ESTIMATING THE REDUCTION OF CARBON DIOXIDE (CO_2) EMISSION FROM PRIVATE VEHICLES IN PENANG ISLAND

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2019

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2019

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2017/2018

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title:

Name of Student:

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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(Signature of Examiner)

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Date :

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest appreciation to my Final Year Project (FYP) supervisor, Dr. Nur Sabahiah Abdul Sukor, for her patience, insightful comments, helpful information, practical advice and unceasing ideas that have always helped me tremendously. I am grateful to my supervisor, who guided me and provided me with the necessary information about my project. It would never have been possible for me to complete this project without her incredible support and encouragement.

In addition, my utmost gratitude to my Final Year Project course manager, Assoc. Prof. Dr. Noor Faizah Fitri Md. Yusof and other lecturers for giving me a lot of guidance in preparing this dissertation. I am also grateful to the lecturers and staff of PPKA for their kindness, hospitality and technical support.

Finally, I am truly grateful to my parents for their unconditional love and care throughout my degree life. I would also like to expand my gratitude to all those who have directly and indirectly guided me in writing this dissertation. A paper is not enough for me to express the support and guidance that I have received.

ABSTRAK

Pertambahan bilangan kenderaan yang semakin banyak saban hari di jalan raya di Pulau Pinang mempunyai keburukannya tersendiri. Ruang terhad di pulau bersejarah ini hanya memburukkan lagi keadaan apabila jalan mengalami kesesakan lalu lintas yang teruk terutama pada waktu puncak. Kesesakan lalu lintas menyebabkan pelepasan asap kenderaan yang lebih ketara. Gas yang dikeluarkan oleh kenderaan terdiri daripada karbon dioksida (CO_2), sulfur dioksida (SO_2) dan hidrokarbon (HC) di samping gas-gas yang lain. Gas-gas ini amat berbahaya kepada alam sekitar dan dalam jangka masa panjang, ia boleh menjejaskan kesejahteraan makhluk di muka bumi. Ia juga membuktikan ketidaklestarian. Kajian ini mengkaji kesan jumlah pelepasan gas CO_2 jika kenderaan persendirian di atas jalan raya telah berkurang. Berdasarkan cadangan pembangunan Light Rail Transit (LRT) Pulau Pinang, tujuh lokasi di sepanjang penjajaran LRT yang juga terletak di sebelah timur Pulau Pinang telah dipilih sebagai kawasan kajian. Tujuh lokasi itu ialah Zon Bandar Sri Pinang (BSPZ), Zon Skycab (SKYZ), Zon East Jelutong (EJZ), Zon Batu Uban (BUSZ), Zon Sungai Nibong (STZ), Zon Bukit Jambul (BJZ) dan Zon Jalan Tengah (JTZ). Dalam kajian ini, data telah dikumpul melalui kaedah tinjauan lalu lintas menggunakan rakaman video GoPro di semua tujuh lokasi. Data yang telah dianalisis menunjukkan jumlah pelepasan karbon dioksida (CO_2) semasa berada pada kadar 1803 kgCO_2/PCU. Pengurangan kenderaan persendirian dalam bentuk PCU sebanyak 40%, 50% dan 60% menunjukkan pengurangan langsung sejajar kepada jumlah pelepasan CO_2 iaitu 1443 kgCO_2/PCU, 1331 kgCO_2/PCU dan 1254 kgCO_2/PCU. Penemuan dalam kajian ini boleh digunakan sebagai rujukan bagi kerajaan negeri dalam membantu dasar kerajaan negeri terhadap pertumbuhan yang mampan.

ABSTRACT

The staggering number of vehicles on the road in Penang Island that keeps increasing as the day goes by has its drawbacks. The limited space of the historical island only worsens the situation as the roads suffer from massive traffic jam especially during peak hours. Traffic jam causes greater vehicle emissions to be released on the road. The gases released by vehicles comprise of carbon dioxide (CO_2), sulphur dioxide (SO_2) and hydrocarbons (HC) among many others. These gases are harmful to the environment and in the long run, it may affect the well-being of the creatures on earth. It also proves to be unsustainable. This study investigates the effect of CO_2 emission when private vehicles travelling on the road are reduced. Based on the proposed future Penang LRT alignment, seven locations along the Light Rail Transit (LRT) alignment which are also located on the eastern side of Penang Island were chosen for the study. The seven locations are Bandar Sri Pinang zone (BSPZ), Skycab zone (SKYZ), East Jelutong zone (EJZ), Batu Uban zone (BUSZ), Sungai Nibong zone (STZ), Bukit Jambul zone (BJZ) and Jalan Tengah zone (JTZ). In this study, data were collected by means of traffic count survey using GoPro video recording at all seven locations. The data extracted were analysed and total current carbon dioxide (CO_2) emission stood at 1803 kgCO_2/PCU. Reduction of private vehicles in PCU by 40%, 50% and 60% shows a directly proportional reduction of total CO_2 emission which was 1443 kgCO_2/PCU, 1331 kgCO_2/PCU and 1254 kgCO_2/PCU. The findings in this study could be used as a reference for state government in facilitating state government's policy towards sustainable growth.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

PTMP	**P**enang **T**ransport **M**aster **P**lan
MRT	**M**ass **R**apid **T**ransit
LRT	**L**ight **R**ail **T**ransit
BRT	**B**us **R**apid **T**ransit
OECD	**O**rganisation for **E**conomic **C**ooperation and **D**evelopment
DT	**D**istance **T**ravel
PCE	**P**assenger **C**ar **E**mission

NOMENCLATURES

CO_2	Carbon Dioxide
N_i	Passenger Car Units (PCU)
FE	Fuel Consumption Rate
EC	CO_2 Emissions Coefficient
D_i	Length of The Vehicle Travelling in The Block (m)

CHAPTER 1

INTRODUCTION

1.1 Background

According to Ma (1998) carbon dioxide (CO_2) is referred as a greenhouse gas (GHG) that absorbs and emits heat radiation, causing a greenhouse effect. In addition to other greenhouse gases such as nitrous oxide and methane, CO_2 is essential in maintaining the planet's ideal temperature which is liveable for most living creatures: our planet would simply be freezing cold if there were no GHGs at all.

On the other hand, excessive GHG emission can cause global warming and fluctuating climate have a range of potential impacts on the environment, physical and health. Some of these include extreme weather events such as floods, droughts, storms and heatwaves. It also causes rise of sea-level, crop growth altered and water systems disrupted (Field et al., 2017).

