DEVELOPMENT OF A DECISION PROCESS BASED ON GREEN PERFORMANCE INDEX FOR ELECTRIC BUS OPERATION

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DEVELOPMENT OF A DECISION PROCESS BASED ON GREEN PERFORMANCE INDEX FOR ELECTRIC BUS OPERATION

By

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ABSTRACT

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Goh Siew Yoke

Globally, the transportation sector had contributed approximately 23% carbon dioxide emission due to the rapid urban development. With the increasing demand in transportation, the environmental issues have arisen and shortage of the non-renewable natural resources incurred. These issues also associated with numerous harmful effects on human health. Therefore, electric bus operation, which carries zero tailpipe emission and lower noise, is proposed as a promising solution. However, a limited study quantifies the overall environmental performance of electric bus operations.

In order to quantify the green performance of electric bus operations, this study aims to develop an environmental assessment framework, so that beneficial decision process for electric bus operation can be built. In particular for fleet planning and operation purposes, the developed approach can help electric bus operators make better decisions in operating electric buses. The assessment of environmental performance of the electric bus operation includes several environmental factors (energy consumption, emission, and noise) as well as numerous influencing aspects (government policy and subsidy enforcement, passengers' feedback and response, bus technical features, and financial cost) that

are closer to the realistic application for more relevant and insightful implementation.

Through Gini Index Approach, the green index for the respective environmental factor (i.e., energy consumption, emission and noise) can be formulated. In order to capture the subjective judgment of the transportation expert in electric bus operational planning, Analytic Hierarchy Process is adopted (with the aid of a survey) to determine the weightage of each green index. And, several improvement strategies are proposed to enhance the environmental performance of electric bus operations in respect of Green Performance Index (GPI).

In order to evaluate the applicability of the proposed study, an illustrative case study in Putrajaya, Malaysia was conducted. From the results obtained, it could be seen that the improvement strategy with load factor increment shows the greenest performance. Besides, the green performance of electric bus is greatly affected by a variety of elements, including bus capacity, bus frequency, and the speed and charging duration of electric bus. Overall, the findings reveal that the resulted GPI can be used as a beneficial decision tool in electric bus planning and operation. This would result in a win-win situation to the environment as well as the community (including the bus operators).

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APPROVAL SHEET

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SUBMISSION OF THESIS

It is hereby certified that ***Goh Siew Yoke*** (ID No: ***1506662***) has completed this thesis entitled "***Development Of A Decision Process Based On Green Performance Index For Electric Bus Operation***" under the supervision of ***Assist. Prof. Ts. Dr. Teoh Lay Eng*** (Supervisor) from the Department of Mathematical and Actuarial Sciences and ***Prof. Ir. Dr. Khoo Hooi Ling @ Lai Hooi Ling*** (Co-Supervisor)* from the Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science.

I understand that University will upload softcopy of my thesis in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

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(*Goh Siew Yoke*)

DECLARATION

I hereby declare that the dissertation is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

Name GOH SIEW YOKE

Date 25.04.2022

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LIST OFABBREVIATIONS

A	Area between line of equality and Lorenz curve
AHP	Analytic Hierarchy Process
Av_c	Average of row c
Av_d	Average of column d
a	Frontal area of the bus
B	Area below Lorenz curve
b	Number of passengers
C	Resistance coefficient of the bus
Cat_n	Cumulative percentage of operating routes in the category n
c	Row of matrix
CI	Consistency index
CR	Consistency ratio
D	Bus route length
d	Column of matrix
e_i	GHG emission factor for different electricity mixes i
E_r	Energy consumption for bus route r
EM^{WTT}	Direct emission from fuel consumption
EM^{TTW}	Indirect emission from electricity generation
EM^{WTW}	Total emission well-to-wheel per bus
EM_r^{WTW}	Total emission well-to-wheel for bus route r
f	Friction force of the bus
F	Decisional criteria
GI	Green Index
GEI	Green Energy Index
GMI	Green Emission Index
GNI	Green Noise Index
GPI	Green Performance Index
g	Acceleration of gravity
h	Bus frequency
i	Type of electricity mixes
j	Type of green index
K_n	Cumulative percentage of proportion of income K

l	Electricity loss of the power transmission system
L_{ext}	Exterior noise
L_{int}	Interior noise
L	Total noise level per bus
L_r	Total noise level for bus route r
LF	Load factor for number of passenger
m	Total mass of the electric bus
P_0	Baseline sound pressure in Pascal
P_{ref}	Reference sound pressure in Pascal
P_y	Increased sound pressure during acceleration in Pascal
P_z	Sound pressure during constant speed in Pascal
q	Bus quantity
RI	Random index
R_d^*	Average of row d of matrix R
r	Bus route
S_j	Score of green index j
S_{EN}	Score for energy consumption
S_{EM}	Score for emission
S_{BN}	Score for noise
s	Size of matrix
T	Bus operating time per bus route
t	Time duration that a person is affected by the noise from a bus
U	Matrix
U_{cd}	Component at the row c and column d of the matrix
U_d^*	Average of row c of matrix U
V	Bus speed
W_j	Weightage of green index j
W_{EN}	Weightage for energy consumption
W_{EM}	Weightage for emission
W_{BN}	Weightage for noise
WTW	Well-to-Wheel
WTT	Well-to-Tank

TTW	Tank-to-Wheel
x	Bus capacity
y	Environmental factor
z	Key aspect
ε	Number of bus stop
γ	Number of accelerations during bus movement
α	Angle of inclination of the road
η	Energy efficiency in recuperation between wheel to battery and back to wheel
∂	Charging efficiency of the battery in percentage
ρ	Density of air
λ_{max}	Largest eigenvalue

CHAPTER 1

INTRODUCTION

1.1 Background

Environmental issues have been discussed globally over the last decade. Among the environmental issues are climate change (i.e., global warming), land degradation, deforestation, poor air quality, and the scarcity of natural resources (David and Claire, 2014). All these issues are the consequences of various pollutants' actions and human activities. From the environmental issues, the biggest threats facing living creatures are the long-term health effects due to air pollution and the damage to physiological health due to excessive loud noise (i.e., hypertension, hearing loss, sleep disturbances) (Münzel et al., 2018; Helen, 2020).

One of the key contributors to the environmental issue is the transportation sector, as it is the major user of energy. Transportation needs energy to operate, where the energy is generated by using either renewable natural resources (i.e., from solar, wind, biomass) or non-renewable natural resources (i.e., petroleum, nuclear power, coal). Due to the inexpensive cost of extracting non-renewable resources, the variety of technology and methods deployed to generate energy has caused the release of pollutants (mainly CO_2) during the burning process and application. Different types of engine propulsion for various transports determine different amounts of waste gas emissions.

In considering the environmental issues' effects on future generations, going green and maintaining sustainability need to go hand in hand with each other. If both are neglected in future planning, the planet will be badly affected and it is essential to eliminate the threat of the impact of human actions on the future generation. Hence, numerous green projects have been introduced, for example, green cities, green buildings, green vehicles, etc. Green projects mainly utilise renewable energy (i.e., minimise the usage of fossil fuels) and reduce carbon emissions. However, the cost of green projects is expensive as there is an involvement of technological inventions with a limited source of knowledge, which needs a longer duration of research and development.

In the transportation sector, countless efforts have been made to protect the environment. The electric bus is one popular example, which has been proposed to meet passenger demand as well as to replace existing conventional buses (Teoh et al., 2018; Pojani and Stead, 2015; Hassani and Ghorbani, 2020). Electric buses come in many different shapes and sizes, and they can be fuelled by a range of different sources (e.g., batteries or fuel cells). Any method of generating electricity can result in indirect emissions. This has been largely ignored; eventually, zero-emission policies should include resource creation. In particular, an electric bus is not a zero-pollution vehicle (He et al., 2018; Song et al., 2018; Dreier et al., 2018).

In comparison, an electric bus's energy consumption is comparable to that of a conventional bus. Both the source and the manufacture of these elements have an impact on the environment. During the operation, a diesel bus releases direct emissions from the exhaust as well as indirect pollutants from the fuel manufacturing process. Waste gases are created throughout the electricity generation process, even though the electric bus has no direct tailpipe emissions.

Furthermore, the varied engines used in each conventional and electric bus will produce different levels of noise. Comparatively, a diesel conventional bus's internal combustion engine produces a lot of noise, whereas the propulsion engine of an electric bus makes lesser noise (quieter with a lower noise level), especially when arriving at bus stops and when halted (Laib et al., 2019; Borén, 2019). With these critical environmental factors in mind, meticulous planning and environmental concerns must be considered when making decisions for green fleet planning and operation. The operating system, however, differs in some ways. A traditional bus, for example, has more moving parts in the mechanism and thus requires more maintenance (e.g., engine oil changes after a specific mileage, regular tune-ups for optimal performance), resulting in greater maintenance costs. An electric bus uses a sealed battery that requires minimal maintenance, although there is a battery life span limit that necessitates replacement. There isn't much of a visual difference between an electric bus and a conventional bus (Teoh et al., 2018).

Many countries have started to adopt electric buses into their public transportation systems to minimise emissions. For example, China, the USA, Japan, Malaysia, and India. This is part of the effort to achieve their goal of reducing the carbon footprint. In 2015, at COP21 (21st Conference of the Parties), every country pledged to work together to keep global warming well below 2 degrees Celsius, with a target of 1.5 degrees Celsius, to respond to the effects of climate change, and to ensure funding is available to achieve those goals. However, it was eventually discovered that the aim established at COP21 was not met (UKCOP26, 2021). As a result, the countries agreed at the recent COP26

(Conference of the Parties 26) to "revisit and strengthen the 2030 targets in their nationally determined contributions by the end of 2022," as well as to establish a new annual high-level ministerial meeting starting in 2022 and a leaders' summit in 2023. This will put pressure on governments to maintain their desire to meet the Paris Agreement's temperature objective at a faster rate than the Paris Agreement specifies. In particular, different regions of the world may have different electric bus systems due to the weather, geographical structure, and culture (i.e., the lifespan of the battery may be different for different climates as well as the charging facility) (Basma et al., 2020)

The electric bus, in particular, is recognised as a green vehicle, but its green level, which has a significant environmental impact, is unclear or too vague. When the demand for electric buses grows, the fleet size grows as well. As a result, the pollutants created by electric buses (energy consumption, emissions, and bus noise) will increase. Electric buses rely on electricity to operate, and the source of electricity during the generation will cause environmental issues though there is no tailpipe pollution from electric buses. Any noise produced by electric buses may be minimal, but it has a considerable influence on the environment, especially when the fleet size is growing and the noise level is increasing (Borén, 2019). Therefore, a crucial need for green indicators is required to provide reference in electric bus fleet planning and operation.

Proper and effective bus fleet planning and operation play an important role in a public transport system, especially during the use of an electric bus, as it has a limited range of autonomy and the need to be recharged at stations (Pternea et al., 2015). This bus fleet planning and operation also includes bus transit network design, in which designing an effective bus transit network is vital for the social and economic structure in the metropolitan area (Fan et al., 2013). With the aid of the green performance indicator, a greener fleet plan and operation of electric buses can be formed.

1.2 Problem Statements

The growing demand for transportation due to urban development has become one of the most important trends globally. With the rapid growth of the population, the number of urban transportation options has increased to meet their needs. However, when the public transport system is insufficient to provide good service and fulfil needs, the ownership of private vehicles is expected to be increased. This can be seen in Figure 1.1, where car sales have been escalating rapidly around the world since 2005.

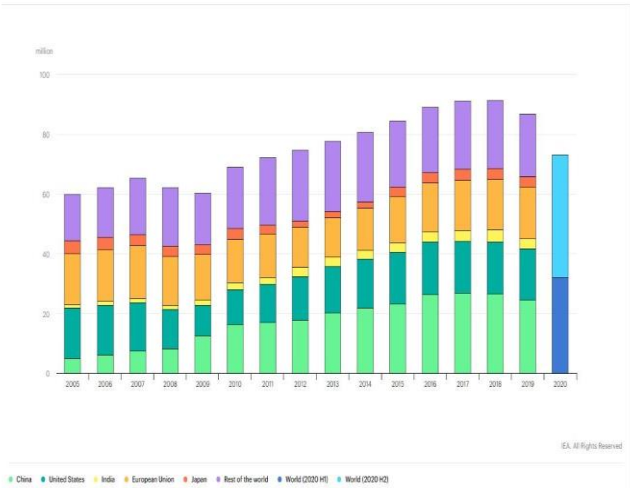


Figure 1.1: Global car sales in year 2005-2020 (IEA, 2020)

Besides this, it is found that there has been a fast rise in fuel consumption in the transportation sector since 1971, as shown in Figure 1.2. This consumption will not only burden the environment but also accelerate the scarcity of natural resources (petroleum). It can be revealed in Figure 1.3 how many years are left for fossil fuel.

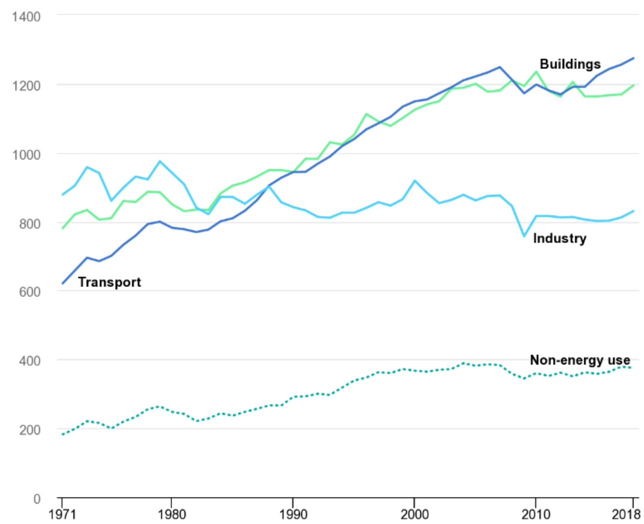


Figure 1.2: Total fuel consumption by sector (IEA, 2020)

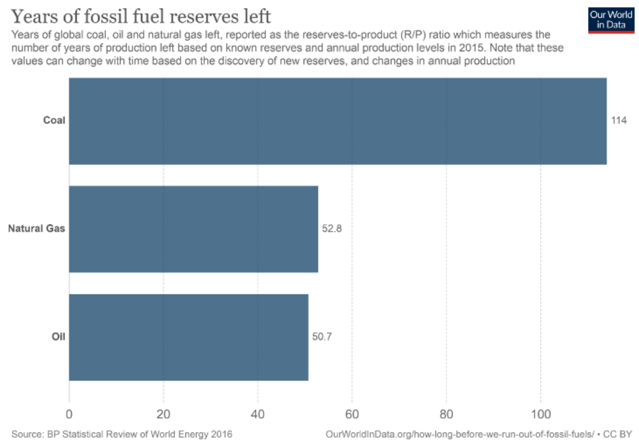


Figure 1.3*: Years of fossil fuel reserves left (BP Statistical Review of World Energy, 2016)*

Moreover, when the environmental pollution issue is neglected, the living creatures on earth will be threatened, in terms of health, habitat, or socio-economics (Münzel et al., 2017; Helen, 2020). As shown in Figure 1.4, air pollution is ranked 4^{th} among the risk factors that cause death. The number of deaths due to air pollution can be reduced as it is caused by human activities and hence some efforts are needed to minimise the risk. With the heavy dependency and intense usage of fossil oil, the reduction of fossil oil sources will cause a bad outcome for human mobility and economic growth. Thus, the electric bus, which is one of the invented technologies to replace the convention bus as well as be environmentally friendly, is proposed (Teoh et al., 2018; Pojani and Stead, 2015; Hassani and Ghorbani, 2020). The purpose of this is to reduce carbon emissions and dependency on fossil oil.

