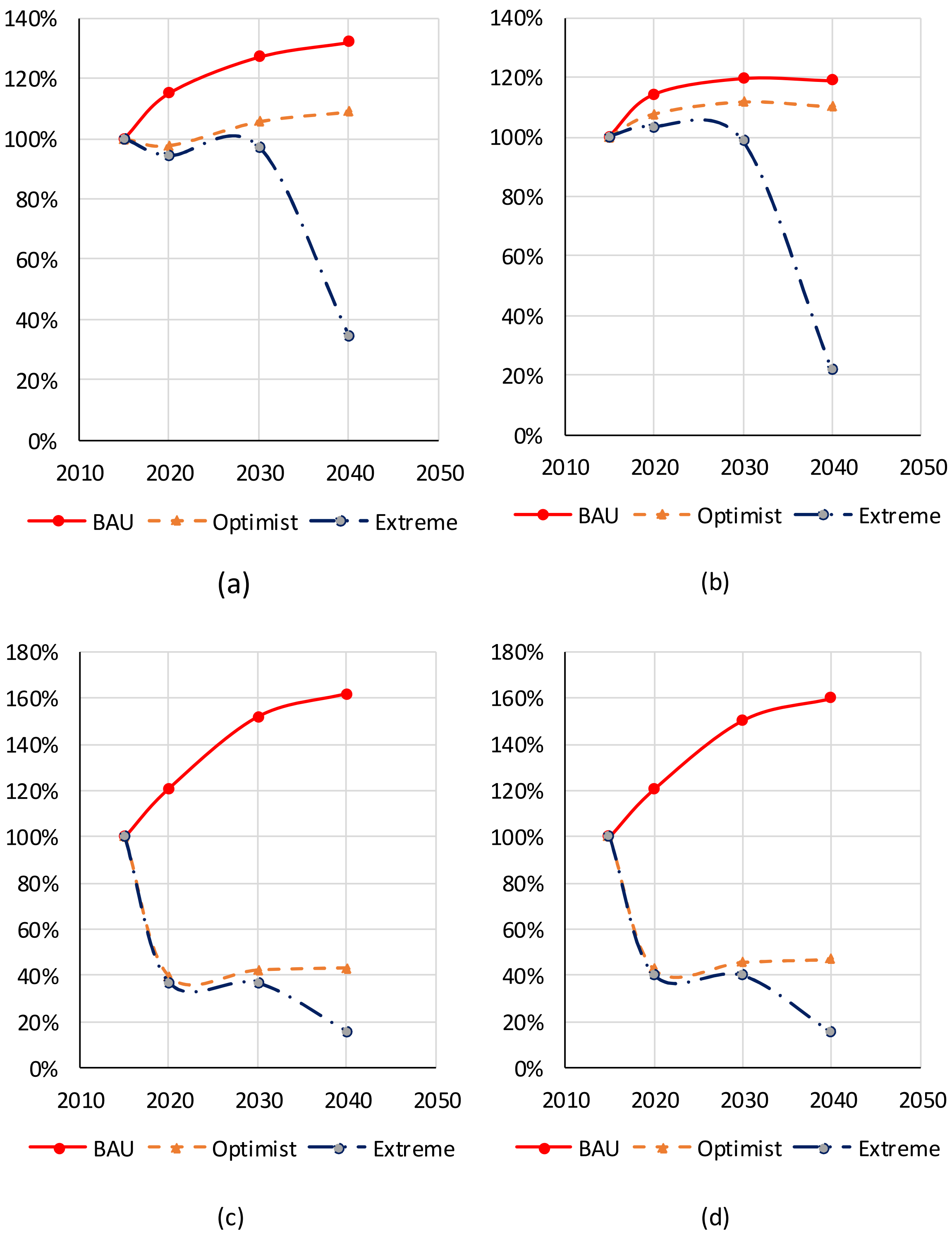

Figure 5.10 Correlation between (a) GHG emissions, (b) Carcinogenic Impact, (c) Acidification Impact and (d) DALY Impact, (2015 – 2040).

Table 5.7 Overall Environmental Impacts from Personal Vehicle Transportation Sector in 2015, and Correlations Changes in 2030 and 2040 Under Different Scenarios.

			Business-as-Usual		***Optimistic Scenario***		***Extreme Scenario***	
Impact Indicator	**unit.**	**2015**	**2030**	**2040**	**2030**	**2040**	**2030**	**2040**
GHG	million ton CO_2 eq.	54	127%	132%	106%	109%	97%	35%
DALY	year lost	185,261	119%	119%	112%	110%	99%	22%
Acidification	tons SO_2 eq.	6,046	152%	162%	42%	43%	37%	16%
Eutrophication	tons-phosphate eq.	92,267	152%	162%	42%	43%	37%	16%
Carcinogen	tons-benzene eq.	205,714	119%	119%	112%	110%	99%	22%

The graphical result representation shows the opportunity for impact reduction of different path taken for future environmental safeguard. It also shown the high reduction especially in GHG emissions and Carcinogenic Impact between Optimist and Extreme measures application. The result can also be found in Table 5.7 in its absolute values and percentage of change. Interestingly the change percentage for Acidification and Eutrophication is noticeably similar, while DALY and Carcinogen shows a common changing traits. Nonetheless, the absolute value of the impact category has different consequences. The extreme condition also has possible backlash as the extreme ruling shorten vehicle usable age significantly, and requires more frequent replacement. As such, policymakers and stakeholders need to rethink their priority of either safeguarding the environment through intervention, or keeping things as it is and risk the sustainability.

5.4.2 Special Provisions

Another important suggestion is the better and transparent vehicle tax structure. The current method of vehicle ownership taxation is only known to few people, creating dissatisfaction and high uncertainty on vehicle pricing. Better transparency of tax system will support more invent on HEV and EV technology, as the whole community can better plan for their needs.

- End-of-life vehicle (ELV) management is also needed to be implemented, in particular the better information management. New bodies responsible in collection, maintaining and sharing ELV related information such as vehicle inspection authorities and vehicle registration age. This bodies will support the introduction of vehicle age limitation regulations.

- Vehicle age limit control measures can be implemented with higher frequency of vehicle inspection, tighter regulation, as well as higher charge of inspection. Current situation of voluntary inspection of RM25 (JPY625) is too low to have any effect on user's perception. Higher inspection cost on vehicles aged 12 or 10 years old can be used as offset on revenue loss from tax reduction.

- Payment of vehicle recycling fees during new vehicle purchases is also proposed. Currently vehicle owners are unexpected to send their retired vehicles for recycling as the money received is highly unattractive. However, the idea of reimbursement of paid monies have a positive impact on owner's mind set. Moreover, the availability of this fees is expected to increase number of vehicle recycling activities, giving rise to new economy previously left untapped.

- Special provisions also needed to be provided to certain quarters in order to maintain social justice to the less fortunate which relies on their vehicle as basic necessity. This group may be from rural areas, people with disabilities, or people under economic challenges such as owners with the bottom 10% income earners. Vehicle inspection is a service, which requires no intangible products thus having a very low cost. Therefore, this is method of protection is feasible. This group of people mentioned above should be given discount vouchers for vehicle inspection.

- Second provision group receiver should be owners of special vehicles such as Collectables, Classic, Vintage, and Antique cars. This kind of vehicles are a piece of history, or going to have significant historical significant. Owners of classical cars are supposed to be exempted from the regulation. However, this kind of vehicles are usually owned by wealthy individuals thus provided an income opportunity in term of extra fee. They also required to be registered to classical car association. Classical cars have lower production quality standards, posing safety and environmental risk. Mileage is also need to be limited to 5000km annual or less, usable age limit is also needed to be removed.

5.5 Conclusion

In this chapter, passenger vehicle management policies are put to test. This Chapter combined all the fragmented and smaller scope of previous chapters, which includes vehicle quantity estimates, vehicle usage characteristics, as well as vehicle manufacturing impacts.

The first part is the estimation of number of possible vehicle quantity and its type with the number of expected end-of-life vehicles, followed by GHG emissions and other environmental impact components, before proceeding to policy options and its effects.

GHG emissions is also seeing high increase in this time period. From 2016 to 2020, passenger vehicle usage and manufacturing is expected to add 54 Megaton CO_2 equivalent gases annually into the environment, and increases to 71 Megaton GHG annually in 2036 to 2040 period.

Health impact in loss of healthy year DALY is also expected to reach average of 208,000 annually in 2016-2020 before increasing to average of 295,000 in 2035-2040 period.

However, under certain policy changes, the amount of GHG emissions can be reduced 19 Megaton at extreme as compared to 72 Megaton in Baseline, or business-as-usual condition. Effect of DALY can also be reduced by up to 90% from 300,000 in Baseline situation. This high reduction is attributable from introducing a mix of policies including more stringent tailpipe emission regulation, lower average vehicle age, lower vehicle price through taxation as well as only allowing Electric Vehicles to be registered from 2030 onwards.

Looking at other impact category, the application of the extreme policy also has 88% higher chance of avoiding direct impact towards fauna, which is caused by acid rain and algae blooming in 2040. This is equally important in safeguarding vegetation as food sources.

Alas, this chapter provided a complete and comprehensive quantitative assessment of environmental impacts from multiple impact categories, covering from the common such as GHG emission, impact of vegetation and food protection, and impact on overall human health. Knowledge gained in this chapter is expected to provide additional information for policy makers to make proper policy planning in order to guarantee our sustainability on this planet.

Chapter 6. Conclusion and Future Work

The 2015 UN Climate Conference held in Paris sees Malaysia voluntarily pledge to reduce GHG emission intensity per GDP by 45% of 2005 level (UNCCC, 2015). This steep reduction, initially thought to be impossible, is nearly achieved by 2014 (European Comissions, 2015). However, comparison of actual GHG emission per capita is actually 13% higher in 2014 as compared to 2005 (The World Bank, 2016), requiring a new strategy for the environmental footprint.

Quantitative transportation environmental modeling and policy modeling and analysis for Malaysia are scarce. Kamarudin et al. (2009) constructed an optimization model to conclude minimum cost–maximum benefit for a delivery network of hydrogen fuel while Mustapa and Bekhet (2015) performed multiple regression analysis to discover the root cause of Malaysian transportation emissions. Time series study was very limited. Hosseini, Wahid and Aghili (2013) uses simple reduction of GHG by switching fuel source for energy mix, Ang (2008) used time series analysis and GDP to find out historic CO2 emissions for 1970 to 1998 time period while Safaai et al. (2011) and Azam et al. (2015) used Long-range Energy Alternatives Planning (LEAP) model for the estimation. Both study also uses extrapolation of historical data until the end of simulation year and GDP is being used to study the emission from transportation sector. Safaai et al (2011) covers Business-As-Usual scenario over the time period of 2000 until 2020, while Azam et al (2015) covers time period of 2012 to 2040 with policy scenarios involving substitution of CV with NGV, HEV and Biodiesel vehicles in certain percentage.

Compared to the abovementioned studies, this dissertation aims to improve the estimation details using System Dynamics Modeling which covers bigger aspect of the simulation. Chapter 1 reviews the transportation scene in Malaysia and its problems. Chapter 2 estimates the annual vehicle stock and flow. This chapter provides a quantification method of demand estimation for new vehicle technologies and generation of vehicle waste. Chapter 3 introduces the method of assessing GHG emissions and pollutions from vehicle usage. The result offers quantitative insight and improved accuracy of passenger vehicle emissions from transportation activity for Malaysia. Chapter 4 explores the environmental impact from vehicle manufacturing activities. It involves three main impact group: GHG generation, human health, and biodiversity to compare advantage and disadvantage for each vehicle type from environmental sustainable point of view. Chapter 5 integrated the findings of previous chapters in order to conclude the overall impact covering the vehicle lifecycle. Final conclusion from this chapter is the total lifecycle impact in term of GHG and DALY with discussion regarding policy recommendations.

6.1 Passenger Vehicle Stock & Flow Estimation

This was the first study done in an attempt to estimate future vehicle demand, and vehicle stock until the year 2040, using System Dynamic modeling method. Moreover, demand for EVs and HEVs and new vehicles in general was estimated by more realistic variables such as specific population, the ones within the allowable age to use a vehicle. This study also estimated vehicle stock not as using exponential increase, but rather a more convincing 'limit-based' growth, and included income capability and vehicle pricing as enabler for vehicle choice options. Apart from vehicle demand, this study took the advantage of estimating vehicle waste generation from End-of-Life Vehicles.

This study is expected to contribute a more detailed method of vehicle stock & flow estimation especially for middle income and developing countries. Moreover, results from this study estimation can be implemented directly into black-box model such as LEAP. As result, studies such as Safaai *et al.* (2011) and Azam *et al.* (2015) can be expanded and improved.