From the data published by Ritchie and Roser (2017), electricity and heat production in 2014 resulted in around half of global emissions worldwide. Meanwhile, the transportation and manufacturing industries attributed about 20 percent; residential, commercial and public services accounted for around 9 percent, while other sectors contributed 1 to 2 percent. Figure 1.1 shows a chart of carbon dioxide (CO_2) emission by sectors from 1960 to date.

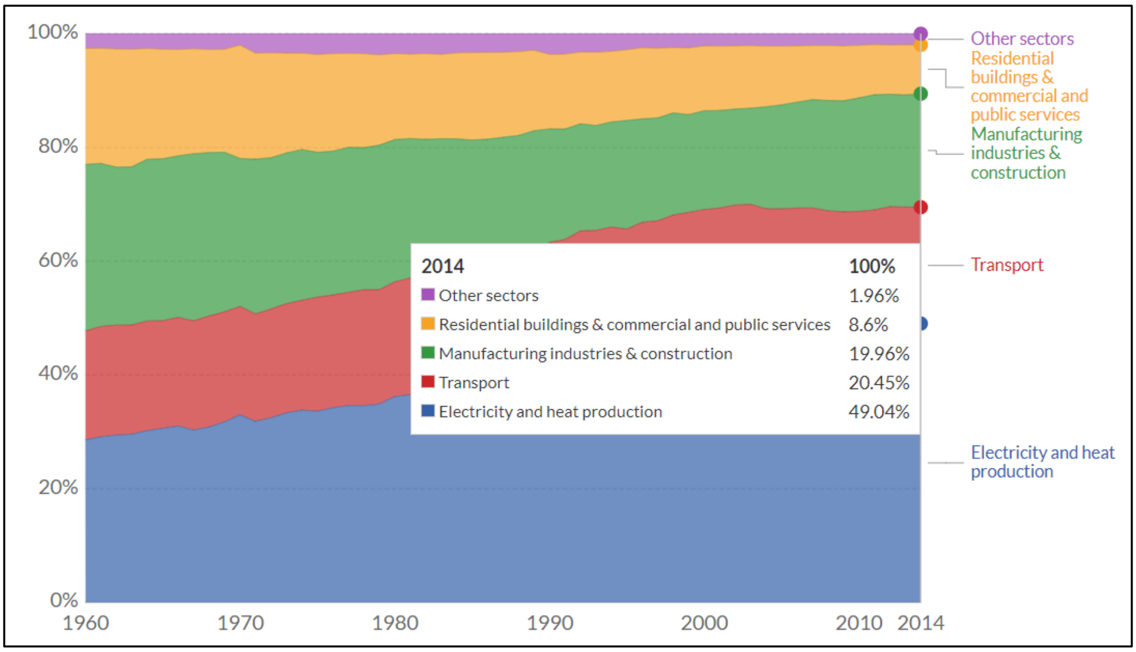

Figure 1.1: Global CO_2 emission by sector (Ritchie and Roser, 2017)

In addition, Babatundea et al. (2018) stated that transport systems, electricity generation, industrial sectors and residual were noted as the main contributors to CO_2 emissions in Malaysia. The viewpoint duration for carbon emissions from energy consumers is projected in Malaysia to grow by approximately 4.2% annually to 414 million tons of dioxide carbon in 2030.

The need for research into reducing GHGs in different countries is highly drawn attention to when statistics are showing upward trend of CO_2 emission over the years (Hosseini et al., 2013). The agricultural activities, disposal of waste materials as well as water treatment are also some of Malaysia's other sources of GHG generation besides fuel combustion. Figure 1.2 shows the fraction of CO_2 emissions from different sources in Malaysia (Safaai et al., 2011).

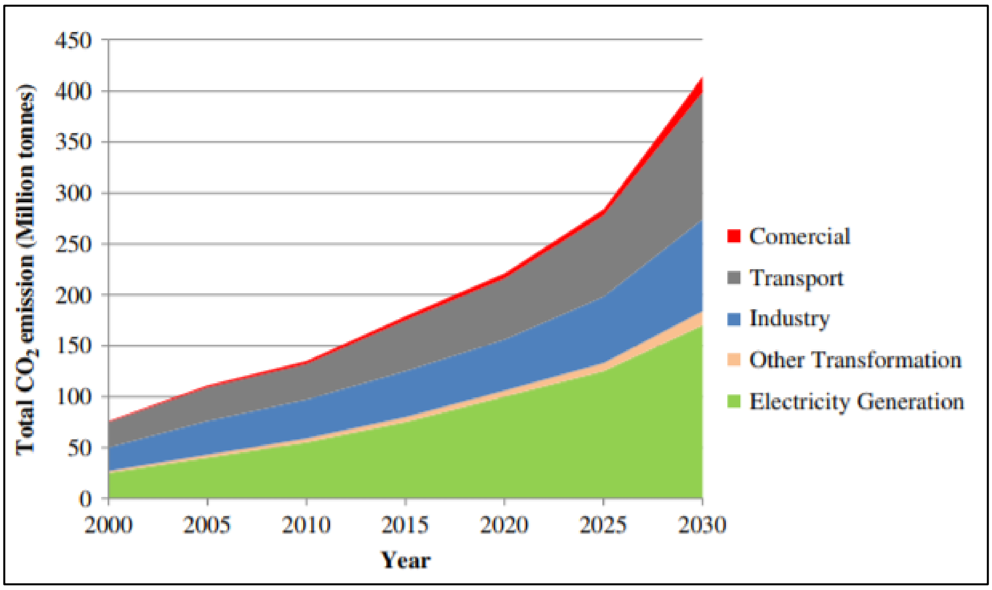

Figure 1.2: Emission of CO_2 by sector in Malaysia (Safaai et al., 2011)

A study by Briggs and Leong (2016) have found that Malaysia's transport sector accounts for approximately 35 percent of total national energy consumption and produces nearly 50 million metric tons (Mt) of CO_2 per year in 2015, second only to the generation of electricity. The vast majority of emissions which comes from transportation, 85.2 percent are contributed from road transport. Due to the high rate of private vehicle ownership, private cars account for approximately 59 percent of total transport emissions, while freight accounts for 27 percent. Although the number of cars and motorcycles on the roads is roughly equal, motorcycles account for only 11% of the CO_2 emissions from the transport sector. As the economy continues to expand, the rate of energy consumption increases and the corresponding emissions of greenhouse gas (GHG) are also increasing. This ultimately leading to an almost linear rate of CO_2 emissions per gross domestic product (GDP).

