OPERATIONAL CARBON EMISSION AND ECONOMIC ANALYSIS OF GREEN TECHNOLOGY IMPLEMENTATION AT REST AND SERVICE AREA

MUHAMMAD ROZAID BIN RAMLI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy in Environment

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

NOVEMBER 2019

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Professor Dr. Zainura Zainon Noor, for encouragement, guidance, critics and friendship. I am also very thankful to my co-supervisor Dr. Eeydzah Aminudin for their guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Lembaga Lebuhraya Malaysia (LLM) for funding my Masters study. I am indeed thankful to those who have shown their full support to the making of this dissertation especially my family members, who constantly supported my life.

I also would like to take this opportunity to say warm thanks to all my beloved friends, who have been so supportive along the way of doing my thesis especially to Che Fatihi, Near and Santi. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

Last but not the least, I would like to thank my family and my wife, for supporting me spiritually in master life. I am grateful to have all of you in my life.

ABSTRACT

Malaysia has committed to reduce its greenhouse gas (GHG) emissions by 45% in the year 2030. With increasing urbanization and living standards of people in Malaysia, there is certainty a substantial increase in human activities especially in mobility via networks of highway. Rest and Service Area (RSA) is one of the important facilities in highway network that operates 24 hours and utilizes significant amount of energy from its daily activities. Therefore, substantial amount of carbon is emitted from the RSA due to electricity usage, water consumption, solid waste and wastewater, as well as fuel consumption from staff commuting and transportation of goods. The aim of this study is to set a baseline target for energy reduction of RSA. In achieving this, the sources of GHG emissions were identified and measured in terms of carbon dioxide equivalency (t CO_2-e) in order to quantify the amount of GHG emitted from its sources. Next, the setting of reduction target were evaluated based on carbon and cost impact of suggested counter-measure. The collected data and questionnaire survey was analysed using Microsoft Excel software. From the overall analysis, it was found that average amount of CO_2-e emissions from electricity consumption contribute about 89% of carbon release for each selected RSA. Therefore, in order to overcome the substantial amount of carbon, LED, solar-powered LED on street light and motion sensor were proposed. Overhead Bridge Restaurant Ayer Keroh which labelled as RSA 2 was chosen as a case study in order to estimate the cost of investment in 20-year period of time prediction. For technology in retrofitting street light, it has shown that solar-powered LED produces longer payback period with 8.89 years compared to LED which is 1.23 years. However, solar-powered LED reduce 51% more carbon emission compared to LED technology. Unlike RSA building, using LED and motion sensor technology shows a shorter payback period with an average of 1.71 - 2.36 years. Although the installation cost for motion sensor is higher than LED technology, the reduction of carbon emissions from motion sensor was found to be 14.28% more than that of LED technology. As conclusion, this study projected that the combination between solar- powered LED for street light and LED or motion sensor technology for RSA building will reduce carbon emissions by about 40% from its baseline year in just 10 years after implementation. Therefore, this study has optimized to set a reduction target of 40% from its baseline by the year 2030.

ABSTRAK

Malaysia telah komited untuk mengurangkan pelepasan gas rumah hijau (GHG) sebanyak 45% pada tahun 2030. Dengan peningkatan urbanisasi dan taraf hidup rakyat di Malaysia, terdapat kepastian peningkatan besar dalam aktiviti manusia terutamanya dalam pergerakan melalui rangkaian lebuh raya. Kawasan Rehat dan Perkhidmatan (RSA) merupakan salah satu kemudahan penting dalam rangkaian lebuh raya yang beroperasi 24 jam dan menggunakan sejumlah besar tenaga dari kegiatan hariannya. Oleh itu, sejumlah besar karbon dipancarkan dari RSA disebabkan oleh penggunaan elektrik, penggunaan air, sisa pepejal dan air kumbahan, serta penggunaan bahan bakar dari pengangkutan dan pengangkutan barang. Tujuan kajian ini adalah untuk menetapkan sasaran asas pengurangan tenaga RSA. Dalam mencapai ini, sumber pelepasan GHG telah dikenal pasti dan diukur dari segi kesamaan karbon dioksida (t CO_2-e) untuk mengira jumlah GHG yang dipancarkan dari sumbernya. Seterusnya, penetapan sasaran pengurangan telah dinilai berdasarkan nilai karbon dan kesan kos cadangan pengubahsuaian. Data yang dikumpulkan dan tinjauan soal selidik dianalisis menggunakan perisian Microsoft Excel. Daripada analisis keseluruhan, didapati bahawa jumlah purata pelepasan CO_2-e daripada penggunaan elektrik menyumbang kira-kira 89% pelepasan karbon untuk setiap RSA terpilih. Oleh itu, untuk mengatasi sejumlah besar karbon, teknologi LED, lampu jalan LED berkuasa solar dan sensor pergerakan dicadangkan. Restoran Atas Jambatan Ayer Keroh yang dilabelkan sebagai RSA 2 dipilih sebagai kajian kes untuk menganggarkan kos pelaburan dalam ramalan masa 20 tahun. Bagi teknologi dalam cahaya jalan pengubahsuai, ia telah menunjukkan bahawa lampu jalan LED berkuasa solar menghasilkan tempoh bayaran balik yang lebih lama dengan 8.89 tahun berbanding lampu LED iaitu 1.23 tahun. Walau bagaimanapun, lampu jalan LED berkuasa solar mengurangkan pelepasan karbon sebanyak 51% berbanding dengan lampu LED. Tidak seperti bangunan RSA, penggunaan lampu LED dan sensor pergerakan menunjukkan tempoh bayaran balik yang lebih pendek dengan purata 1.71 - 2.36 tahun. Walaupun kos pemasangan untuk sensor pergerakan lebih tinggi daripada teknologi lampu LED, pengurangan pelepasan karbon dari sensor gerakan didapati 14.28% lebih daripada teknologi LED. Sebagai kesimpulan, kajian ini memperlihatkan bahawa gabungan antara LED berkuasa solar untuk lampu jalan dan LED atau pergerakan sensor untuk bangunan RSA akan mengurangkan pelepasan karbon sebanyak 40% dari tahun asasnya hanya dalam tempoh 10 tahun selepas pelaksanaan. Oleh itu, kajian ini mengoptimumkan untuk menetapkan sasaran pengurangan sebanyak 40% daripada garis dasarnya menjelang tahun 2030.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