Model utilization reveals that high efficiency vehicles such as HEV and EV is estimated to reach 2.5 million vehicles of total existing vehicle in 2040 under MA12 policy as opposed to 1.4 million under business-as-usual policy. Moreover, new vehicle registration has the potential to reach 800,000 units in 2024 but the growth is unlikely to be sustained. This revealing issues can guide policymakers in making correct decision to avoid this inconvenience.

6.1.1 Limitation & Recommendation

This environmental impact modeling was build based on information gathered from a developing country. Although this study manages to solve some related problem it is not without limitation. The first is the transferability to other nation as the model is made specific. For an example, it is not able to be run successfully on nations with shrinking vehicle market such as Japan, nor nation with saturated vehicle market. Secondary problem is, the model does not apply the increasing wage or income of its people. The decision to omit this variable is due to the limitation on solid data which can predict income of up to 2040. The third limitation is the omission of electric vehicle price reduction. EV, as with other technological products will have price reduction when it is produced is mass quantity. However, given that it was only being re-introduced recently, acceptance on EV still vary. It is estimated that production cost of EV have the potential to be lower than current generation internal combustion engine vehicles due to fewer components and process required in production of EV(Noori, Gardner and Tatari, 2015). Moreover, newer, better and improved battery technology with higher capacity and lower weight is being introduced, while plenty of research on advanced electricity storage is still on-going. Highly efficient carbon-graphite battery which can be produced in fraction of cost and weight of Lithium Ion battery today have the high potential to revolutionize electric mobility (Zhang *et al.*, 2014). This cost-performance improvement has massive effect on future EV adoption rate.

6.2 Vehicle Usage Impact Estimation

Assessment related to the whole vehicle usage within Malaysia is presented in the third chapter. This study offers quantitative insight and improved accuracy of passenger vehicle emissions from transportation activity for Malaysia, with expansion of the previous vehicle stock & flow estimation. Input data such as population, vehicle quantity, purchasing preferences, and current policy application have been used in constructing this study's model. The methodology proposed offers a compliment problem solving method which address multiple variable, uncertainty and input use as distribution issues. Moreover, the model can be further expanded to include other vehicle classes and their emissions throughout the lifecycle. Several vehicle management policies have been estimated and tested at the national level through 2040, involving several policy combinations which involves Government, Users, and Industry (Chapter 3: Table 3.2). This analysis found that greenhouse gas emissions and pollutants in 2040 can be reduced by up to 30%, compared to emissions of 2020, without affecting the economy and vehicle demand, and a 10% reduction can be achieved if catalytic converter upgrades were performed on all vehicles.

6.2.1 Limitation & Recommendation

The prototype model developed for vehicle usage impact estimation also have several limitations. For instance, the study only simulated the emission reduction from EURO 2 to EURO 4 while the rest of developed world are shifting to EURO 6b implementation (Delphi Incorporated, 2017). At the moment, real measured effect of EURO 5 and 6 emissions standard on catalytic converter deterioration rate studies is yet to be done. Knowing the deterioration rate factor will help to analyse the emissions of NOx, CO, HC, as well as particulate matter being released to the surrounding area. This expansion of scope can also include all the NMVOC emissions generated from gasoline and diesel burning, as well as energy generation for EVs. Analysis done in this chapter also opens the door for additional expansion on targeting the potential specific areas or geographic locations with high impact on vehicle pollution. It will help with the necessary intervention plans to reduce, capture or control vehicle caused pollutions in this high risk areas. Applications such as google traffic API metadata and mapping software such as Google Maps or GIS can be used to pinpoint the exact location of high risk areas. Future research should also broaden the scope of vehicle type to include motorcycle and goods transporter. Motorcycles releases about one-quarter of CO_2 (Chan *et al.*, 1995; Vasic and Weilenmann, 2006) while goods transporter emitted up to twice the amount of CO_2 compared to passenger vehicles (Browne, Rizet and Allen, 2014; Liimatainen *et al.*, 2014).

6.3 Vehicle Production Impact Quantification

EV excel in reduction of GHG and pollutants during its usage stage, creating a biased assumption for it. An estimation was done related to vehicle production stage in an attempt to balance the assumption. A lifecycle study using Life Cycle Inventory Analysis on all vehicle within the study scope was done for this matter. LCI analysis done was based on local inventory data and power generation of Malaysia. This novel study which covers light and compact vehicle and new Lithium Ion battery chemistry added new knowledge to the growing list of existing LCI studies (Schweimer, 2000; H L Maclean and Lave, 2003; Notter *et al.*, 2010; Hawkins, Gausen and Strømman, 2012; Volkswagen AG, 2012; Dunn *et al.*, 2015; Onat, Kucukvar and Tatari, 2015; Kim *et al.*, 2016). Main output from this study is the GHG emissions, as well as total impact on human health. The study also added impact trade-offs for locally produced vehicles. This study found out that a compact conventional vehicle generates 4,166kg of CO_2 during its journey from mining until completion while EV generated about 1625kg more than that of EV based on 2017 power generation plan (Chapter 4: Figure 4.3). However, this inconvenience is being balanced by reduction in other impact indicators which creates a positive trade-off. As result, final DALY impact for EV is significantly lower against CV and HEV (Chapter 4: Figure 4.8). This result strengthens the environmental benefit of EV so that improvement of policies supporting it is further justified.

6.3.1 Limitation & Recommendation

Further limitation found during this assessment is the lack of data availability for local production materials. LCA results may have limited value in two areas: (I) local and/or transient biophysical processes and (2) issues involving biological parameters, such as biodiversity, habitat alteration, and toxicity (Owens, 1997). This problem can be settled by using a delocalised data and understanding the uncertainty of it (de Eicker *et al.*, 2010). Any model constructed is not without a certain level of uncertainty (Chatfield, 2006). At the parameter level, data inaccuracy, data gaps, and the use of unrepresentative data have been recognized as sources of uncertainty in life cycle related assessments (Bojacá and Schrevens, 2010). Characterizing the associated uncertainty, the reliability of assessment results cannot be understood or ascertained (Lo, Ma and Lo, 2005). Utilization of LCI tool such as MiLCA reduces the capability to provide proper uncertainty analysis. However, this problem can be overcome through standardization (Björklund, 2002) and representing a basic entity like the uniform distribution in just one database (ecoinvent), one LCA-program (CMLCA) and mathematical statistics (Heijungs and Huijbregts, 2004). Another proposal is by using Monte Carlo simulation and fuzzy set theory to compliment the study (Lloyd and Ries, 2007) or taxonomy approach for LCAs based on extensive research in the LCA, management, and economic literature (Herrmann *et al.*, 2014).

6.4 Integrated Passenger Vehicle Lifecycle Impact Assessment

Final analysis done in this dissertation was related to the assessment of the whole vehicle fleet impact throughout its lifecycle. Additionally, the impact of fuel production is also included which effectively reduce the environmental advantage of CV and HEV. Although common for transportation related study for developed nation, this detailed integration under the scope of Malaysia is the first of its kind. Policy makers and stakeholders have the opportunity to grasp the impact of their decisions from the sensitivity analysis provided (Chapter 5: Figure 5.4). Result in Section 5.4 reveals that the country is expected to generate 72 Million ton CO_2 and 300,000 DALYs in the future by simply not taking any action. Several policy scenario application was also introduced in this chapter. It involves the application of Optimistic Scenario which sees among others, reduction of vehicle tax to 45% from current 75% as well as better management of vehicle emissions through tighter emission regulation. Another scenario application, the Extreme involves a regulation that only allows EV to be registered starting in 2030. This extreme scenario reduces the GHG emissions which was accumulated since 2012, from 1867 Million tons to 1375 Million tons. Hopefully, results from this chapter will provide a better guideline for legislators in improving the nations regulations. Methodology provided may also guide transportation related research in other countries, specifically developing nations.

6.4.1 Limitation & Recommendation

Current integrated Lifecycle Impact Assessment avoids the consideration of vehicle recycling activities into the assessment. This is intentional since vehicle recycling activities usually results in reduction of environmental burden (Hawkins, Gausen and Strømman, 2012) yet such activities are minimal in the country. It however leads to key limitation for this study. Developed countries have been studying end-of-life vehicle waste for years, and have developed serious relative recycling technologies

(Zhang and Chen, 2014). The recycling activities for end-of-life vehicles can be divided into reuse, recycle, remanufacture, and recovery (Azmi *et al.*, 2013) and one of the most important item need to be addressed as ELVs treatment in Malaysia are being reused on road, left abandoned or being dumped illegally (Mamat, Saman and Sharif, 2013). Currently, Malaysia is also considering a development of ELC recycling framework and management (Ahmed *et al.*, 2014). An expansion of the model to include this stage of lifecycle will be suited for this reason. Apart from MiLCA, other tools can also be used for replacement on studying the impact values of end-of-lifecycle stage of a vehicle with careful attention on uncertainty studies (Heijungs and Huijbregts, 2004). Future studies can utilize ecoinvent database as ancillary inventory should the chosen tool database is limited. Second evident limitation is related to economic point of view. The proposed alternative scenarios involve a stark reduction in vehicle taxation system from the current 75% (Chapter 2: Table 2.4). It will create a significant reduction in government`s current MYR8 billion annual income (Ministry of Finance Malaysia, 2016a). Balancing this shrinkage involves out-of-the box thinking. One method is through carbon trading (Lohmann, 2006; Spash, 2010; Amran, Zainuddin and Zailani, 2013) and transferring the loss tax from vehicle sale to fuel taxation (Xu, 2007; Börjesson and Ahlgren, 2012). The latter have positive effect (Xu, 2007) which increase public awareness of fuel efficient vehicles and public transportation, reducing overall annual travel distance, and fast forwarding vehicle technology adoption.

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Appendices

Appendix 1

Table B 1 : Potential Number of Owners for passenger vehicles in Malaysia.

Year	***All population***	***Population Aged 20 to 80***
2012	29240	21052
2013	29717	21471
2014	30188	21891
2015	30651	22340
2016	31106	22741
2017	31552	23193
2018	31991	23685
2019	32426	24187
2020	32858	24670
2021	33288	25127
2022	33714	25563
2023	34136	25972
2024	34550	26359
2025	34956	26729
2026	35353	27056
2027	35741	27359
2028	36120	27649
2029	36488	27940
2030	36846	28239

Table B 1 : Potential Number of Owners for passenger vehicles in Malaysia. (continued)

Year	***All population***	***Population Aged 20 to 80***
2031	37192	28517
2032	37528	28804
2033	37852	29098
2034	38167	29393
2035	38471	29687
2036	38765	29948
2037	39049	30209
2038	39324	30471
2039	39591	30736
2040	39850	31001

Appendix 2

Table B 2 : Historical Vehicle Type Distribution, 2012.

Age	*CV*	*HEV*	*CNG*	*EV*
0	0.077996	0.637365	0.047076	0.81250
1	0.079116	0.349252	0.043708	0.18750
2	0.070314	0.013383	0.079511	
3	0.069909	0	0.046122	
4	0.061325	0	0.297095	
5	0.059987	0	0.11658	
6	0.070407	0	0.079822	
7	0.061797	0	0.085663	
8	0.055597	0	0.054513	
9	0.054661	0	0.077876	
10	0.055746	0	0	
11	0.045138	0	0.072035	
12	0.041586	0	0	
13	0.042586	0	0	
14	0.039843	0	0	
15	0.037101	0	0	

Table B 2 : Historical Vehicle Type Distribution, 2012 (continued).

Age	*CV*	*HEV*	*CNG*	*EV*
16	0.013888	0	0	
17	0.010556	0	0	
18	0.008548	0	0	
19	0.008128	0	0	
20	0.007906	0	0	
21	0.007958	0	0	
22	0.006217	0	0	
23	0.00428	0	0	
24	0.003992	0	0	
25	0.002212	0	0	
26	0.001649	0	0	
27	0.000915	0	0	
28	0.000262	0	0	
29	0.000378	0	0	

Appendix 3

Table B 3 : Planned Energy Mix. Malaysia Energy Generation Plan until 2040. Source: Malaysia Energy Statistics Handbook (Ministry of Energy Green Technology and Water, 2013).

Year	***Coal (%)***	***Gas (%)***	***Hydro (%)***	***Nuclear (%)***	***Renewables (%)***	***Import (%)***
2012	43.0	51.5	4.2	0	1.2	0
2013	43.0	51.5	4.2	0	1.2	0
2014	45.0	49.5	4.1	0	1.4	0
2015	48.1	46.3	4.0	0	1.6	0
2016	52.4	41.4	4.4	0	1.8	0
2017	52.8	40.9	4.3	0	2.0	0
2018	57.2	36.4	4.2	0	2.3	0
2019	62.2	31.3	4.1	0	2.5	0
2020	62.5	30.9	3.9	0	2.6	0
2021	61.4	32.0	4.0	0	2.6	0
2022	60.1	33.4	4.0	0	2.7	0
2023	57.2	26.2	4.1	0	2.6	9.9
2024	58.4	25.3	4.0	0	2.6	9.7
2025	49.7	24.4	4.0	9.6	2.8	9.5
2026	50.6	24.0	4.0	9.4	2.7	9.5
2027	51.3	23.6	3.9	9.3	2.7	9.3
2028	51.9	23.4	3.8	9.1	2.6	9.2
2029	52.6	23.1	3.8	9.0	2.6	9.0
2030	52.3	23.5	3.8	8.9	2.6	8.8

Table B 3 : Planned Energy Mix. Malaysia Energy Generation Plan until 2040. Source: Malaysia Energy Statistics Handbook (Ministry of Energy Green Technology and Water, 2013) (continued).

