THE OPTIMIZATION OF ELECTRIC BUSES IN ISKANDAR MALAYSIA

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DEDICATION

Dedicated to my family and loved ones

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ABSTRACT

The public transport sector has a significant share of global CO_2 emission due to combustion of fossil fuel that could be catastrophic to the environment. Hence, evidence suggests that the implementation of battery electric buses (BEB) is necessary in order to reduce climate change and other environmental impacts. However, it raises a concern to bus operators regarding the conversion to BEB. This is because BEB have a fixed battery capacity, which have limited mileage, and the number of buses required to replace conventional buses due to limited charging stations available. In order to alleviate this situation, a proper fleet planning is required in order to know the amount of buses that are dispatched and the distance that the specific bus can travel. Hence, this study is conducted to optimize the cost of implementing electric buses in Iskandar Malaysia. Moreover, this study is also done to determine the optimal charging cycle that is required to cover Iskandar Malaysia and the number of buses needed to replace the existing conventional buses in order to fulfil the number of trips set by Perbadanan Pengangkutan Awam Johor (PAJ) Furthermore, a scenario analysis will be done by selecting two routes around Johor Bahru (i.e., the longest route and shortest route) with consideration of worst case scenario (i.e. high traffic) using the existing Bas Muafakat Johor's routes, which will assist in optimizing the ideal charging cycle and number of electric buses required for each location using an optimization software called General Algebraic Modelling System (GAMS) through various scenario selection such as (a) the buses will be charged for every trip or (b) the buses will be charged after complete depletion of its battery level (i.e. 3 trips) or (c) another bus will be added for the subsequent trip. Based on the GAMS, scenario (a) and scenario (b) is both selected. This is because continuous flow of buses is required during peak hours hence suitable for scenario (b) whereas scenario (a) is much more suitable for non-peak hours. Electric buses can save up to 132.52 kg of CO_2 per trip and also saves about 536.45 kWh of energy which equivalent to 53.65 L of diesel when compared to diesel buses.

ABSTRAK

Sektor pengangkutan awam mempunyai bahagian yang besar dalam pelepasan CO_2 global disebabkan oleh pembakaran bahan api fosil yang boleh menjadi bencana kepada alam sekitar. Oleh itu, bukti menunjukkan bahawa pelaksanaan bas elektrik bateri (BEB) adalah perlu untuk mengurangkan perubahan iklim dan kesan alam sekitar yang lain. Walau bagaimanapun, ia menimbulkan kebimbangan kepada pengusaha bas mengenai penukaran untuk BEB. Ini kerana BEB mempunyai kapasiti tetap bateri, yang telah perbatuan terhad, dan bilangan bas diperlukan untuk menggantikan bas konvensional kerana terhad mengecas stesen yang tersedia. Dalam usaha untuk mengatasi masalah ini, perancangan armada yang betul diperlukan untuk mengetahui jumlah bas yang dihantar dan jarak yang bas tertentu boleh melakukan perjalanan. Oleh itu, kajian ini dijalankan untuk mengoptimumkan kos melaksanakan bas elektrik di Iskandar Malaysia. Selain itu, kajian ini juga dilakukan untuk menentukan kitaran pengecasan optimum yang diperlukan untuk menampung Iskandar Malaysia dan bilangan bas diperlukan untuk menggantikan bas konvensional yang sedia ada bagi memenuhi bilangan perjalanan yang ditetapkan oleh Perbadanan Pengangkutan Awam Johor (PAJ) Tambahan pula , analisis senario akan dilakukan dengan memilih dua laluan di sekitar Johor Bahru (iaitu, laluan yang paling lama dan laluan terpendek) dengan pertimbangan senario kes terburuk (iaitu trafik yang tinggi) menggunakan laluan yang Bas Muafakat Johor yang sedia ada, yang akan membantu dalam mengoptimumkan ideal mengecas kitaran dan bilangan bas elektrik diperlukan untuk setiap lokasi menggunakan perisian pengoptimuman bergelar Ketua algebra Sistem Model (GAMS) melalui pelbagai pilihan senario seperti (a) bas akan dikenakan bayaran untuk setiap perjalanan atau (b) bas akan dikenakan selepas kekurangan lengkap tahap bateri (iaitu 3 perjalanan) atau (c) bas lain akan ditambah untuk perjalanan seterusnya. Berdasarkan GAMS, senario (a) dan senario (b) adalah kedua-dua yang dipilih. Ini adalah kerana aliran berterusan bas diperlukan semasa waktu puncak itu sesuai untuk senario (b) manakala senario (a) adalah lebih sesuai untuk waktu bukan puncak. bas elektrik boleh menjimatkan sehingga 132.52 kg CO_2 setiap perjalanan dan juga menjimatkan kira-kira 536.45 kWh tenaga yang bersamaan dengan 53.65 L diesel berbanding bas diesel.