GHG	-	Greenhouse Gas Emissions
GDP	-	Gross Domestic Product
CO_2	-	Carbon Dioxide Emission
LED	-	Light Emitting Diode
COP	-	Conference of the Parties
PV	-	Photovoltaic
UTM	-	Universiti Teknologi Malaysia
DBST	-	Double Bituminous Surface Treatment
JKR	-	Malaysian Public Works Department
MHA	-	Malaysia Highway Authority
RSA	-	Rest and Service Area
ROI	-	Return of Investment
BaU	-	Business as Usual
HVAC	-	Heat Ventilation and Air Conditioning

LIST OF SYMBOLS

P_{OT}	-	Power Output
Si	-	rate of solar intensity
P_p	-	Payback Period
AI	-	Additional Investment
YT_{RM}	-	Yearly Total Energy Savings
L_{ES}	-	Lifetime Energy Savings
LT_{MS}	-	Lifetime Total Maintenance Cost
L_{CP}	-	The Life Cycle Period
E_t		Electric Tariff
TO		Total operation
YT_{kWh}		Yearly Total Energy Savings
$AT_{kWh/d}$		Total Power consumed per day (kWh) after retrofit
$BT_{kWh/d}$		Total Power consumed per day (kWh) before retrofit
Ps		Power saving per day
$T_{kWh/d}$		Total Power consumed per day
PL		Power Lighting
EF		Emission Factor

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Roads are one of the most common forms of public infrastructure in the world, which require continuous investments and improvements to remain serviceable (Mao *et al.*, 2017). In Malaysia, road network system can be divided into three categories, namely state road (61,100 km), federal road (17,500 km) and expressway (1,700 km) (Azhar, 2014). State roads generally comprise of the primary roads providing intra-state travel between the district administrative centres while federal roads are all roads declared under the Federal Roads Ordinance (1959) and the major interurban roads joining the state capitals and roads leading to points of entry to and exit from the country (JKR, 2014).

On the other hand, an expressway is a high-speed road with partial access and extra facilities like access ramps and lane dividers (Wang *et al.*, 2018). According to Malaysian Highway Authority's (MHA) annual report, the expressway network in Malaysia is considered as the best expressway network in Southeast Asia and also in Asia after Japan and China (LLM, 2016). The expressway will link many major cities and towns in western Peninsular Malaysia which acts as the main highway network of the west coast of the peninsular (PLUS, 2018).

Latest, MHA has set a worldwide standard with their best amenities and high standards for safety and comfort of highway users. One of the amenities is Rest and Service Area (RSA) or in Malaysian term Rehat and Rawat (R&R) (Izzul Ramli *et al.*, 2017). Usually, RSA is located at a certain distance alongside highways in order to provide an extra fantastic ride to the visitor (The Star, 2014;Illinois, 2016). According to Wang *et al.* (2018), RSA is an expressway facility, which is established to meet vehicle safety operation requirements and basic physiological and psychological needs of passengers during long time, closed driving on the expressway (Wang *et al.*, 2018). Besides that, it also will assist in reducing the users fatigue and hence keeping off accidents from occurring (Rozana *et al.*, 2013).

This is a necessary facility in highway that provides safety and comfort element for users. For the relaxation and protection purpose, RSAs are commonly placed every 80 to 100 kilometres (Ainee, 2012). RSAs generally run 24 hours per day and use energy for their lighting, cooling, and additionally the restaurants' activities (Rozana *et al.*, 2013). Thus, the operations at RSA will generate a large quantity of carbon footprint from waste, energy consumption and fuel consumption from the users' automobile.

On the other hand, previous report shows that the carbon dioxide (CO_2) emission has accelerated rapidly over the previous few decades (Saeed Balubaid *et al.*, 2015). According to Nor Sharliza *et al.* (2010), almost 30 billion tonnes of CO_2 enters the ecosystem as a result of human activities every year and RSA building is one of the contributors for Greenhouse Gas (GHG) emissions. When many developed nations have effectively decreased the GHG emission, Malaysia continues to enlarge its emission level. They projected that without any mitigation measures, Malaysia's CO_2 emission in 2020 will be amounting to 285.73 million tonnes; a 68.86 % expansion in contrast to year 2000 (Nor Sharliza *et al.*, 2010).

Similarly, Malaysia has an agreement to decrease its GHG emissions intensity of Gross Domestic Product (GDP) by 45% by year 2030 relative to the emissions intensity of GDP in year 2005. This consists of 35% on an unconditional basis and a similar 10% is situation upon receipt of climate finance, technology transfer and capacity building from the developed nations (ASEAN Social Forestry Network, 2015). In order to achieve this target, energy conservation and environmental protection will be necessary for the equipment of service area (Wang *et al.*, 2018).

The reduction of power use in RSA building can be made via a proper design with suitable condition of ventilation system, day lighting and green landscape which can provide beautification of the view and also supply hues for buildings. Wang *et al.*

(2018) also revealed evidence that the operation and management of service area is the key to offering potential value which may increase carbon sink and decrease carbon emission. Therefore, it is a good opportunity to explore and study about the carbon emissions and energy conversation at RSAs which can enable the decision-making process for local government and concessionaire on selecting more climate friendly technologies.