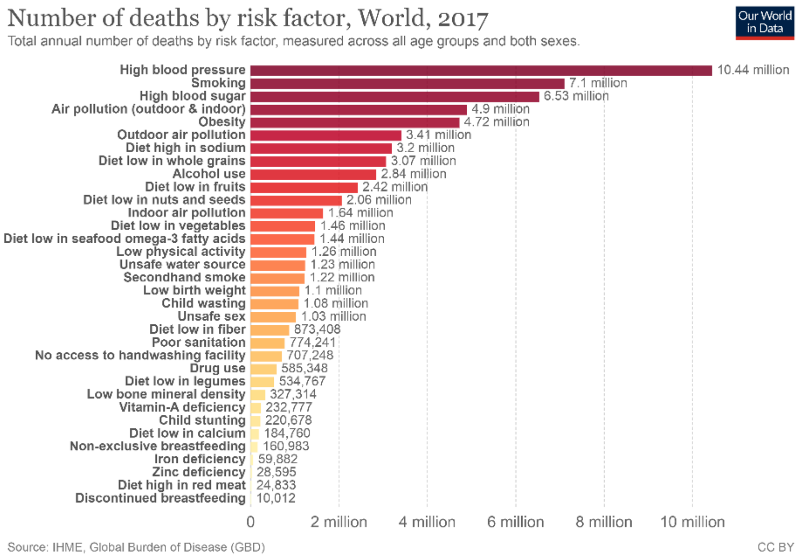


Figure 1.4: The number of deaths by risk factor (IHME, 2020)

However, He et al. (2018), Song et al. (2018), and Dreier et al. (2018) mentioned that an electric bus will still produce pollutants, but the impact on the environment could be minimal as compared with a conventional bus. Electric buses need electricity to operate, and the source of electricity generation and production could be one of the concerns over the environmental issue. Therefore, the sustainability of greener performance from the electric bus needs to be enhanced and prioritized.

The existing environmental assessment mainly focuses on the overall environmental performance of the proposed project or development as well as analyses the impact on the environment (i.e., Environment Impact Assessment (EIA)). The assessment is not able to provide clearer guidelines and references on how well the green performance of the transportation system works, specifically the electric bus. Previous research has found that three critical elements (energy consumption, emissions, and bus noise) have a significant impact on the environment (Holland et al., 2021; Laib et al., 2019). Hence, it can be one of the inputs for environmental performance assessment on electric buses, which is an essential tool for the bus operator to refer to when making the decision on electric bus fleeting planning and operation.

There are a few limitations to current electric bus technologies that must be addressed. For example, limited autonomous driving range, re-training of drivers to handle new technologies, charging station locations, and insufficient electricity supply (James and Matthew, 2019; Lin et al., 2019; Jefferies and Göhlich, 2020). The limitations could greatly affect the ability of the bus to operate within a restricted distance, or more charging facilities need to be provided, which could be one of the concerns when assessing the environmental performance of the bus operation.

1.3 Significance of Study

Transportation is one of the important sectors, and it plays an important role in mobility from one place to another. An enormous amount of money is invested in transportation by the government due to population growth and mass development as well as to solve traffic problems (Duranton and Turner, 2012).

When there is population growth, especially in an urban area, severe congestion and the emission of air pollutants can be expected. The root cause of these is the increasing demand for and usage of vehicles. Consequently, the living creatures will face health and physiological problems. Therefore, a good and well-planned green transportation system is needed to be in place where it can be environmentally friendly and, in addition, be able to motivate mode shift (from non-public vehicles to public transport). When there is a higher ridership of electric buses, it will indirectly reduce the emission of pollutants when the passengers choose to change from private vehicles to public transport (Yoshitaka et al., 2011; Boedisantoso et al., 2019).

Besides this, by deploying electric buses, the utilisation and reliance on non-renewable natural resources (fossil oil) can be minimised and used wisely. Electricity generation is not only produced by fossil oil or non-renewable natural resources, but it could also be produced by other alternatives, for example, renewable resources (solar, wind). These multiple options can further assist in achieving the objective of sustainable energy as well as protecting and preserving the environment.

Although the electric bus has been categorised as one of the green vehicles, there is analysis revealing that it still manages to produce minor harmful pollutants (He et al., 2018; Song et al., 2018; Dreier et al., 2018). This study is to develop the environmental assessment tool for electric buses when making decisions for the electric bus fleet's planning and operation. With this, a clearer picture and position of how green performance is defined in the electric bus fleet planning and operations can be identified.

Furthermore, with the improved green performance, the energy consumption, emissions, and noise of electric buses could be reduced further by implementing a variety of alternatives, is no doubt that the use of an electric bus is able to reduce pollutants compared with a conventional bus. However, an assessment tool for the green performance of an electric bus is important for bus operators to refer to when making decisions in the fleeting planning and operation of electric buses.

1.4 Research Scope

This study discovers the characteristic (vital output) of the electric bus during operation and the assessment framework for the environmental performance of the electric bus operation. The effectiveness of using electric buses in combating the produced pollutant has been concerned and disputed.

The introduction of environmental performance for electric buses could be good to kick-start the measurement of the green performance of the electric bus operation for which the amount of pollution as well as the level of environmental performance of the electric bus can be achieved simultaneously. Figure 1.5 illustrates the general framework of this study that aims to quantify environmental performance of electric bus operation. Numerous elements have a substantial impact on the decision-making for the planning and operation of an electric bus fleet. Environmental factors, namely government subsidies, financial costing, passengers' needs, and electric bus technical features, all factors play a role.

Each element has a secondary effect on the others. For instance, when a government subsidy is implemented or introduced, it may have a significant impact on the financial cost of the bus fleet. Low bus fares may potentially increase ridership when financial costs are reduced. When demand rises, there is a trend towards the enhancement of bus technical qualities (e.g., improved energy efficiency or reduced maintenance costs) as well as passenger comfort. When the bus fleet grows, environmental protection becomes more important, and the impact on the environment must be addressed. As a result, when operating an electric bus fleet, all of these key elements need to be considered. As shown in Figure 1.5, all of the aforementioned components have a significant impression on these factors.

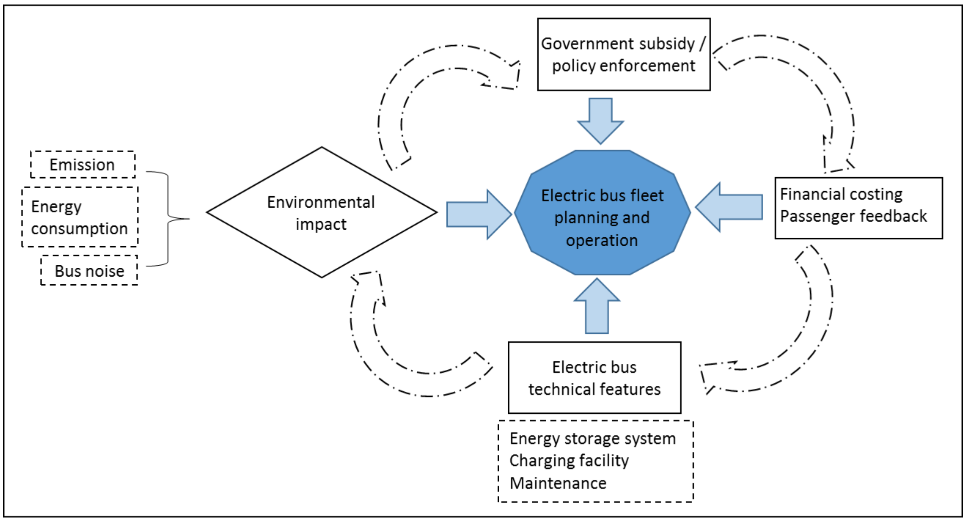


Figure 1.5: The overall framework for electric bus fleeting planning and operation

In this study, three major factors that affect the environment during the operation of an electric bus are identified: energy consumption, emissions, and bus noise. Numerous parameters (e.g., bus capacity, bus frequency, load factor, bus-traveling time, charging opportunity) play a significant role that influences the bus operations largely. The environmental factors (energy consumption, emission and bus noise) are then towards the decisional criteria (government subsidy /policy enforcement, bus technical features, financial cost and passengers' feedback) are incorporating in decision making of the electric bus fleet planning and operation. Subsequently, the collective result from the survey can provide a closer and more accurate approach on this. Each decisional criteria may signifies.

Overall, this research can be used as an environmental evaluation indicator in decision-making for electric bus fleet planning and operation, as well as guidance for bus operators in decision-making. For analysis purposes, Putrajaya, Malaysia (one of the low-carbon cities that the Malaysian government is attempting to create) was chosen as the case study in this study to assess the applicability of the proposed methodologies (GEF MTR, 2019). In addition, Putrajaya is a location where the possibility of replacing the existing natural gas-powered bus fleet with electric buses while maintaining the current bus route and frequency can be investigated (Putrajaya Corporation, 2012). Potentially, there are continuing mixed developments in Putrajaya which include residential properties that are connected with broader business, retail, entertainment, or even transportation services, which would be a good fit for this study (Chen, 2021).

1.5 Research Objectives

The research objectives with hypothesis are listed as below:

(1) To quantify the environmental (green) performance of the electric bus fleet

and operational planning by capturing influential environmental factors (energy consumption, emission and noise).

Hypothesis: Green performance assessment with influential environmental factors ensures that the electric bus emits as few pollutants as possible.

(2) To develop a decision process for electric bus operation by assessing the green performance of the operating electric buses.

Hypothesis: The development of the decision process can aid the bus operator in having proper and better planning for the electric bus operation.

(3) To include numerous influencing aspects (government policy/subsidy enforcement, passengers' feedback/response, bus technical features, and financial cost) in quantifying the environmental performance of electric bus operation.

Hypothesis: Various influential aspects are captured appropriately into the environmental performance assessment of electric bus operation in order to provide realistic and insightful information for the electric bus operator.

1.6 Thesis Overview

The study is structured as shown below:

Chapter 1: The Introduction addresses the goals and scope of the study, as well as the associated approach and value.

Chapter 2: **Literature review** explores previous research, that are intently linked to this study which included the improvement of the electric powered cars and buses, the specifications of electric bus (energy storage system, fleet planning, transit network design), the environmental affect from the electric bus operation and the application of the electric bus in specific countries. Last section of the discussion covers the utility of Analytic Hierarchy Process (AHP) and green evaluation in transportation.

Chapter 3: Methodology is divided into four sections. The first section highlights the importance of the role of environmental performance, while the second part focuses on the Green Performance Index evaluation framework, which employs the Gini Index Approach to construct the green indexes, which include the Green Energy Consumption Index, Green Emission Index, and Green Noise Index. The topic then moves on to how the separate green indexes are combined to generate the Green Performance Index. As a measure of green performance, the proposed weightage-grading approach is used. Weightage can be determined in two ways: either it is defined based on the outcomes of some previous studies or by utilizing the Analytic Hierarchy Process (AHP). The third section describes how to use AHP to calculate the weightage. It includes the questionnaire design and survey findings, with the results assisting in the weightage computation for the Green Index. In addition, a numerical example (derived from AHP) is presented in the third section. To achieve greener performance, enhancing strategies (increase load factor, adjust bus frequency, fleet planning, reduce bus frequency, and change charging facility) are outlined accordingly.

Chapter 4: Results and discussion primarily focuses on the assessment of environmental performance based on a benchmark scenario and improvement strategies with a case study serving as the benchmark scenario. In the first part, three sets of weightage are proposed to quantify the green performance of the electric bus operation. The improvement strategies are then compared with the benchmark scenario to analyse for the enhancement stage and effectiveness as well as to recognize the satisfactory strategy. The second part of the chapter focuses on quantifying the weightage for the Green Performance Index with the application of the Analytic Hierarchy Process. The resulted weightage would be applied in the computation of the Green Performance Index in the benchmark scenario and improvement strategies. Further from there, upon the comparison between benchmark and improvement strategies, the best strategy can be recommended. Precisely, the comparison of the results (by applying different types of weightage) is conducted and analysed.

Chapter 5: Conclusions provides a succinct review of this study, as well as some suggestions for future research and accomplishments.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews the previous literature on some major aspects of this research. It comprises of three parts. The first part discusses the development of an electric vehicle. The second part of the chapter is dedicated to discuss the specification, environmental impact and the global application of electric bus. Moreover, the third part deliberates the application of green assessment and Analytic Hierarchy Process (AHP).

2.1 History of Electric Vehicle

Environmental issues have been raised over a decade. The invention of the small model car powered by an early type of electric motor was introduced in 1828 by Anyos Jedlik. After that, the rechargeable battery (the invention of lead-acid battery in 1859) had brought viable means to the electric vehicle industry. Further from this invention, the first human-carrying electric vehicle (tricycle) was successfully tested at a Paris street in 1881 by Gustave Trouve (Fessler, 2018; Situ, 2009).

Numbers of inventors applied the electric motors in few others vehicles, for example Gustave Trouve adapted it to Marina propulsion where invested the outboard motor, the overhead tramway in London was the innovation of Thomas Parker. With the widespread development of the electric vehicle, the main and first support came from France and United Kingdom. In Europe, Germany was the first country that built the first real electric car in 1888 (Fessler, 2019; Situ, 2009).