As of June 30, 2017, the Malaysian Automotive Association (MAA) released Malaysian vehicle registration data with the total number of vehicles on our roads standing at 28,181,203 units. That is 0.88 vehicles for every person in the country. The majority of vehicles was registered in the Federal Territories–including Kuala Lumpur, Putrajaya and Labuan–were 6,320,329. Standing at second is Johor which had 3,611,611 units, while Selangor is in the 3rd place with 2,904,476 units. Close behind are Penang (2,655,679 units) and Perak (2,260,242 units). The data for on-the-road vehicles in respective states in Malaysia was presented in Table 1.1. Therefore, the increasing number of vehicles in Malaysia leads to the unsolved problem of traffic congestion.

Table 1.1: Malaysian vehicle registration data up to 30th June 2017 (Lee J., 2017)

State	**Private Vehicles**		**Public Service Vehicles (PSV)**	**Goods Vehicles**	**Others**	**Total**
	Cars	**Motorcycles**				
Perlis	26,510	84,500	385	2,007	1,365	114,767
Kedah	341,197	954,751	7,273	40,710	20,104	1,364,035
Penang	1,130,601	1,408,528	9,586	80,254	26,710	2,655,679
Perak	772,591	1,359,771	9,534	75,638	42,708	2,260,242
Selangor	1,157,268	1,423,821	24,273	194,390	104,724	2,904,476
Federal Territories	3,987,468	1,863,260	78,752	268,340	122,509	6,320,329
Negeri Sembilan	343,007	557,482	4,635	50,160	7,845	963,129
Melaka	344,459	472,701	3,425	28,486	8,830	857,901
Johor	1,498,587	1,873,005	20,365	153,471	66,183	3,611,611
Pahang	392,200	600,470	4,310	45,640	14,663	1,057,283
Terengganu	211,124	393,228	2,159	22,172	6,015	634,698
Kelantan	309,663	549,363	3,928	29,689	7,264	899,907
Sabah	697,541	402,237	9,574	116,292	65,807	1,291,451
Sarawak	813,569	798,227	5,834	95,373	71,782	1,784,785
Business Partners Portals	1,263,012	191,698	1,002	3,122	2,076	1,460,910
Total	**13,288,797**	**12,933,042**	**185,035**	**1,205,744**	**568,585**	**28,181,203**

Meanwhile, Zhang and Batterman (2013) observed that congestion of the traffic increases vehicle emissions and deteriorates ambient air quality. Drivers, commuters and those living near major roads also have excess morbidity and mortality. Besides, according to Chee and Fernandez (2013), traffic congestion resulting from wider use of private transport has not only led to a loss of efficiency but has also led to a deterioration of the environment, especially the deterioration in the air quality caused by automotive pollution. In order to reduce such congestion, the promotion of public transport would be crucial.

Actions to encourage the shift of private transport to public transport should be taken. In order to address the current state of public transport, accessibility, ease and convenience of travelling can be improved. Moreover, reliability and safety should be enhanced (Almselati et al., 2011).

Therefore, based on Ma et al. (2019) study, in building new urbanization, sustainable urban transport plays a vital role. The degree of effectiveness in the infrastructure of the traffic network determines the mode of travel chosen by urban residents. The more responsive urban public transport, the better chances that public transport will become the main mode of travel and the easier it will be to establish a sustainable urban transport system.

In conclusion, in order to combat the effects of excessive GHGs emission, a fundamental step should be taken, that is to reduce the GHGs emission from source. Thus, this study was needed to be conducted to forecast the reduction of CO_2 emission if private vehicles usage is reduced as well as to show how this study could be mean of support for future public transportation strategy.

1.2 Problem Statement

The Penang State Government has identified three main concerns that need to be addressed which are crime, cleanliness and traffic congestion (Penang Transport Master Plan PTMP, 2016). Momentous progress has been made in cutting down crime, enhancing public safety and maintaining a clean, comfortable environment through continuous efforts. Nonetheless, traffic congestion remains a major concern; worsen by the progressive of economic growth and tourist inflow to this lively heritage city.

According to Shariff (2012), the population of Penang Island was 575,498 in 2000 and 740,200 in 2010 with 29 percent increase over the last 10 years. This led to 111,882 new registered vehicles in Penang Island alone in 2010. Since ownership of private vehicles was also linked to external factors such as traffic congestion, accidents, inadequate parking spaces and pollution, local and regional transport policy was part of an important component.

Realizing the challenges arose, a Transport Master Plan Strategy Report known as Penang Transport Master Plan (PTMP) was commissioned by the Penang state with the aim of improving the current state transport system by introducing a holistic approach to public transport and highway improvement in 2020. The Penang Transportation Master Plan (PTMP) represents an all-encompassing, efficient, and well-connected transport approach and provides the Penangites with an integrated, modern land-and sea-based transportation system.

This transport plan includes various transport systems and services including elevated Light Rails Transit (LRT), Monorail, Bus Rapid Transit (BRT), tram, taxi, E-hailing, ferry and water taxi. Besides, PTMP is aimed at achieving a 40:60 share modal split of public: private transport by 2030. Figure 1.3 shows the interlink between KTM Komuter, Bayan Lepas LRT, Georgetown-Butterworth LRT, Tg. Tokong Monorail, Ayer Itam Monorail, Raja Uda – Bukit Mertajam Monorail and P/Tinggi – Batu Kawan BRT which are a part of PTMP plan.