Year	***Coal (%)***	***Gas (%)***	***Hydro (%)***	***Nuclear (%)***	***Renewables (%)***	***Import (%)***
2031	52.9	23.6	3.7	8.7	2.5	8.6
2032	54.0	22.7	3.6	8.7	2.5	8.5
2033	54.0	22.7	3.6	8.7	2.5	8.5
2034	54.0	22.7	3.6	8.7	2.5	8.5
2035	54.0	22.7	3.6	8.7	2.5	8.5
2036	54.0	22.7	3.6	8.7	2.5	8.5
2037	54.0	22.7	3.6	8.7	2.5	8.5
2038	54.0	22.7	3.6	8.7	2.5	8.5
2039	54.0	22.7	3.6	8.7	2.5	8.5
2040	54.0	22.7	3.6	8.7	2.5	8.5

Starting in 2023, energy will be imported from Bakun hydroelectric project. Therefore, we calculate its impact using hydroelectric energy production.

Appendix 4

Table B 4 : Factorized Impacts from Vehicle Production based on 2017 power generation.

GWP (GHG, kg CO_2 equivalent)	***Factorization***	***CV***	***HEV-NiMH***	***HEV - NMC***	***EV***
Carbon Dioxide (Biogenic)	0	0	0	0	0
Carbon Dioxide (Fossil)	1	3994	4608	4402	5609
Methane	21	44	56	48	76
Methane (Fossil)	21	0	0	0	0
Nitrous Oxide	310	38	50	44	97
Tetrafluoromethane	6500	94	106	107	24
Sulfur Hexafluoride	23900	0	0	0	0
Total GWP		4170	4820	4601	5806
ACIDIFICATION (kg SO_2 Equivalent)		**CV**	**HEV-NiMH**	**HEV - NMC**	**EV**
Ammonia	5.99	0.02	0.02	0.02	0.01
Hydrogen Chloride	2.61	0.00	0.00	0.00	0.00
Nitrogen Dioxide	0.72	0.00	0.00	0.00	0.01
Nitrogen Oxides	0.72	2.99	3.74	3.38	2.05
Sulfur Dioxide	1.00	0.83	0.88	0.88	1.28
Sulfur Oxides	1.00	8.11	18.42	9.23	2.43
Total Acidification		11.95	23.06	13.52	5.77
EUTROPHICATION (kg Phosphorus Eq.)		**ICEV**	**HEV-NiMH**	**HEV - NMC**	**EV**
Ammonia	0.09	0.00	0.00	0.00	0.00
Ammonium	0.20	0.00	0.00	0.00	0.00
Chemical Oxygen Demand	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.01	0.21	0.78	0.21	0.11
Phosphorus	1.00	0.00	0.00	0.00	0.00
Total Eutrophication		0.21	0.78	0.22	0.11

Table B 4 : Factorized Impacts from Vehicle Production based on 2017 power generation (continued)

CARCINOGEN (kg Benzene Eq.)	**Factorization**	**ICEV**	**HEV-NiMH**	**HEV - NMC**	**EV**
Cadmium - Air	3764	0.00	0.01	0.00	0.01
Cadmium - Water	7500	0.00	0.00	0.00	0.00
Nickel - Air	84	0.01	0.01	0.01	0.01
Nickel - Water	182	0.03	0.03	0.03	0.01
Nickel Compounds - Water	8114	0.05	0.29	0.15	0.38
PCDDs	185555963	0.22	0.73	0.43	0.85
Total Carcinogen		0.30	1.06	0.62	1.27

Appendix 5

Table B 5 : Estimated Annual Greenhouse Gas generation from Personal Vehicle Fleet, CO_2 equivalent, in kilotons.

Year	*Vehicle Production*	*Fuel Production*	*Fuel Combustion & Electric Production*	*Total*
2012	2.64E+03	6.50E+03	3.93E+04	4.85E+04
2013	2.71E+03	6.75E+03	4.09E+04	5.04E+04
2014	2.79E+03	7.01E+03	4.25E+04	5.23E+04
2015	2.86E+03	7.26E+03	4.41E+04	5.43E+04
2016	2.92E+03	7.51E+03	4.57E+04	5.62E+04
2017	2.95E+03	7.75E+03	4.73E+04	5.80E+04
2018	2.95E+03	7.98E+03	4.87E+04	5.97E+04
2019	2.92E+03	8.18E+03	5.01E+04	6.12E+04
2020	2.87E+03	8.35E+03	5.13E+04	6.25E+04
2016-2020	**1.46E+04**	**3.98E+04**	**2.43E+05**	**2.97E+05**
2021	2.81E+03	8.50E+03	5.24E+04	6.37E+04
2022	2.76E+03	8.62E+03	5.33E+04	6.47E+04
2023	2.72E+03	8.72E+03	5.41E+04	6.56E+04
2024	2.69E+03	8.80E+03	5.48E+04	6.63E+04
2025	2.68E+03	8.86E+03	5.54E+04	6.70E+04
2021-2025	**1.37E+04**	**4.35E+04**	**2.70E+05**	**3.27E+05**
2026	2.68E+03	8.91E+03	5.59E+04	6.75E+04
2027	2.69E+03	8.95E+03	5.63E+04	6.79E+04
2028	2.71E+03	8.98E+03	5.66E+04	6.83E+04
2029	2.73E+03	9.01E+03	5.70E+04	6.87E+04
2030	2.76E+03	9.03E+03	5.72E+04	6.90E+04
2026-2030	**1.36E+04**	**4.49E+04**	**2.83E+05**	**3.42E+05**

Table B 5 : Estimated Annual Greenhouse Gas generation from Personal Vehicle Fleet, CO_2 equivalent, in kilotons.

Year	***Vehicle Production***	***Fuel Production***	***Fuel Combustion & Electric Production***	***Total***
2031	2.79E+03	9.05E+03	5.75E+04	6.93E+04
2032	2.83E+03	9.06E+03	5.77E+04	6.96E+04
2033	2.86E+03	9.08E+03	5.79E+04	6.99E+04
2034	2.90E+03	9.10E+03	5.81E+04	7.01E+04
2035	2.94E+03	9.12E+03	5.83E+04	7.04E+04
2031-2035	**1.43E+04**	**4.54E+04**	**2.90E+05**	**3.49E+05**
2036	2.98E+03	9.14E+03	5.85E+04	7.06E+04
2037	3.01E+03	9.17E+03	5.87E+04	7.09E+04
2038	3.04E+03	9.21E+03	5.89E+04	7.12E+04
2039	3.07E+03	9.25E+03	5.91E+04	7.14E+04
2040	3.09E+03	9.29E+03	5.93E+04	7.17E+04
2036-2040	**1.52E+04**	**4.61E+04**	**2.95E+05**	**3.56E+05**

Appendix 6

Table B 6 : Estimated Annual Acidification Potential from Passenger Vehicle Fleet, SO_2 equivalent, in kilotons.

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage Acidification***	***Total***
2012	7.57E+00	7.92E+00	1.42E-05	5.29E+03	5.30E+03
2013	7.79E+00	8.23E+00	3.68E-05	5.52E+03	5.54E+03
2014	8.00E+00	8.54E+00	6.60E-05	5.78E+03	5.80E+03
2015	8.20E+00	8.85E+00	1.04E-04	6.03E+03	6.05E+03
2016	8.37E+00	9.16E+00	1.51E-04	6.28E+03	6.30E+03
2017	8.48E+00	9.45E+00	2.10E-04	6.54E+03	6.56E+03
2018	8.48E+00	9.72E+00	2.84E-04	6.79E+03	6.81E+03
2019	8.39E+00	9.97E+00	3.73E-04	7.05E+03	7.07E+03
2020	8.23E+00	1.02E+01	4.78E-04	7.30E+03	7.32E+03
2016-2020	**4.20E+01**	**4.85E+01**	**1.50E-03**	**3.40E+04**	**3.40E+04**
2021	8.07E+00	1.04E+01	6.03E-04	7.54E+03	7.56E+03
2022	7.92E+00	1.05E+01	7.52E-04	7.78E+03	7.80E+03
2023	7.81E+00	1.06E+01	9.27E-04	8.01E+03	8.03E+03
2024	7.74E+00	1.07E+01	1.13E-03	8.23E+03	8.25E+03
2025	7.71E+00	1.08E+01	1.38E-03	8.43E+03	8.45E+03
2021-2025	**3.92E+01**	**5.30E+01**	**4.80E-03**	**4.00E+04**	**4.01E+04**
2026	7.71E+00	1.09E+01	1.67E-03	8.62E+03	8.63E+03
2027	7.74E+00	1.09E+01	2.02E-03	8.75E+03	8.77E+03
2028	7.79E+00	1.10E+01	2.42E-03	8.89E+03	8.91E+03
2029	7.85E+00	1.10E+01	2.91E-03	9.03E+03	9.05E+03
2030	7.93E+00	1.10E+01	3.48E-03	9.17E+03	9.19E+03
2026-2030	**3.90E+01**	**5.47E+01**	**1.25E-02**	**4.45E+04**	**4.46E+04**

Table B 6 : Estimated Annual Acidification Potential from Passenger Vehicle Fleet, SO_2 equivalent, in kilotons (continued).

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage Acidification***	***Total***
2031	8.02E+00	1.10E+01	4.15E-03	9.30E+03	9.32E+03
2032	8.12E+00	1.10E+01	4.94E-03	9.40E+03	9.42E+03
2033	8.21E+00	1.11E+01	5.87E-03	9.50E+03	9.52E+03
2034	8.32E+00	1.11E+01	6.95E-03	9.58E+03	9.60E+03
2035	8.42E+00	1.11E+01	8.22E-03	9.65E+03	9.67E+03
2031-2035	**4.11E+01**	**5.53E+01**	**3.01E-02**	**4.74E+04**	**4.75E+04**
2036	8.53E+00	1.11E+01	9.68E-03	9.69E+03	9.71E+03
2037	8.62E+00	1.12E+01	1.14E-02	9.73E+03	9.75E+03
2038	8.71E+00	1.12E+01	1.33E-02	9.76E+03	9.78E+03
2039	8.78E+00	1.13E+01	1.56E-02	9.77E+03	9.79E+03
2040	8.84E+00	1.13E+01	1.81E-02	9.77E+03	9.79E+03
2036-2040	**4.35E+01**	**5.61E+01**	**6.80E-02**	**4.87E+04**	**4.88E+04**

Appendix 7

Table B 7 : Estimated Annual Eutrophication Potential from Passenger Vehicle Fleet, Phosphate equivalent, in kilotons.

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage***	***Total***
2012	1.33E-01	4.92E-07	1.69E-09	8.08E+01	8.09E+01
2013	1.37E-01	5.11E-07	4.37E-09	8.44E+01	8.45E+01
2014	1.40E-01	5.30E-07	7.85E-09	8.83E+01	8.85E+01
2015	1.44E-01	5.49E-07	1.23E-08	9.21E+01	9.23E+01
2016	1.47E-01	5.68E-07	1.80E-08	9.59E+01	9.61E+01
2017	1.49E-01	5.86E-07	2.50E-08	9.99E+01	1.00E+02
2018	1.49E-01	6.03E-07	3.38E-08	1.04E+02	1.04E+02
2019	1.47E-01	6.19E-07	4.43E-08	1.08E+02	1.08E+02
2020	1.44E-01	6.32E-07	5.69E-08	1.12E+02	1.12E+02
2016-2020	**7.35E-01**	**3.01E-06**	**1.78E-07**	**5.19E+02**	**5.20E+02**
2021	1.41E-01	6.43E-07	7.18E-08	1.15E+02	1.15E+02
2022	1.39E-01	6.52E-07	8.94E-08	1.19E+02	1.19E+02
2023	1.36E-01	6.60E-07	1.10E-07	1.22E+02	1.22E+02
2024	1.35E-01	6.66E-07	1.35E-07	1.26E+02	1.26E+02
2025	1.35E-01	6.71E-07	1.64E-07	1.29E+02	1.29E+02
2021-2025	**6.86E-01**	**3.29E-06**	**5.70E-07**	**6.11E+02**	**6.12E+02**
2026	1.35E-01	6.74E-07	1.99E-07	1.32E+02	1.32E+02
2027	1.35E-01	6.77E-07	2.40E-07	1.34E+02	1.34E+02
2028	1.36E-01	6.80E-07	2.88E-07	1.36E+02	1.36E+02
2029	1.37E-01	6.82E-07	3.46E-07	1.38E+02	1.38E+02
2030	1.38E-01	6.83E-07	4.14E-07	1.40E+02	1.40E+02
2026-2030	**6.80E-01**	**3.40E-06**	**1.49E-06**	**6.79E+02**	**6.80E+02**

Table B 7 : Estimated Annual Eutrophication Potential from Passenger Vehicle Fleet, Phosphate equivalent, in kilotons (continued).