The first gasoline-electric hybrid vehicle was produced by Lohner Porsche in 1899. The term had changed to plug-in hybrid when the vehicle can charge from a standard electrical wall socket (Fessler, 2018; Situ, 2009). After 15 years use of electric vehicles in Europe, United States had developed the first electric car that invested by William Morrison of Dei Moines. The attention from the public begun after the first electric tricycle was introduced in United States (Fessler, 2018; Situ, 2009).

The attention and interest was greatly increased in the late 1880s and early 1900s. 'Hummingbird' the electric battery-powered taxis started to be available and were introduced to the street in London in 1897. In 1900s, electric vehicles became more competitive as no vibration, no smell or noise as well as no gear changes required, compare to gasoline cars. Due to the ease control of electric vehicles, it was once known as 'women's cars' and very famous for those customers who used as city cars. In the United States, the electric cars became the most accepted vehicles, which led the United States to be the country with the highest percentage of electric cars where there were variety luxury features designed in the electric cars (Fessler, 2018; Situ, 2009).

However, due to the development of road infrastructures, the requirement for electric car became higher. The longer traveling time, lack of charging facility, high speed and lighter battery became greater challenges for electric cars. The needs of wider range than offered by electric cars was created and highly in demand. With the discovery of large amounts of petroleum all over the world, gasoline has become more affordable, making gas-powered cars more cost-effective when travelling long distances. Numbers of improvement conducted in gasoline cars such as easier to handle, noise reduction, can travel farther and higher speed. This led the gasoline car to become popular for the nation. However, in certain application, electric vehicles were still the most favourable, for instance forklift trucks in Yale, milk floats in London and electric golf carts was produced by Lektro. Sadly, the electric car industry had totally disappeared in 1920s (Fessler, 2018; Situ, 2009).

Nevertheless, after World War II, the countries with limited source of petroleum begun to work together to produce a new electric car, the Henney Kilowatt. This electric car can travel longer on a single charge and had higher speed (96km/h). Due to the very expensive purchasing price of the vehicle compared with the equivalent gasoline cars, the production stopped in 1961(Fessler, 2018; Situ, 2009).

Some efforts (i.e., battery-electric car and electric version of gasoline car) were put in to develop the electric car in the mid-1960s, yet no fabrication seen. In 1971, the Lunar Roving Vehicle was the first electric car on the moon. It was developed by Boeing and Delco Electronics. This vehicle applied during the Apollo 15 mission.

From 1960s to 1990s, the renewable energy application in electric cars had raised great interest in the industry. In United States, the conversion from existing manufactured models to battery electric vehicles were produced by some companies and mostly used by the government agencies and electric utility companies, as the cost was high and in a limited range. Besides, the United State government also provided some incentive and policy enforcement to encourage the research development in the electric car. However, the interest in environmentally friendly declined in United States as the consumers more favour to the sport utility vehicles, which were more affordable to operate due to lower gasoline price (Fessler, 2018).

Among the important features for an electric car, the combination of metal-oxide-semiconductor (MOS) technology steered the development of modern electric car. This technology had brought the reduction of power losses, lower price, made the electric car easier to drive and better battery management. In addition, lithium-ion battery was invented and capable the long distance travel.

The first battery swapping model electric car was introduced by Better Place in 2010 where the battery exchange process took five minutes (Nio, 2020). Nevertheless, another option of electric car (plug-in hybrid vehicle) was a good selection with the intention to minimize the GHG emission. The commercial development for plug in hybrid electric powered automobiles was started after 2002. In 2000s, various electric car makers (i.e., Tesla, Nissan, Chevrolet, Better Place, Toyota) had started the electric car development and production globally by providing high specification of electrics cars. The awareness of the green environment became greater when the consumers started to accept electric cars as their private vehicles, example in Norway, 10% of all cars on the road are electric (Fessler, 2018).

Further from the invention of electric vehicles, the first electric bus was introduced in London in 1907 and it was a battery electric bus. The electric bus was equipped with lead-acid batteries and carried 34 passengers with the ability to travel 60km on a single charge (Li, 2016). The design of the electric bus changed from time to time in order to have better function and features and manage to meet the social needs. Before the mid of 2000s, majority of the electric buses took at least 6 hours as the regular charging with the size of 6.7m. However, since the mid-2000s, the development and operation of electric bus specifically charging facility and energy storage systems had been improved and enhanced (Li, 2016). The next section will further elaborate on the electric bus.

2.2 An Overview of Electric Bus

The development started from an electric vehicle with only usage of a battery/batteries before expanding into a hybrid electric vehicle which consists of the use of battery and other power sources, such as diesel and hydrogen. From there, it turned into a plug-in hybrid electric vehicle (Atmaja and Amin, 2015). The issue of battery and charging efficiency has been a major emphasis since the electric bus was first introduced, as it requires electricity to run.

Electric bus is powered by electricity. The types of electric buses depend on how electricity is generated to the bus, for example, a battery electric bus solely depends on the battery placed in it, a hybrid electric bus relies on the diesel engine, which generates electricity and a fuel cell electric bus uses hydrogen fuel cells to generate electricity. Figure 2.1 explains the type of electric bus and components.

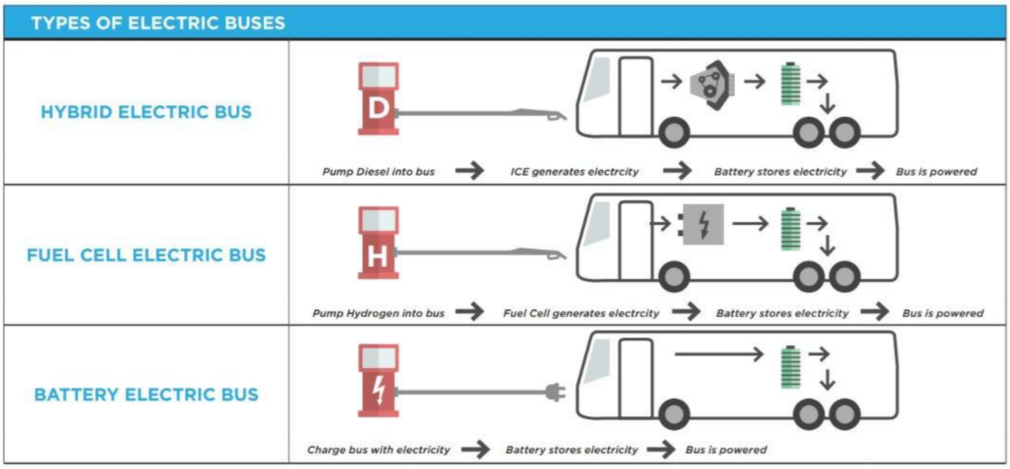


Figure 2.1: Type of electric bus and components (MRCagney, 2017)

When an electric bus is compared with a conventional bus, the conventional bus is equipped with an internal combustion engine that uses diesel to operate where the fuels ignite under compression. A battery electric bus operates with an electric motor and a hybrid electric bus operates with an internal combustion engine and an electric motor. A fuel cell electric bus generates electricity through a chemical reaction between hydrogen and oxygen. Figure 2.2 to Figure 2.4 show type of electric buses available in the market.

Figure 2.2: Battery electric bus- Mercedes Citaro Electric (Sustainable Bus, 2018)

Figure 2.3: Hybrid electric bus in New York City (Barnitt, 2008)


Figure 2.4: Fuel cell electric bus (Fuel cell bus, 2020)

The advantages of using an electric bus when compare with a conventional bus are that the electric bus has less or zero tailpipe emission, lower bus noise, lesser operating cost and high energy efficiency of electric motor (Sheth and Sarkar, 2018; Teoh et al., 2018). As a result, the operating cost of an electric bus is lower and it can be a cost saving for long-term benefit (Sheth and Sarkar, 2018). However, the disadvantages of the electric bus are the short driving range, requires charging infrastructures, high purchase cost and heavy battery weight (Aamodt et al, 2021). Dirks et al. (2021) has proposed a guide on how to convert the existing bus network into the electric bus operation. Few requirements (i.e., charging infrastructure, fleet management, costing, bus scheduling) have been identified in the proposed guide; however the environmental aspect is ignored.

Besides, ultra-capacitor (namely super capacitor) was designed as the energy storage system for an electric bus instead of a battery. Both play a crucial role as the energy storage system in the electric bus which able to determine the service quality of it. To have a well-planned and smoother electric bus operation, few factors need to be taken into consideration as well. For example, fleet management, transit network design, maintenance features and costing. Each factor may have mutual impact in affecting the decision-making for the electric bus fleet planning and operation (Teoh et al., 2018; Ibarra-Rojas et al., 2015; Shafahi and Khani, 2010; Lin and Xu, 2017; Song et al, 2020; Wang et al., 2014).

Fleet planning may encompass the decision on bus type, bus capacity, number of bus or bus frequency for the whole bus operation as well as when designing the bus scheduling. During this planning process, the transit network design needs to be counted in as the allocation of the location of the charging facility is essential to be identified (Teoh et al., 2018; Filippo et al., 2014; Clairand et al., 2019; Pternea et al., 2015). Type of charging facility (fast charging kiosk or slow charging depot) must be determined, so that the whole bus operation will not be affected due to insufficient energy. The total length of each designated bus route as well as its traveling time also need to be known and this will be an important factor in allocating the charging facility.

Compare with a conventional bus, an electric bus requires lesser maintenance. Different types of electric buss may need different services of maintenance in tuning up the bus performance. From there, the cost of maintenance can be lower and this is important for bus operator to consider in the decision making for the electric bus fleet planning and operation (FCH-JU, 2012). Lastly, the financial cost of an electric bus in comparison to a conventional bus is always an important factor in the planning and operation of an electric bus fleet. The cost may consist of an initial capital cost, maintenance cost and environmental cost. However, there are some other important specifications (transit network design and fleet management problems) as well as environmental issues that also need to be considered in the sustainability of the electric bus (Goh et al, 2016). The following section will discuss further on the features of electric bus.

2.2.1 Electric Battery

A battery plays a very important role for the electric bus as it provides primary electrical energy for the bus to operate (Lorenzo et al., 2014). The importance of battery is the same as fuel function for the conventional bus. The required electric energy is stored in the battery that is placed within the electric bus. The resultant electric energy is the conversion of the chemical energy that is stored in the electrochemical cells that will form a battery.

Different batteries may have different specifications and may be subject to the needs they require. Hence, a careful selection of the battery type is crucial as it may affect the entire electric bus fleet planning and operation. Some common specifications laid within battery usage are the battery capacity (measure in watt-hour (Wh), level of charge of the battery relative to the capacity (namely state of charge (SoC) and measure in percentage). There have been several types of batteries since the invention of the electric bus in the 1880s. For example, lead acid batteries, nickel base batteries, and lithium batteries (Li and Zhang, 2009).

The lead acid battery is the very first battery invented for the use of an electric vehicle. It is commonly found in conventional ICE vehicles. However, the lead acid battery is not environmentally friendly, especially during the disposal process. The only advantage of this battery is that its purchase price is cheaper when compared with others. Nevertheless, this battery is bulky in size and heavier as well. One of the main concerns with this battery is that it takes a longer time to recharge (Cignini et al., 2020).

The lithium battery is always recommended for the use of an electric vehicle due to its smaller size and fast charging (Li and Zhang, 2009). Besides, there is no poisonous content in the structure of a lithium battery. In addition, it has a higher level of specific energy, specific power, and energy density. Moreover, the lithium battery tends to have higher energy density and better power efficiency (Korsesthakam and Sripakagorn, 2014). However, the disadvantage of the lithium battery is the high production cost (Lajunen and Suomela, 2012). Lithium batteries are classified into several types, including lithium metal batteries, lithium sulphur batteries, lithium-ion polymer batteries, lithium–titanate batteries, and lithium–iron phosphate batteries. Each different type of lithium battery has its own advantages and disadvantages. In term of cost, lithium metal is the most expensive battery. In addition, lithium-iron phosphate with higher power density is safer due to its superior thermal and chemical stability characteristic. As for current practice, the lithium–titanate battery is the most desirable and is found in the electric vehicle (EV) application due to its fast charging characteristic.

Beside lithium batteries, there are some good and suitable nickel based batteries for the electric vehicle (EV) application. The common nickel based batteries found in the market are nickel-zinc, nickel-iron, nickel-cadmium and nickel-metal hydride battery. Each nickel-based battery owns a different special characteristic in operation. Nickel–metal hydride (NiMH) is the most appropriate nickel based battery to be used in EV application (Iclodean et al., 2017). On top of being an environmental friendly battery, NiMH is safer and lower in cost as compared to lithium-ion batteries. Besides, NiMH has a high power and energy density as well (Iclodean et al., 2017). These advantages have made NiMH one of the preferable choices for industry and consumer applications. However, NiMH takes a longer time to recharge, and chargers that are more expensive are necessary.

Another type of nickel based battery such as the nickel-zinc battery has a short life cycle though it is found to be more environmental friendly and non-toxic (Squiller and Brody, 2011). Li and Zhang (2009), Squiller and Brody (2011) and Iclodean et al. (2017) showed that different specifications of batteries may give a different impact to the environment but did not show the environmental performance during the electric bus operation further from application of batteries in electric buses.

2.2.2 Charging Facility

Different charging opportunities enable us to classify the types of electric buses. Different types of electric buses are equipped with different charging facilities, and the charging specifications are inclusive of charging period and charging efficiency. Besides, the charging facility locations also need to be considered as the electric energy storage of the electric bus will vary after it operates for a certain range of travel distances or duration. Khoo et al. (2017) and Chong (2016) highlighted that the charging duration will significantly affect the bus frequency as well as the bus fleet. The charging duration can be slow charging or fast charging. Slow charging may take up to 1 day or 8 hours, subject to the battery type and charging facility. As for fast charging, it enables the battery to recharge in a shorter period, for example, 80kWh in 10 minutes.

The trolley bus consists of trolley poles, roof structures, engine, compressor and diesel electric power unit. The electric energy is generated from overhead wires by using spring-loaded trolley poles to drive the motor of the bus (Kuhne, 2010).

A fuel cell electric bus contains polymer electrolyte fuel cells that produce the electrical energy for the vehicle's propulsion. The fuel cell is fed by high purity hydrogen gas. A battery electric bus has installed batteries that store the electric energy supplied during charging and feed the electric motor for the vehicles propulsion (Lorenzo et al., 2014).