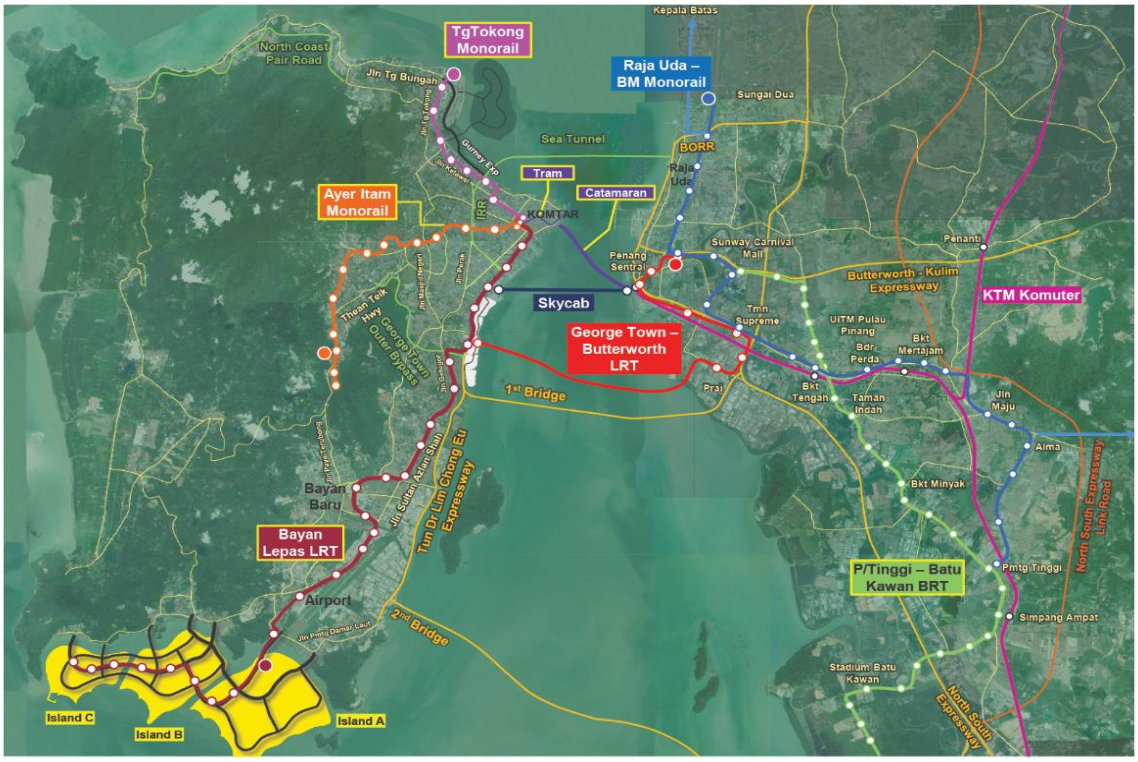

Figure 1.3: An Inclusive Transport System for Penang (Source: Penang Transport Master Plan (PTMP, 2016)

Penang government has also come up with future LRT network in Penang Island. The LRT alignment is shown in Figure 1.4.

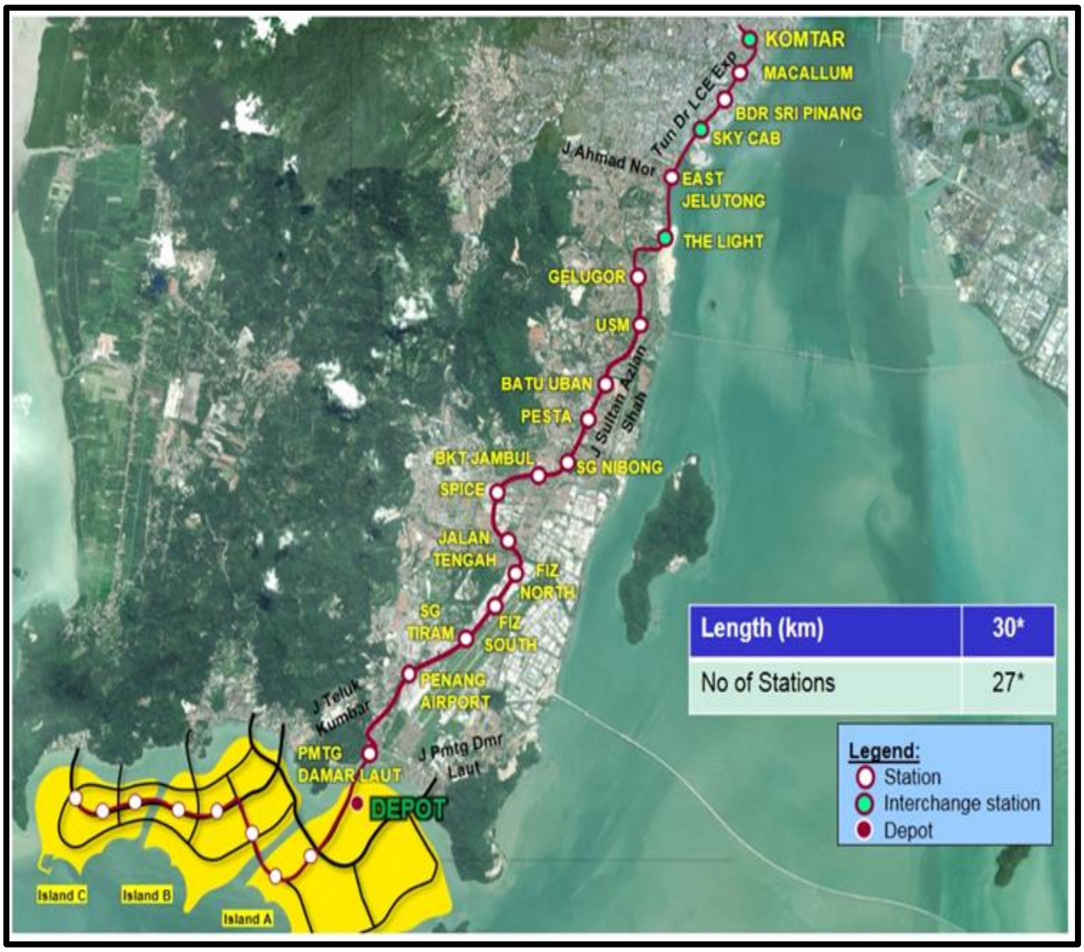

Figure 1.4: Proposed LRT alignment in Penang
Source: Penang Transport Master Plan (2016)

On a different note, according to Ministry of International Trade and Industry, 2017 (MITI), Penang is obliged to go along with the proposed adaptation of Malaysia to the United Nations Framework Convention on Climate Change (UNFCCC) as stated in Malaysia's Second National Communication (NC2). It is also reported that Malaysia is as firmly on track to achieve its GHG reduction target by 2030 with the following programs:

1) Green Technology Master Plan (2017-2030)

- To make Malaysia a low-carbon, resource-efficient economy by implementing Green Catalyst projects to reduce carbon intensity by 40% by 2020.

2) Energy Efficiency Action Plan

- The goal is to reduce CO_2 emissions equivalent to 13,113 million tons by 2030.

3) Transportation Sector

- The launching of the Mass Rapid Transit (MRT) phase one has successfully removed 9.9 million cars in 2017 and estimated to remove additional 62-89 million cars in between year 2020 to 2030.

4) Low Carbon Cities Framework

- To implement a carbon reduction plan for decision - making on greener solutions by local authorities and developers.

