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ENVIRONMENTAL CO-BENEFITS OF MASS RAPID TRANSIT SYSTEM IMPROVEMENT INITIATIVE IN SELANGOR, MALAYSIA

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By

AZADEH GHADIMIZADEH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

September 2018

DEDICATION

Dedicated to my Father
A strong and gentle soul for earing an honest living for us and supporting and encouraging me to believe in myself…you are my Angle on the ground…

To my mother
Who taught me to believe in hard work and that so much could be done with little.
You are my hero forever…

To love
The only strength in the life that everyone needs.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ENVIRONMENTAL CO-BENEFITS OF MASS RAPID TRANSIT SYSTEM IMPROVEMENT INITIATIVE IN SELANGOR, MALAYSIA

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September 2018

Chairman : Professor Ahmad Makmom Abdullah, PhD
Faculty : Environmental Studies

The world have gradually experienced the impacts of climate change due to increase in human population and activities. Transportation sector is one of the major contributors to greenhouse gas (GHG) emissions and other local air pollutants which are NO_2, CO and $PM_{2.5.}$ In line with this issue, more cities in developing countries have taken innovative initiatives to create sustainable urban mobility revitalizing the role of their public transport systems. Co-benefits approach has been identified as a solution that aims to align climate change issue with local development goals. Implementation of co-benefits approach aims to strengthen policy making process, which is identified as being especially important in the context of developing cities. The aim of this study is calculating environmental co-benefits of modal shift by MRT. Emission inventories for CO_2 and local air pollutants such as NO_2, CO and $PM_{2.5}$ were developed for road transport sector for year 2011 and were used as a basis to explore intervention that is likely to reduce air pollution and GHG emission in this sector. The current study also presents a methodology to measure the environmental co-benefits of transport initiatives, defined here as GHG emissions in conjunction with local air pollution in Selangor. The methodology adopted the co-benefit approach to estimate the environmental co-benefits of both air quality improvement and CO_2 emission reduction generated by modal shift to MRT. According to MRT daily ridership, two main scenarios were defined to show modal shift to MRT. Scenario (a) when the car riders shift to MRT and scenario (b), is motorcycle user's modal shift. Also this study used the maximum and minimum occupancy of cars and motorcycles to show the range of emission reduction in each modal shift scenario. One of the main ways that MRT can generate environmental co-benefits is to reduce car and motorcycle ridership. According to MRT daily ridership, certain percentage of cars and motorcycle are expected to be off roads in study area. This amount of reduction in vehicles on Selangor roads will lead to reduction of vehicle kilometere travelled and also the amount of reduction in emission of CO_2 and local pollutants. Specifically, this

reduction comes from avoided emission that should have been emitted by MRT passengers if they are to use their motorized modes (cars and motorcycles). Modal shift analysis identifies that scenarrio 1a recorded the highest reduction for all the pollutants. Values recorded include 4.56% for CO_2, 3.55% for NO_2, 4.01% for CO and 0.51% for $PM_{2.5}$. For CO_2 and NO_2, reduction is directly related with changes in scenarios as one moves from scenario 1a to scenario 2b. While CO and $PM_{2.5}$ reduction do not follow any direct sequence (from scenario 1a to scenario 2b). In all the scenarios, CO_2 emission recorded the highest reduction followed by CO, NO_2 and $PM_{2.5}$. Lowest reduction was recorded in scenario 2b for CO_2, CO and NO_2 while scenario 1b recorded the lowest reduction for $PM_{2.5}$. In this study also integrated modelling approach (MM5-SMOKE-CMAQ) was established and simulations on meteorological conditions, emissions, and air pollution dispersions were performed to show CO_2 emission reduction through different modal shift scenarios across the study area. The study showed that the existence of MRT has potentially contributed to the reduction of global and local environmental pollution through mainly the avoided motorized trips by shifting to MRT particularly from cars and motorcycles.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MANFAAT BERSAMA ALAM SEKITAR BAGI INITIATIF PEMBAIKAN PENGANGKUTAN AWAM: KES SISTEM TRANSIT LAJU MASSA DI SELANGOR MALAYSIA