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LIST OF ABBREVIATIONS

BEB	-	Battery Electric Bus
PAJ	-	Perbadanan Pengangkutan Awam Johor
BMJ	-	Bas Muafakat Johor
GAMS	-	General Algebraic Modelling System
GHG	-	Greenhouse Gases
MBJB	-	Majlis Perbandaran Johor Bahru

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CHAPTER 1

INTRODUCTION

1.1 Background

According to the International Energy Agency (2012), an estimation of global CO_2 emissions resulted by combustion of fossil fuel results to a rise to 37.0 gigatons (Gt) in the year 2035 from 31.2 gigatons (Gt) in the year 2011 based on the New Policies Scenario provided that the existing policies are taken into consideration. Based on the Efficient World Scenario (Investments regarding energy efficiency are economically viable and necessary policies are taken into account), the CO_2 emissions will peak at 32.4 gigatons (Gt) before the year 2020 and it will decrease at a steady pace to 30.5 gigatons (Gt) in the year 2035. The main source of CO_2 emissions is due to the combustion of fossil fuels in both the energy sector and the transport sector. Figure 1.1 shows that the heat and electricity sector are the major contribution the world's total CO_2 emissions which is about 50.14% and followed by the transport sector that accounts for about 22.43% of the world's total CO_2 emissions. Furthermore, the CO_2 emissions based on those two sectors in various countries are illustrated in Figure 1.2. The transport sectors CO_2 emission ranges from 7% to 40% whereas the electricity and heat sector ranges from 13% to 60% in various countries.

Based on Figure 1.3, This situation is similar to Malaysia where the most of the CO_2 emission comes from the energy sector, which is about 55% followed by the transportation that accounts up to 21% in 2011 (Biennial Update Report To The UNFCCC, 2015).

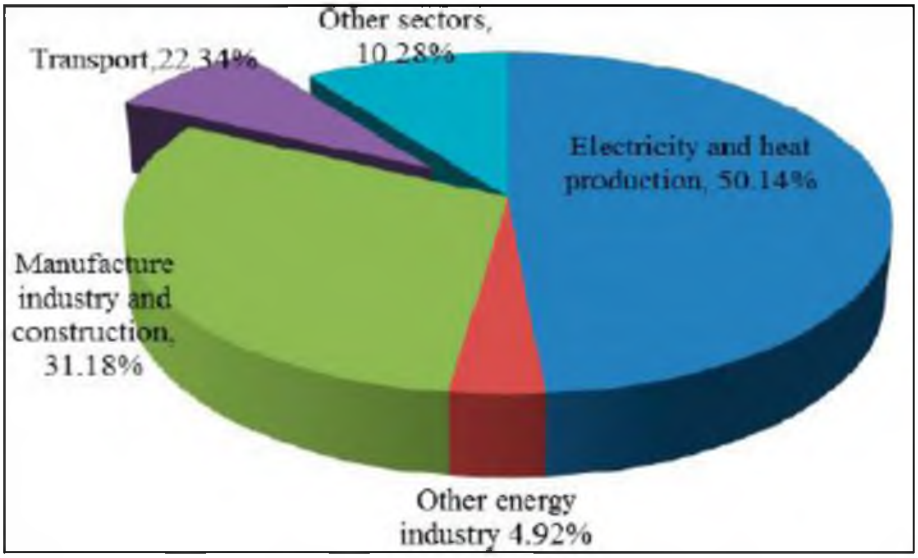

Figure 1.1 CO_2 emissions from various sectors (International Energy Agency, 2013)