1.2 Problem Statement

RSA can be categorised as a commercial area where highways users rest and relax in between travelling long distance (Paul *et al.,* 2017). The usefulness and amenity expectations of RSA by the public have considerably grown over the past decade. In term of operation, an RSA normally operates 24 hours and utilizes energy for its lighting, cooling, and also restaurant activities (Rozana *et al.*, 2013). Since the operation of RSA will be 24 hours per day, there will be a huge quantity of GHG released on every day basis. Every day, there are massive amount of electricity used and wasted every day at RSA. However, the users' awareness of electricity saving is debatable such as in the case where the fan in the common dining area operates almost 24 hours a day even when there is no visitor at the areas.

Noranai and Azman (2017) studied about the breakdown of electricity consumption in building and concluded that the major contribution to electrical energy is air conditioning with 75% followed by electricity for lighting and other equipment with 25%. Another study carried out in Malaysia also concluded that the utilization of full Heat Ventilation and Air Conditioning (HVAC) system at RSA will cause enlargement in electricity consumption and the CO_2 emission (Ainee, 2012). The study additionally highlighted two major reasons that lead to power wastage which are the use of spotlight that was not environmentally friendly at the parking vicinity and the operation of fan.

Moreover, in United States reported that about 35 to 40% of total energy is consumed in buildings and approximately 80 to 90% of the energy in buildings is utilized during the operational phase of a building's life-cycle (U.S. Energy Information Administration, 2017). With the high amount of energy used and wasted, the electricity consumption in commercial building is expected to grow from 60% to 90% between year 2005 to 2050 (Ürge-Vorsatz *et al.*, 2012) as a result of increasing GHG emissions. In order to minimize the greenhouse effect caused by carbon emission at RSA, green technology is one of the effective solutions that should be introduced to the highway developers (Saeed Balubaid *et al.*, 2015).

Dong and Frangopol noted that equipment retrofitting such as LED lighting, solar photovoltaic systems, water-efficient toilets and motion sensor is also helpful in decreasing the amount of energy used and enhancing energy overall performance (Dong and Frangopol, 2011). Acheampong (2014) also mentioned that the consumption level could be substantially reduced for the same level of lighting that would be provided if less energy wastage occurs from the use of inefficient lighting technologies, lack of adequate controls, failure to make better use of natural daylight and wide variations in recommended lighting levels.

However, previous research is found that most of the studies which have been conducted are focusing on the carbon footprints assessment on construction building and operation and maintenance of building such as study from Airaksinen and Matilainen (2011) and Lim *et al.* (2017). There was lack of study from Ainee (2012) that associated with the carbon footprints with regards to the RSA especially in Malaysia which usually the operation of RSA is 24 hours/day. Therefore, it is crucial to understand the amount of carbon footprint since it has not been quantify and recorded substantially.

For example, the detail of cost and benefit after retrofitting the lighting technology system in terms of return on investment and carbon reduction. This detailed information is very important in order to make a decision in choosing the right technology for better management in reduction of carbon besides avoiding from losing huge sum of money. For that reason this study has aim to analyse the carbon emissions and set a baseline year with reduction target goal for RSA at Malaysia.

1.3 Aim and Objectives

The aim of this study is to set a baseline target for energy reduction of Rest and Service Area (RSA) at Malaysian Highway. In achieving this aim, several scenario analyses were carried out. The specific objectives of the scenario analysis are as follows:

i. To identify and establishes the inventory of GHG emission sources through primary data collection.

ii. To calculate the operational carbon footprint in terms of metric tonnes carbon dioxide equivalent (t CO_2-e) based on establish inventory GHG emission sources.

iii. To set a baseline year based on GHG emission trends and to come up with specific counter – measures.

iv. To evaluate carbon and cost impact based on selected counter-measure scenarios in order to archieve the reduction target.

1.4 Scopes of study

The following are designated scopes of study to support objectives of the study:

i. The carbon footprint was measured in terms of carbon dioxide equivalency (CO_2-e).

ii. The research focused on the operational of Rest and Service Area located alongside PLUS Highway which are under Malaysian Highway Authority. The vehicle passing by or stop at RSA are exclude from this study as stated in guideline GHG Protocol.

iii. The Rest and Service Area being assessed were Ayer Keroh (Northbound), Overhead Bridge Restaurant (OBR) Ayer Keroh and Pagoh (Northbound) which the designs and application are almost same with other location RSA in Malaysian Highway.

iv. The assessment of carbon footprint was based on year 2013 until 2017 data.

v. The emissions of greenhouse gases generated by the RSA was calculated using carbon footprint as the environmental indicator to measure the global warming and climate change which continue to increase every year.

vi. This research used the standard method and guidance from GHG Protocol of World Resource Institute (WRI) and ISO 14064 Standard.

1.5 Significance of the study

RSAs have a lot of potential to use alternative energy in the facility operations and reduce the overall carbon footprint. In the U.S., they used solar energy (direct and passive), wind energy and geothermal energy in order to reduce GHG emissions and save financial resources in the long term. Therefore, the data from this study will present the carbon emission for the operation of RSA and hopefully it will be useful for future research in order to promote a green building technology and attempt into the practice of sustainable living by cutting down the energy use from fossil fuel.

Besides that, the study will determine the baseline year which is a very important step before setting the carbon reduction target goal. Usually in a normal practice, baseline year is chosen as the highest emission year within a 5-year time period. Thus, the assessment was from year 2013 until 2017 in order to set a baseline year and a reduction goal in GHG emission. The carbon reduction target will help MHA to achieve the federal GHG reduction goal which is 45% carbon intensity reduction by year 2030 and change the highway facilities to green facilities (ASEAN Social Forestry Network, 2015).

Other than that, CO_2 has been recognized in GHG as the main cause that leads the world into climate change phenomena. According to Sustainable Energy

Development Authority Malaysia (SEDA), buildings represent the biggest opportunities for carbon reduction in mitigating climate change, which is responsible for about 80-90% of the carbon emissions during their operations (SEDA, 2017). Realizing the impacts of CO_2 towards national and global climate change scenario, this study suggested the feasible counter-measures and provided the estimated cost investment and return on investment. The feasible counter-measures were compared with the carbon reduction potential and return on investment of that technology.