As traffic congestion increases, CO_2 emissions and fuel consumption in parallel are also known to increase. Therefore, the growing in numbers of private vehicles in Penang along with its traffic congestion will increase the CO_2 emission and it is needed for Penang government to fulfil its aspiration in reducing the state's GHG emission.

1.3 Objectives

The objectives of this study are listed as below:

1. To determine the existing traffic volume at selected locations in Penang Island.

2. To calculate CO_2 emissions based on current traffic volume at the selected locations in Penang Island.

3. To estimate the reduction of CO_2 emissions with 40%, 50% and 60% reduction of private vehicles at selected locations in Penang Island.

1.4 Scope of Work

This research study was done to estimate the current carbon dioxide (CO_2) emission of private vehicles at seven selected locations on the eastern side of Penang Island. The locations were chosen as they are along the alignment of future Penang's Light Rail Transit (LRT) as proposed in Penang Transport Master Plan (PTMP).

Comparison of current carbon dioxide (CO_2) emission and future reduction of carbon dioxide (CO_2) emission when people shift to public transport was done. As the selected locations are along the LRT alignment, assumption of shift mode of private vehicles to public transport by 40%, 50% and 60% was made. Private vehicles in this study include cars and motorcycles only.

The traffic count was done during the weekdays except for Monday and Friday. For every location, six hours of traffic count were done. Morning traffic count started from 6.30 a.m. to 9.30 a.m. and evening traffic count started from 4.30 p.m. to 7.30 p.m. The traffic count procedures were in accordance to the guideline of Highway Capacity Manual (Highway Planning Unit, Ministry of Works, Malaysian Government, 2015).

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, preceding studies related to forecasting private vehicular emissions are reviewed. This is to ensure a better comprehension in order to perform a thorough research dissertation. The topics covered in this chapter include greenhouse gases (GHGs), private vehicles, public transport as well as sustainable transport.

2.2 Greenhouse Gases

Environmental Protection Agency of United States (2016) states that greenhouse gases (GHGs) are essentially known as gases which trap heat in the atmosphere. Generally, greenhouse gases consist of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases. Figure 2.1 shows the percentage of global greenhouse gas emission by type of gas in 2010. The figure also shows that carbon dioxide (CO_2) is the biggest type of gas emitted onto the atmosphere at 76% followed by methane (CH_4), nitrous oxide (N_2O) and fluorinated gases at 16%, 6% and 2% respectively.

Meanwhile, highest greenhouse gases emission by sector was dominated by electricity and heat production sector followed by agriculture and forestry, industry, transportation, other energy as well as buildings. This can be referred in Table 2.1.

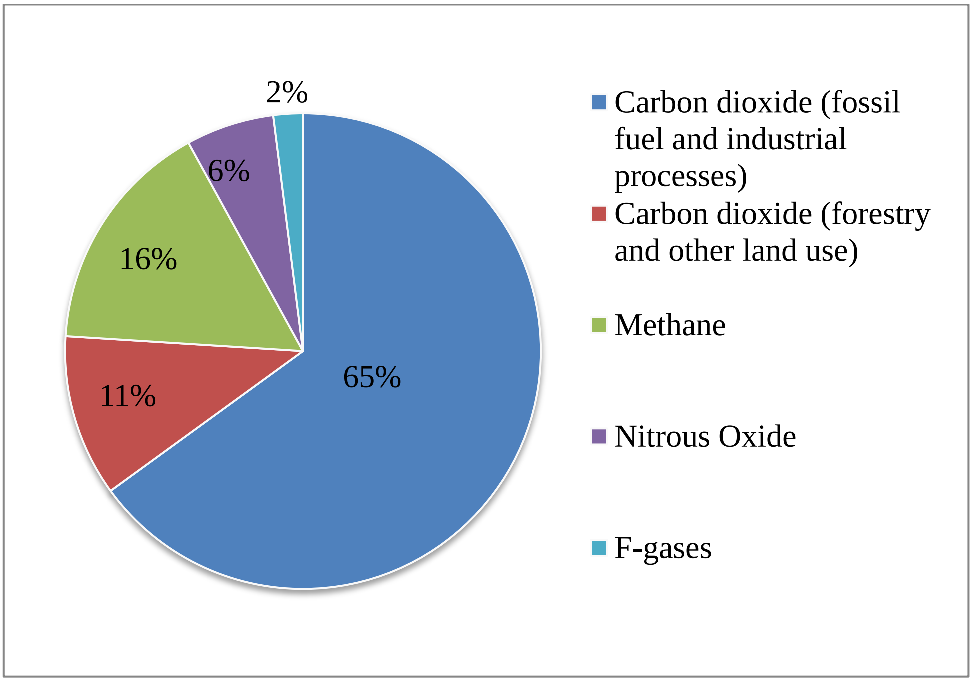

Figure 2.1: Global Greenhouse Gas Emission by Gas from 2010 (Edenhofer, 2015)

Table 2.1: Global Greenhouse Gas Emissions by Economic Sector from 2010 (Edenhofer, 2015)

Sector	Gas Emissions Percentage
Electricity and Heat Production	25%
Agriculture, Forestry and Other Land Use	24%
Industry	21%
Transportation	14%
Other energy	10%
Buildings	6%

On the other hand, Boden et al. (2009) has found that global carbon emissions from fossil fuels have significantly increased since 1900. Since 1970, CO_2 emissions have increased by around 90%. Contributions of 78% of total greenhouse gas emissions increase from 1970 to 2011 are emissions from fossil fuels and industrial processes. The second-largest contributors were agriculture, deforestation and other land-use changes. The pattern of global carbon emissions from fossil fuels can be seen in Figure 2.2.