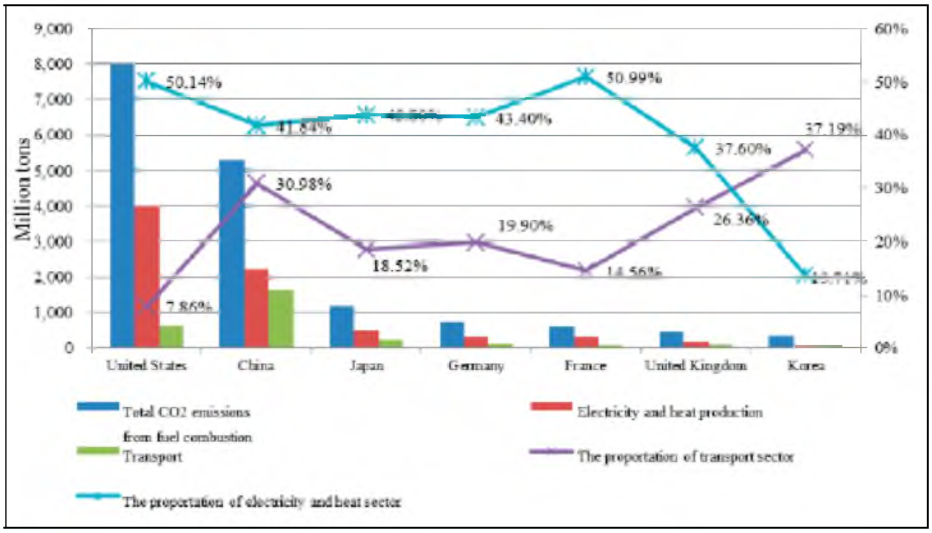

Figure 1.2 CO_2 emissions by both the transport and energy sector in various countries (International Energy Agency, 2013)

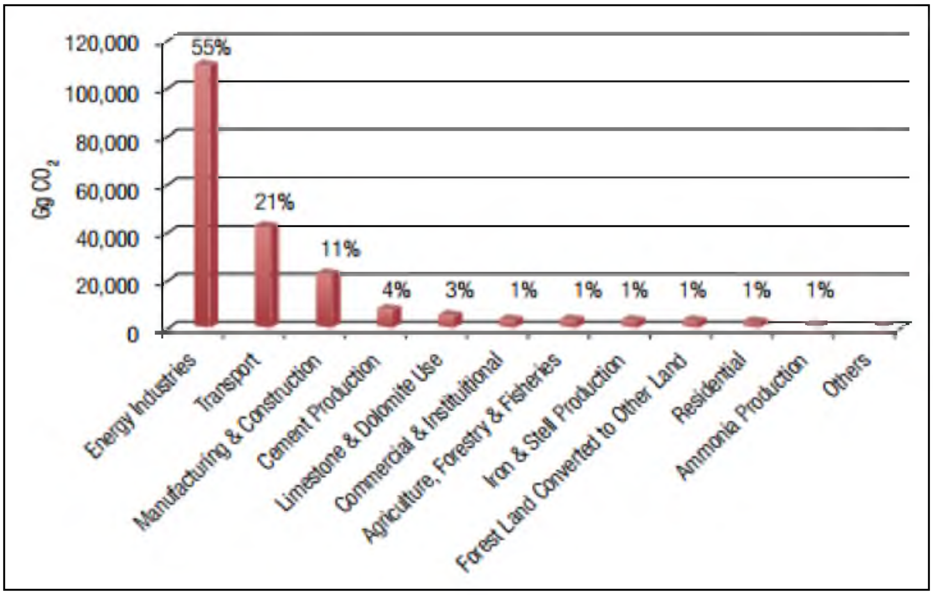

Figure 1.3 CO_2 emissions based on various industries in Malaysia (Biennial Update Report to the UNFCCC, 2015)