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage***	***Total***
2031	1.40E-01	6.84E-07	4.94E-07	1.42E+02	1.42E+02
2032	1.41E-01	6.86E-07	5.88E-07	1.44E+02	1.44E+02
2033	1.43E-01	6.87E-07	6.98E-07	1.45E+02	1.45E+02
2034	1.45E-01	6.88E-07	8.27E-07	1.46E+02	1.47E+02
2035	1.47E-01	6.90E-07	9.77E-07	1.47E+02	1.48E+02
2031-2035	**7.15E-01**	**3.43E-06**	**3.58E-06**	**7.25E+02**	**7.25E+02**
2036	1.48E-01	6.92E-07	1.15E-06	1.48E+02	1.48E+02
2037	1.50E-01	6.94E-07	1.35E-06	1.49E+02	1.49E+02
2038	1.51E-01	6.97E-07	1.58E-06	1.49E+02	1.49E+02
2039	1.53E-01	7.00E-07	1.85E-06	1.49E+02	1.49E+02
2040	1.54E-01	7.03E-07	2.15E-06	1.49E+02	1.49E+02
2036-2040	**7.56E-01**	**3.48E-06**	**8.09E-06**	**7.44E+02**	**7.45E+02**

Appendix 8

Table B 8 : Estimated Annual Carcinogenic Potential from Passenger Vehicle Fleet, Benzene equivalent, in kilotons.

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage***	***Total***
2012	1.91E-01	2.31E-05	2.94E-07	1.84E+02	1.84E+02
2013	1.97E-01	2.40E-05	7.60E-07	1.91E+02	1.92E+02
2014	2.03E-01	2.49E-05	1.37E-06	1.98E+02	1.99E+02
2015	2.09E-01	2.58E-05	2.14E-06	2.06E+02	2.06E+02
2016	2.14E-01	2.67E-05	3.13E-06	2.12E+02	2.13E+02
2017	2.18E-01	2.75E-05	4.35E-06	2.19E+02	2.19E+02
2018	2.20E-01	2.83E-05	5.87E-06	2.25E+02	2.25E+02
2019	2.19E-01	2.90E-05	7.71E-06	2.30E+02	2.30E+02
2020	2.16E-01	2.96E-05	9.89E-06	2.34E+02	2.35E+02
2016-2020	**1.09E+00**	**1.41E-04**	**3.10E-05**	**1.12E+03**	**1.12E+03**
2021	2.13E-01	3.02E-05	1.25E-05	2.38E+02	2.38E+02
2022	2.11E-01	3.06E-05	1.55E-05	2.41E+02	2.41E+02
2023	2.09E-01	3.10E-05	1.92E-05	2.43E+02	2.43E+02
2024	2.08E-01	3.12E-05	2.35E-05	2.45E+02	2.45E+02
2025	2.09E-01	3.15E-05	2.85E-05	2.46E+02	2.46E+02
2021-2025	**1.05E+00**	**1.54E-04**	**9.92E-05**	**1.21E+03**	**1.21E+03**
2026	2.10E-01	3.16E-05	3.45E-05	2.46E+02	2.46E+02
2027	2.12E-01	3.18E-05	4.17E-05	2.46E+02	2.46E+02
2028	2.14E-01	3.19E-05	5.01E-05	2.46E+02	2.46E+02
2029	2.17E-01	3.20E-05	6.01E-05	2.46E+02	2.46E+02
2030	2.20E-01	3.20E-05	7.19E-05	2.46E+02	2.46E+02
2026-2030	**1.07E+00**	**1.59E-04**	**2.58E-04**	**1.23E+03**	**1.23E+03**

Table B 8 : Estimated Annual Carcinogenic Potential from Passenger Vehicle Fleet, Benzene equivalent, in kilotons (continued).

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage***	***Total***
2031	2.24E-01	3.21E-05	8.58E-05	2.45E+02	2.45E+02
2032	2.27E-01	3.22E-05	1.02E-04	2.45E+02	2.45E+02
2033	2.31E-01	3.22E-05	1.21E-04	2.44E+02	2.44E+02
2034	2.35E-01	3.23E-05	1.44E-04	2.44E+02	2.44E+02
2035	2.39E-01	3.24E-05	1.70E-04	2.43E+02	2.43E+02
2031-2035	**1.16E+00**	**1.61E-04**	**6.23E-04**	**1.22E+03**	**1.22E+03**
2036	2.43E-01	3.25E-05	2.00E-04	2.43E+02	2.43E+02
2037	2.46E-01	3.26E-05	2.35E-04	2.43E+02	2.43E+02
2038	2.50E-01	3.27E-05	2.76E-04	2.43E+02	2.43E+02
2039	2.53E-01	3.28E-05	3.22E-04	2.43E+02	2.43E+02
2040	2.56E-01	3.30E-05	3.74E-04	2.43E+02	2.44E+02
2036-2040	**1.25E+00**	**1.63E-04**	**1.41E-03**	**1.22E+03**	**1.22E+03**

Appendix 9

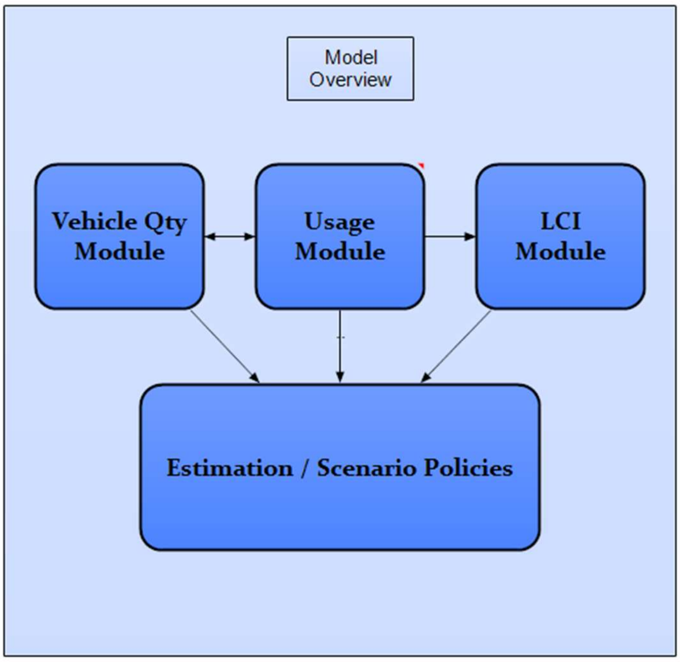
Table B 9 : Estimated Disability-Adjusted Life Year (DALY) from Passenger Vehicle Fleet, 2012 – 2040.

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage***	***Total***
2012	1.20E+03	1.54E+03	5.06E-03	1.60E+05	1.63E+05
2013	1.24E+03	1.60E+03	1.31E-02	1.67E+05	1.70E+05
2014	1.27E+03	1.66E+03	2.35E-02	1.75E+05	1.78E+05
2015	1.30E+03	1.72E+03	3.69E-02	1.82E+05	1.85E+05
2016	1.33E+03	1.78E+03	5.39E-02	1.90E+05	1.93E+05
2017	1.35E+03	1.84E+03	7.49E-02	1.98E+05	2.01E+05
2018	1.35E+03	1.89E+03	1.01E-01	2.05E+05	2.08E+05
2019	1.34E+03	1.94E+03	1.33E-01	2.13E+05	2.16E+05
2020	1.31E+03	1.98E+03	1.70E-01	2.20E+05	2.23E+05
2016-2020	**6.68E+03**	**9.44E+03**	**5.33E-01**	**1.03E+06**	**1.04E+06**
2021	1.29E+03	2.02E+03	2.15E-01	2.27E+05	2.31E+05
2022	1.26E+03	2.05E+03	2.68E-01	2.34E+05	2.38E+05
2023	1.24E+03	2.07E+03	3.30E-01	2.41E+05	2.45E+05
2024	1.23E+03	2.09E+03	4.04E-01	2.48E+05	2.51E+05
2025	1.23E+03	2.10E+03	4.91E-01	2.54E+05	2.57E+05
2021-2025	**6.25E+03**	**1.03E+04**	**1.71E+00**	**1.20E+06**	**1.22E+06**
2026	1.23E+03	2.12E+03	5.95E-01	2.59E+05	2.62E+05
2027	1.23E+03	2.12E+03	7.17E-01	2.63E+05	2.67E+05
2028	1.24E+03	2.13E+03	8.63E-01	2.67E+05	2.71E+05
2029	1.25E+03	2.14E+03	1.03E+00	2.71E+05	2.75E+05
2030	1.27E+03	2.14E+03	1.24E+00	2.75E+05	2.79E+05
2026-2030	**6.22E+03**	**1.07E+04**	**4.45E+00**	**1.34E+06**	**1.35E+06**

Table B 9 : Estimated Disability-Adjusted Life Year (DALY) from Passenger Vehicle Fleet, 2012 – 2040 (continued).

Year	***Vehicle Production***	***Fuel Production***	***Electricity Production***	***Usage***	***Total***
2031	1.28E+03	2.15E+03	1.48E+00	2.79E+05	2.83E+05
2032	1.30E+03	2.15E+03	1.76E+00	2.82E+05	2.86E+05
2033	1.31E+03	2.15E+03	2.09E+00	2.85E+05	2.88E+05
2034	1.33E+03	2.16E+03	2.48E+00	2.87E+05	2.91E+05
2035	1.34E+03	2.16E+03	2.93E+00	2.89E+05	2.93E+05
2031-2035	**6.56E+03**	**1.08E+04**	**1.07E+01**	**1.42E+06**	**1.44E+06**
2036	1.36E+03	2.17E+03	3.45E+00	2.91E+05	2.94E+05
2037	1.38E+03	2.18E+03	4.05E+00	2.92E+05	2.95E+05
2038	1.39E+03	2.19E+03	4.74E+00	2.93E+05	2.96E+05
2039	1.40E+03	2.19E+03	5.54E+00	2.93E+05	2.97E+05
2040	1.41E+03	2.20E+03	6.45E+00	2.93E+05	2.97E+05
2036-2040	**6.95E+03**	**1.09E+04**	**2.42E+01**	**1.46E+06**	**1.48E+06**

Appendix 10 Environmental Burden of Personal Vehicle Fleet in Malaysia Analytica Model



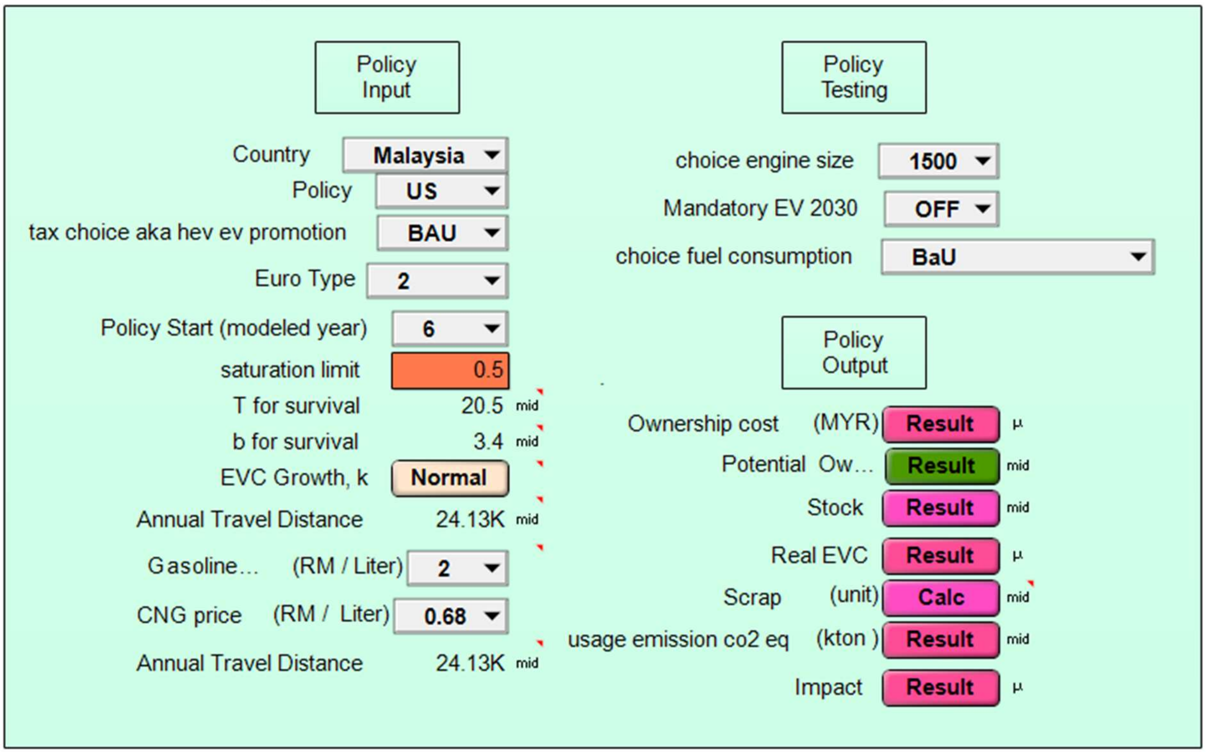


Figure B 1 Model Overview and Policy Change Control Panel

Table B 10 : Variable name and input expressions used throughout the model.