In the end, the finding of this study optimistically would be very useful for local governments to enable the decision-making process on selecting climate friendly technologies, reduce resources consumption whilst sustaining national financial growth and decreasing the project cost due to proper project management and with the development in green technology. The contribution from the communities in the highway development such as concession companies, consultants, contractors, RSA's employee and any associated government will give consciousness about the carbon footprint that they produced every day especially to the highway users.

1.6 Layout of the Thesis

In general, this thesis is divided and arranged into five chapters in accordance with the overall work progress. The arrangement of the chapters is as follows:

1.6.1 Chapter 1 – Introduction

This chapter discusses about the introduction and background of the study. The chapter includes the problem statements, research questions, research aim, research objectives, research scopes and also the significance of the research. This chapter is more about discussing the importance in doing the research.

1.6.2 Chapter 2 – Literature Review

This chapter explains on the theory related to the research being conducted and it is based on researches that have been done by other researchers and scholar. The information such as the definitions of carbon footprint, scope of carbon emission, derivation of carbon footprint calculations, strategies being implemented associated with carbon footprint and the barriers towards the implementation of carbon footprint strategy are also explained in this chapter.

1.6.3 Chapter 3 – Research Methodology

This chapter presents the details of the methodology including research design and procedure, research objectives, research framework, research area, sampling method, research methods and analysis methods that were used to achieve the objectives of the study. The study was conducted at the RSAs at PLUS Highway in Johor and Melaka Region which are Ayer Keroh Northbound, Overhead Bridge Restaurant Ayer Keroh Northbound/Southbound and Pagoh Northbound. The preparation of the questionnaire survey is also being specified in this chapter. Moreover, this chapter also explains on suitable techniques used to analyse the data.

1.6.4 Chapter 4 – Result and Discussion

This chapter explains on the methods used in this research and for the analysis. These also include how the data were collected such as data on vehicle distance travelled, level of CO_2 and initial investment cost. The data gained from the survey were analysed to fulfil the objectives of the proposed study. At this stage, Microsoft Excel software was used as a tool to analyse the collected data. The data are described in the form of graph, pie chart and table to facilitate understanding of this case study. Reviews from PLUS Expressway, journal and other related sources were also carried out in target to achieve the objectives of the study. The analysis provides both descriptive statistics and exploratory details representing the information.

1.6.5 Chapter 5 – Conclusion and Recommendation

This chapter is the last chapter in report writing of the research where the final output is expressed and summarized. All these four objectives are clearly presented in this chapter. The conclusions will be explained based on the objectives of the study. The recommendations for future research are also proposed in this chapter.

REFERENCES

Abd. Aziz, P. D., Wahid, S. S. A., Arief, Y. Z., & Ab. Aziz, N. (2016). Evaluation of Solar Energy Potential in Malaysia. *Trends in Bioinformatics*. 9(2), 35–43.

Abdul-Azeez, I. A., & Ho, C. S. (2015). Realizing Low Carbon Emission in the University Campus towards Energy Sustainability. *Open Journal of Energy Efficiency*. 04(02), 15–27.

Acheampong, P. (2014). Feasibility of Using Solar PV and Light Emitting Diodes (LEDs) for Street-Lights in Ghana: A Case Study of Wenchi Municipality. Master of Science, University of Science and Technology, Kwame Nkrumah.

Ainee, F. (2012). Energy Consumption And Potential Retrofitting Of Highway Rest and Service Areas (RSAs). Master of Science (Construction Management), Universiti Teknologi Malaysia, Skudai. Unpublished thesis

Al-Mansour, F., & Jejcic, V. (2017). A Model Calculation of The Carbon Footprint of Agricultural Products: The Case of Slovenia. *Energy*. 136, 7–15.

Al-Mofleh, A., Taib, S., & Salah, W. A. (2010). Malaysian Energy Demand and Emissions from The Transportation Sector. *Transport*. 25(4), 448–453.

Aman, M. M., Jasmon, G. B., Mokhlis, H., & Bakar, A. H. A. (2013). Analysis of the performance of domestic lighting lamps. *Energy Policy*. 52, 482–500.

Anish, K. R., A. Rahim, M., Balslev-olesen, O., Steve, L., & Tang, C. K. (2005). Low Energy Office Building in Putrajaya, Malaysia. Case Studies and Innovations. *The 2005 World Sustainable Building Conference*. 27-29 September. Tokyo, 446–453.

ASEAN Social Forestry Network. (2015). Intended Nationally Determined Contribution of the Government of Malaysia. In *The United Nations Framework Convention on Climate Change (UNFCCC)*.

Azar, E., & Menassa, C. C. (2012). A Comprehensive Analysis of The Impact of Occupancy Parameters in Energy Simulation of Office Buildings. *Energy and Buildings*. 55, 841–853.

Azhar, W. N. A. W. (2014). An Assessment Score for Green Pavement Technology Elements. Master of Engineering (Highway & Traffic), Universiti Teknologi Malaysia. Unpublised thesis.

Bardsley, C., Navigant, C., Radcliffe A., Inc., & SB C. (2012). *Solid-State Lighting Research and Development: Multi-Year Program Plan*. U.S. Department of Energy.

Bhoye, H., & Sharma, G. (2014). An Analysis of One MW Photovoltaic Solar Power Plant Design. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Energy*. 3(1), 6969–6973.

BRE. (2011). BRE Group Building a Better World Together. Retrieved April 27, 2018, from http://bregroup.com/

Cadarso, M., Gómez, N., López, L. A., & Tobarra, M. (2016). Calculating tourism's carbon footprint: Measuring the impact of investments. *Journal of Cleaner Production*. 111, 529–537.