Oleh

AZADEH GHADIMIZADEH

September 2018

Pengerusi : Profesor Ahmad Makmom Abdullah, PhD
Fakulti : Pengajian Alam Sekitar

Dunia kini secara beransur-ansur telah mengalami kesan perubahan cuaca akibat peningkatan populasi dan aktiviti manusia. Sektor pengangkutan merupakan salah satu sumbangan utama bagi emisi gas rumah kaca (GHG) dan pencemaran udara setempat lain, iaitu NO_2, CO_2 dan $PM_{2.5}$. Berhubung dengan isu ini, lebih banyak bandar di negara membangun telah mengambil initiatif inovatif untuk mewujudkan mobiliti bandar kelestarian dengan mengukuhkan semula peranan sistem pengangkutan awam mereka. Pendekatan manfaat bersama telah dikenal pasti sebagai penyelesaian yang bertujuan untuk mengimbangi isu perubahan cuaca dengan matlamat pembangunan setempat. Pengimplementasian pendekatan manfaat bersama bertujuan untuk memperkukuh proses penggubalan polisi yang telah dikenal pasti sebagai sangat penting dalam konteks pembangunan bandar. Tujuan kajian ini adalah untuk mengukur manfaat bersama alam sekitar bagi anjakan modal oleh MRT. Inventori emisi bagi CO_2 dan pencemaran udara setempat seperti NO_2, CO_2 dan $PM_{2.5}$. telah dibangunkan bagi sektor pengangkutan pada tahun 2011 dan telah digunakan sebagai asas untuk meneliti intervensi yang mungkin dapat mengurangkan pencemaran udara dan emisi GHG dalam sektor ini. Kajian ini juga mengutarakan metodologi bagi mengukur manfaat bersama alam sekitar bagi initiatif pengangkutan yang didefinisikan di sini sebagai emisi CO_2 yang berkaitan dengan pencemaran udara setempat di negeri Selangor. Metodologi ini menggunakan pendekatan manfaat bersama bagi menganggarkan manfaat bersama alam sekitar bagi kedua-dua penambahbaikan kualiti udara dan pengurangan emisi CO_2 yang dijana oleh anjakan modal kepada MRT. Berdasarkan ridership harian MRT, dua senario utama telah dijelaskan untuk menunjukkan anjakan modal kepada MRT. Senario (a) apabila pengguna kereta beranjak kepada MRT dan scenario (b), ialah anjakan modal pengguna motosikal. Kajian ini juga menggunakan kepenghunian maksimum dan minimum kereta dan motosikal bagi memperlihatkan julat pengurangan emisi dalam

setiap senario anjakan modal.Salah satu cara MRT supaya dapat menjana manfaat bersama alam sekitar adalah untuk mengurangkan pengguna kereta dan motosikal. Berdasarkan pengguna harian MRT , beberapa peratus kereta dan motosikal dijangka tiada di jalan raya di kawasan yang dikaji. Jumlah pengurangan kenderaan di jalan raya Selangor akan menyebabkan pengurangan kenderaan laluan per kilometer dan juga jumlah pengurangan emisi CO_2 dan pencemaran setempat. Lebih khusus lagi, pengurangan tersebut wujud dari emisi yang dihindari yang sepatutnya dikeluarkan oleh penumpang MRT sekiranya mereka menggunakan mod kenderaan (kereta dan motosikal). Analisis anjakan modal mengenal pasti bahawa senario 1a merekodkan pengurangan tertinggi bagi semua polutan. Nilai direkodkan termasuk 4.56% untuk CO_2, 3.55% untuk NO_2, 4.01% untuk CO dan 0.51% untuk $PM_{2.5}$. Bagi CO_2 dan NO_2, pengurangan secara langsung berkaitan dengan perubahan dalam senario disebabkan satu gerakan dari senario 1a ke senario 2b. Manakala pengurangan CO dan $PM_{2.5}$ tidak mengikuti sebarang urutan langsung (dari scenario 1a ke scenario 2b). Dalam semua senario, emisi CO_2 merekodkan pengurangan paling tinggi diikuti oleh CO, NO_2 dan $PM_{2.5}$. Pengurangan paling rendah direkodkan dalam senario 2b untuk CO_2, CO dan NO_2 manakala senario 1b direkodkan pengurangan paling rendah untuk $PM_{2.5}$. Dalam kajian ini pendekatan modeling integrasi (MM5-SMOKE-CMAQ) telah diwujudkan dan simulasi ke atas keadaan meteorologi, emisi, dan penyebaran pencemaran udara telah dilaksanakan bagi menunjukkan pengurangan emisi CO_2 melalui senario anjakan modal berbeza yang merentasi kawasan kajian. Kajian ini menunjukkan bahawa kewujudan MRT mempunyai potensi yang menyumbang kepada pengurangan pencemaran alam sekitar secara global dan setempat melalui terutamanya perjalanan berkenderaan yang diekurangkan dengan mengubah kepada MRT, terutamanya bagi kereta dan motosikal.