Module Name	Variable Name	Input Expression
Vehicle Qty Module	Real BAU	Table(Vehicle_type)(0 ,coefficient_HEV_choi ,coefficient_CNG ,coefficient_EV_choic)
Vehicle Qty Module	Country	Choice(Self,1)
Potential Ownership	Max Potential EVC - Type	potential_ownership*Sum(EVC,Vehicle_type)
Potential Ownership	Secondary Time	Sequence(1,40,1)
Potential Ownership	Coefficient EV Choice	Ev_estimate /Sum(Max_potential_EVC___,Vehicle_type)
Potential Ownership	Ev Estimate	(EVadaptationdataEV*Max_potential_EVC___[Vehicle_type='EV'])*100
Potential Ownership	Coefficient HEV Choice	HEV_estimate /Sum(Max_potential_EVC___,Vehicle_type)
Potential Ownership	HEV Estimate	Market_penetration*Max_potential_EVC___[Vehicle_type='HEV']
Potential Ownership	Coefficient CNG	CNG_estimate /Sum(Max_potential_EVC___,Vehicle_type)
Potential Ownership	CNG Estimate	0.005*Sum(Max_potential_EVC___,Vehicle_type)
Potential Ownership	Market Penetration	(a_limit3*Exp(-b_faktor_b3*(Exp(-c_faktor_c3*Time))))
Potential Ownership	Realhevdata 3	LinearInterp(Market_penetration,time_s_curve,22.4,time_s_curve)
Potential Ownership	A Limit	1
Potential Ownership	B Faktor B	4
Potential Ownership	C Faktor C	0.147

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
EV	Evadaptation dataev	(a_limit2*Exp(-b_faktor_b2*(Exp(-c_faktor_c2*Time))))
EV	A Limit	1
EV	B Faktor B	10.7
EV	C Faktor C	0.023
EV	Va7	EVadaptationdataEV*Max_potential_EVC___[Vehicle_type='EV']
Car price & income variable	Tax Choice Aka Hev Ev Promotion	Choice(Self,2,False)
Car price & income variable	Final Car Price (Local Car)	Table(Vehicle_type)(80K,90K,85K,180K)
Car price & income variable	Final Car Price (Local Car)	Table(Vehicle_type)(35K,90K,50K,180K)
Car price & income variable	Nilai Cukai	Table(Vehicle_type)(0.75,0.75,0.75,0.75)
Car price & income variable	Harga Tanpa Cukai (Normal)	Final_Car_Price2/(nilai_cukai+1)
Car price & income variable	Harga Tanpa Cukai (Harga Minimum)	Final_Car_Price3/(nilai_cukai+1)
Car price & income variable	Initial Car Price	harga_tanpa_cukai

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Car price & income variable	Minimum Car Price	harga_tanpa_cukai1
Car price & income variable	Nota:Distribusi Harga	0.476
Car price & income variable	Final Car Price	(Initial_Car_Price+(Initial_Car_Price*Tax)-Subsidy)
Car price & income variable	Final Car Price (Min)	Minimum_Car_Price+(Minimum_Car_Price*Tax)-Subsidy
Car price & income variable	Ansuran Annual	Final_Car_Price/(Expected_car_age_usa)
Car price & income variable	Ansuran Annual (Minimum)	Final_Car_Pricemin/(Expected_car_age_usa)
Car price & income variable	Ansuran Annual Compare	[ansuran_annual_min,ansuran_annual]
Car price & income variable	Monthly Payment	Ansuran_annual_compa/12
Car price & income variable	Final Car Price (Compare)	[Final_Car_Price,Final_Car_Pricemin]/Expected_car_age_usa
Car price & income variable	Habis Hutang	Final_car_price1/A20__of_income

Car price & income variable	Annual Travel Distance	Normal(24129, 3001)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Car price & income variable	Electricity Cost	(Annual_Travel_Dist/12*EV_Power_req/1000)*0.25667
Car price & income variable	EV E-Consumption	Electricity_cost*12
Car price & income variable	Target Engine Size	Choice(Vehicle_CC,11)
Car price & income variable	Fuel Consumption	Table(Vehicle_type)(fc[Vehicle_type='CV',Vehicle_CC=Target_engine_size] , fc[Vehicle_type='HEV',Vehicle_CC=Target_engine_size] ,fc[Vehicle_type='CNG',Vehicle_CC=Target_engine_size] ,0)
Car price & income variable	Fuel Consumption (Myr)	Table(Vehicle_type)(Fuel_consumption1*Gasoline_Price2 , Fuel_consumption1*Gasoline_Price2 , Fuel_consumption1*CNG_price ,0)
Car price & income variable	Annual Fuel Cost	Table(Vehicle_type)((Annual_Travel_Dist*Fuel_Consumption2[Vehicle_type='CV']) ,(Annual_Travel_Dist*Fuel_Consumption2[Vehicle_type='HEV']) ,(Annual_Travel_Dist*Fuel_Consumption2[Vehicle_type='CNG']) ,EV_e_consumption)
Car price & income variable	Lifetime Fuel Cost	Annual_Fuel_Cost*Expected_car_age_usa
Car price & income variable	Ownership Cost	(Final_Car_Pricemin + Lifetime_fuel_cost)/Expected_car_age_usa
Car price & income variable	Expected Car Age Usage	Sequence(1, 18, 1)

Car price & income variable	20% Of Income	Income_per_person*.2

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	**Variable Name**	**Input Expression**
Car price & income variable	Va6	if A20__of_income >= 38000 then 1 else 0
Car price & income variable	Kemampuan	A20__of_income/Ansuran_annual_compa
Car price & income variable	15% Of Income (Month)	Income_per_person/12*0.15
Car price & income variable	Household Income (Household)	LogNormal(median:5000, mean:6141)
Car price & income variable	Household Income (Annual)	Household_income1*12
Car price & income variable	Income Per Person	Household_income/2
Car price & income variable	Prices At Max Loan 9 Years	ansuran_annual_min[Expected_car_age_usa=9]
Car price & income variable	Income Per Person Month	Household_income1/2
Car price & income variable	Affordability Ratio	if A20__of_income >= prices_at_max_loan_9 then 1 else 0

Car price & income variable	Coefficient Affordability	Sum(affordability_ratio,Vehicle_type)
Car price & income variable	Potential Ownership	Mean(affordability_ratio)/ Mean(coefficient_affordab)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Tax Module	Bau Tax	Table(Vehicle_type)(0.75,0.75,0.75,0.75)
Tax Module	Ma14 Tax	Table(Vehicle_type)(0.5,0.45,0.5,0.4)
Tax Module	Ma12 Tax	table(Vehicle_type)(0.3,0.15,0.3,0.15)
Tax Module	Tax	if tax_choice_aka_hev_e= 'BAU' then Bau_tax else if tax_choice_aka_hev_e='MA14' then MA14_Tax else if tax_choice_aka_hev_e='MA12' then MA12_Tax else 900M
Subsidi module	Bau Subsidi	Table(Vehicle_type)(0,0,0,0)
Subsidi module	Ma14 Subsidi	Table(Vehicle_type)(0,0,0,0)
Subsidi module	Ma12 Tax	table(Vehicle_type)(0,0,0,5000)
Subsidi module	Subsidy	if tax_choice_aka_hev_e= 'BAU' then Bau_subsidi else if tax_choice_aka_hev_e='MA14' then MA14_Subsidi else if tax_choice_aka_hev_e='MA12' then MA12_Tax1 else 900M
Gasoline Price	Gas Price Bau	2
Gasoline Price	Gasoline Price	if Time < Policy_Start then Gas_Price_BaU else Gasoline_Price
Gasoline Price	Gasoline Price	[1.5,1.6,1.7,1.8,1.9,2,2.1,2.2,2.3,2.4,2.5,2.6,2.7,2.8,2.9,3,3.1,3.2,3.3,3.4,3.5,3.6, 3.7,3.8,3.9,4,4.1,4.2,4.3,4.4,4.5,4.6,4.7,4.8,4.9,5,5.1,5.2,5.3,5.4,5.5]

Gasoline Price	Gasoline Price	Choice(Gasoline_Price1,26,False)
CNG Price	CNG_Price_Bau	0.68
CNG Price	CNG Price	if Time < Policy_Start then CNG_price_bauelse CNG_price

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
CNG Price	CNG Price Index	[0.6800000000000001,0.8,0.9,1]
CNG Price	CNG Price	Choice(CNG_price_index,1,False)
commitment elasticity	Elas Pump Price	Elasticity(Monthly_commitment,Gasoline_Price)
commitment elasticity	Elas Expected Car Age Use	Elasticity(Monthly_commitment,Expected_car_age_usa)
commitment elasticity	Elas Engine Size	Elasticity(Monthly_commitment,Target_engine_size)
commitment elasticity	Elas Tax	Elasticity(Monthly_commitment ,nilai_cukai)
commitment elasticity	Elasticity	[elas_pump_price,elas_expected_car_ag,elas_engine_size,elas_tax]
price sensitivity - tornado	Vars - Price	[Target_engine_size,Gasoline_Price,Expected_car_age_usa,nilai_cukai]
price sensitivity - tornado	Level - Price	Table(Level)(0.9,1.1)
price sensitivity - tornado	Tornado Price	WhatIfAll(Monthly_commitment,vars___price,vars___price*level___price)

Population Database	Age	Sequence(0, 100, 5)
Template	Population	Table(Time)(0,29.239927K,29.716965K,30.187896K,30.651176K,31.105696K,31.551772K,31.991028K,32.425925K,32.858107K,33.287893K,33.714225K,34.135677K,34.550221K,34.95625K,35.353308K,35.741379K,36.119823K,36.488019K,36.845517K,37.192055K,37.527608K,37.85233K,38.166537K,38.470577K,38.764546K,39.048702K,39.323785K,39.590729K,39.850315K)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Template	Potential Owner	Pop_xxx*Age_xxx*1000
Template	Age 20-69	Table(Time)(0,0.635634453,0.641778223,0.647950655,0.654395251,0.6584646750000001,0.663146526,0.668073999,0.672714842,0.676902994,0.680667292,0.684092279,0.687217863,0.690149363,0.69289941,0.694625295,0.696074597,0.697504027,0.699199565,0.701350479,0.703082392,0.7052819890000001,0.707933726,0.710928503,0.714165842,0.716729225,0.719541382,0.722574645,0.725766025,0.729061339)
Malaysia	Population	Table(Time)(29.239927K ,29.716965K ,30.187896K ,30.651176K ,31.105696K ,31.551772K ,31.991028K ,32.425925K ,32.858107K ,33.287893K ,33.714225K ,34.135677K ,34.550221K ,34.95625K ,35.353308K ,35.741379K ,36.119823K ,36.488019K ,36.845517K ,37.192055K ,37.527608K ,37.85233K ,38.166537K ,38.470577K ,38.764546K ,39.048702K ,39.323785K ,39.590729K ,39.850315K, 40K)*1000
Malaysia	Potential Owner Mal	Pop_Mal*Age_20_80
Malaysia	Age 20-80	Table(Time)(0.635634453,0.641778223,0.647950655,0.654395251,0.6584646750000001,0.663146526,0.668073999,0.672714842,0.676902994,0.680667292,0.684092279,0.687217863,0.690149363,0.69289941,0.694625295,0.696074597,0.697504027,0.699199565,0.701350479,0.703082392,0.7052819890000001,0.707933726,0.710928503,0.714165842,0.716729225,0.719541382,0.722574645,0.725766025,0.729061339,0.7331)
Indonesia	Population	Table(Time)(246.864191K,249.865631K,252.812245K,255.708785K,258.552717K,261.340778K,264.076812K,266.766347K,269.413457K,272.018268K,274.57959K,277.098431K,279.575728K,282.011425K,284.405219K,286.754715K,289.054927K,291.299361K,293.48246K,295.601865K,297.655821K,299.6401