A hybrid diesel-electric bus mainly consists of an internal combustion engine (ICE) and an electric motor (Jia et al, 2006). The internal combustion energy produces electric energy to drive the electric motor, the battery unit as an auxiliary unit where will be charged by the regeneration braking energy (Jia et al, 2006). The hybrid fuel cell electric bus power system includes a fuel cell unit and a power control unit. The fuel cell unit produces electric energy to drive the electric motor and the battery unit is same as the hybrid diesel-electric bus. The fuel cell unit is fed by hydrogen.

A plug-in hybrid electric bus does the recharging of a battery from an external electric source when there is low battery capacity. It can be constructed in series, parallel or series-parallel for the propulsion system. The electric energy for vehicle propulsion is produced purely by an installed battery, while gasoline or diesel acts as the auxiliary power unit (Cheng et al., 2009).

An on-line electric vehicle is defined as a wireless transportation system (Jung and Jang, 2015). The bus's battery is charging via inductive magnetic field when the bus is driving. The magnetic field is created from a road embedded power rail.

The energy storage system (battery or ultra-capacitor) as well as the charging infrastructure location need to be planned properly as the charging structure may increase the initial cost (Olmos et al., 2019). Different locations for the charging infrastructure can be considered, for example, placement of the charging facility at the bus station, the shortest path between any two points (Funke et al., 2016). The environmental impact of the indirect emissions from charging facilities was not clearly assessed and applied, especially during the decision-making on electric bus fleet planning and operation.

2.2.3 Ultra-capacitor

Ultra-capacitor (UC) or super-capacitor is an electrochemical device for storing large amount of electrical charge (Kumbhar et al., 2020). According to Cao and Emadi (2009), it is one of the most effective power drive systems for overcoming the difficulties associated with chemical storage batteries (for example, stored energy safety concerns, limited life cycle, imprecise extent of state of charge and current delivery or absorption during regenerative braking constraints). Driving behaviour and road conditions can have a negative impact on the life of the battery when random charges and discharges are incurred (Cao and Emadi, 2009).

Although a battery with high power density is attractive, but the higher cost and thermal management of the battery due to increased power density is also a key concern. UC has capability of fast charging and yet slow discharge rate compare with normal capacitor (Kumbhar et al., 2020). Besides, longer life cycle and insensitive to changes in environment temperature are one of the significant advantages of UC (Zhang et al., 2015). To get a better performance in driving range and prolong battery life, hybrid energy storage system (HESS) is proposed in some electric bus applications to combine the ultra-capacitor and the battery.

2.2.4 Fleet management

Fleet planning affects the transit network timetabling and frequency setting as it is one of the crucial elements in the transit network planning (Ibarra-Rojas et al., 2015). As mentioned in previous section, the battery is the major source of energy for electric bus. Hence, to produce effective electric bus fleet planning and operation, battery charging plays an important role as an electric bus has limited range autonomy and needs to be recharged (Pternea et.al, 2015).

However, there are differences between a conventional bus and an electric bus when making decisions in fleeting planning. To avoid any delay in bus travelling or passenger travelling time, the charging duration has to be one of the inputs as well. Shorter bus routes may require a larger bus fleet to allow additional downtime for recharging (Miler and Potter, 2014). Hence, a well-planned battery charging infrastructure in a bus network may be able to solve the arising charging problem in the fleet planning. Various types of energy storage systems with fleet management can produce optimal fleeting planning (Korsesthakam and Sripakagorn, 2014).

Good and proper planning is very important, especially for the cost-saving operation of an electric bus fleet (Teoh et al., 2018). One of the primary concerns in charging facility planning is the high cost of the charging facility. Although the investment and initial cost of an electric bus is high, it can be replaced by the lower energy and environmental cost (Fusco et al., 2013).

Besides, the decision on bus quantity and bus type will also affect the general user (passenger) cost, for instance, in-vehicle travelling time, passenger waiting time, and passenger travelling time. As a result, the bus frequency has come into solution where the bus capacity is needed to be considered in the modelling as well (Ibarra-Rojas et al., 2015). The demand might also vary at some stage in the bus operation, such as peak hour, off-peak hour, weekend, weekday, rainy season or disturbance elements, so the version of the demand needs to be considered as well. Therefore, Amiripour et al. (2014) viewed the seasonal demand variation and utilized it in their developed approach, which was based on the base sturdy network. However, environmental factors were no longer taken into consideration in the decision-making of an inexperienced bus fleet.

2.2.5 Transit network design

Transit network design is one of the important processes when determining transit operational planning (Shafahi and Khani, 2010). Many factors (i.e., land use, demand, operating cost) are mutually affected by the transit network design. A functional and efficient transit network design is important because it can ensure traffic flow and reduce pollution. The minimal cost of passengers and bus operators needs to be taken into consideration (Amiripour et al., 2014). The passenger is more focused on the quality of bus service (i.e., the punctuality and minimum wastage of waiting or travelling time), while for the bus operator, investment cost, maintenance cost, and technical features (additional training for the bus driver) could be the main concerns.

Several suggestions for an optimal transit network design have been proposed. For instance, Pternea et al. (2015) proposed generating and configuring the optimal route as well as determining the bus service frequency initially. Besides, some optimization models were suggested to solve the transit network design problem (Gallo et al., 2011) and penalty imposed due to the unserved demand (Beltran et al., 2009; Cipriani et al., 2012; Fan et al., 2013; Fusco et al., 2013).

Conventional buses only need to focus on the bus station locations, yet electric buses need to consider the locations of the charging facilities in which the charging will happen along the bus route or at a specific charging station. As a result, some critical factors for the design of an electric bus transit network, such as charging station specifications, battery capacity limitations, charging duration, total travelling time, and the length of route for returning before the battery runs out, must be considered. For certain types of electric buses, the charging times may occur a few times in a day. As a result, it is necessary to allocate a charging station location in a transit network (Pternea et al., 2015). Besides, Filippo et al. (2014) suggested that battery swapping could be one way to ease the transit network design problem. As for the stochastic demand in transit network design, Amiripour et al. (2014) have presented a solution approach where multiple-demand for each season is considered in their base robust network.

2.3 Environmental Aspect of Electric Bus

Previous studies have highlighted that the environmental aspects of electric powered buses consist of energy consumption, emission, and noise (Aamodt et al., 2021; Abbasi, 2018; Borén, 2019; Krystian and Oliwia, 2020). These factors can have a wide range of negative effects on the environment and the living creatures on the planet. Among the hazardous gases, CO_2 is one of the most important gases that is accountable for the greenhouse impact and global warming. Transportation has a close relationship with CO_2 emission control because it contributes to energy consumption. Furthermore, numerous research studies on one-of-a-kind propulsion devices and alternative fuel utilities have been conducted because of these environmental aspects. For example, the innovation of gas cells, hybrids, or pure battery electric drives. It confirmed that there is no emission produced by an electric bus throughout the use phase, but there is an emission at some stage in the charging segment (the electricity generation production). Besides, an electric-powered bus is in a position to make minimal noise in the course of the bus operation compared with a traditional bus. The noise may prove to be a different challenge to the electric powered bus driver's use pattern and avenue conditions.

Nevertheless, the environmental gain of the electric bus has become a motivational key for the electrification of transportation (Poullikkas, 2015; Zivanovic et al., 2012). The following section discusses some additional points concerning energy consumption, emissions, and noise.

2.3.1 Energy Consumption

The transportation sector is the second largest user of electric energy in today's world, which is also the major contributor of air pollutants and GHG emissions (Atabani et al., 2011). Though electricity had become the main driving power for road transport at the end of the 19th century, with the invention of the internal combustion engine and the lower cost of fuel, the use of electric vehicles started to be ignored until humanity started to be aware of the pollution produced by the internal combustion engine (Tomic et al., 2018).

The environmental benefit of the electric bus has become one of the key motivations for the electrification of transportation (Poullikkas, 2015; Zivanovic and Nikolic, 2012). Various sources of energy (i.e., hydrogen, electricity, and biofuel) are applicable to different types of electric buses (Conti et al., 2015; Mierlo et al., 2006). Thus, the bus's operational performance could still be affected by the respective energy source (Mahmoud et al., 2016).

As battery is one of the energy storage systems for an electric bus, there is a need to determine the most suitable and adequate battery size. Basma et al. (2020) proposed an energy modelling for battery to evaluate the required energy by the electric bus during the bus operation. Besides, the energy storage systems of electric buses have significant impact on the energy efficiency (Zivanovic and Nikolic, 2012). Energy efficiency has been reviewed based on Well-to-Wheel (WTW) assessment, which comprises of Well-to-Tank (WTT) and Tank-to-Wheel (TTW) (Mahmoud et al, 2016; Ribau et al., 2014; Garcia et al., 2013; Torchio and Santarelli, 2010) which depends on the production method and it may vary significantly. WTW refers to the entire process from the production of the energy source to the vehicle has been driven (Mahmoud et al., 2016). Meanwhile, WTT is equal to the ratio of energy generation volume to energy consumed during the process, whereas TTW is the energy consumption which varies during the driving conditions (congestion, geographical conditions, number of stops or speed) and type of propulsion (hybrid, battery type and fuel cells type). Song et al. (2018) considered a different electricity mix to compute energy consumption for which different countries apply various resources to generate electricity whereas Mahmoud et al. (2016) highlighted that the production method of electricity has a great impact on energy efficiency.

Additionally, the energy consumption of an electric bus was found to be impressed by several significant factors, i.e., driving behaviours, number of passengers, traffic conditions, route characteristics, number of bus stops and speed of the bus (Borén et al., 2016; Li et al., 2021; Ma, et al., 2021). Besides, uncontrollable external factors such as extreme weather conditions also affect the energy consumption of the electric bus (Basma et al., 2020).

Perrotta et al. (2014) revealed that more energy spent from most demanding bus route where more stops performed in shorter distance throughout the electric bus operation. Additionally, it was found that the energy demand of a bus line can be influenced by the driving condition even with similar route length (Gallet et al., 2018). Bunzel and Baker (2018) also discovered that speed-time profile as well as any external condition (climate) could affect the energy demand of an electric bus. However, Borén et al. (2016), Gallet et al. (2018), Perrotta et al. (2014), and Bunzel and Baker (2018) merely analysed the energy requirement of an electric bus in various conditions.

Although the afore-mentioned studies highlight that there is a need to consider the battery capacity and recharging facility in the operating system of an electric bus, some influential factors (e.g., load factor, bus quantity, bus frequency, and bus type) are not clearly discussed in these studies. The existing studies also did not deliberate the green assessment of energy consumption for the electric bus fleet planning and operation. In actual practice, the subjective perception of transport experts and bus operators is essential to consider. However, it is not found in these studies.

2.3.2 Emission

Air pollution produces waste gases, which comprise of nitrogen oxides (NO_x), particulate matter (PM_{25}), carbon dioxide (CO_2), methane (CH_4) and sulfur dioxide (SO_2). Amongst these gases, CO_2 is the primary greenhouse gas emitted from transportation activities (EPA, 2020). The environmental performance of electric bus in greenhouse gas (GHG) emission is presented in the form of WTW evaluation system (Zheng et al., 2020; Mao et al., 2020).

Compared to the conventional bus, the outcome of WTW evaluation system is different for an electric bus. The emission of the electric bus is the indirect pollutant created during the electricity generation process (namely WTT) where the indirect emission from the upstream process is being ignored (Song et al., 2018). In particular, Song et al. (2018) also revealed that the charging efficiency and electricity distribution loss of electric bus plays significant role in controlling the GHG emission. Mateo-Pla et al. (2021) applied a novel calculation model (which required real time traffic data) to measure the total quantity of GHG mission contributed by all road transports. However, this method is unable to identify the exact source of emission.

Besides, it was found that energy consumption is correlated with WTW (GHG emission) (He et al., 2018; Dreier et al., 2018). He et al. (2018) revealed that GHG emission from electric buses was partly affected by energy consumption. Specifically, different bus types and operating time can have a different TTW energy utilized which could be an influence to the GHG emissions (Dreier et al., 2018). Özener and Özkan (2020) revealed the correlation of the emission and bus acceleration. It was found that the bus emission increases when the bus is accelerating especially when the bus is taking off from the bus stop and a traffic light.

Besides, Miles and Potter (2014), Offer et al. (2010) and Haddad et al. (2019) highlighted the environmental benefit of electric bus, for example, with the usage of low-emission buses on the road could reduce the CO_2 direct emission of the electricity production up to 75%. However, the percentage of emission reduction may vary with the electric generation mix production method.

In short, the existing studies mainly analysed the total produced emissions by the electric bus without conducting any green assessment (emissions). Apart from that, some other factors that affect electric bus fleet planning (bus quantity, load factors, bus frequency) are not clearly stated in these studies. Obtaining data from the transportation expert is also crucial when quantifying the green assessment. This is because it will provide information that is closer to its daily life application. Regardless of how, this measure is not considered in these studies.

2.3.3 Bus Noise

Cucurachi et al. (2019) disclosed that the noise pollution is one of the most influencing but being ignored environmental issues. It was found out that the loudness of noise may damage human health and causing sleep disturbance (WHO, 2011). The statistic showed that 79% of noise pollution comes from transportation, which is known as one of the main noise contributors (Steven, 2005). Different noise is generated during the bus operation in considering the type of mechanical part, road condition, bus type as well as the driver's driving behaviour. By comparing with diesel bus, the electric bus with the absence of mechanical parts is able to reduce the noise level (Laib et al., 2019).

Generally, three types of noise (exterior noise, interior noise and indoor noise) are produced during the operation of an electric bus. While exterior noise is produced during the acceleration process, interior noise is produced at constant speed or idling (Borén, 2019). As for indoor noise, it can be considered as occupational noise, which affects mainly bus drivers with various driving behaviours and the bus type (Zannin, 2008). Basically, it measures the difference between the outdoor noise and the attenuation of the bus window (Turcsany, 2016).

Laib et al. (2019) revealed that an electric bus is able to reduce the production of noise significantly, especially at the bus stop, compared with a conventional bus. Besides, it was found that low bus speeds as well as driving characteristics can have a significant impact on the noise level of electric buses (Ross and Staiano, 2007; Laib et al., 2019). Steven (2005) and Laib et al. (2019)

discussed the potential for the noise reduction of road traffic. In addition, Ross and Staiano (2007) and Borén (2019) analysed the comparison of noise levels between a conventional bus and an electric bus. In particular, they have shown that an electric bus is able to minimize the noise level and energy consumption, which leads to zero emissions during the bus operation (Borén, 2019).