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Thura Sheikhy Narani

I certify that a Thesis Examination Committee has met on 21 September 2018 to conduct the final examination of Azadeh Ghadimzadeh on her thesis entitled "Environmental Co-Benefits of Mass Rapid Transit System Improvement Initiative in Selangor, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

CMAQ	Community Multi-scale Air Quality Model
DOSM	Department of Statistic Malaysia
GIS	Geographical Information System
GHG	Green House Gases
JKR	Public Works Department
LULC	Land Use and Land Cover
MM5	Fifth generation PSU/NCAR Mesoscale Model
MRT	Mass Rapid Transit
NCAR	National Center for Atmospheric Research National
NCAR	National Center for Atmospheric Research
PM	Particulate Matter
PBL	Planetary Boundary Layer
SMOKE	Sparse Matrix Operational Kernel Emission
JPBD	Town and Country Planning Department
USEPA	United States Environmental Protection Agency
UCAR	University Corporation for Atmospheric Research
VKT	Vehicle Kilometer Travelled

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The transport sector is the major consumer energy making it the primary man made source of greenhouse gases (GHGs) as well atmospheric source of local air pollutants such as NO_2, CO and $PM_{2.5}$. Urban transport pose more problem than other sectors. Apart from threat of climate change, large consumption of fossil fuels during daily transportation activities in urban areas results to several adverse social consequences and also causes threat to the local environment (Mrkajic, Vukelic, & Mihajlov, 2015).

Transport sector largely depends on fuels which makes it the major cause of this drift (Davis *et al.*, 2009). According to CSI (2009), growth in urban areas, higher incomes and low prices of fuels contributes largely to the increase in vehicles owned by people as well as increase in vehicle kilometre travelled (VKT). Essentially, vehicle emission in the transport sector depends on the number of kilometres travelled, fuel consumption and intensity as shown in Table 1.1. Therefore, these components can be used to strategize the reduction of transport emissions.

Table 1.1 : Causes of GHG emissions in relation to transport sector and possible mitigation strategies

Causes of GHG emissions	Possible mitigation strategy
Vehicle Kilometre Travelled	Modifying land use systems to discourage the possible need to travel, shifting the mode of transport from cars to public transport
Fuel consumption	Improve fuel efficiency
Fuel carbon intensity	Electric cars powered by renewable energy

(Source: Adapted from Dirgahayani, 2013)

The life of urban residents, local and global environment is directly related to local transport development decisions. Countries like Malaysia is a typical example of such scenarios where multiple local development and sustainability challenges are common (Mrkajic *et al*., 2015). With regards to transport sector, there exist problems that are connected to development of new infrastructure, rearrangement of transport system and reduction of local environment quality (IPCC, 2014).

Mrkajic (2015), reported that globally, cities in developing countries are causing an increase in the emission of GHGs as a result of urbanization, rapid growth and increase in vehicles. Hence, for effective response to climate change at the global level, it has

become apparent that mitigation is upon not only cities in developing countries but also on cities from developing countries. Nevertheless, maintaining a balance in atmospheric GHGs emission has become a policy of most industrialized countries. While the developing countries are not compel by any international law to decrease their GHGs emissions owing to global justice and equity issues.