		04K,301.550166K,303.382406K,305.13469K,306.806161K,308.396322K,309.905375K,311.333675K)*1000
Indonesia	Potential Owner Ind	Pop_Indo*Age_Indo

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Indonesia	Age 20-69	Table(Time)(0,0.617305035,0.620781367,0.6246426390000001,0.628588654,0.633102053,0.637161836,0.641088435,0.645370707,0.650195773,0.653954855,0.6583278930000001,0.663168728,0.668200868,0.673305147,0.678025909,0.682845762,0.687596278,0.692123815,0.696326479,0.699409376,0.7021352320000001,0.7046218050000001,0.707042738,0.709528426,0.711317078,0.713147951,0.715050016,0.717021652,0.719072429)
Thailand	Population	Table(Time)(66.785001K ,67.010502K ,67.222972K ,67.400746K ,67.540824K ,67.651959K ,67.7378K ,67.804876K ,67.857997K ,67.897365K ,67.921043K ,67.929311K ,67.922252K ,67.899866K ,67.862376K ,67.809757K ,67.741394K ,67.656412K ,67.554088K ,67.434265K ,67.29686K ,67.141331K ,66.967057K ,66.773603K ,66.560888K ,66.329031K ,66.078106K ,65.80828K ,65.519821K)*1000
Thailand	Potential Owner Tha	Pop_Thai*Age_Indo1
Thailand	Age 20-69	Table(Time)(0,0.738308441,0.742780811,0.747069573,0.751210217,0.7553296510000001,0.759248021,0.76298501,0.76657341,0.770064138,0.773432872,0.776660143,0.779747008,0.782711209,0.785564643,0.788134931,0.790528478,0.7926636110000001,0.794504385,0.796083814,0.797296374,0.798222176,0.798851828,0.799174331,0.799208034,0.798789914,0.798144089,0.797317011,0.796349654,0.795297457)
Japan	Population	Table(Time)(127.249704K,127.143577K,126.999808K,126.818019K,126.598396K,126.342324K,126.052189K,125.731101K,125.381724K,125.005586K,124.603623K,124.177237K,123.727745K,123.256495K,122.764877K,122.254372K,121.726497K,121.182799K,120.624738K,120.053759K,119.471099K,118.877759K,118.274604K,117.662624K,117.042963K,116.417018K,115.786332K,115.152567K,114.517258K)/1000
Japan	Potential Owner Jap	Pop_Jap*Age_Jap
Japan	Age 20-69	Table(Time)(0,0.787859546,0.786540983,0.785306935,0.784291174,0.782675374,0.781379421,0.780327623,0.779416089,0.778575225,0.777320959,0.775998231,0.774652572,0.773384999,0.772213537,0.770308091,0.76851618,0.766743062,0.764806646,0.762596127,0.759571835,0.756422664,0.7533581620000001,0.750668893,0.74849654,0.746423687,0.744772401,0.743407063,0.742368062000001,0.741768145)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Vietnam	Population	Table(Time)(90.796K,91.68K,92.548K,93.387K,94.191K,94.962K,95.697K,96.395K,97.057K,97.68K,98.264K,98.812K,99.326K,99.811K,100.267K,100.695K,101.096K,101.474K,101.83K,102.166K,102.481K,102.775K,103.046K,103.293K,103.516K,103.715K,103.889K,104.036K,104.155K)/1000
Vietnam	Potential Owner Vie	Pop_viet*Age_viet
Vietnam	Age 20-69	Table(Time)(0,0.6716,0.6797,0.6866,0.6922,0.6967,0.6995,0.7015,0.7035,0.7061,0.7086,0.7115,0.7149,0.7187,0.7227,0.7268,0.7311,0.7355,0.7401,0.7447,0.7485,0.7524,0.756,0.7594,0.7625,0.7647,0.7667,0.7685,0.77,0.7711)
Stock Distribution Database	Stock_Dist_Indo	Left blank for further expansion
Stock Distribution Database	Stock_Dist_Thai	Left blank for further expansion
Stock Distribution Database	Stock_Dist_Jap	Left blank for further expansion
Stock Distribution Database	Stock_Dist_Viet	Left blank for further expansion
Stock Macro	Mal Distri	Table(Vehicle_type)(0.995480416,3.09m,1.43m,4.110000000000001u)
Stock Macro	Mal Sum	7,639,847
Stock Macro	Malaysia	Round(Mal_sum*Mal_distri, 0)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Stock Distribution Database	Sd Malaysia	Table(Vehicle_Age,Vehicle_type)(0.077996195,0.637364921,0.047075773,0.8125, 0.079115982,0.34925187,0.043707655,0.1875, 0.070313712,0.013383209,0.079510942,0, 0.06990873,0,0.046121797,0, 0.061324788,0,0.297095242,0, 0.059987327,0,0.116579706,0, 0.07040716900000001,0,0.07982244400000001,0, 0.061796526,0,0.08566311,0, 0.055597056,0,0.054512888,0, 0.054661042,0,0.077875555,0, 0.055746012,0,0,0, 0.045137946,0,0.07203488800000001,0, 0.041586303,0,0,0, 0.042585725,0,0,0, 0.039843438,0,0,0, 0.03710115,0,0,0, 0.013887713,0,0,0, 0.010556101,0,0,0, 8.547946000000001m,0,0,0, 8.128435m,0,0,0, 7.905917m,0,0,0, 7.958275000000001m,0,0,0, 6.217402m,0,0,0, 4.28019m,0,0,0, 3.992227m,0,0,0, 2.212086m,0,0,0, 1.649248m,0,0,0, 914.9400000000001u,0,0,0, 262.44u,0,0,0, 377.979u,0,0,0)
Stock Macro	Indonesia	Left blank for further expansion
Stock Macro	Thailand	Left blank for further expansion

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Stock Macro	Japan	58,729,343
Stock Macro	Vietnam	Left blank for further expansion
PC	Stock	Dynamic(Stock_age_Distributi*Stock_macro_2012, if Vehicle_Age=0 then Real_EVC else carryover_with_vehic[time=time-1][Vehicle_Age=Vehicle_Age-1])
PC	Export New Car	Dynamic(0,15589)
PC	Pv	EVC_summary -EVC1[Vehicle_type='HEV']-EVC1[Vehicle_type='EV']
PC	Evc	Round(Vehicle_choice*Estimated_Sale)
PC	Vehicle Choice [Vehicle Type]	If EV_Promotion='Low' then Low else if EV_Promotion='Mid' then Mid1 else if EV_Promotion='High' then High else if EV_Promotion='Mandatory' then Mandatory else if EV_Promotion='Technology Advancement' then Technology_Advanceme else if EV_Promotion='Rapid Acceptance' then Rapid_Acceptance else if EV_Promotion='BaU' then real_BAU else 0
PC	Average V Age S0	stock1/Sum(Stock1,Vehicle_Age)
PC	Average V Age S0	Cumulate(Average_V_age_s0,Vehicle_Age)
PC	Actual Average Fleet Age	LinearInterp(Average_V_age_s1, Vehicle_Age,0.5, Vehicle_Age)
PC	Real Gdp Malaysia	Table(Time)(0,21.22,21.52,21.99,22.61,23.21,23.85,24.52,25.21,25.94,26.68,27.44,28.21,29,29.79,30.61,31.43,32.26,33.1,33.94,0,0,0,0,0,0,0,0,0,0)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
PC	Ev Promotion	Choice(Self,10)
PC	Va9	Sum(Stock_macro_2012)
PC	Stock Age Distribution	if Country='Malaysia' then Stock_dist_mal else if Country='Indonesia' then Stock_Dist_Indo else if Country='Thailand' then Stock_Dist_Thai else if Country='Vietnam' then Stock_Dist_Viet else if Country='Japan' then Stock_Dist_Jap else 0
PC	Carryover With Vehicle Type	Dynamic(Stock1*Srate_sum)
PC	Va4	0.005*EVC_summary
PC	EVC Summary	Sum(EVC, Vehicle_type)
PC	Ev Promotion	Choice(Self,10)
PC	Stock_Macro_2012	if Country='Malaysia' then Stock_Malaysia else if Country='Indonesia' then Stock_Indo else if Country='Thailand' then Stock_Thai else if Country='Japan' then Stock_Jap else 0
PC	Stock Macro 2012 (Sum)	Table(Vehicle_type)(Mal_sum ,0 ,0 ,0)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
PC	**Stock**	**Dynamic(Stock_Macro_2*Stock_age_Distributi, if Vehicle_Age=0 then EVC else CarryOver[time=time-1][Vehicle_Age=Vehicle_Age-1] Dynamic(Stock_Macro_2*Stock_age_Distributi, if Vehicle_Age=0 then EVC else CarryOver[time=time-1][Vehicle_Age=Vehicle_Age-1] Dynamic(Stock_Macro_2*Stock_age_Distributi, if Vehicle_Age=0 then EVC else CarryOver[time=time-1][Vehicle_Age=Vehicle_Age-1])**
PC	Evc	Estimated_Sale*original_choice
PC	Estimated Sale, Demand	Dynamic(Sales_year_0, Self[Time-1] * (1+effective_growth_rat[Time-1]))
PC	Sales Year 0	if Country='Malaysia' then Malaysia_S_Y0 else if Country='Indonesia' then Indo_S_Y0 else if Country='Thailand' then Thai_S_Y0 else if Country='Japan' then Japan_S_Y0 else if Country='Vietnam' then Viet_S_Y0 else if Country='Test' then 633231
PC	Current Capacity	Stock_macro_2012[Time=2012]/Pot_owner[Time=2012]
PC	Capacity	Stock/Pot_owner
PC	Original Choice	Table(Vehicle_type)(1,0,0,0)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
PC	Effective Growth Rate, NCI	EVC_Growth * (1 - (Estimated_Sale / annual_allowable_sal))
PC	EVC Growth, K	Normal(0.042, 0.074)
PC	Time 0	18.59M
PC	Dynamic Population	Dynamic(time_0, Self[Time=Time-1]+(Self[Time=Time-1]*Pot_test))
PC	Potential Owner	if Country='Malaysia' then Potential_Owner_Mal else if Country='Indonesia' then Potential_Owner_IND else if Country='Thailand' then Pot_Own_Thai else if Country='Japan' then Pot_Own_Jap else if Country='Vietnam' then Pot_Own_Viet else if Country='Test' then dynamic_population else 0
PC	Carryover	Dynamic(Stock*Srate_sum)
PC	Pot_Test	Normal(1.61E-02, 0.004885772)
PC	Maximum Market	saturation_limit*Pot_owner
PC	Potential Market	Pot_owner * saturation_limit - stock_summary_i
PC	Stock Summary I	Sum(Stock,Vehicle_Age, Vehicle_type)
PC	Percentage Of Saturation	capacity/saturation_limit*100
PC	Saturation Limit	0.5

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
PC	Annual Max Allowable Stock	Pot_owner * saturation_limit
PC	Annual Allowable Sale	annual_max_allowable-stock_summary_i
Real EVC	Mandatory EV	Table(Vehicle_type)(0 ,0 ,0 ,Sum(Real_EVC2,Vehicle_type))
Real EVC	Real EVC	if Time <= 18 then Real_EVC2 else if Mandatory_EV_2030='On' then mandatory_EV else if Mandatory_EV_2030='OFF' then Real_EVC2
Real EVC	Real EVC	Table(Vehicle_type)(PV1 ,EVC1[Vehicle_type='HEV'] ,EVC1[Vehicle_type='CNG'] ,EVC1[Vehicle_type='EV'])
Real EVC	Mandatory EV 2030	Choice(Self,2,False)
Country Sales	Malaysia	633231
Country Sales	Indonesia	Left blank for further expansion
Country Sales	Thailand	Left blank for further expansion
Country Sales	Vietnam	Left blank for further expansion
Country Sales	Japan	Left blank for further expansion
Country GDP	Malaysia	Left blank for further expansion
Country GDP	Indonesia	Left blank for further expansion
Country GDP	Thailand	Left blank for further expansion

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Country GDP	Vietnam	Left blank for further expansion
Country GDP	Japan	Left blank for further expansion
Scrap	Scrap	Dynamic(Stock1 *Drate_sum)
Scrap	Scrap	Round(Scrap2)
Scrap	Old PC L	if Vehicle_Age<15 then 0 else Scrap
Scrap	Total Scrap L	Dynamic(Scrap, (Self [Time-1] + Scrap[time=time-1]))
Scrap	Export Used Vehicle	Dynamic(Scrap*Export_rate)
Scrap	Collect Vehicle	Dynamic(Scrap*(1-Export_rate))
Scrap	Export Rate	0
Survival	Policy Start (Modeled Year)	Choice(Self,6,False)
Survival	Policy	Choice(Self,1,False)
Survival	T For Survival	if Policy='US' then 20.5 else if Policy='UK MA14' then 18.1 else if Policy='JAPAN MA12' then 17 else if Policy='Control - Long life' then 30 else if Policy='Control - Short Life' then 12 else if Policy='Brazil' then 23