Carbon Disclosure Project. (2010). *Carbon Disclosure Project: The Carbon Chasm (Vol. 44)*. [Brochure]. United Kingdom

Chueco, F., López, F., & Bobadilla, M. (2015). Technical and economic evaluation of fluorescent and LED luminaires in underground mining. A case study: New mine level of El Teniente. *Energy and Buildings*. 93, 16–22.

Cong, X., Zhao, M., & Li, L. (2015). Analysis of Carbon Dioxide Emissions of Buildings in Different Regions of China Based on STIRPAT Model. *Procedia Engineering*. 121, 645–652.

De Wolf, C., Pomponi, F., & Moncaster, A. (2017). Measuring Embodied Carbon Dioxide Equivalent of Buildings: A Review and Critique of Current Industry Practice. *Energy and Buildings*. 140, 68–80.

Defra. (2012). Methodology Paper for Emission Factors. Methodology Paper for Emission Factors, p. 59. London

Dong, Y., & Frangopol, D. M. (2011). Assessment of Air Quality and Performance of Central Ventilation System. *Journal of Performance of Constructed Facilities*. 25, 326–335.

Dutta, A., Bouri, E., & Noor, M. H. (2018). Return and Volatility Linkages Between CO_2 Emission and Clean Energy Stock Prices. *Energy*. 164, 803–810.

Eco-Ideal Consulting Sdn Bhd (2017). *National Corporate GHG Reporting Programme for Malaysia*. Penerbit Ministry of Natural Resources and Environment (NRE) Malaysia.

Environmental Protection Agency (EPA). (2017). Carbon Pollution from Transportation. United States Environmental Protection Agency. Retrieved from https://www.epa.gov/air-pollution-transportation/carbon-pollutiontransportation.

Ezeonyebuchi, I. (2014). Cost Efficient Occupancy Sensor. Bachelor of Science, Worcester Polytechnic Institute. Unpublished thesis.

Federal Government Administrative Centre. (2015). Eleventh Malaysia Plan 2016-2020 - Anchoring Growth on People. In Percetakan Nasional Malaysia Berhad.

Fu, F., Luo, H., Zhong, H., & Hill, A. (2014). Development of a Carbon Emission Calculations System for Optimizing Building Plan based on the LCA Framework. *Mathematical Problems in Engineering*. 2014, 13.

Ganandran, G. S. B., Mahlia, T. M. I., Ong, H. C., Rismanchi, B., & Chong, W. T. (2014). Cost-benefit Analysis And Emission Reduction of Energy Efficient Lighting at the Universiti Tenaga Nasional. *Scientific World Journal*. 2014, 11.

Garðarsdóttir, S. Ó., Normann, F., Skagestad, R., & Johnsson, F. (2018). Investment Costs and CO_2 Reduction Potential of Carbon Capture from Industrial Plants – A Swedish Case Study. *International Journal of Greenhouse Gas Control*. 76, 111–124.

Gårder, P. E. (2002). Quantifying Roadside Rest Area Usage. New England Transportation Consortium.

Gates, T. J., Savolainen, P. T., Datta, T. K., & Todd, R. G. (2013). Ecnomic Assessment of Public Rest Areas and Traveler Information Centers on Limited Access Access Freeways. *Transportation Research Board*. 2346, 63–71.

Gigatera. (2016). LED Lighting Catalog. [Brochure]. GigaTera (M) Sdn Bhd. Malaysia.

Ghadimzadeh, A., Ahmad Makmom, A., Kato Hosea, M., Asgari, N., Shamsipour, R., & Sheikhy Narany, T. (2015). Review on CO_2 Emission from Transportation Sector in Malaysia. *IOSR Journal of Environmental Science Ver. I*. 9(5), 2319–2399.

Greenhouse Gas Protocol (GHG). (2013). Technical Guidance for Calculating Scope 3 Emissions (version 1.0). World Resources Institute Contributors

Harangozo, G., & Szigeti, C. (2017). Corporate Carbon Footprint Analysis In Practice - with a Special Focus on Validity and Reliability Issues. *Journal of Cleaner Production*. 167, 1177–1183.

HEFCE. (2012). Measuring Scope 3 carbon emissions: Water and Waste. Arup and De Montfort University.

Hu, A. H., Huang, L. H., Lou, S., Kuo, C. H., Huang, C. Y., Chian, K. J., Hong, H. F.

(2017). Assessment of The Carbon Footprint, Social Benefit of Carbon Reduction, and Energy Payback Time of A High-Concentration Photovoltaic System. *Sustainability*. 9(1), 1–20.

Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., & Acquaye, A. (2013). Operational vs. Embodied Emissions in Buildings - A Review of Current Trends. *Energy and Buildings*. 66, 232–245.

International Energy Agency, IEA. (2017). CO_2 Emissions from Fuel Combustion 2017 - Highlights.

Illeperuma, I. A. (2014). A Cost Benefit Analysis of Improving Energy Efficiency of a Fitness Facilty A Cost Benefit Analysis of Improving Energy Efficiency of a Fitness Facilty. *Journal of Environmental and Resource Economics at Colby*. 01(01), 8.

Illinois. (2016). Bureau Of Design And Environment Manual. In Illinois. Chapter Sixteen: Rest Areas / Weigh Stations. (p. 45).

IPCC. (2014). Climate Change 2014: Mitigation of Climate Change. Summary for Policymakers and Technical Summary. In Climate Change 2014: Mitigation of Climate Change. Part of the Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

ISO. (2018). ISO (International Organization for Standardization). Retrieved December 21, 2018, from ISO (International Organization for Standardization) website: https://www.iso.org/home.html

Izzul Ramli, Sitti Asmah Hassan, M. R. H. (2017). Parking Demand Analysis of Rest and Service Area Along Expressway in Southern Region, Johor Malaysia. *Malaysian Journal of Civil Engineering*. 118(1), 108–118.