Other than the afore-mentioned aspects (bus speed, driving characteristics, and road traffic conditions), it was found that the noise released from electric buses can be reduced by improving their gearbox (Lei et al., 2020). In order to calculate the noise footprint immediately from the use of private and public transport, Cucurachi et al. (2019) have proposed combining the noise impact life cycle assessment (N-LCA) and transport simulation model (MATsim). It has been proven that the road transport issue is the major contributor to the total amount of noise, and with the application of electrification, the reduction of the noise impact can potentially reach up to 55%.

Apparently, the existing studies evaluated the total bus noise of an electric bus by considering only some influential factors (i.e., bus speed, route length, driving characteristics, road traffic condition, bus technical specification, and number of bus stops). However, the fleet-based factors (bus quantity, bus frequency, and load factors) are not pondered in these studies. Furthermore, there is no green assessment of bus noise that can provide reference and guidelines to a bus operator in the electric bus fleet planning and operation. Besides, some important insights from transportation professionals were not considered in the existing studies.

2.4 Application of Electric Bus

As protecting the environment is the key responsibility of each individual on earth, many countries have imposed various policies and conducted various researches to improve the features of the electric bus. The primary goal is to reduce pollution caused by human activities as much as possible. Besides, it is also meant to ensure the sustainability of natural resources for the next generation. However, different regions of the world may have different electric bus systems due to the weather, geographical structure, and culture.

The following section will discuss the application of electric buses in Malaysia and a few developed countries. These countries were selected to be in this study as they are part of the main contributors to pollution due to the rapid development as well as the high use of electric buses.

2.4.1 Application of Electric Bus in Malaysia

In Malaysia, due to smog, Port Klang, Putrajaya, Banting and Seremban documented unhealthy Air Pollution Index (API) readings (over 100) in March 2014 (Malaysian Insider, March 2014). According to Department of Statistic Malaysia, motor vehicles have contributed 70.4% of emission of pollutants to the atmosphere in year 2017 (Department of Statistic Malaysia, 2018). The government has put in some efforts in order to increase the awareness of public and corporate on the importance of green environment. In a bid to meet the government's target of reducing carbon emission by 40% by 2020, the vehicle emission problem which is one of the main causes of the air pollution needs to be addressed (Yuen, 2014).

In year 2015, Malaysia government has made a commitment to reduce the CO_2 emission per unit of GDP by 45 % (compare the level in year 2005) at the Paris Climate Conference and Conference of Parties (COP) 21 (Khoo, 2019). Hence, the government has persevered much effort to further promoting the Low Carbon Cities Framework (LCCF), which was launched in year 2011. One of the effort from the LCCF is through the Green Technology Application for the Development Low Carbon Cities (GTALCC) project. Few cities are participating in this project, for example Putrajaya, Cyberjaya, Petaling Jaya, Melaka and Iskandar Malaysia (GEF MTR, 2019). From this project, there are numbers of public transport projects launched since year 2014 and different types of electric buses were applied.

Further from GTALCC, Malaysia had its very first battery electric bus, which integrated in the public transport fleet in the historical city, Malacca. This electric bus is able to carry 60 passengers with the length of 12m long and 2.5m wide as shown in Figure 2.5. It has cost RM1.35 million for each bus (Daily express, 2015). This electric bus is manufactured by a famous green automobile company – Build Your Dream (BYD) and it manages to travel up to 180km after fully charged. This bus is equipped with an iron-phosphate battery which is disposable and it takes approximately 5 hours to fully replenish the battery (with the power input of 60kW) (BYD, 2015). The maximum speed of the electric bus is 76km per hour. The charging station is located at the Melaka Sentral Bus

Terminal, which is also known to be the main depot for all the buses from other states.

Figure 2.5: First electric bus in Melaka (The Star, 2015)

There was another green effort that the elevated electric bus, Bus Rapid Transit (BRT) was officially opened and operated in Kuala Lumpur (Menon, 2015). The BRT is operated by 15 electric buses supplied by BYD. Upon a single charge, the bus can go as far as 250km. This BRT system is similar with the railway transit, which the bus operates on the exclusive lane and fully elevated as shown in Figure 2.6. The average speed is 45km/h and a 5.4km length route was designed to connect two-railway interchange station (KTM and LRT) which covered major development in Sunway. In year 2017, the ridership for BRT was only 7,244 daily (Nur Ayuni, 2018), Sooner after that, the BRT's ridership increased to 16, 444 daily in year 2019 after 30% of the fares reduction (Bernama, 2019).

Figure 2.6: Bus Rapid Transit in Sunway (Sunway, 2015)

Besides, another Malaysia made electric bus project produced by ESync R&D Sdn. Bhd. through Elektrik Bas Inovasi Malaysia (EBIM) program in 2016. The 12-meter-long bus which able to carry the load of 67 passengers; with optimum speed of 65km/h and covered 70km in a single charge during the first trial. This electric bus was designed in accordance with UNECE (United Nations Economic Commission for Europe) Regulations and received Vehicle Type Approval (VTA) and TUV certification (EBIM, 2016). This is one of the efforts from the private sector in supporting the government to protect the environment.

As one of the efforts to turn Putrajaya into a low carbon city, there was an electric bus pilot programme (namely Putra NEDO EV Bus project) held in Putrajaya in December 2017. This project involved four electric buses with 12m long which operate up to 30km after each charge. It was targeted to have 150 electric buses available in Putrajaya by year 2025. DRB-Hicom Defence Technologies (DEFTECH) has been assigned as the maker of the first Super Quick Charge (SQC) Electric Vehicle (EV) that will manufacture and maintain the electric buses as well as responsible for the charging infrastructures. The electric bus equipped with SCiB (From Toshiba Japan) batteries uses lithium titanium oxide in its anode. This battery has a long lifespan, low temperature performance and fast charging feature (10 minutes for a full charge) (Toshiba, 2017). Each electric bus costs RM1.5million and to be assembled in Perak.

The government has introduced the Stage Bus Service Transformation Program (SBST) to improve the bus service across the country and five cities (Kangar, Seremban, Ipoh, Kuala Terengganu and Kuching) were chosen as part of the pilot project in year 2015. This is a long-term plan which aims to improve the bus service by stages (Chan, 2015). Under SBST, the first city in the country to transform the existing bus services into incorporate the use of electric bus is Kuala Terengganu (Timbuong, 2018). The total length of the bus route is about 236km, which aim to provide more bus services to the locals.

As being part of the Green Technology Application for the Development Low Carbon Cities (GTALCC) project with the involvement of the education sector, Universiti Teknologi Malaysia is selected to be the first university to use electric powered buses in it campus as part of its environmental preservation efforts (Ahmad, 2018). This effort goal to have more exposures in the research and coaching in electric powered motors as well as to reduce the carbon stages in the campus. Figure 2.7 showed the electric bus with its rechargeable battery has the fastest charging station (approximate 20 minutes) and can go for as long as 88 km per drive. With this application of electric bus, the bus can save diesel cost approximate 60 per cent.

Figure 2.7: First electric bus in UTM (Ahmad, 2018)

As part of the government's efforts in promoting a green environmental and developing low carbon city, a memorandum of understanding was signed in March 2020 with a foreign company, which is specializing for the electric buses solutions (Azman, 2020). One hundred electric buses will be purchased and utilized for the public transit with several stages of implementation. This effort will assist the government to improve the green environment as well as creating more jobs opportunity for the Malaysians.

In March 2021, The Sarawak Tourism, Arts and Culture Ministry has offered the first ever-free e-Bus (Bernama, 2021). Four buses (can lift 26 seated passengers) are catered to grant free transportation offerings and options in the city of Kuching, Sarawak. A completely charge e-Bus is in a position to function 300 km.

2.4.2 Application of Electric Bus in Other Selected Countries

Transportation sectors in **China** have caused severe urban air pollution and the country has been facing challenges of energy security. Hence, for a start to promote the plug-in electric vehicle market, the Chinese government has introduced several of national incentive policies (i.e., purchase subsidy) since year 2009. However, the subsidy scheme is revised in year 2017 after receiving some negative feedbacks. The subsidy scheme provided is based on the set up energy storage system (normal charging and fast charging) (Du et al., 2019). It was found out that with higher subsidies would help to increase battery electric bus penetration but the scheme needed to be more logical and motivate for the viable growth of battery electric bus industry (Du et al., 2019).

In year 2015, 98% of the total electric buses in the world applied in China, which made China as the leader in the global electric bus market (He et al., 2018). Majority of the electric buses that used in China are battery operated. The usage of electric bus in China is rising from time to time (i.e., a year on year increase of 20%), in particular the city of Beijing aimed to get 10,000 electric bus in year 2020.

Land Transport Authority (LTA) **Singapore** has targeted to have complete electrify bus fleet by year 2040 with the objective to reduce noise pollution and zero tailpipe emission in Singapore (LTA, 2018). For a start, the first 50 diesel-electric hybrid buses (model Volvo 7900 Hybrid) have been operating since March 2019. In April 2020, 10 fully electric buses have gone into the operation and another 50 electric buses estimated to be in operation before year 2021. Two major challenges of electric buses facing in Singapore are the range and the charging. Due to the high demand in public transports, the electric buses must be operated in high availability which similar as the diesel-powered buses. As for charging, the electric bus needs to have adequate range of the bus trips as well as sufficient charging infrastructures installed at the depots or designated stations. Besides, lack of extra potential in the existing electrical distribution network is viewed to be one of the major problems when dealing with charging facility design and locations (Land Transport Guru, 2018).

Germany is the country which famous with most popular cars in the world. The first electric bus was introduced in Germany in year 1970. It was equipped with its108kWh batteries (with trailer) which only managed to operate for 50km and the bus capacity was 99 passengers. However, this bus was having two batteries (at the trailer) where it could switch to the other battery after 2-3 hours of driving. At the 1972 Munich Olympics, the electric bus was used to transfer all the athletes (Insideevs, 2020). To have a lower indirect emission from the electric bus, the electricity generated by renewable energy had increased to 30% in year 2016 (Rupp et. al., 2019). As per the commitment stated in the Paris Agreement, the emission in the European Union needs to be brought down at least 40% in year 2030. The European Commission has approved funding for the electric bus projects in Germany in order to meet the target of the emission reduction in year 2030 (Mehmet, 2020).

Japan has set the goal to reduce the CO_2 emissions in the country by 60% in year 2050 as one of its national objectives of to become a low-carbon society

(Kakuhama et. al., 2011). Besides, Japan emphasizes on the improvement in the electric bus service which is not only able to reduce pollutants (emission and noise), but also to encourage mode shift from private vehicles to public buses. One of the key contributions of using public transports to promote a low carbon society is the reduction of CO_2 emissions. With the mode shift, (from private vehicle to public transport) this will result in the reduction of CO_2 emissions to about one eighth for each person.

In year 2015, Japan government purchased 5 pure electric buses (for long range) from BYD Company Ltd (the world largest electric bus manufacturer) for the Kyoto's public transportation. Each bus can drive more than 250km on a single charge (BYD, 2015). In year 2017, BYD supplied the fleet of 10 electric buses to the Okinaan city of Naha and expected to provide more than 100 units in year 2018 (Nikkei Asia, 2017).

According to Mead (2019), twenty-three Indian cities are among the top 30 polluted cities in the world where New Delhi is ranked as the world's most polluted capital. The Indian government has put in some efforts to reduce the pollution across the country. In year 2019, the government released a 5-year plan to decrease the air pollution by 20-30 percent in year 2024 (Li, 2019). To reach this target, the Ministry of Environment, Forests and Climate Change (MoEFCC) has launched the National Clean Air Program (NCAP) (Jaiswal, 2019). In this program, some cities in India have been selected to take specified actions which include the procuring of more electric buses to replace the diesel buses (i.e., the city of Ahmedabad has budgeted to purchase 1000 electric buses, Pune has started to purchase 500 electric buses). In year 2014, the India's first electric bus was launched in Bangalore. A fully air-conditioned bus catering 41 passengers and can run for 250km. As for its charging duration, this bus takes no less than 6 hours to be fully charged (The Economic Times, 2014).

In **Hong Kong**, the first electric bus has started its operation in year 2013 after the government allocated funds to purchase the electric bus in order to improve the air quality. Thirty-six units more consist of two types of electric buses, are supplemented in HK (namely battery electric bus and super capacitor bus) since year 2018 (Gov HK, 2018). The super capacitor bus takes approximately 20 minutes to get a full charge and it is able to travel up to 20-30km after fully charged, this indicates that the super capacitor bus is more suitable for short route. As for the battery electric bus, it can travel about 190km after a complete charge. However, the minibus is the unique public transport in Hong Kong. The government has allocated budgets to develop green-energy transports, specifically for the electric minibus and ferries in year 2023 (Bangkok Post, 2020). The government's effort is to popularize the electric vehicles as well as to improve the air quality.

In the **United States**, transportation is the largest contributor to the greenhouse gas emission (EPA, 2019). There are 650 electric bus fleets in United States, which grew 37% since year 2018, and this is one of the efforts to improve the air quality (CALSTART, 2019). United States has targeted to have at least a third of 70,000 public buses to be converted into electric buses by year 2045 (Horrox and Casale, 2019). In the United States, the public transports in each state will be in-charged by the states itself or the states transit agencies, which is different from other countries' policy. The upfront cost of electric bus has been one of the main concerns for the transit agency in United States (Marshall, 2019). The packed urban areas, charging locations and electricity are the challenges aroused as well. Seneca, South Carolina in the United States became the first city in the world with all electric buses fleet in year 2014 (Horrox and Casale, 2019). Clemson Area Transit (CAT) in Seneca is in-charge of the transit fleet. The electric bus in Seneca takes 6 minutes to a full charge and able to travel 40 miles.

2.5 Green Assessment

The environmental assessment has been applied in urban development to ensure that the green environment sustainability is always in place. However, there are very limited studies on the environment impact assessment of the transportation, especially on electric bus.

Besides, Gini Index also involves in the transportation planning process (Jang et al., 2017; Ben-Elia and Benenson, 2019; Henke et al., 2020). Ben-Elia and Benenson (2019) adopted Gini Index approach to evaluate the versions in the equity of public transit accessibility in pre and post of the transit network restructuring. The computation of the accessibility has considered two modes of transports (public transit and car) and the travel time (from origin building to a stop). Ben-Elia and Benenson (2019) highlighted that with the sensitivity of Gini Index, it enables the multi-criteria evaluation, in which is to ensure a balanced evaluation of projects' conceivable advantage to the society and economic system can be obtained.