Moreover, sustainable development goals are in contrast with local development goals (e.g. increase in urbanization and economic growth). Reduction of GHGs emission at the local level are put into jeopardy by poor political commitment and policy effectiveness (Mrkajic *et al*., 2015). The co-benefits approach happened to be an emerging concept that can be used to tackle these issues (Doll & Balaban, 2013). The concept is based putting up climate change issues with local development goals. It helps to increase awareness in policies established at international and national levels, especially those associated with GHGs emission which ought to be executed at the local level for successful implementation (Jiang *et al*., 2013)

The principle behind co-benefits approach is the conventional use of climate mitigation problems within local level policies which will lead to local environmental co-benefits in addition to reducing GHGs emission (Mrkajic *et al*., 2015). According to this, it is widely speculated that transport policies particularly those necessitate public transport improvement can decrease both global and local (environmental) burdens (Mrkajic *et al.*, 2015). Undeniably, urban public transport improvement has been seen as a promising urban mobility policy that both addresses global climate change and local environmental issues (Doll & Balaban, 2013).

Co-benefits approach is particularly relevant to developing countries who mostly give little concern to GHGs or local air pollutant emission during the development process disputing that the need for development supersedes the concern to tackle environmental problems. In order to achieve this, classic development course is carried out where development of countries is based on local conditions such as air quality. At certain level of the developmental process, local conditions put into consideration through remediation and technological improvement (Doll & Balaban, 2013).

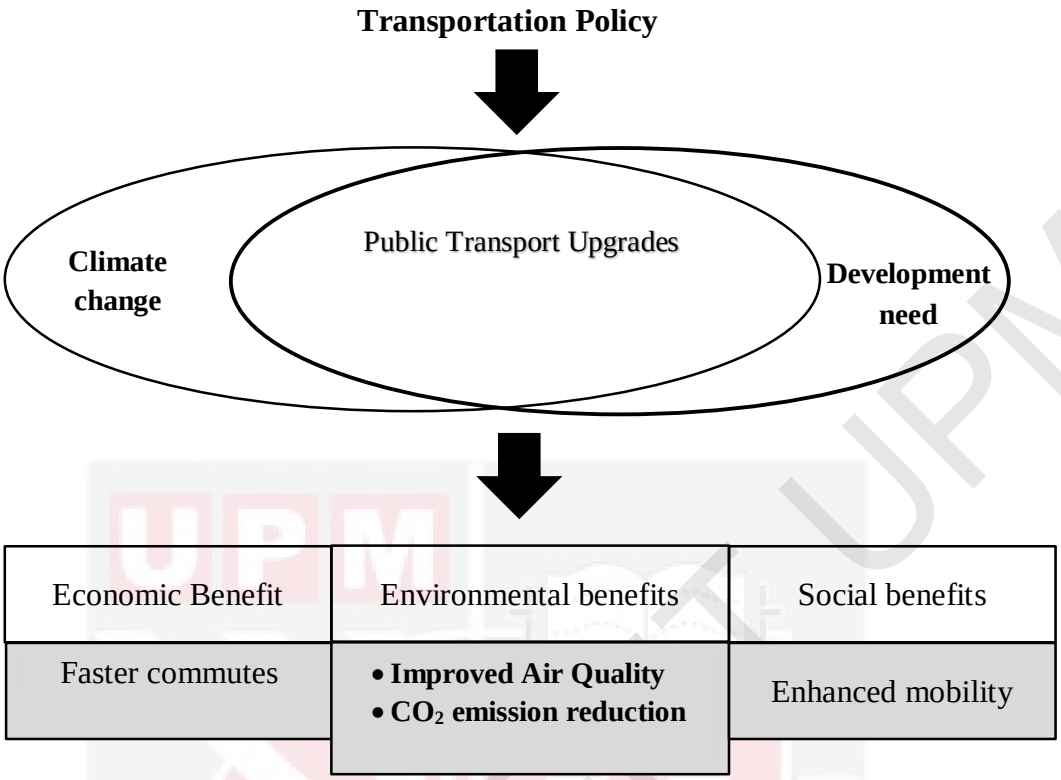

Figure 1.1 : Environmental co-benefits of public transport improvements
(Source: Romero & Zusman, 2011)

Figure 1.1 shows environmental co-benefits of public transport improvements. Policy benefits that are applied for several reasons at the same time such as climate change mitigation, acknowledge that most policies are designed to take into consideration that GHGs have other equally important bases (e.g. those related to objectives of development, sustainability and equity) (IGES, 2011).