Jabatan Pengurusan Sisa Pepejal Negara. (2013). *Survey on Solid Waste Composition, Characteristics & Existing Practice of Solid Waste Recycling in Malaysia.* Kementerian Kesejahteraan Bandar, Perumahan Dan Kerajaan Tempatan Jabatan

Jainudin, N. A. (2013). Cost Benefits Study Of Solar Photovoltaic Implementation For Residential Areas In Malaysia. Master of Science (Construction Management), Universiti Teknologi Malaysia, Skudai.

Jeannie Piekarz (2012). Dormitory Motion Sensor Lighting. Electrical, Computer, and Software Engineering Honor Society Project. 603, 1-11.

JKR. (2014). *Road Safety Plan Of Malaysia 2014-2020*. Jabatan Keselamatan Jalan Raya, Kementerian Pengangkutan Malaysia.

Jolliffe, I. T., & Cadima, J. (2016). Principal Component Analysis: A Review And Recent Developments. *Philosophical Transactions A*. 374(2), 202.

Jones, K. W., Cannon, J. B., Saavedra, F. A., Kampf, S. K., Addington, R. N., Cheng, A. S., … Wolk, B. (2017). Return on Investment from Fuel Treatments to Reduce Severe Wildfire and Erosion in a Watershed Investment Program in Colorado. *Journal of Environmental Management*. 198, 66–77.

Kahn, M. E., Kok, N., & Quigley, J. M. (2014). Carbon Emissions from the Commercial Building Sector : The Role of Climate, Quality and Incentives. *Journal of Public Economics*. 113, 1–12.

Khan, I. J., Khan, Y. H., Rashid, S., Khan, J. A., Campus, I., & Bannu, T. (2015). Installation of Solar Power System used for Street Lights and Schools in Khyber Pakhtunkhwa, Pakistan. *International Journal Of Multidisciplinary Sciences And Engineering*. 6(10), 13–17.

Khorasanizadeh, H., Parkkinen, J., Parthiban, R., & Moore, J. D. (2015). Energy and economic benefits of LED adoption in Malaysia. *Renewable and Sustainable Energy Reviews*. 49, 629–637.

Koezjakov, A., Urge-Vorsatz, D., Crijns-Graus, W., & van den Broek, M. (2018). The Relationship between Operational Energy Demand and Embodied Energy in Dutch Residential Buildings. *Energy and Buildings*. 165, 233–245.

Kreminski, R., Hirsch, A., & Boand, J. (2011). *Assessment of Colorado Department of Transportation Rest Areas for Sustainability Improvements and Highway Corridors and Facilities for Alternative Energy Source Use*. Colorado Department Of Transportation.

Lin, J., Hu, Y., Cui, S., Kang, J., & Ramaswami, A. (2015). Tracking Urban Carbon Footprints from Production and Consumption Perspectives. *Environmental Research Letters*. 10, 1-13.

Liu, J., Chen, S., Wang, H., & Chen, X. (2015). Calculation of Carbon Footprints for Water Diversion and Desalination Projects. *Energy Procedia*, *75*, 2483–2494.

LLM. (2012). *Laporan Tahunan Annual Report 2012*. Lembaga Lebuhraya Malaysia.

LLM. (2016). *Laporan Tahunan Annual Report 2016*. Lembaga Lebuhraya Malaysia.

Lutron. (2014). *Occupancy / Vacancy Sensor, Design and Application Guide*. [Brochure]. Lutron Electronics Co., Inc., Coopersburg.

Mao, R., Duan, H., Dong, D., Zuo, J., Song, Q., Liu, G., and Dong, B. (2017). Quantification of Carbon Footprint of Urban Roads via Life Cycle Assessment:

Case Study of a Megacity-Shenzhen, China. *Journal of Cleaner Production*. 166, 40–48.

Martinez, N., Usaid, E., Dc, W., Trowbridge, A., Usaid, E., & Dc, W. (2017). *Cost-Benefit Analysis of Off-Grid Solar Investments in East Africa*. USAID From The American People.

Mckinnon, A. (2016). *Setting Targets for Reducing Operations : Principles and Practice*. K. S. Pawar et al. (eds), Development in Logistics and Supply Chain Management (pp. 266–278). London.

McKinnon, A., & Piecyk, M. (2012). Setting Targets for Reducing Carbon Emissions from Logistics: Current Practice and Guiding Principles. *Carbon Management*. 3(6), 629–639.

Menikpura, N. (2013). *User Manual Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Lıfe Cycle Perspective*. Penerbit Institute For Global Environmental Strategies.

Metham, M., & Benjaoran, V. (2015). The Assessment of Greenhouse Gas Emissions for Evaluating Actual Road Construction Operations. *Procs 31st Annual ARCOM Conference*. 7-9 September. Lincoln, UK, Association of Researchers in Construction Management, 257–266.

Mukherjee, S., & Ghosh, P. B. (2014). Estimation of Carbon Credit and Direct Carbon Footprint by Solar Photovoltaic Cells in West Bengal, India. *International Journal of Low-Carbon Technologies*. 9(1), 52–55.

Neida, B. Von, Manicria, D., & Tweed, A. (2001). An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems. *Journal of the Illuminating Engineering Society*. 30(2), 111–125.

Noor, Z. Z., Yusuf, R. O., Abba, A. H., Abu Hassan, M. A., & Mohd Din, M. F. (2013). An Overview for Energy Recovery from Municipal Solid Wastes (MSW) in Malaysia Scenario. *Renewable and Sustainable Energy Reviews*. 20, 378–384.

Nor Sharliza Mohd Safaai, Zainura Zainon Noor, Haslenda Hashim, Zaini Ujang, J. T. (2010). Projection of CO_2 Emissions in Malaysia. *Environmental Science & Technology*. 33(2), 482–489.

Noranai, Z, & Azman, A. (2017). Potential Reduction of Energy Consumption in Public University Library. *IOP Conference Series: Materials Science and Engineering*. 243, 012023.