Apart from that, it was found that the Gini Index is able to act as one of the tools to assess and compare the impact on different public transit modes with the implementation of new transit line (Jang et al., 2017). Through the application of the Gini Index and the Lorenz curve in computing the spatial equity of the public transportation service, the effectiveness of various proposed strategies can be measured.

Henke et al. (2020) highlighted that the Gini Index is used to assess the social fairness effect with respect to transport accessibility, which is not the common application of the Gini Index (i.e., measuring the equality of element distribution in a region). Notably, the focus of the approach was not on the absolute value of the Gini Index but the variation (changes) of the Gini Index. With social equity being a variable that is unable to be quantified directly, the Gini Index has facilitated the measurement of the effectiveness of the new project implementation. The percentage changes (reduced 19%) in the resulted Gini indices have provided significant evaluation in the decision-making for the project revamping planning. It revealed that transport accessibility has increased, which indicates that the implementation of the new project will lead to a reduction in travel time for transport users.

Besides, the Gini Index has been proposed to evaluate the inequality in carbon emissions and footprints across countries (Semieniuk and Yakovenko, 2020). The use of the Gini coefficient and the Lorenz Curve is capable of measuring the inequality emission, and it has resulted in the equal emission correlating with the adequate and balanced development in multiple sectors in the cities with similar socio-economic (Cheng et al., 2020). The Gini Index also acts as a tool for the allocation and distribution of water pollutants and the actual situation is represented by the weight of the indices (established from the Gini coefficient) (Wang et al., 2011; Zhang et al., 2010).

More recently, Soares et al. (2018) applied the Gini Index to evaluate the CO_2 emission concentration in the leading countries. The application is based on Data Envelopment Analysis (DEA) to measure the environmental technical efficiency by considering the income and availability of technology in the country. However, it is just a reference to identify the overall CO_2 emissions of the country, which are interrelated with economic activities. For the highway and pavement projects, Boclin and Mello (2006) proposed using the fuzzy logic approach as the decision support method in order to assess the environmental impact. Meanwhile, for other sectors (not the transport sector), the green index derived from binary classification, namely NDVI (Normalized Difference Vegetation Index) measurements, plays an important role for city planners and administrators in urban areas due to population growth (Gupta et al., 2012).

Teoh (2015) established the green fleet index for airlines to analyse the environmental performance of aircraft in the air transportation sector. The green fleet index is determined by the relevant green level (aircraft emission, fuel efficiency, and noise). Aside from that, other technological specifications and operational aspects of the air transportation system were taken into account (with the aid of Gini Index).

In summary, the existing studies highlight the importance of environmental performance assessment in various aspects and industries. Yet, there is no measurement of the environmental performance of electric bus fleet planning and operation.

2.6 Analytic Hierarchy Process

Saaty (1977) describes the Analytic Hierarchy Process (AHP) as a decision-making technique that, taking into consideration multiple criteria, is capable of seizing up a complicated multi-criteria selection problem into a hierarchy. AHP was made available by Saaty (1977), which aimed to choose and arrange the actions given by assessing a set of prearranged principles in order to generate several criteria judgements. AHP decomposes the problem into a hierarchy, which consists of a minimum of three levels, i.e., main objective, criteria, and alternative (Ignaccolo et al., 2017). When the hierarchy structure of AHP is built, the pairwise comparison with a fundamental scale (ranging from one to nine) can be conducted, and the decision makers can rank their preference accordingly. AHP is defined as "a theory of measurement based on pairwise comparisons that depends on expert opinion to derive priority scales" (Saaty, 2008).

In particular, the AHP is fundamentally a process of classifying the significance of each objective and then rating how well each alternative meets each objective (Abuizam and Lucas, 2013). As such, the AHP manages to provide a good quality of evaluation made by the decision makers (Coyle, 2004). Relatively, the AHP is uncomplicated as well as easy to use and comprehensible compared to any of the different multi-criteria choice methods (Velasquez and

Hester, 2013).

AHP is being recognized as one of the most popular methods used for selecting problems in the transportation sector (Broniewicz and Ogrodnik, 2020). For instance, it has been used to quantify the qualitative indicator of the provider of highway passenger transport (Wen and Lin, 2011). Boujelbene and Derbel (2015) applied AHP to evaluate the performance of the public transport operator in similar conditions and from there; the best performing public transport operator was identified.

Similarly, Bubalo (2020) applied different variables (i.e., punctuality, bus speed, bus route, accident rate, bus age and on-board information) in assessing the best bus service provider. Besides, AHP has also been applied to other transportation systems, for instance, the evaluation of the road transportation system of a city cluster in Wuhan City to study the integration degree of road transportation (Zhang and Chen, 2008). The resulted system assists in investment decision-making as well as system optimization. Nonetheless, Ignaccolo et al. (2017) discovered that AHP is appropriate for dealing with complex transportation decisions (which are multi-stakeholder with multi-criteria perspectives) and decisions involving the construction of new bus stations, for which a few alternatives have been proposed.

AHP can be used to quantify the green fleet index for the air transport sector, which is made up of the green index of specific environmental issues, in addition to road transport. Teoh (2015) employs a variety of traits and circumstances. However, there appear to be no studies that have used AHP to calculate the green performance for electric buses.

2.7 Other relevant studies

In order to encourage and motivate the industry's involvement in adhering to the green environmental concept, the government may enforce a green policy for those who operate electric buses. At the same time, the government could promote an incentive programme (such as a company tax rebate or subsidy) for those who actively participate in the deployment of electric buses (Lin and Xu, 2017; Song et al., 2020; Wang et al., 2014). Therefore, government policy/subsidy enforcement is outlined as one of the vital decisional criteria for electric bus planning and operation purposes.

Besides, bus technical features need to be considered as the electric bus operates differently in terms of mechanism when compared with conventional buses. It also depends on the driver's capability and driving behaviour. From time to time, during the bus operation, the battery of an electric bus needs to be recharged when there is a reduction in energy. However, different types of batteries may have different energy storage capacities and charging efficiency (Gill et al., 2014; Shi et al., 2020; Li and Ouyang, 2011). Apparently, the availability of the charging station (facility) as well as the battery limitation are a few of the main challenges for electric buses (Clairand et al., 2019). Ultimately, the charging duration (e.g., fast charging or long charging time) may also affect the decision-making of the charging station location, type of charging system (i.e., wireless, plug-in) and route planning. Thus, consideration of bus technical features is vital in operating an electric bus.

Certainly, the financial cost is one of the crucial concerns of the bus operator when making decisions for electric bus fleet planning and operation. There is additional cost (e.g., capital, operational) or cost-saving (e.g., energy consumption, maintenance, charging facility cost) which is foreseen to be incurred in operating electric buses (Potkány et al., 2018; Teoh et al., 2018; FCH-JU, 2012). The high purchase cost of electric buses and batteries is also a barrier in the bus operator's decision-making in the electric bus fleeting planning and operation (Mathieu, 2018). Hence, the incorporation of financial costing into the electric bus fleet planning and operation is essential to ensure the sustainability of the electric bus operation for the long run.

In addition, there is a need to maintain a source of income for the bus company. Thus, passengers' feedback is important for bus operators to improve the bus service as well as profit margin. Besides, their feedback on the bus service quality, i.e., punctuality, convenience is vital and needs to be taken into consideration in the decision-making during the electric bus fleet planning and operation (Kwon et al, 2020; Eboli and Mazzulla, 2007; Munim and Noor, 2020).

However, while these studies demonstrate the importance of important aspects in electric bus planning and operation, they do not take environmental considerations into account.

2.8 Summary

Existing study highlighted the importance of deploying electric buses in order to improve the environmental issue with the aim to achieve zero pollution. However, the main limitation and lack of attention from the existing studies are the impacts on the environment from electric bus fleet. This is where the environmental aspect of electric bus needs to be addressed.

Electricity supply as well as bus noise have to be incorporated into the decision-making of electric bus fleet planning and operation in order to achieve a greener performance. Besides, revenue and profit are the main targets of the majority of past studies of decisions in electric bus fleet planning. On top, it was found out that important factors are not considered in the existing study when concerning the environmental impact of the electric bus, for example, initial cost, bus technical, passenger feedback, and government policy.

The existing study also does not have any exact approach or any environmental performance decision tool that could be used to measure the environmental performance of electric buses. The tool is useful for the electric bus operator to refer to when making decisions in fleet planning and operation. However, the existing environmental assessment is only mainly for the overall performance of the project or city development. In order for the electric bus operator to justify how green the electric bus operation is in a bus fleet, a tool as reference and guidance are required. This will motivate more electric bus operators to convert their conventional bus fleets into electric bus fleets.

CHAPTER 3

METHODOLOGY

3.1 The Role of Environmental Performance

An electric bus is one of the first green vehicles, with numerous advantages such as lowering harmful air pollution, being more cost-effective in bus maintenance, producing less noise than conventional buses, and being powered by a variety of sources, including renewable energy. An electric bus operates with the assistance of electric energy. Nevertheless, electrification is identified as one of the core contributors of GHG emissions, specifically in the road transportation application (He et al., 2018).

There are three major environmental factors associated with electric buses, including noise, emission (from electricity generation) and energy consumption (Abbasi et al., 2018; Borén, 2019; Teoh et al., 2020). These three major environmental factors have had some negative impacts on the environment.

Correspondingly, a well-defined monitoring system is vital to reduce the scale of these major environmental factors and up keep the good quality of the environment. Therefore, a properly-designed modelling system for the green index is required to quantify the environmental sustainability in order to ensure the green performance of the electric bus is capable of supporting the current operating network and meeting the demand of passengers.

The overall performance of the electric bus in terms of the Green Performance Index (GPI) can be compiled appropriately by having the modelling framework in place. The GPI plays a crucial role not only in revealing the green performance of the electric bus at present (by considering bus noise, emission, and energy consumption), but also in providing constructive recommendations on the beneficial improvement strategies that can be carried out in order to further enhance the environmental performance of the entire operating networks of electric buses. Furthermore, the efficiency of the improvement strategy could also be recognised as the further actions of the bus operators in order to provide a higher level of service to the passengers.

3.2 Assessment Framework: A Conceptual Model of Gini Index

The developed assessment framework to quantify the green performance of electric bus is displayed in Figure 3.1.

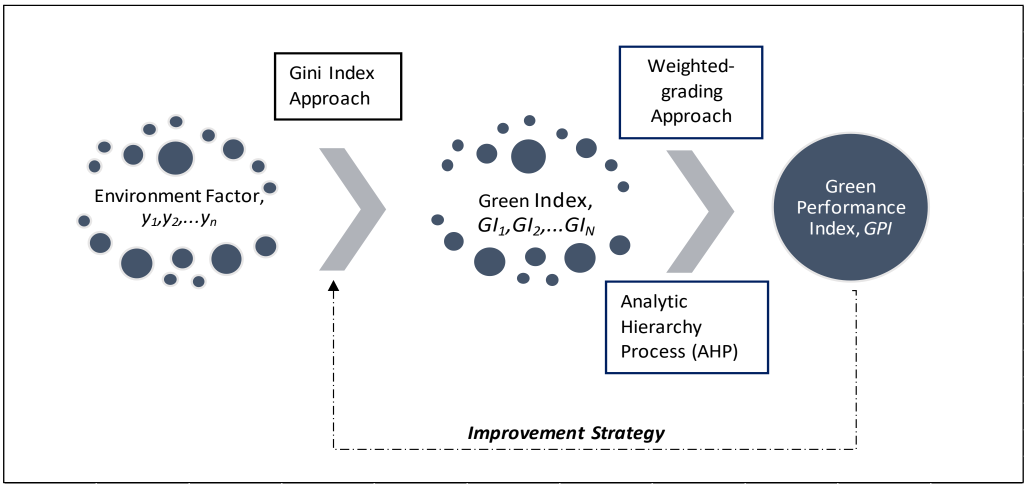


Figure 3.1: The assessment framework for Green Performance

From Figure 3.1, it could be seen that various environmental factors, y (e.g., y_1 = noise, y_2 = energy consumption and y_3 = emission) can be considered specifically in order to obtain the respective Green Index, GI (e.g., GI_1= Green

Noise Index (GNI), GI_2 = Green Energy Index (GEI), GI_3 = Green Emission Index (GMI)). This can be done with the aid of the Gini Index Approach. Before applying the Gini Index Approach, the identified environmental factors, *y* must be determined in terms of the individual amounts of pollutants (energy consumption, emissions, and noise) produced during the electric bus operation. Subsequently, the weighted-grading approach and the Analytic Hierarchy Process (AHP) will be applied to attain the GPI by integrating the respective green indexes. Besides, multiple improvement strategies could be proposed to yield a better GPI.

The concept of the Green Index Approach was derived from the Gini Index, which is a measure that represents a country's wealth distribution and is commonly used in inequality measurement. The Gini Index (GI) is a common metric for measuring inequality in the distribution of goods and services (such as income, wealth, and transportation access) across various industries (e.g., economics, transportation planning). When it approaches zero, it shows a higher level of equality, which signifies that wealth distribution is more evenly distributed in society. When it approaches one, however, it denotes complete inequality, implying that the high-income earner receives a larger share of the nation's total remunerations (Free-range statistic, 2017). The Gini Index, as reviewed in the previous chapter, can be used to assess the efficacy of a new strategy, system, or infrastructure, particularly when aspects that are difficult to quantify directly are involved (Henke et al., 2020).

Similarly, determining the impact (green level) of an electric bus's environmental performance is not straightforward. The overall amount of electric bus emissions, noise, and energy consumption (together with a range of operating variables) are the most important factors in evaluating environmental performance. The influence (severity level) of electric bus operating on the environment can be quantified by considering these components (emissions, noise, and energy consumption). The green level of each environmental component for electric bus operation can be recognized considerably by analysing the resultant Gini Index in various scenarios.

From an operational standpoint, when electric bus emissions, energy, and noise are reduced (or when the data set is closer together), the variance of the measured data sets and average tends to be smaller, resulting in a lower Gini Index (approaching to zero). A lower Gini Index indicates that the electric bus operating is more environmentally friendly. However, if the generated GI value is approaching to one, this indicating that the current operating network is tended to a poorer green performance. These variations could be described by using the Lorenz curve, which consists of two areas separated by a 45-degree straight line (line of perfect equality) as presented in Figure 3.2. The Gini Index is the ratio of the area, A which keeps apart the Lorenz curve and the line of perfect equality over the whole region underneath the line of equality ($A+B$). From Figure 3.2, both axes are ranging from 0 to 1. Hence, the total area below the line of equality (A+B) is 0.5.