This research attempts to estimate the environmental co-benefits, both local air quality improvement and CO_2 emission reduction generated by the urban public transport improvement project. It takes Mass Rapid Transit (MRT) initiative introduced in Selangor as the case study.

1.2 Problem Statement

Recently most cities in developing countries are posed with challenges such as climate change, society development and environmental pollution. These challenges interact with each other one way or the other. One of the greatest anthropogenic challenge of 21st century is climate change. The impact and causes of climate change were fully studied in recent years by many researchers (Doll NHC, 2013). On the other hand, studies on air pollution sources and impacts were studied comprehensively as well. The interactions of these two components (air pollution and climate change) on each other have been also being previously studied for many years. Few researches exist in the literature that combines effect of air pollution, climate change domain and society development mainly for cities in developing countries like Malaysia, that encounter triple challenges of development, climate change adaptation and environmental pollution problems (Kwan & Hashim, 2016). There is so far little emphasis on environmental co-benefits from shift to public transport research in Malaysia. The country which represents one of the largest economies in Asia has little consideration on GHG emissions within environmental co-benefits framework, with opportunities for control of emissions and simultaneous reduction of local air pollution and GHGs. According to this problem, it is difficult to establish nomenclature for this domain. Actually researches on climate change, air pollution and community are not integrated and holistic. In Malaysia Different agencies involved in managing the air pollution like NRE, DOE and KETTHA on climate change issues. Also there are different policies for climate change and air pollution and different targets. In this research, co-benefit will emerge as a new concept that will serve as a vital linking tool to development and environmental issues. It enhances the link between air quality, community and climate change as well as helps to decrease the cost and time to conduct these three aspects. Assessment of co-benefits indicates improvement in all parts of environmental perspectives (Kwan & Hashim, 2016). Co-benefits increase the use and positive effects from society development at both global and local scales and it is important to make aware to the policy makers the significance of policy implementation to mainstream climate strategy considerations in to the development agenda (Puppim De Oliveira 2013).

1.3 Scope of the research

The study focuses on estimation of environmental co-benefits of CO_2 emission reduction and air quality improvement generated by MRT project. For this purpose, this research used three main areas; society development, environmental pollution and climate change components to quantify environmental co-benefits by public transport. The study area is Selangor, the most important state in Malaysia. To show air pollution situation and emission profile in the study area, a method was developed for estimation emission inventory. CO_2 emission for climate change and three local air pollutants (NO_2, CO and $PM_{2.5}$) were used indicators in estimation emission inventories. Transportation sector was used as an emission source and vehicles on road including six types of vehicles were used to estimate and develop emission inventories. Geographical Information System (GIS) technique involving statistical spatial

distribution and interchange emission values was constructed and Selangor digital road network map was generated and produced in this study. Three types of roads, federal, highway and state roads were used to calculate emission inventories. This study also demonstrates the method on developing local emission data set and emission inventories for GHGs (CO_2) and also local air pollutants such as NO_2, CO and $PM_{2.5}$ for quantifying environmental co-benefits of modal shift based on vehicle kilometre travelled, fuel consumption, fuel share and emission factors. The fuel types used in this research were petrol and diesel. The study also used the bottom up approach to calculate total vehicle kilometre travelled in transportation sector in Selangor.In this study Geostatistical analysis was used to generate CO_2 and local air pollutants such as CO, NO_2 and $PM_{2.5}$ spatial distribution maps .Public transport (MRT) daily ridership was used to define different modal shift Scenarios and calculate environmental co-benefits that is defined as CO_2 reduction in conjunction with local air improvements. This study also modified a tool and showed the method to calculate environmental co-benefits by modal shift of mass rapid transit in Selangor. Two main modal shift scenarios were explored to quantifying the environmental co-benefits. This study used the modal shift by MRT ridership to calculate environmental co-benefits. In this research climate change and air pollution policies were not taken in to the account. Similarly, this study also focused on establishing an integrated mesoscale air quality model (MM5-SMOKE –CMAQ) which includes simulating meteorological condition using local land use emission inventory as input for the models. in this stage Meteorological Modelling (MM5) was used to simulate the atmospheric conditions of study area and the Sparse Matrix Operator Kernel Emissions (SMOKE) program was used to process global anthropogenic emissions To the regional domain and provide dynamical boundary conditions from global simulations to the regional Community Multi-scale Air Quality (CMAQ) model that is Chemistry transport modelling system for simulation of the chemical transformation and destiny of CO_2 in the study area. CO_2 emission reduction through different modal shift scenarios and interaction between meteorological conditions and dispersion of CO_2 emission to demonstrate local and climate benefit were also discussed in this study.