Based on current situation in International Energy Agency (2018), the global CO_2 has increased to 32.31 gigatons in the year 2016 due to combustion of fossil fuel thus proving the theory that was predicted by IEA in 2012. In 2016, the majority of CO_2 is produced due to the combustion of fossil fuel in the power generation sector, which accounts up to 42% of the global CO_2 emission. However, the transport sector comes in second place this time with 24% of global CO_2 emission as shown in Figure 1.4.

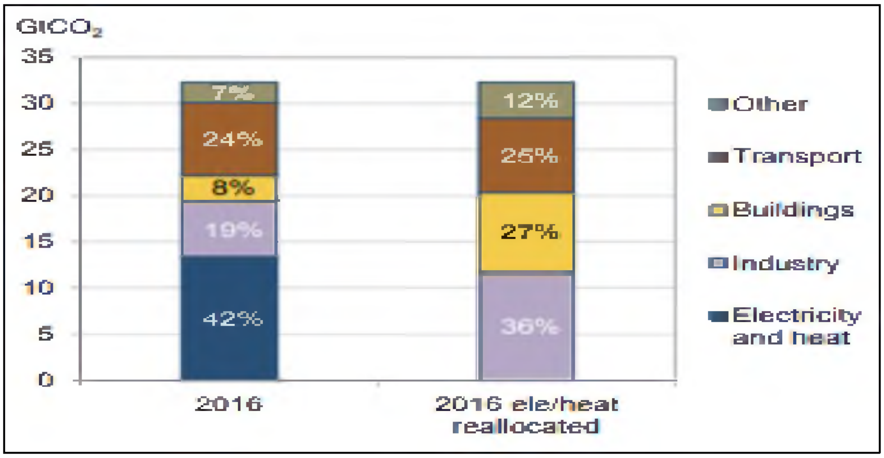

Figure 1.4 The global CO_2 emission in 2016. (IEA, 2018)

GHG emissions in the transport sector have been rising from the 1990 to 2007. Although there has been a decrease in the GHG emission after the 2007 but the 1990 mark cannot be reached. The increase in GHG emission especially in the transport sectors requires immediate responses from governmental sectors such as policy changes. Hence, one solution to the effects of internal combustion engine (ICE) car usage is electromobility. Thus, the introduction of electric vehicles (EVs) into the market has changed the way the world looks at the transport sector.

Recently, during the United Nations Climate Change Conference that is COP24 in December 2018, where the collaborative effort has resulted in the "Driving Change Together - Katowice Partnership for Electromobility" (UNFCCC, 2018). It serves to encourage electromobility by involving 38 countries to involve in the development and implementation of electromobility in both the transport and logistics. Apart from GHG emissions, conventional vehicles cause air and noise pollution, which will result in health effects that is quite common in urban areas (OECD, 2014). The dependency of petrol and diesel causes the country to rely on the import of fuel source that will jeopardize the energy security of a certain country. Hence, one way of solving this issue is by adapting to the use of electric vehicle.

It is quite difficult to force citizens to buy electric vehicles since they are more expensive than conventional vehicles. Therefore, the public transport sectors are a better suggestion for electromobility. Buses would be a best alternative for public transportation when compared to trains and trams since buses are often cheaper, has more route possibilities and more comfortable since most trains nowadays runs on electric and airplanes requires high fuel efficiency in order to operate (Martz Group, 2018). For example, the ridership for Light Rail Transit (LRT) Kelana Jaya line can go up to 270, 000 daily ridership per year whereas the free GoKL Bus has only a mere daily ridership of 63,000 per year (Bernama, 2018). This shows that buses are one of the most underrated form of public transport due to its low ridership level.