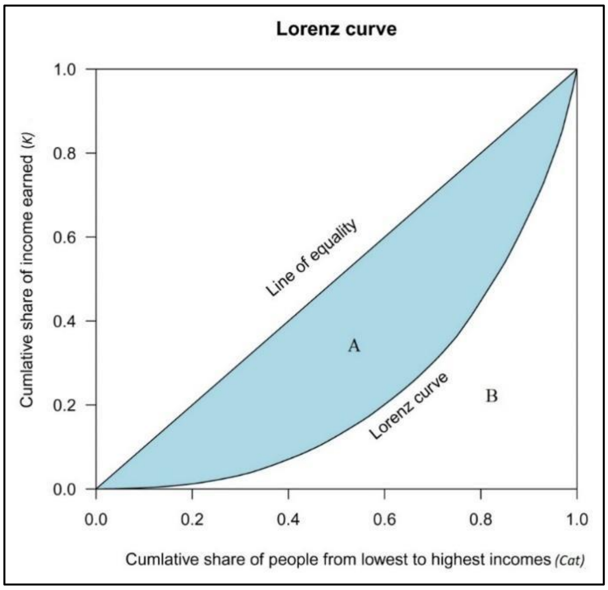


Figure 3.2: Gini Index (Free-range statistic, 2017)

.

Therefore, the Gini Index is computed as shown in Equation 3.1:

$$\text{Gini Index} = 2A \tag{3.1}$$

Where *A* is the vicinity betwixt the perfect line and the Lorenz curve that could be determined as below:

$$\mathrm{A} = \frac{1}{2} - \frac{1}{2}\sum_{\forall n}(K_n + K_{n-1})(Cat_n - Cat_{n-1}) \tag{3.2}$$

From Equation 3.2, the Gini Index is then further evaluated as follows:

$$\text{Gini Index} = 1 - \sum_{\forall n}(K_n + K_{n-1})(Cat_n - Cat_{n-1}) \tag{3.3}$$

As shown in Figure 3.2, K_n reflects the cumulative percentage of proportion of income *K* (vertical axis) and Cat_n indicates the cumulative percentage of population (horizontal axis) in category *n*. For category *n*, it adverts to the number of groups of proportion of income (with the corresponding population). To determine *n*, firstly is to sort the income *K* in ascending order. Then split it evenly into *n* parts (which means a number of subinterval with the same length) (Fellman, 2012). It is usually defined for five quintiles (i.e., *n* = 1, 2…5,) or *n* = 1, 2…10 for 10 deciles (Fellman, 2012).

To compute the Green Index for the environmental factor, the concept of Gini Index is adopted as indicated in Equation (3.4). A lower value of Gini Index (with a smaller variance) will lead to a better green performance. However, wider gap of data set tends to have a higher value of Gini Index (a poorer green performance). Remarkably, Appendix A shows that the respective improvement strategy is beneficial to yield a greener performance for electric bus operations (with a smaller value of variance, average as well as Green Index).

In other words, electric bus with lesser noise, energy consumption and emission amount can be resulting from smaller variance and average, which corresponding to enhance the electric bus greener performance.

Therefore, the Green Index (*GI*) of environmental factor could be determined as follow:

$$\text{Green Index, GI} = 1 - \sum_{\forall n} (K_n + K_{n-1})(Cat_n - Cat_{n-1}) \tag{3.4}$$

In overall, $GI \rightarrow 0$ indicates that the green level of the electric bus is getting better by producing lesser noise, energy consumption and emission for the bus operation, however when $GI \rightarrow 1$, it designates a poorer performance of green level of the electric bus where more noise, energy consumption and emission are produced during the bus operation.

3.2.1 Green Energy Index (GEI)

An electric bus operates with the help from electric energy and it is furnished with a battery, which stores the electric energy and is utilized during the engine propulsion. For a particular daily operating bus route *r*, the energy consumption level of electric bus, E_r with bus frequency h and bus quantity, q can be expressed as follows:

$$\text{Total of energy consumption for bus route } r, E_r$$
$$= \sum_{\forall r} LF\left(\left((f \times \cos(\alpha) + \sin(\alpha)) \times m \times g + \left(C \times A \times \rho \times \frac{1}{2} \times V^2\right)\right) \times V \times T\right) \times q \times h \qquad (3.5)$$

where V refers to the bus speed with the bus frontal area, a and, bus weight, m when operates on a road gradient, α with bus friction force, f.

Equation 3.5 is a modified version of the total energy consumption equation from Bunzel and Baker (2018) by adding the bus operating time, load factor, bus quantity and bus frequency which are more realistic for the bus daily operation consideration. In Equation 5, the bus speed, road gradients, bus specification and bus design (inclusive of bus dimensions and weights) are also taken into consideration (Bunzel and Baker, 2018).

By computing the total of energy consumption for the bus route as stated in Equation (3.5), the Green Energy Index, GEI, can be calculated by using the following equation:

$$\text{Green Energy Index, GEI} = 1 - \sum_{\forall n}(E_{r,n} + E_{r,n-1})(Cat_n - Cat_{n-1}) \qquad (3.6)$$

for which $E_{r,n}$ and Cat_n individually refers to the cumulative percentage of energy consumption (vertical axis) and bus routes (horizontal axis) in the category n. GEI→0 indicates that the green level of bus energy consumption is getting better by using lesser energy for the bus operations. On the other hand, GEI→1 indicates the electric bus may consume more energy for which the green energy performance is poorer during the bus operations.

3.2.2 Green Emission Index (GMI)

An electric bus has zero emission from its tailpipe, but it has indirect waste gas emission (at WTT stage) specifically during electricity production and generation. The electric bus relies on energy to operate and the amount of energy is correlated with the indirect waste gas emission, where the energy source comes from electricity supply.

The emission factor is used to measure the quantity of GHG produced per unit of electricity production from the grid. Different country will have different emission factors as each electricity production supply is varied. For the electric bus, all the indirect emission from the electricity energy consumption depends on the electricity sources. The emission of electric bus only consists of indirect GHG emission (from the electricity generation) and the electricity generation may come from various resources or supplier in the nation (Song et al, 2018). This is more practical as different nations may produce electricity energy via different natural resources.

Further to this, Equation 3.7 is modified from the total emission equation of Song et al. (2018) by adding the element of load factors *LF*, bus quantity *q* and bus frequency *h* which aims to get a more realistic result from the bus daily operation. The total emission of an electric bus, $EM_{r,n}^{WTW}$ for a particular daily operating bus route *r* with bus frequency, *q* and bus quantity, *h* can be expressed as follows.

$$\text{Total emission for bus route } r, EM_r^{WTW} = \sum_{\forall r} LF\left(\sum_{i-1}^{z} \frac{E_r}{\partial \times (1-l)} \times e_i\right) \times q \times h \qquad (3.7)$$

Subsequently, the Green Emission Index, GMI, is then calculated by using the following equation:

$$\text{Green Emission Index, GMI} = 1 - \sum_{\forall n} \left(EM_{r,n}^{WTW} + EM_{r,n-1}^{WTW} \right) \left(Cat_n - Cat_{n-1} \right) \quad (3.8)$$

for which $EM_{r,n}^{WTW}$ and Cat_n sequentially adverts to the cumulative percentage of emission level (vertical axis) and bus routes (horizontal axis) in the category *n*. GMI→0 indicates that the green level of bus emission is getting better by producing lesser emission from the bus operation. When the GMI→0, it indicates that the green emission performance is not optimistic when there is an increasing amount of emission.

3.2.3 Green Noise Index (GNI)

During the bus operation, there will be different bus speed incurred and different sound pressure to be obtained. Throughout the journey, the number of acceleration consists of how frequent the bus passes by traffic lights, bus stops or roundabouts (Boren, 2019) and indicates that traffic and road conditions may give significant impact to the noise level of a bus.

As shown in Equation 3.9 (Boren, 2019), the total noise for the bus route is the combination of two stages of noise which are the interior noise and the exterior noise. By modifying the formula, the load factors *LF*, bus quantity *q* and bus frequency *h* are considered in Equation 9 to get the total noise for the bus daily operation accurately.

Thus, the noise level of electric bus, L_r for r a particular daily operating bus route r with bus frequency q and bus quantity h can be expressed as follows.

$$\text{Total of noise level for bus route } r, L_r = \sum_{\forall r} LF\left(10\log\left[\frac{V}{D}\int_0^{\frac{D}{V}}\frac{P_0^2\left(\frac{D}{V}\right)+\left(P_y+P_0\right)^2(\in+\gamma)t}{P_{ref}^2}dt\right]+10\log\left[\frac{V}{D}\int_0^{\frac{D}{V}}\frac{P_z^2}{P_{ref}^2}dt\right]\right)\times q\times h \quad (3.9)$$

Correspondingly, the Green Noise Index, GNI, is then calculated by using the following equation:

$$\text{Green Noise Index, GNI} = 1-\sum_{\forall n}\left(L_{r,n}+L_{r,n-1}\right)\left(Cat_n - Cat_{n-1}\right) \quad (3.10)$$

for which $L_{r,n}$ and Cat_n respectively refers to the cumulative percentage of noise level (vertical axis) and the bus routes (horizontal axis) in the category n. GNI→0 indicates that the green level of bus noise is getting better by producing lesser noise during the bus operations and when GNI→1, the green performance of bus noise is poorer by producing more noise.

3.2.4 Green Performance Index (GPI)

Green performance index (GPI) consists of the combination of three indexes, which are the Green Energy Index (GEI), the Green Emission Index (GMI) and the Green Noise Index (GNI).The formula of the Green Performance Index, GPI is stated as follows:

$$\text{Green Performance Index, GPI} = \frac{\sum_{j=1}^{n} W_j S_j}{\sum_{j=1}^{n} W_j} \quad (3.11)$$

for which W_j and S_j reflects the weightage and score for the respective Green Index.

In the event of quantifying the Green Performance Index (GPI), there is a designated weighted-grading approach as shown in Table 1. This approach has altogether eight grades (from I to VIII) which can be used as a reference for the bus operator in fleet planning and bus operations management by considering the environmental impact. The resultant grade plays a significant role in reflecting the achievement of the green performance for which grade I represents the best (greenest) environmental performance, while grade VIII shows the worst green performance.

Table 3.1: Weighted-grading approach for Green Performance Index (GPI)

Grade	Green Index	Score, *S*
I	0.0000 – 0.2000	4.0000 (the best green performance)
II	0.2100 – 0.2500	3.6700
III	0.2600 – 0.3000	3.3300
IV	0.3100 – 0.3500	3.0000
V	0.3600 – 0.4000	2.6700
VI	0.4100 – 0.4500	2.3300
VII	0.4600 – 0.5000	2.0000
VIII	0.5100 – 1.0000	0.0000 (the worst green performance)

In the weighted-grading approach, the range for grade is from I to VIII, where grade I with score of 4 indicates the best green performance (with reduced noise, energy consumption and emission) for the bus operation, while grade VIII with 0 score represents the poorest performance with the highest pollutant emitted from the operational network of electric bus. To determine the grades, the green index for each environmental factor will be categorized accordingly. Then, Equation 11 can be applied to evaluate the GPI after determining the set of weightage. Various sets of weightage can be considered subject to the bus operator's preference and priority towards the respective environmental factor. In other words, the weightage can be varying and subject to the needs of the bus operators.

Two approaches are used in this study to quantify the importance of the environmental factors. The first technique employs three weighting sets (as shown in Table 3.2), whereas the second way applies the Analytic Hierarchy Process (AHP), which will be explained in depth in the following section.

For the first approach, Set 1 and Set 2 weightages are selected based on the focus of the existing studies (preference on energy consumption and emission) (Mahmoud et al., 2016; Zivanovic et al., 2012; Borén et al., 2016; Dreier et al., 2018; Turcsany, 2016; He et al., 2018), while Set 3 is the average weightage (%) for the green index. The total weightage for each set is 100%. Each set is measured with three different main factors (e.g., green energy consumption, green emission, and green noise). In particular, a higher weightage indicates the most preferred in the selected environment factor, while a lower weightage shows the least preference in that particular factor.

Table 3.2: Three sets of weightage for Green Index calculation

Set	Weightage (%)			
	Green Energy Consumption, W_{EN}	Green Emission, W_{EM}	Green Noise, W_{BN}	Total of weightage
Set 1	40	40	20	100
Set 2	35	35	30	100
Set 3	$33\frac{1}{3}$	$33\frac{1}{3}$	$33\frac{1}{3}$	100

3.3 Multi-Criteria Modelling Framework

3.3.1 The Role of Analytic Hierarchy Process (AHP)

Numerous environmental factors (for instance energy consumption, emission and noise) could be applied (as insightful inputs) to quantify the Green Performance Index (GPI) in the electric bus fleet planning and operation. To determine the GPI, it is essential to identify the weightage of each environmental factor for which a higher weightage indicates a higher priority of the designated environmental factor given by the bus operator. On the other hand, a lower weightage signifies the lesser preference of the relevant environmental factor by the bus operator.

In practice, there are multiple criteria (such as passengers' feedback, financial cost, bus technical/operational concern and government policy/subsidy enforcement) which could greatly affect the operational and environmental performance of electric buses (Filippo et al.,2014; Goh et al.,2016; Fusco et al., 2013; Amiripour et al., 2014; Hosapujari and Verma, 2013). As a result, the multi-criteria decision-making might be resolved well with the help of the Analytic Hierarchy Process (AHP), as the AHP allows the decision maker to select the best alternative when given several possibilities (Saaty, 2007, 1980). One of AHP's benefits is how simple it is to use. Its use of pairwise comparisons helps simplify the process of weighing coefficients and comparing options for decision-makers. Because of its hierarchical nature, it is scalable and can simply alter in size to fit decision-making issues (Velasquez and Hester, 2013).

Similarly, the AHP's assessment of environmental elements and decisional criteria is presented as a pairwise comparison using the fundamental scale of 1-9 (as shown in Table 3.3), which indicates how much more essential one aspect is than another in multi-criteria decision and planning. Scale of 1 indicates the equal importance while the scale of 9 represents the absolute importance. Comparatively, the scales of 2, 4, 6 and 8 reflect the matching intermediate value between the two neighbouring judgments (Saaty, 1977, 1980). When there is a disagreement about the value on the crucial scale of 1-9, the AHP has the ability to spot the ambiguity in several criteria judgement (Saaty and Tran, 2007). The genuine difficulty in electric bus fleet planning and operation can be expressed in a clearer manner with AHP's capacity.