1.4 Research questions

1- Can modeling of air pollution and GHGs emission estimate the co-benefits?
2- Can indicators used in relating the climate change, local air pollution and society address the co-benefits well?
3- Are the three integrated model used in this study suitable in showing the environmental benefits?

Research objectives

This study focused on calculating the environmental co-benefits of modal shift by Mass Rapid Transit in study area. To achieve this goal, several objectives are listed as below.

1. To establish greenhouse gas emission inventory and local air pollutants (NO_2, CO and $PM_{2.5}$) profiles from on road vehicles for Selangor.
2. To quantify environmental co-benefits by modal shift (cars and motorcycles) by Mass Rapid Transit in Selangor.
3. To simulate the dispersion patterns and concentration of CO_2 emission and reduction of CO_2 through different modal shift scenarios in study area using integrated modelling MM5-SMOKE-CMAQ system.

1.5 Significance of the Study

This study focusses on environmental co-benefits resulting from transport modal shift by public transport (MRT) that provides a better understanding of the several effects of a policy, thereby improving the ability to inform many decisions. The use of co-benefit approach to solve numerous environmental issues has the power to progressively change Asian countries and attain positive impacts that enhance the quality of urban residents and the quality of ecosphere upon which all are totally and mutually interdependent. (Nizam, Muhammad, Abdullah, & Newaz, 2013). The application of environmental co-benefits approach to different urban sectors of Malaysia will enable the development of innovative urban management tools that provide effective and efficient resources for identifying, preventing, and solving urban problems such as basic infrastructure including environmental services and increase in population. In addition, when environmental co-benefits approach is efficiently developed, it can become a valuable way of creating public awareness to land use planners and decision makers, whose target are to carry out developmental strategies at the expense of environmental ones (Doll & Balaban, 2013).

Also, with modelling platform established in this research, additional study on other types of target pollutants could be easily carried out and air quality of an area of interest could be easily examined. The integrated model could help to investigate the relationship between climate change, land use changes urbanization and air pollution. Decision and policy makers in Malaysia could utilize the model as one of the tools in preventing and reducing adverse impacts on environment due to air pollution and acid deposition. Emission inventories established during the study could be further refined by gathering more detail information which will increase the accuracy and useful for the air pollution modelling in future (Shamsudin, Minhans, & Puan, 2014).

1.6 Organization of the thesis

In order to have a holistic approach to the subject of the environmental co-benefits of modal shifts to public transport (MRT) in study area, the following steps were taken in this study: Chapter I is on the introductory aspect of the study. This involved an overview of transportation, rapid growth and changing transport sector, the pollution resulted from emission and co-benefit. Likewise scope and objectives, significance of the study also limitations were highlighted. Chapter II focuses on a literature review that covers the discussion on the background of public transport, interventions and policies in transport sector three integrated model application and also environmental co-benefits in transport sector at global level and Malaysia as well. The methodology section presents the quantitative aspects of the evaluation of co-benefits. Chapter IV presents the results of the Scenarios explored by the tool, discusses the major challenges to quantification and strengthening of co-benefits in terms of issues with data collection, the result of the modelling stage and discussion on CO_2 reduction through modal shift Scenarios. Chapter V covers conclusion and recommendations.

1.7 Original contribution

The novelty of this research is firstly in the methodology used to establish emission inventories of CO_2 and local air pollutants in transportation sector and also the methodology to quantify the environmental co-benefits of modal shift by MRT. Secondly, the work provide a guidance which can serve as a valuable quantitative tool for policy makers. MRT was chosen in this study as a pre-existing transport project. This study therefore, does not assume that the MRT is the most suitable solution to address the transport requirements of Selangor. The aim is to provide an understanding of environmental co-benefits of MRT given that it has already been developed.

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