Noranai, Zamri, Mohamad, M. H. H., Salleh, H., & Yusof, M. Z. M. (2014). Energy

Saving Measures for University Public Library: A Case Study of UTHM Library. *Applied Mechanics and Materials*. 660, 1072–1075.

North Carolina Energy Office. (2010). *Occupancy Sensors: Energy Saving -Fact Sheet*. [Brochure]. Land-of-Sky Regional Council (Waste Reduction Partners).

Nunoo, S., Attachie, J. C., & Abraham, C. K. (2015). Using Solar Power as an Alternative Source of Electrical Energy for Street Lighting in Ghana. *Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES),* 27-29 September. Waltham, MA, USA: IEEE, 467–471.

Othman, J., and Yahoo, M. (2014). Reducing CO_2 Emissions in Malaysia: Do Carbon Taxes Work?. *Persidangan Kebangsaan Ekonomi Malaysia Ke-9 (PERKEM Ke-9).* 17 – 19 Oktober. Kuala Terengganu, Terengganu, 175 - 182.

Paul H. A. Steel, Chuan Kua, J. M. and C. Lo. (2017). Investing in Highway Commercial Development : An Introduction to Alberta's Commercial Safety Rest Area Project. *2017 Conference of the Transportation Association of Canada*. 1–18.

PLUS. (2018). Plus Malaysia Berhad - Rest and Service Areas (RSA). Retrieved February 23, 2018, from Plus Malaysia Berhad website: http://www.plus.com.my/index.php?option=com_content&view=article&id=75&Itemid=168&lang=en

Qin, X., Wei, Q., Wang, L., & Shen, Y. (2015). Solar Lighting Technologies for Highway Green Rest Areas in China: Energy Saving Economic and Environmental Evaluation. *International Journal of Photoenergy*. 2015(4), 1-10.

R Velaga, N., & Kumar, A. (2012). Techno-economic Evaluation of the Feasibility of a Smart Street Light System: A case study of Rural India. *Procedia - Social and Behavioral Sciences*. 62, 1220–1224.

Rahman, H. a., Hassan, M. Y., Majid, M. S., Nor, K. M., & Atan, N. A. (2009). Economic Study on the Effectiveness of Photovoltaic Street Lighting in Universiti Teknologi Malaysia. *12th International Middle-East Power System Conference*. 14 January. Aswan, Egypt: IEEE, 624–629.

Raja Shazrin Shah Raja Ehsan Shah. (2016). Carbon Tax : Are Malaysian Industries Prepared? [Brochure]. Malaysia.

Ramachandra, T. V., Aithal, B. H., & Sreejith, K. (2015). GHG Footprint of Major Cities in India. *Renewable and Sustainable Energy Reviews*. 44, 473–495.

Ramadhan, M., & Naseeb, A. (2011). The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait. *Renewable Energy*. 36(2011), 1272-1276.

Reed, A. (2008). *Wi-Fi on the Highway: Rest Stops Go High-Tech*. Retrieved on 27 April, 2010, from http://www.roadtripamerica.com/dashboarding/Wi-Fi-On-The-Highway.htm.

Relander, B. (2018). Investing in Green Technology - The Future Is Now. Retrieved on January 14, 2019, from Investopedia website: https://www.investopedia.com/articles/investing/040915/investing-green-technology-the-future-now.asp

Ren, P., & Zhao, T. (2013). Feasibility Analysis on Electric Energy Saving Methods An Interactive Qualifying Project Report. Degree of Bachelor of Science, Worcester Polytechnic Institute, USA. Published Thesis.

Riyanto, I., Margatama, L., & Hindarto, D. E. (2018). Motion Sensor Application on Building Lighting Installation for Energy Saving and Carbon Reduction Joint Crediting Mechanism. *Applied System Innovation*. 1(23), 1–7.

Rooshdi, R. R. R. M., Rahman, N. A., Baki, N. Z. U., Majid, M. Z. A., & Ismail, F. (2014). An Evaluation of Sustainable Design and Construction Criteria for Green Highway. *Procedia Environmental Sciences*. 20, 180–186.

Rozana, Z., Foo, K. S., Ainee, F., Majid, M. Z. A., Zin, R. M., Hainin, M. R., Nurfatimah, M. (2013). Energy Consumption and Potential Retrofitting of Rest and Service Areas (RSAs) in Malaysia Case Study. *Applied Mechanics and Materials*. 284–287, 1311–1314.

Saeed Balubaid, Mastura, B., Rozana, Z., Foo, K. S., Ainee, F., Majid, M. Z. A., Zin, R. M., Hainin, M. R., (2015). Assessment Index Tool for Green Highway. *Jurnal Teknologi*. 77(16), 99–104.

Saidur, R. (2009). Energy Consumption, Energy Savings and Emission Analysis in Malaysian Office Buildings. *Energy Policy*. 37(10), 4104–4113.

SEDA. (2017). Seda Portal. Retrieved November 24, 2018, from SEDA Malaysia website: http://www.seda.gov.my

Shabrin, N., & Kashem, A. (2017). A Comprehensive Cost Benefit Analysis of Green Building. *Proceedings of 94th The IIER International Conference*. 1-2 February. Dhaka, Bangladesh. IIER. 1-9.

Skoric, D. (2004). Cost Benefit Analysis of Potential Energy Conservation Program at Oklahoma State University. Bachelor of Science, University of J.J. Strossmayer

Osijek, Croatia.

Solaymani, S., Kardooni, R., Yusoff, S. B., & Kari, F. (2015). The Impacts of Climate Change Policies on the Transportation Sector. *Energy*. 81, 719-728.

Sreedhar, S., Jichkar, P., & Biligiri, K. P. (2016). Investigation of Carbon Footprints of Highway Construction Materials in India. *Transportation Research Procedia*. 10-12 December, Mumbai, India, 291–300.