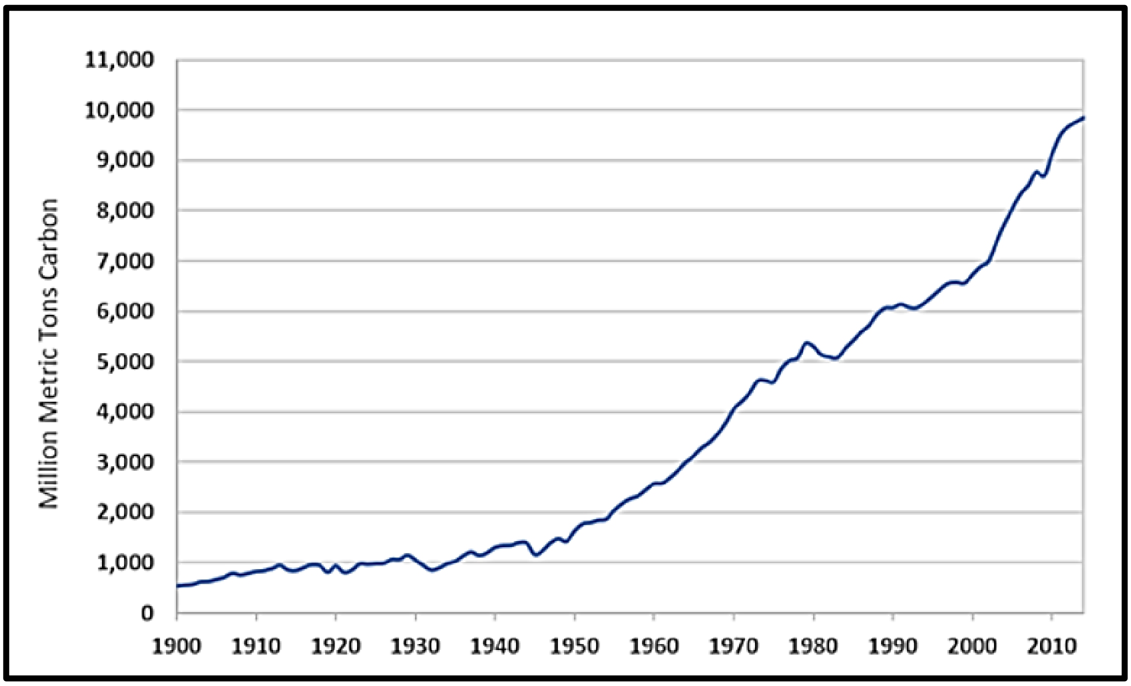

Figure 2.2: Global Carbon Emissions from Fossil Fuel from 1900 to 2014 (Boden et al., 2009)

Greenhouse gas absorbs heat and warms the planet. Over the last 150 years, human activities are liable for almost all of the growth in atmospheric greenhouse gas (Change, 2007). Meanwhile, in the United States the total emission of GHGs in 2017 is equal to 6,456.7 million metric tons of CO_2 equivalent. As shown in Figure 2.3, in 2017 carbon dioxide (CO_2) was the major gas emitted into the atmosphere at 82% from the total greenhouse gases followed by methane, nitrous oxide and fluorinated gases.

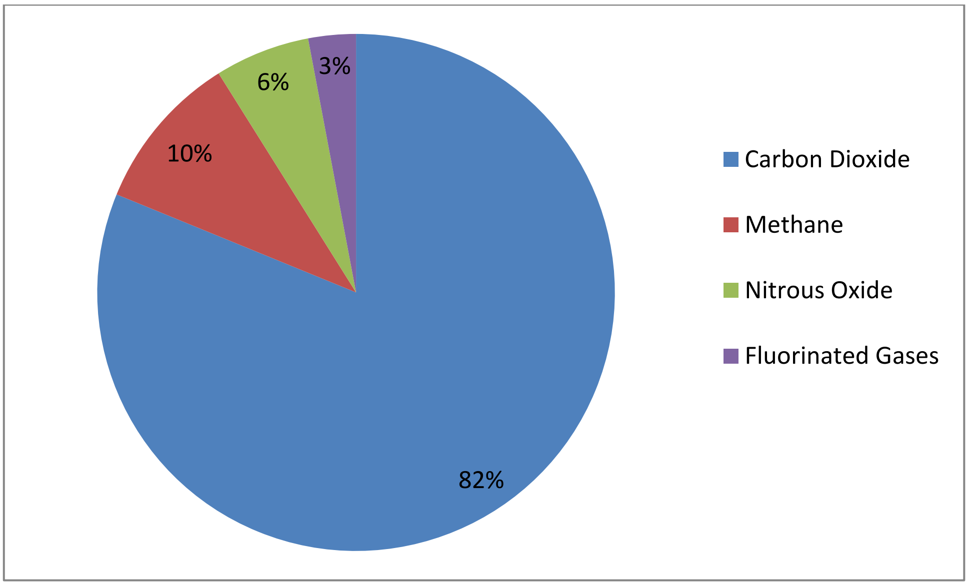

Figure 2.3: Percentage of greenhouse gases emission in the United States in 2017 (Environmental Protection Agency of United States (2016)

The significant effects of increase in greenhouse gases (GHGs) are seen by the increase of dryness as well as frequent rainfall and flood. Besides, increase of earth temperature and tendency for forest to catch fire, rising of sea water level, occurrence of severe storm and damage to water resources, farming and the ecosystems are part of the effects. In addition to the threat to human health, greenhouse gas in various countries could also be detrimental to national safety (Samimi and Zarinabadi, 2012).

Malaysia has signed numerous international greenhouse gas emissions agreements, including Montreal's 1987 Protocol, the 1992 Kyoto Protocol, the 2009 Copenhagen Agreement and the 2010 Cancun Agreement (Shahid et al., 2014). Furthermore, Malaysia has also acknowledged that its greenhouse gas emissions will be cut down by up to 40 percent by 2020, which is comparable to 2005 levels in order to implement the Cancun Agreements and the Bali Declaration on the joint efforts of both developed and developing countries to reduce emissions.

According to Salahudin et al. (2013), in order to mitigate emissions, Malaysia's government is actively engaged in several international agreements including Montreal 1987, Kyoto protocol in 1997 and the climate summit in Copenhagen Denmark in 2009. On 24th July 2009, Malaysia's government recently introduced the National Green Technology policy (NGTP), developing five strategic trusts, including public awareness in Malaysia's tenth plan. Furthermore, National Green Technology Policy (NGTP) also has the initiative to implement green technology which can produce zero or low emissions of greenhouse gas (GHG). The five strategic trusts are as follows:

1. **Development on a sustainable Path** – Integrate response of climate change into national development plans in order to accomplish the country's desire for sustainable development.
2. **Conservation of environmental and natural resources** – Enhanced implementation of actions on climate change that contribute to the conservation of the environment and sustainable use of natural resources.
3. **Coordinated Implementation** – Include climate change considerations into implementation of climate change responses.
4. **Effective Participation** – For effective implementation of climate change responses, participation of stakeholders and major groups has to be revised.
5. **Common but differentiated Responsibilities and Respective Capabilities** – International climate change engagement will be based on the principle of shared but differentiated responsibility and capabilities.