Besides, buses can be a good alternative to reduce traffic congestion since there are nearly 14 million private cars in Malaysia compared to buses which accounts to about 61,000 buses in 2017 (CEIC, 2018). The electromobility of public buses can be a leap of faith for the government of Malaysia to influence the public into moving towards electric vehicles.

1.2 Problem Statement

Expenses when it comes to purchasing a Battery Electric Bus (BEB) is quite expensive and it ranges from $120,000 for a school bus to a whopping $770,000 for a high mileage, 40 ft. bus (Nunno, 2018 and Gerdes, 2018). At this price point, most bus operators are discouraged to own an electric bus. Apart from that, operators also worry about the maximum distance that an electric bus can travel in a single charge. A transit electric bus comes with a smaller capacity battery and rather smaller electric motor, which is not suitable especially for long distance travellers, which are designed for short distance travel. For example, the 12-metre electric bus that launched in Putrajaya covers an estimated distance of 30 km (Tong, 2017).
However, an expensive 40-foot electric bus (EV) that are developed by Proterra are capable of covering more than 560 km on a single charge (Uhler, 2017). The availability of public charging stations does raise a concern among consumers.

According to ChargEV Malaysia (2018), there are 250 charging stations in Malaysia, which are available mostly in developed areas such as Kuala Lumpur, Johor Bahru and Selangor. Thus, this inhibits the bus operators to invest in electric buses.

From a technical perspective, charging in short bursts/opportunity charging which occurs in between trips is needed to be done in at a high-power rating such as 100 kW compared to regular charging that accounts to about 20 kW (Yilmaz & Krein, 2012) . Frequent short burst charging results in battery degradation thus reducing its lifespan due to high charge and discharge rate in and out the battery (Shirk & Wishart, 2015). Apart from that, there are no existing models that considers number of trips for optimization thus making this research more difficult since most of them focus on charging location (Xylia, Leduc, Patrizio, Silveira, & Kraxner, 2017).

1.3 Objectives

There are two objectives of this study, which are:

a) To minimize the total cost of the entire electric bus system in Iskandar Malaysia specifically around Majlis Perbandaran Johor Bahru (MBJB) by optimizing the number of buses and charging schedule in order to replace conventional buses.
b) To determine the energy savings and CO_2 emission comparison between diesel bus and electric bus.

1.4 Scope of Study

The scope of study comprises:

a) A case study would be done by selecting two different routes in Iskandar Malaysia, which are: 1) longest route and 2) shortest route by considering worst case scenario (i.e. high traffic) using the existing Bas Muafakat Johor's routes in order to determine the travel demand necessary.

b) The case study considers secondary data collection the type of bus used, the ridership of the bus, the route use, battery capacity, charging capacity and traffic conditions along Iskandar Malaysia Route.

c) A superstructure will be developed using the travel demand data provided by Perbadanan Pengangkutan Awam Johor (PAJ) through its Bas Muafakat Johor scheme

d) A scenario analysis would be done for route P-102 where 3 charging scenarios would analysed which are: (a) The buses will be charged for every trip or (b) the buses will be charged after complete depletion of its battery level (i.e. 3 trips) or (c) another bus will be added for the subsequent trip.

e) A mathematical model is developed and optimized using General Algebraic Modelling System (GAMS).

f) The energy savings and CO_2 emission will be calculated for both electric bus and diesel bus.

1.5 Significance of Research Work

The main reason for this case study is to determine the optimal charging schedule and number of buses based on worst case scenario conditions in MBJB since PAJ has provided some data on the routes, total ridership per month, the number of buses required for each route and the total number of trips for each route. Apart from that, Bas Muafakat Johor (BMJ) is an intercity bus, which can help reduce intercity traffic and promote the use of public transportation. Furthermore, Iskandar Malaysia is targeted to be a Low Carbon Society by 2025 that is significant to this case study.

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