Star, T. (2014). Malaysia's highway RSA: Come, weary traveller, rest awhile - Malaysia. Retrieved February 23, 2018, from https://www.thestar.com.my/travel/malaysia/2014/05/03/malaysias-highway-randrs-come-weary-traveller-rest-awhile/

Suehiro, S., & Shibata, Y. (2011). Electricity Saving Potential and Cost anf Benefit of LED Lighting in Japan. *The Institute of Energy Economics, Japan*. 2 July, Japan: IEEJ, 1–13.

Suk, S., Lee, S. Y., & Jeong, Y. S. (2016). A Survey on the Impediments to Low Carbon Technology Investment of The Petrochemical Industry in Korea. *Journal of Cleaner Production*. 133, 576–588.

Suruhanjaya Tenaga. (2017). Energy in Malaysia: Towards a Brighter Future (Vol. 12) [Brochure]. Malaysia.

Syafruddin, S. (2012). Scoring Assessment Of Regional Materials For Green Highway. Master of Engineering (Civil – Transportation and Highway), Universiti Teknologi Malaysia, Skudai.

Syahril, M., Samsudin, N., Teknologi, U., Rahman, M., Teknologi, U., Abdul, M., Rahman, M. (2016). Sustainable Power Generation Pathways in Malaysia : Development of Long-range Scenarios Akademia Baru Sustainable Power Generation Pathways in Malaysia: Development of Long-range Scenarios. *Journal of Advanced Research in Applied Mechanics*. 24(1), 22–38.

Tata Steel. (2014). Steel Construction Embodied Carbon. [Brochure]. The British Constructional Steelwork Association.

The Carbon Neutral Company. (2012). *A Handbook to Internal Greenhouse Gas Reduction Targets and Plans (Vol. 44)*. The Carbon Neutral Company.

The Crown Estate. (2014). *Tackling Embodied Carbon in Buildings*. UK Green Building Council.

The Energy Observer. (2007). Occupancy Sensors for Lighting Control. [Brochure]. The Energy Observer.

The Star. (2017, Jun 3). Sungai Udang Landfill Nearing Full Capacity. *The Star Online*. p. 2-3.

The World Bank. (2011). *Malaysia Economic Monitor: Smart Cities*. The World Bank.

TNB. (2014). *Electricity Tariff Schedule 2014.* [Brochure]. Tenaga Nasional Berhad.

TravelSmarter. (2014). Highway Facilities: Safety, Convenience and Comfort. Retrieved February 25, 2018, from http://www.travelsmarter.com.my/?p=8770.

U.S. Department of Energy. (2016). *Wireless Sensors for Lighting Energy Savings*. [Brochure]. Federal Energy Management Program.

UNFCCC. (2015). *Conference of the Parties, (COP) 21*. United Nations.

Ürge-Vorsatz, D., Petrichenko, K., Antal, M., Staniec, M., Labelle, M., Ozden, E., & Labzina, E. (2012). *Best Practice Policies for Low Energy and Carbon Buildings: Based on Scenario Analysis*. Global Buildings Performance Network.

Venmatthy, Z. Z. N. (2014). *Final Report for Three-Year Trend (2012-2014) Assessment of SAJ's Carbon Footprint*. UTM IPASA.

Walga. (2014). *A Project Manager's Guide to Reducing Greenhouse Gas Emissions*. Working For Local Government.

Wang, M., Mao, X., Gao, Y., & He, F. (2018). Potential of Carbon Emission Reduction and Financial Feasibility of Urban Rooftop Photovoltaic Power Generation in Beijing. *Journal of Cleaner Production*. 203, 1119–1131.

Wang, S., Zhao, J., Wang, K., & Liu, Y. (2018). *Study on the Low-Carbon Operating Evaluation Model in Expressway Rest Area*. In W. Wang et al., (eds.) Green Intelligent Transportation Systems (pp. 247-261). Singapore.

WBCSD. (2015). *Energy Efficiency in Buildings: Transforming the Market*. World Business Council For Sustainable Development (WBCSD).

Weng, K., & Boehmer, K. (2006). *Launching of ISO 14064 for greenhouse gas accounting and verification*. ISO Management Systems.

Wild-Scholten, M. de. (2011). Environmental Profile of PV Mass Production: Globalization. *26th European Photovoltaic Solar Energy Conference*. 34(2), 281–293.

Wintergreen, J., & Delaney, T. (2006). *ISO 14064, International Standard for GHG Emissions Inventories and Verification*. [Brochure]. Boonton.

World Resources Institute. (2015). *GHG Protocol Scope 2 Guidance*. Greenhouse Gas Protocol.

Wu, M. S., Huang, H. H., Huang, B. J., Tang, C. W., & Cheng, C. W. (2009).

Economic Feasibility of Solar-Powered LED Roadway Lighting. *Renewable Energy*. 34(8), 1934–1938.

Wu, P., Ma, X., Ji, J., & Ma, Y. (2017). Review on Life Cycle Assessment of Greenhouse Gas Emission Profit of Solar Photovoltaic Systems. *Energy Procedia*. 105, 1289–1294.

Yao, B. (2013). Stormwater Runoff Quality Control in Green Highway Projects. Master of Science (Construction Management), Universiti Teknologi Malaysia, Skudai.

Yazlin, S. (2015). Development of a Framework for Green Product Development. Master of Engineering (Construction), Universiti Teknologi Malaysia, Skudai.

Yau, Y. H., & Hasbi, S. (2013). A Review of Climate Change Impacts on Commercial Buildings and their Technical Services in the Tropics. *Renewable and Sustainable Energy Reviews*. 18, 430–441.

Zhou, Z., Zhang, S., Wang, C., Zuo, J., He, Q., & Rameezdeen, R. (2016). Achieving Energy Efficient Buildings via Retrofitting of Existing Buildings: A Case Study. *Journal of Cleaner Production*. 112, 3605–3615.