2.3 Carbon Dioxide (CO_2) Emission

As stated by Schmalensee et al. (2001), majority of the scientists believe that if the concentrations of carbon dioxide (CO_2) and other so-called greenhouse gasses continue to increase in the atmosphere, the climate of the earth will become warmer.

Robertson (2006) has studied that the probability if the concentration of carbon dioxide (CO_2) in the atmosphere reaches 426 ppm in less than two generations from today, the health of at least some sections of the world's population, including those of developed nations, will deteriorate. It is also clear that the ecosystem and humanity are seriously threatened if the extremes of conditions described above eventuate.

The severity of the harmful climate change caused by humans is not only on the extent of the change, but also on the likeliness for irreversibility. Solomon et al. (2009) stated that the climate change resulting from an increase in the concentration of carbon dioxide (CO_2) is largely irreversible for 1,000 years following the end of emissions.

On the other hand, Ahmad and Wyckoff (2003) claimed that most of carbon dioxide (CO_2) is emitted during the burning of fossil fuels and the organisation for economic cooperation and development (OECD) countries account for more than half of the world's total carbon dioxide emissions, while some other four countries (Brazil, China, India and Russia) account for another quarter of the global total. They also reported that these policies which aimed at reducing these emissions set emission reduction targets were based on some previous levels. For example, for many countries the 1990 Kyoto Protocol was used as a benchmark for success and compliance with the Protocol.

Elhadi et al. (2015) noted that the rising demand for energy and strong dependence on fossil fuels in transportation will increase the level of carbon dioxide (CO_2) emissions. Carbon dioxide (CO_2) is the main emission of road transports. The amount of carbon dioxide (CO_2) emissions is directly associated to the amount of fuel consumed. Besides, other gas emissions also depend on the amount of fuel used and they are affected by the vehicle type, the fuel consumption rate and the emission factor of each fuel.

Likewise, Barth and Boriboonsomsin (2010) claimed that road transport plays a vital role in carbon dioxide (CO_2) emissions, accounting for roughly a third of the inventory of the United States. Therefore, transport policymakers seek to make vehicles more efficient and increase the use of carbon-neutral alternative fuels in order to reduce CO_2 emissions in the future. For example, CO_2 emissions can be improved by reducing traffic congestion.

In addition, Papagiannaki and Diakoulaki (2009) stated that the steady increase in energy use and CO_2 emissions from private vehicles lead to more study of fundamental drivers' behaviours influencing the change in emissions. At the same time, the growing demands for energy and highly dependent on fossil fuels in transport will also increase Malaysian CO_2 emission levels (Indati and Bekhet, 2014). Table 2.2 shows total CO_2 emissions from transportation sector in Malaysia.

Table 2.2: Total CO_2 emissions from transportation sector in Malaysia (Indati and Bekhet, 2014)

Year	CO_2 Emissions (Tons)
1995	23,923,654
1996	27,362,020
1997	31,362,250
1998	29,911,387
1999	34,856,822
2000	36,954,241
2001	40,214,007
2002	41,137,864
2003	43,677,614
2004	47,082,204
2005	46,746,590
2006	45,294,132
2007	47,976,559
2008	50,085,110
2009	49,187,895
2010	51,338,726
2011	53,060,646

2.4 Drawbacks of Private Vehicles

Read (2005) in his innovation proved that private vehicles have changed the urban life in term of offering the opportunity and accessibility to travel all over the place. Besides, private vehicle has a reliability and availability rate near 100%. However, the cost of owning a private vehicle was reported higher than the average income. In addition, the increase in private vehicle ownership has created congestion in urban areas.

Meanwhile, studies by Mohamad and Kiggundu (2007) and Borhan et al. (2014) have found the same finding which shows that private car is now an essential and has become dominant means of transportation in many cities today. The rising in people's choice of private car usage as a transport mode is due to its clear advantages. One of the important reasons many people opt to own a car is the unregulated freedom that car users enjoy. While public transport modes require services to be shared with strangers, the private car offers its user with privacy and comfort. It is also suggested that as more and more active car usage has led to more accessibility problems in and around industrialized countries because of traffic jams and parking problems. Private vehicles also cause serious problems in addition to road congestions including CO_2, global warming and noise.

Motor vehicles produce particles matter <2.5 μm ($PM_{2.5}$), so $PM_{2.5}$ levels tend to be higher in proximity of busy streets or in another words urban area (Buckeridge et al., 2002). McCubbin (1999) says the health costs of motor vehicles are much higher than reported in the past. Particulates are the most detrimental pollutant when compared to ozone and other pollutants which have lesser consequences. Due to higher particulate emissions, diesel vehicles cause more damage per mile than gasoline vehicles.

According to Marshall et al. (2005), motor vehicles are a primary source of criteria pollutants and harmful air pollutants that are ever-present in urban areas of US as well as worldwide. Meanwhile, a study by Afroz et al. (2003) have found that over the last five years the major source of air pollution has been emissions from mobile sources (i.e. private vehicles), accounting for 70% to 75% of total air pollution in Malaysia.

2.5 Contribution of Private Vehicles to CO_2 Emission

The fuel efficiency of passenger vehicles is frequently highlighted as one of the most important areas of action to reduce CO_2 emissions in the transport sector. This can be made possible either through automotive technological development, or through demand-based measures such as influencing the choice of first time car buyers Jordan-Joergensen, J (Cowi, 2002).

Papagiannaki and Diakoulaki (2009) stated that in the cases of Greece and Denmark, private vehicles are responsible for half the emissions from road transport including their upward pattern, which causes a decomposition analysis to be carried out focused precisely on this road transport section. The factors evaluated in the current analysis of decomposition are associated with ownership of vehicles, fuel mix, motor power, car technology, and the annual miles. Results comparison showed the difference in transport profile in both countries and the effects on the CO_2 emission trend were demonstrated in Table 2.3.