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Survival	B For Survival	if Policy='US' then 3.4 else if Policy='UK MA14' then 3.48 else if Policy='JAPAN MA12' then 3.5 else if Policy='Control - Long life' then 3.0 else if Policy='Control - Short Life' then 3.6 else if policy='Brazil' then 3.4
Survival	K For Survival	2.836
Survival	T For Survival Bau	20.5
Survival	B For Survival Bau	3.4
Survival	Survival Function	if [Time<Policy_Start] then (exp(-((Vehicle_Age + b_for_survival_BaU)/ T_for_survival_BaU)^(b_for_survival_BaU))) else (exp(-((Vehicle_Age + b_for_survival)/ T_for_survival)^(b_for_survival)))
Survival	Survival Rate	if Vehicle_Age=0 then 1 else Survival_function[Vehicle_Age=Vehicle_Age]/Survival_function[Vehicle_Age =Vehicle_Age-1]
Survival	Srate Sum	Sum(Survival_rate,Survival_function)
Survival	Drate Sum	Sum(Disposal_rate,Survival_function)
Survival	Disposal Rate	if Vehicle_Age=0 then 0 else (Survival_function[Vehicle_Age=Vehicle_Age-1]- Survival_function)/Survival_function[Vehicle_Age=Vehicle_Age-1]
Survival	Average Age (Target)	LinearInterp(-Survival_function, Vehicle_Age, -0.5, Vehicle_Age)
Main	Emission Euro	['Euro 2','Euro 4']

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Emission Fleet	['CO2','CH4','NOx','CO','HC']
Main	Vehicle CC	Sequence(500, 3500, 100)
Main	Vehicle Age	Sequence(0, 29, 1)
Main	Vehicle Type	['CV','HEV','CNG','EV']
Main	Population	if Country='Malaysia' then Pop_Mal else if Country='Indonesia' then Pop_Indo else if Country='Thailand' then Pop_Thai else if Country='Japan' then Pop_Jap else if Country='Vietnam' then Pop_viet else if Country='Test' then dynamic_population else 0
Main	Per-Capita Emission	usage_emission_co2_e/population*1000
Main	EV Power Req (Wh)	Normal(144,21)
Main	Annual Travel Distance	Annual_Travel_Dist
Main	Usage Emission Co2 Eq	[GHG,CO_sum,HC_sum]/1000/1000
Main	Ghg	CO1+CH4_sum+NOX_sum
Main	Co2	Sum(Total_Emission[Emission_Fleet='CO2'], Vehicle_Age, Vehicle_Type)
Main	Ch4	(Sum(Total_Emission[Emission_Fleet='CH4'], Vehicle_Age, Vehicle_Type))*25
Main	Nox	(Sum(Total_Emission[Emission_Fleet='NOx'], Vehicle_Age, Vehicle_Type))*298

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Co	Sum(Total_Emission[Emission_Fleet='CO'], Vehicle_Age, Vehicle_Type)
Main	Hc	Sum(Total_Emission[Emission_Fleet='HC'], Vehicle_Age,Vehicle_Type)
Main	Total Emission	Table(Emission_Fleet,Vehicle_type)(total_co2_pv ,total_co2_hev ,total_co2_cng ,Electric_Generation_[Emission_Fleet='CO2'] , Total_CH4_PV ,Total_CH4_HEV ,Total_CH4_CNG ,Electric_Generation_[Emission_Fleet='CH4'] , NOx_PV ,NOx_HEV ,NOx_CNG ,Electric_Generation_[Emission_Fleet='N2O'] , CO_PV ,CO_HEV ,CO_CNG ,Electric_Generation_[Emission_Fleet='CO'] , HC_PV ,HC_HEV ,HC_CNG ,Electric_Generation_[Emission_Fleet='HC'] , 0,0,0,Electric_Generation_[Emission_Fleet='N2O'])
Main	Stock Base	Round(Stock1)
Main	Stock PV	Stock_base[Vehicle_Type='CV']
Main	Stock HEV	Stock_base[Vehicle_Type='HEV']
Main	Stock CNG	Stock_base[Vehicle_Type='CNG']
Main	Stock EV	Stock_base[Vehicle_Type='EV']
Main	Vehicle Per Cc Dist	Table(Vehicle_type)(Stock_PV*Engine_Size_Distribu ,Stock_HEV*Engine_Size_Distribu ,Stock_CNG*Engine_Size_Distribu ,Stock_EV*Engine_Size_Distribu)
Main	Stock EV2	Sum(Vehicle_per_cc_dist[Vehicle_Type='EV'],Vehicle_CC)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Engine size distribution	Choice Engine Size	Choice(Self,2,False)
Engine size distribution	Policy 2 Engine Size Reduction	Table(Vehicle_CC)(0,0.021881677,0.021881677,0.021881677,0.021881677,0.049731083,0.0596773,0.08454284099999999,0.248655415,0.08454284099999999,0.06663965099999999,0.06663965099999999,0.057197837,0.057197837,0.057197837,0.057197837,6.217156m,6.217156m,6.217156m,405.856u,405.856u,405.856u,405.856u,405.856u,405.856u,405.856u,352.14u,352.14u,352.14u,352.14u,352.14u)
Engine size distribution	Original Engine Size Dist	Table(Vehicle_CC)(0,0.020902592,0.020902592,0.020902592,0.020902592,0.020902592,0.041505146,0.041505146,0.041505146,0.23002852,0.23002852,0.05750713,0.05750713,0.05750713,0.05750713,0.05750713,6.250775m,6.250775m,6.250775m,408.051u,408.051u,408.051u,408.051u,408.051u,408.051u,408.051u,354.044u,354.044u,354.044u,354.044u,354.044u)
Engine size distribution	Engine Size Distribution	if choice_engine_size=1500 then Original_engine_size else if choice_engine_size=1300 then Policy_2_engine_size
Travel Module	Travel Km	Annual_Travel_Dist1*Vehicle_per_cc_dist
Travel Module	Travel PV	Travel_Km[Vehicle_Type='CV']
Travel Module	Travel HEV	Travel_Km[Vehicle_Type='HEV']
Travel Module	Travel CNG	Travel_Km[Vehicle_Type='CNG']
Travel Module	Travel EV	Stock_EV2*Annual_Travel_Dist1
FC module	Uncertainty	Table(Vehicle_Type)(1.436252465,1.051465837,0.198656365,0)
FC module	Fc	Fuel_Consumption/100
FC module	Fc Pv	fc[Vehicle_Type='CV']

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
FC module	Fc Hev	fc[Vehicle_Type='HEV']
FC module	Fc Cng	fc[Vehicle_Type='CNG']
FC module	Fuel Used Pv	Sum(FC_PV*Travel_PV, Vehicle_CC)
FC module	Fuel Used Hev	Sum(FC_HEV *Travel_HEV, Vehicle_CC)
FC module	Fuel Used Cng	Sum(FC_CNG *Travel_CNG, Vehicle_CC)
FC module	Total Fuel Used	Table(Vehicle_type)(Fuel_Used_PV ,Fuel_Used_HEV ,0,0)
Fuel Consumption	Choice Fuel Consumption	Choice(Self,1,False)
Fuel Consumption	Fuel Consumption Bau	Table(Vehicle_type)((4.021+(2.119m*Vehicle_CC)),(2.87+(1.552m*Vehicle_CC)),(6.067+(1.432m*Vehicle_CC)),0)
Fuel Consumption	Fuel Consumption 10% More Efficient	Fuel_Consumption_bau-Fuel_Consumption_bau*0.1
Fuel Consumption	Fuel Consumption	if choice_fuel_consumpt='BaU' then Fuel_Consumption_bau else if choice_fuel_consumpt='10% more efficient' then Fuel_Consumption_10_
Emission non-IPCC	Euro Type	Choice(Self,1,False)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Emission non-IPCC	**Odometer**	**Table(Vehicle_Age)(Annual_Travel_Dist1*1 ,Annual_Travel_Dist1*2 ,Annual_Travel_Dist1*3 ,Annual_Travel_Dist1*4 ,Annual_Travel_Dist1*5 , Annual_Travel_Dist1*6 ,Annual_Travel_Dist1*7 ,Annual_Travel_Dist1*8 ,Annual_Travel_Dist1*9 ,Annual_Travel_Dist1*10 ,Annual_Travel_Dist1*11 ,Annual_Travel_Dist1*12 ,Annual_Travel_Dist1*13 ,Annual_Travel_Dist1*14 ,Annual_Travel_Dist1*15 ,Annual_Travel_Dist1*16 ,Annual_Travel_Dist1*17 ,Annual_Travel_Dist1*18 ,Annual_Travel_Dist1*19 ,Annual_Travel_Dist1*20 ,Annual_Travel_Dist1*21 ,Annual_Travel_Dist1*22 , Annual_Travel_Dist1*23 ,Annual_Travel_Dist1*24 ,Annual_Travel_Dist1*25 ,Annual_Travel_Dist1*26 ,Annual_Travel_Dist1*27 ,Annual_Travel_Dist1*28 ,Annual_Travel_Dist1*29 ,Annual_Travel_Dist1*30)**
Emission non-IPCC	Deterioration Factor CO	if Euro_Type = 2 then DetFac_CO_E2 else if Euro_Type = 4 then DetFac_CO_E4
Emission non-IPCC	Co Initial	Table(Vehicle_type)(386.67,181.26,168.67,0)
Emission non-IPCC	CO Per Km	Det_fac_CO*CO_Initial/1000/1000
Emission non-IPCC	Co Pv	Sum(Travel_PV*CO_per_km[Vehicle_Type='CV'], Vehicle_CC)
Emission non-IPCC	Co Hev	Sum(Travel_HEV*CO_per_km[Vehicle_Type='HEV'], Vehicle_CC)
Emission non-IPCC	Co Cng	Sum(Travel_CNG*CO_per_km[Vehicle_Type='CNG'], Vehicle_CC)
Emission non-IPCC	Deterioration Factor HC	if Euro_Type =2 then Detfac_HC_E2 else if Euro_Type=4 then Detfac_HC_E4
Emission non-IPCC	Hc Initial	Table(Vehicle_type)(45.76,26.63,46.08,0)
Emission non-IPCC	HC Per Km	Det_fac_HC*HC_Initial/ 1000/1000