Table 2.3: Ownership, average distance travelled and CO_2 emissions for the entire fleet, gasoline and diesel cars (Papagiannaki and Diakoulaki, 2009)

	Fleet			Gasoline Cars			Diesel Cars		
	CO2	Vehicles/ 1000cap	Distance (km)	CO2	Vehicles/ 1000cap	Distance (km)	CO2	Vehicles/ 1000cap	Distance (km)
Denmark									
1990	4,919	319	16,656	4,434	303	15,834	485	16.2	31,981
1995	5,853	332	19,113	5,334	315	18,360	520	16.8	33,184
2000	6,286	360	18,829	5,577	337	17,884	709	23	32,694
2005	6,423	372	18,262	5,076	329	16,385	1347	43.4	32,484
Greece									
1990	4,573	171	14,688	4,112	168	13,490	462	3.0	80,940
1995	5,381	209	13,977	4,823	205	12,829	558	3.6	78,937
2000	7,014	292	13,005	6,411	288	12,200	603	3.6	76,983
2005	8,985	391	12,276	8,267	387	11,602	718	4.1	75,078

2.6 Measurement of Vehicle Emission

Ragab et al. (2017) has conducted a study to investigate methods to reduce air emissions which are well known for its harmful effects to the mankind. Road traffic has been mainly associated with air emissions, particularly road air emissions. In order to reduce road air emissions, traffic management is very essential. Traffic management has been used solely to improve traffic flow efficiency. However, with the rising of environmental concerns, traffic management can also be used to reduce the negative impacts of traffic on the environment. Improvement of road traffic flow can reduce vehicle emissions and travel time whereas promotion of public transport can reduce air emission but cannot reduce travel time. Ragab et al. (2017) studied three situations to lessen the effect of traffic on air emissions. The situations were:

1) Scenario 0: Original scenario (Real traffic volumes and speeds were used to analyse the chosen network);
2) Scenario 1: Road traffic improvement; and
3) Scenario 2: Public transportation promotion.

Mustapa and Bekhet (2015) examined the key factors of CO_2 emissions in the road transport sector using multiple regressions analyse by using data from 1990 to 2013. The variables used in the analysis were fuel consumption (FC), fuel efficiency (FE), fuel price (FP) and distance travel (DT). The results indicated that the primary factors causing the hike of CO_2 emissions were fuel efficiency (FE), fuel price (FP) and distance travel (DT). For the reduction of CO_2 emissions, the authors proposed some policy recommendations which were:

- Since most passenger cars were running on petrol (93 %), by increasing use of efficient vehicle technology, like hybrid and electric vehicles, can reduce CO_2 emissions in this sector. The government should therefore amplify the promotion of these vehicles and proceed to provide imperative fiscal encouragement to speed up their use.

- Distance travel (DT) was considered the key factor for diesel vehicles and therefore the options for fuel switching can be introduced to reduce FC while satisfying mobility needs. This can be achieved in order to achieve reductions in CO_2 emissions by stepping up the use of alternative fuels, including biofuels that contain less CO_2.
- Now that FP is also shown to have major effect on CO_2 emission reductions, the Government has decided to withdraw the FP subsidies in 2014 for both gasoline and diesel vehicles. Therefore, additional requirements management measures can be implemented to both reducing FC and CO_2 emissions, such as higher vehicle taxes, carbon tax, and congestion charges in city areas.

According to Franco et al. (2013), the development of Emission Factor (EFs) in the formula helped to achieve a more accurate outcome. The method of testing the chassis and engine dynamometer was found to be not adequate, as it cannot depict the actual circumstances of road traffic. Nevertheless, the testing of chassis and engine dynamometers is still an important method for gauging emissions from a vehicle.

For the case of Taichung City, in order for Chang and Lin (2018) to analyse energy consumption and its relevance, the study had calculated the mutual relationship between the emission of carbon dioxide from traffic and building development scale. The duo had used multiplication of the type of vehicles (such as passenger cars, lorries and cars) by fuel type (diesel, petrol, etc.) and then by unit fuel emissions factor or unit mileage emission coefficients to calculate for total traffic CO_2 emissions.

Based on Chang and Lin (2018) analysis, following a count of the total number of vehicles in 24 hours at the road crossing, the linear regression analysis shall be carried out according to the morning and evening high data concerning the forecast model for the total traffic volume at each road crossing. As shown in Equation (2.1) below the prediction of total traffic volume in road crossing is obtained. Figure 2.4 shows the relationship between total traffic volume and hour.

$$y = 2261.52 + 2.36y_1 + 10.18y_2 \qquad R^2 = 0.99 \qquad (2.1)$$

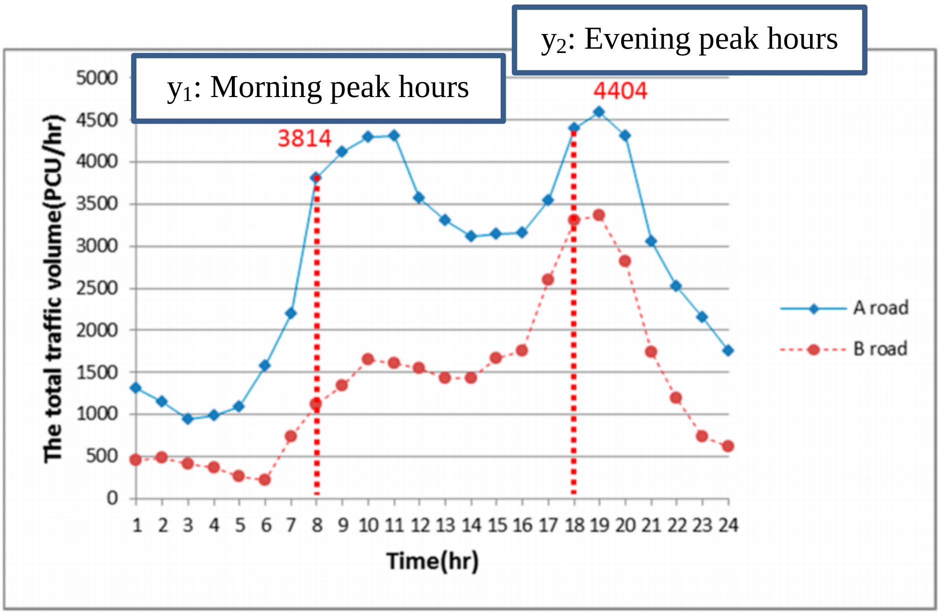

Figure 2.4: Relationship between the traffic volume at the morning peak and evening peak (Chang and Lin, 2018)

In terms of driving behaviour, Tong et al. (2000) had found that fluctuating driving behaviours (i.e., acceleration and deceleration) were more polluting than the constant-speed driving behaviours (i.e., cruising and idling) in terms of g/km and g/sec produced. These results showed that measuring emissions on the road is viable in the derivation of emissions from vehicles and fuel consumption factors in urban driving conditions.

The transport sector currently accounts for 13.5% of global warming. The amount of carbon dioxide (CO_2) emitted from the distance travelled is directly proportional to the fuel economy, with approximately 2.4 kg of CO_2 released from each litre of gasoline burnt (Ong et al., 2011).