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Emission non-IPCC	Hc Pv	Sum(Travel_PV*HC_per_km[Vehicle_Type='CV'], Vehicle_CC)
Emission non-IPCC	Hc Hev	Sum(Travel_HEV*HC_per_km[Vehicle_Type='HEV'], Vehicle_CC)
Emission non-IPCC	Hc Cng	Sum(Travel_CNG*HC_per_km[Vehicle_Type='CNG'], Vehicle_CC)
Emission non-IPCC	Deterioration Factor Nox	if Euro_Type = 2 then Det_fac_NOX_E2 else if Euro_Type=4 then det_fac_Nox_E4
Emission non-IPCC	Nox Initial	Table(Vehicle_type)(24.25,11.26,10.83,0)
Emission non-IPCC	Nox Per Km	Det_fac_nox*NOx_Initial/1000/1000
Emission non-IPCC	Nox PV	Sum(Travel_PV*NOx_per_km[Vehicle_Type='CV'], Vehicle_CC)
Emission non-IPCC	Nox HEV	Sum(Travel_HEV*NOx_per_km[Vehicle_Type='HEV'], Vehicle_CC)
Emission non-IPCC	Nox CNG	Sum(Travel_CNG*NOx_per_km[Vehicle_Type='CNG'], Vehicle_CC)
Emission non-IPCC	Co2-Pv	(1.27+(2369*FC_PV))
Emission non-IPCC	Total Co2 Pv	Sum(co2_pv*Travel_PV/1000, Vehicle_CC)
Emission non-IPCC	Co2-Hev	(-1.414+(2350*FC_HEV))
Emission non-IPCC	Total Co2 Hev	Sum(Travel_HEV *co2_hev/1000, Vehicle_CC)
Emission non-IPCC	Co2-Cng	(2.546+(1761*FC_CNG))
Emission non-IPCC	Total Co2 Cng	Sum(Travel_CNG *co2_cng/1000, Vehicle_CC)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Det Factor CO	Detfac CO E2	1.018*Exp(4u*Odometer)
Det Factor CO	Detfac CO E4	1.082*Exp(4u*Odometer)
Det Factor HC	Detfac HC E2	(20u*Odometer)+1
Det Factor HC	Detfac HC E4	1
Det Factor Nox	Deterioration Factor NOX Euro 2	1.0057*Exp(6e-6*Odometer)
Det Factor Nox	Deterioration Factor Nox Euro 4	0.9948*Exp(3u*Odometer)
EV power generation module	Total Energy Used	Travel_EV*EV_Power_req
EV power generation module	GWH To TJ	Total_Energy_Used*3.6e-9
EV power generation module	Req Energy (MW)	Total_Energy_Used/8.76
EV power generation module	Teu (Gj)	Total_Energy_Used/277777.777777778
EV power generation module	Electricity For EV	GWH_to_TJ*Malaysia_Energy_Plan/100
EV power generation module	Electric Generation Emissions	Sum(Electricity_for_EV*IPCC_2006_emission, Power_Plant_Emission)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
EV power generation module	Malaysia Energy Plan	Table(Time,Power_Plant_Emission)(0.43,0.515,0.042,0,0.012,0, 0.43,0.515,0.042,0,0.012,0, 0.45,0.495,0.041,0,0.014,0, 0.481,0.463,0.04,0,0.016,0, 0.524,0.414,0.044,0,0.018,0, 0.528,0.409,0.043,0,0.02,0, 0.572,0.364,0.042,0,0.023,0, 0.622,0.313,0.041,0,0.025,0, 0.625,0.309,0.039,0,0.026,0, 0.614,0.32,0.04,0,0.026,0, 0.601,0.334,0.04,0,0.027,0, 0.572,0.262,0.041,0,0.026,0.099, 0.584,0.253,0.04,0,0.026,0.097, 0.497,0.244,0.04,0.096,0.028,0.095, 0.506,0.24,0.04,0.094,0.027,0.095, 0.513,0.236,0.039,0.093,0.027,0.093, 0.519,0.234,0.038,0.091,0.026,0.092, 0.526,0.231,0.038,0.09,0.026,0.09, 0.523,0.235,0.038,0.089,0.026,0.088, 0.529,0.236,0.037,0.087,0.025,0.086, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085, 0.54,0.227,0.036,0.087,0.025,0.085)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
EV power generation module	IPCC 2006 Emission	Table(Power_Plant_Emission,Emission_Fleet)(Triangular(95700,107000,119000) ,Triangular(0.3,1,3) ,0,0,0,Triangular(0.5, 1.5,5) , Triangular(54300,56100,58300) ,Triangular(0.3,1,3) ,0,0,0,Triangular(0.03,0. 1,0.3) , 0,0,0,0,0,0, 0,0,0,0,0,0, 0,0,0,0,0,0, 0,0,0,0,0,0)
EV power generation module	Emission Per Km Ev	Electric_Generation_/Travel_EV/Stock_base[Vehicle_Type='EV']
EV power generation module	Power Plant Emission	['Coal','Gas','Hydro','Nuclear','Renewables','Import']
Emission IPCC	Gasoline IPCC	LogNormal(33,,,34,)
Emission IPCC	Natural Gas Ipcc	92
Emission IPCC	Convert Factor	Table(Vehicle_Type)(34.2,34.2,25,0)
Emission IPCC	L/Tj	1/convert_factor*1000000
Emission IPCC	Emission Per Liter	Natural_Gas_IPCC/L_TJ[Vehicle_Type='CNG']
Emission IPCC	Emission Per Liter	Gasoline_IPCC/L_TJ[Vehicle_Type='CV']
Emission IPCC	Total CH4 PV	Total CH4 HEV
Emission IPCC	Total CH4 CNG	Emission_per_liter1 *Fuel_Used_CNG

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Ctg Hybrid Component	Table(IDEA_Index)(200u,117p,413,11.1,0.01,0.3,3770,24)
Main	CTG EV Component	Table(IDEA_Index)(-1.3m,650p,882,-11.8,-0.16,0.87,11.6K,315)
Main	Ctg Icev	Table(IDEA_Index)(1.9m ,0 ,4166 ,11.95 ,0.21 ,0.3 ,0 ,0)
Main	Ctg Hev	Table(IDEA_Index)(2.2m ,0 ,4596 ,13.51 ,0.22 ,0.62 ,0 ,0)
Main	Ctg Bev	Table(IDEA_Index)(1.4m,0,5791,5.76,0.11,1.27,0,0)
Main	Ctg Cng	CTG_ICEV*1.1
Main	CTG Of New Vehicle Manufacturi ng	Table(Vehicle_type)(CTG_ICEV*EVC_CV ,CTG_HEV*EVC_HEV ,CTG_C NG*EVC_CNG ,CTG_BEV*EVC_EV)
Main	Evc Cv	Real_EVC[Vehicle_type='CV']
Main	Evc Hev	Real_EVC[Vehicle_type='HEV']
Main	Evc Ev	Real_EVC[Vehicle_type='EV']
Main	Evc Cng	Real_EVC[Vehicle_type='CNG']
Main	Ctg Icv	CTG_ICEV
Main	Ctg Hev	CTG_HEV
Main	Ctg Ev	CTG_BEV
Main	New Cars Quantity	'New Cars Quantity'
Main	CTG Per Year	Table(Vehicle_type)(CTG_ICV*New_Cars_Quantity ,CTG_HEV1 *New_Cars_Quantity ,0 ,CTG_EV*New_Cars_Quantity)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Sum Ctg Per Year	Sum(CTG_PY, Vehicle_type)
Main	Average Vehicle Age	LinearInterp(-Survival_function, Vehicle_Age, -0.5, Vehicle_Age)
Main	Expected Lifetime	average_vehicle_age*Annual_Travel_Dist1
Main	CTG Per KM	Table(Vehicle_type)(CTG_ICV*New_Cars_Quantity/Expected_Lifetime ,CTG_HEV1 *New_Cars_Quantity/Expected_Lifetime ,0,CTG_EV*New_Cars_Quantity/Expected_Lifetime)
Main	Total Emission	Table(Emission_Fleet,Vehicle_type)(total_co2_pv ,total_co2_hev ,total_co2_cng ,Electric_Generation_[Emission_Fleet='CO2'] , Total_CH4_PV ,Total_CH4_HEV ,Total_CH4_CNG ,Electric_Generation_[Emission_Fleet='CH4'] , NOx_PV ,NOx_HEV ,NOx_CNG ,Electric_Generation_[Emission_Fleet='N2O'] , CO_PV ,CO_HEV ,CO_CNG ,Electric_Generation_[Emission_Fleet='CO'] , HC_PV ,HC_HEV ,HC_CNG ,Electric_Generation_[Emission_Fleet='HC'] , 0,0,0,Electric_Generation_[Emission_Fleet='N2O'])
Main	Co2	Sum(Total_Emission1[Emission_Fleet='CO2'], Vehicle_Age, Vehicle_Type)
Main	Ch4	(Sum(Total_Emission1[Emission_Fleet='CH4'], Vehicle_Age, Vehicle_Type))*25
Main	Nox	(Sum(Total_Emission1[Emission_Fleet='NOx'], Vehicle_Age, Vehicle_Type))*298
Main	N2o	(Sum(Total_Emission1[Emission_Fleet='N2O'], Vehicle_Age, Vehicle_Type))*298
Main	Co	Sum(Total_Emission1[Emission_Fleet='CO'], Vehicle_Age, Vehicle_Type)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Hc	Sum(Total_Emission1[Emission_Fleet='HC'], Vehicle_Age,Vehicle_Type)
Main	GHG Use	CO3+CH4_sum1+NOX_sum1+N2O_sum1
Main	Emission Co2 Eq	[GHG_use,CO_sum1,HC_sum1]/1000/1000
Main	Usage DALY (Inventory)	Table(DALY_index)(0,0,0,0,0,0,0,CO3 ,0,0,0,0,0,CH4_sum1,0,0,NOX_sum1, N2O_sum1 ,0,0,0,0,0,0,0,0)
Main	Daly Factorization	Table(DALY_index)(130,7.9m,7.9m,2u,0.022,0.022,0,130n,0.02,0.048,0.048,0.045,3.3u,3.3u,91u,91u,21u,12u,39u,6.9u,710u,600n,150u,3m,150u,692n)
Main	Usage DALY	Sum(Usage_DALY*DALY_Factorization, DALY_index)
Main	Usage EINES (Inventory)	Table(EINES_index)(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)
Main	Eines Factorization	Table(EINES_index)(157n,22.1f,293n,800n,1.78f,79.3n,257n,15.3n,13.2f,49.9n,11f,11f,180n,675f,582n,365p,1.91f,39.9n,37.6f,115n,12.8f,148n,7.35u,62.80000000000001f,3.17p,204n,127f,651n,5.78p,74.5p,49.2f,68f,549f,243f,118f,291f,12.7n,30.8f,40.59999999999999n)
Main	Usage EINES	Sum(Usage_EINES*EINES_Factorization, EINES_index)
Main	Acidification (Inventory)	Table(Acidification_index)(0 ,NOX_sum1 ,0 ,0 ,0 ,N2O_sum1)
Main	Acidification Factorization	Table(Acidification_index)(1,0.72,1,6,2.6,0.72)
Main	Usage Acidification	Sum(Acidification1*Acidification_Factor, Acidification_index)
Main	Eutrophication	Table(Eutrophication_index)(NOX_sum1+N2O_sum1 ,0 ,0 ,0 ,0)

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Eutrophication Factorization	Table(Eutrophication_index)(0.011,0.202,1m,0.092,1)
Main	Usage Eutrophication	Sum(Eutrophication1*Eutrophication_Facto, Eutrophication_index)
Main	Wtt Gasoline	Table(IDEA_Index)(117n,6.02e-018,0.493,601u,37.3p,1.75n,0.04,2.49)
Main	Total Fuel Used (L)	total_fuel_used
Main	Wtt Cng	Table(IDEA_Index)(10.1n ,0 ,0.0679 ,49.8u ,0 ,0 ,8.64 ,0)
Main	Ctg Fuel	Sum((WTT_Gasoline*Total_fuel_used1),Vehicle_Age,Vehicle_type)
Main	Wtt Electricity	Table(IDEA_Index)(47n,7.5f,0.287,132u,15.7n,2.73u,0,0.0321)
Main	Total Electric Demand	Total_Energy_Used/1000
Main	Ctg Electricity	Sum((WTT_Electricity*Total_Electric_Deman), Vehicle_Age)
Main	CTW Gwp	GHG_use+ sum_ctg_per_year[IDEA_Index='GHG Emission']+ CTG_Fuel[IDEA_Index='GHG Emission']
Main	CTW GWP Mton	CTW_gwp/1000000000
Main	Ctw Daly	CTG_Fuel[IDEA_Index='DALY'] +sum_ctg_per_year[IDEA_Index='DALY'] +CTG_Electricity[IDEA_Index='DALY'] +Usage_DALY1

Table B 10 : Variable name and input expressions used throughout the model. (continued).

Module Name	Variable Name	Input Expression
Main	Ctw Eines	CTG_Fuel[IDEA_Index='EINES'] +sum_ctg_per_year[IDEA_Index='EINES'] +Usage_EINES1+ CTG_Electricity[IDEA_Index='EINES']
Main	CTW Acid	sum_ctg_per_year[IDEA_Index='Acidification']+CTG_Fuel[IDEA_Index='Acidification']+Usage_Acidification+CTG_Electricity[IDEA_Index='Acidification']]
Main	CTW Eutrop	CTG_Fuel[IDEA_Index='Eutrophication']+sum_ctg_per_year[IDEA_Index='Eutrophication']+Usage_Eutrophication+CTG_Electricity[IDEA_Index='Eutrophication']
Main	Water Consumption	sum_ctg_per_year[IDEA_Index='Water Consumption']+CTG_Fuel[IDEA_Index='Water Consumption']+CTG_Electricity[IDEA_Index='Water Consumption']
Main	CTW Cancer	CTG_Fuel[IDEA_Index='Human Toxicity']+sum_ctg_per_year[IDEA_Index='Human Toxicity']+CTG_Electricity[IDEA_Index='Human Toxicity']+total_VOC
Main	Energy Consumption	sum_ctg_per_year[IDEA_Index='Energy Consumption (GJ)']+CTG_Fuel[IDEA_Index='Energy Consumption (GJ)']+CTG_Electricity[IDEA_Index='Energy Consumption (GJ)']
Main	Impact	[CTW_GWP_MTon,CTW_acid,CTW_eutrop,CTW_DALY,CTW_EINES,Energy_Consumption1,Water_consumption1,CTW_cancer]
Main	Impact Index	[GHG,Acidification,Eutrophication,DALY,'EINES','Energy Consumption','Water Consumption','Cancer - Htox']
Main	VOC Emission	Table(VOC)(0.0123)
Main	Total VOC	Sum(((Sum(Travel_PV,Vehicle_CC))+(Sum(Travel_HEV, Vehicle_CC))*VOC_emission)/1000, VOC, Vehicle_Age)