Table 3.3: Fundamental scale (Saaty, 1977, 1980)

Importance level	Numeric Value
Equal importance	1
Weak importance	3
Strong importance	5
Demonstrated importance	7
Absolute importance	9
Intermediate values between two adjacent judgment	2, 4, 6, 8

3.3.2 Modelling Framework of Analytic Hierarchy Process (AHP)

Figure 3.3 showed the proposed modelling framework of the AHP (which contains three phases) to quantify the weightage of environmental factors. As shown in Figure 3.3, the first phase (Phase 1) comprises the judgment and comparisons among the decisional criteria, followed by the Phase 2, which involves the judgment, and comparability of the environmental factors for each decisional criteria. Lastly, the computation of the weightage of environmental factors is carried out in the final phase (Phase 3).

To begin for Phase 1, *s* decisional criteria need to be determined. To do this, the attributes (decisional criteria) for the electric bus fleeting planning and operation need to be identified and a survey is conducted to get the pairwise comparison ratings for each decisional criteria. The ratings of the decisional criteria Judgments are represented (geometric mean) in a reciprocal matrix, which is a square matrix of dimension *n* x *n*. The rows (*c*) and columns (*d*) in this reciprocal matrix equal the number of decisional criteria. In the square matrix, the diagonal element that equals to 1 signifies the comparison of the decisional criteria done against it. The other elements are the reciprocal of each other, for instance $U_{cd} = \frac{1}{U_{dc}}$ in which U_{cd} refers to the component at the row *c* and column *d* of the reciprocal matrix (Saaty, 1980).

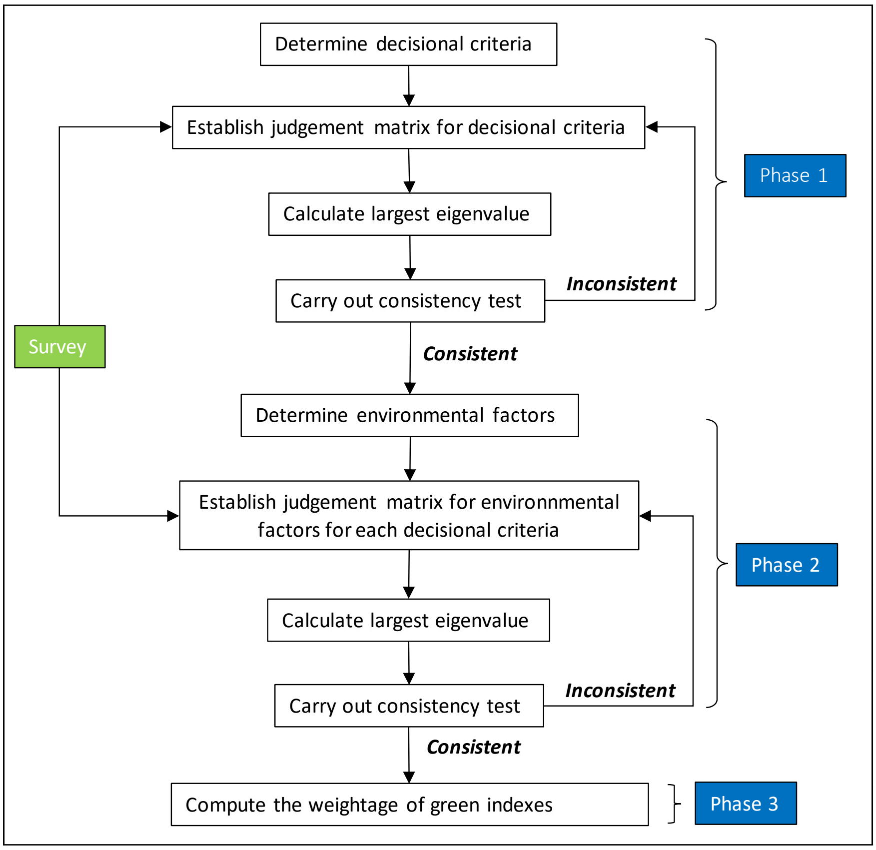


Figure 3.3: The Modelling Framework to Quantify the Weightage of Environmental Factors

At Phase 1, the pairwise comparison between the decisional criteria can be conducted by referring to the fundamental of scale 1-9 (Saaty, 1977, 1980). In addition, a consistency test needs to be carried out to assure the pairwise comparisons are consistent. In performing the consistency test, the ratio of Consistency Index *(CI)* and Random Index (*RI)* is required. CI is the deviation of consistency, while RI is a consistency index of a randomly generated pairwise matrix. When the ratio of CI/RI is < 0.10, the consistency is said to be satisfactory (Mead, 2006; Abuizam and Lucas, 2013). Otherwise, the inconsistent judgment in the matrix needs to be identified and rectified accordingly in order to solve the inconsistency issue.

In Phase 2, the environmental factors need to be defined and subsequently a judgment matrix of environmental factors for each decisional criteria will be formed. The judgment matrix is established by making use of the results (fundamental scale of 1-9) from a survey. Consistency test needs to be conducted and it consists of the ratio of Consistency Index (CI) and Random Index (RI). CI is the measure of deviation from the largest eigenvalue. When CI/RI < 0.10, it is a satisfied level of consistency, whereas if CI/RI > 0.10, it indicates inconsistency occurs, and the AHP may not produce important results (Saaty, 2007). However, some corrective actions can be taken when CI/RI is more than 0.1.

By having the results from the Phases 1 and 2, the weightage of the environmental factors can be computed in the Phase 3 for which the total of the respective weightage of the environmental factors would constitute the GPI. The total weightage of GPI is one (i.e., 100%) where a higher weightage indicates the designated environmental factor is given a higher priority by the decision maker while a lower weightage denotes a lesser preference (importance) on a specific environmental factor. In other words, different weightages of the environmental factors signifies multiple level of preference (i.e., the importance ranking of the environmental factors). The following elaborates three phases as outlined in Figure 3.3.

For **Phase 1** (to establish judgment matrix for decisional criteria):

Step 1: Determine the decisional criteria, F_k

Defining the decisional criteria, F_k, $k= 1, 2, 3...., s$ is crucial as it could give impact to the decision-making in the electric bus fleet planning and operations. Commonly, the government policy/subsidy enforcement, passengers' feedback, financial cost and bus technical/operational concern are found to give an essential influence when making decision in the bus fleet planning and operation (Fusco et al., 2013; Amiripour et al., 2014; Hosapujari and Verma, 2013).

Step 2: Establish judgment matrix for s decisional criteria

For s decisional criteria, a pairwise comparison matrix of decisional criteria, U can be presented as follows:

$$U = \begin{bmatrix} 1 & u_{12} & \cdots & u_{1s} \\ 1/u_{12} & 1 & \cdots & u_{2s} \\ \cdots & \cdots & \cdots & \cdots \\ 1/u_{1s} & 1/u_{2s} & \cdots & 1 \end{bmatrix}_{sxs} \tag{3.12}$$

Where $u_{cc} = 1$, $u_{cd} > 0$ and $u_{cd} = \frac{1}{u_{dc}}$ for $\forall c, d$. In order to establish the judgment matrix for decisional criteria, a survey was conducted by collecting data from the industry and academic experts. In the survey questionnaire, the pairwise comparison ratings range from the scale of 1 to 9 (as per the fundamental scale of AHP). From the responses of survey, geometric mean of judgment of decisional criteria is computed to form the judgment matrix.

Step 3: Calculate the largest eigenvalue

The largest eigenvalue, λ_{max} of the matrix U can be computed as follows (Saaty, 1990):

$$\lambda_{\max} = \sum_{c=1}^{n} u_{cd} \frac{Av_c}{Av_d} \tag{3.13}$$

for which u_{cd} is the element of matrix of U while Av_c and Av_d denote the average of row *c* and column *d* of the matrix of *U*. When the largest eigenvalue is approaching nearer to the matrix size, it indicates that the judgment matrix is more consistent (Saaty, 1980).

Step 4: Carry out consistency test

To examine the consistency of judgment matrix *U*, the consistency index, *CI* and random consistency index *RI* can be measured as follows (Saaty, 1977):

$$CI = \frac{\lambda_{\max} - s}{s - 1} \tag{3.14}$$

$$RI = \frac{1.98(s - 2)}{s} \tag{3.15}$$

Then, the consistency ratio, *CR* (degree of consistency) can be evaluated by utilizing the measurement of *CI* and *RI* as follows:

$$CR = \frac{CI}{RI} \tag{3.16}$$

When the CR is less than 0.1, it is said to be consistent (Saaty, 1980; Abuizam and Lucas, 2013).

However, the inconsistent comparison is likely to be occurred because the respondent may lose track of his/her previous preferences made after making many comparisons (Saaty, 1980). When this matter incurred, the steps can be taken (Saaty and Tran, 2007):

I. Detect the matrix's most inconstant judgment as well as figure out the range of value (of the inconsistent) that can be improved.

II. Further consideration is needed for the decision maker to alter to a possible value in the desired range for which a better understanding for the decision maker is required before further action is taken.

III. Repeat the step I and step II for second and the following inconsistent judgment, until obtain the consistency.

For **Phase 2** (to establish the judgment matrix of environmental factors for each decisional criteria):

Step 1: *Determine environmental factors, y_p*

Environmental factor, y_p, p=1, 2, 3…n is the main element of GPI that has crucial role in the decision-making process of electric bus fleet environmental planning and operation. The number of environmental factors as well as the weightage for each environmental factor may vary for different operators.

Three environmental factors, namely bus energy consumption (EN), emission (EM) and noise (BN) can be considered (Abbasi et al., 2018; Teoh et al., 2020; Boren, 2019). Energy consumption (EN), y_1 refers to the electric energy, which is required by electric bus to operate. The energy is stored in a battery, which is placed in the electric bus, and it is refilled by using the charging facility (when the energy level is low). As for emission (EM), y_2, the waste gases are emitted indirectly during the battery charging process while the bus noise (BN), y_3 is produced during the electric bus engine propulsion in the bus operation.

Step 2: Establish judgment matrix of environmental factors for each decisional criteria

The pairwise comparison matrix, R of environmental factors, i.e., $y_1, y_2 \ldots y_p$ (for each decisional criteria F_k) can be presented as follows:

$$R = \begin{bmatrix} 1 & v_{12} & \cdots & v_{1n} \\ 1/v_{12} & 1 & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ 1/v_{1n} & 1/v_{2n} & \cdots & 1 \end{bmatrix}_{nxn} \qquad (3.17)$$

For which v_{cd} denotes the comparison of environmental factor for each decisional criteria with a square matrix, R with the size of n x n. To establish the judgment matrix of environmental factors for each decisional criteria, a survey is conducted to measure the pairwise comparison ratings between the environmental factors for each decisional criteria. Through this survey, the preference from the industry and academic expertise towards the environmental factors for each decisional criteria could be acquired.

Step 3: Calculate the largest eigenvalue

The largest eigenvalue, λ_{max} of the matrix R (pairwise comparison of environmental factors for each decisional criteria) can be computed as follows:

$$\lambda_{\max} = \sum_{c=1}^{n} v_{cd} \frac{Av_c}{Av_d} \tag{3.18}$$

For which Av_c and Av_d denote the average of row c and column d of the matrix R while v_{cd} is the element of matrix of R.

Step 4: Carry out consistency test

To determine the degree of consistency of the matrix, a consistency test is necessary. The consistency ratio, CR (degree of consistency) can be evaluated by applying the measurement of CI and RI as described in Phase 1. When the value of CR is less than 0.1, it is said to be consistent.

For **Phase 3** (to quantify the weightage of environmental factors)

The weightage of environmental factors can be measured as follows:

$$Weightage, W_j = \sum U_c^* R_c^* \tag{3.19}$$

Where U_c^* denotes the average of row c = 1, 2, 3…s of normalized matrix U while R_c^* denotes the average of row c=1, 2, 3….n of normalized matrix R. The normalization converts the data into the comparable data, which enables a multi-criteria decision making method (i.e., AHP) to rate and rank the alternatives (Vafaei et al., 2016).

3.3.3 Survey

Phase 1 in the AHP is to construct a judgment matrix for decisional criteria, which consists of the identified influential factors in electric bus operation. Meanwhile, Phase 2 of AHP involves environmental factors for each decisional criteria when establishing the judgment matrix. Before starting off on Phase 1 and Phase 2 of AHP, a survey is required to provide the essential input for both phases. In order to have convincing results, the targeted respondents should be from the industry as well as academia. As shown in Appendix B, the survey consists of three sections, which furnish socio-demographic (Section 1), comparison between decisional criteria in terms of importance level (Section 2), and the importance level with the involvement of environmental factors in each decisional criteria (Section 3).

In this study, the survey was conducted in August 2020 and was completed by 32 industry and academic experts from different educational backgrounds and working experiences. To collect the feedback from the targeted group of respondents, the survey form was converted into an online Google form and circulated to all the respondents.

In Section 2 of the survey, four decisional criteria (i.e., government policy/subsidy enforcement, passengers' feedback, bus technical specification and financial cost) were considered in the design of the questionnaire. The decisional criteria were compared among each other by using the fundamental scale ranging from 1 to 9. These four attributes were explained as below:

- *Government policy/subsidy enforcement (GP)*: The adherence to the government/authority's policy for electric bus operations and government incentive program (such as company tax rebate or subsidy) for the deployment of electric bus.
- *Passengers' feedback/respond (PF)*: Passengers' feedback on the service quality in riding electric bus (demand aspect).
- *Bus technical features (BT)*: This considers the operational feasibility of operating electric bus (including bus maintenance, driver capability on handling electric bus, charging facility/time, and battery capacity).
- *Financial cost (FC)*: Additional cost (e.g., capital, operational) or cost-saving (e.g., energy consumption, maintenance) incurred in operating electric bus.

As for Section 3, three environmental factors (i.e., energy consumption, emission and noise) are considered when designing the questionnaire. These environmental factors were compared with one another for each decisional criteria in the electric bus fleet planning and operation. The three environmental factors were explained below:

- *Energy consumption*: The total amount of energy used to operate electric buses (unit per year).

- *Emission:* The total amount of emission gas (such as carbon dioxide, carbon monoxide) emitted from the fleet of bus (unit per year).
- *Noise*: The total amount of noise emitted from the fleet of buses to the environment (unit per year).

From the survey, the preference judgment of respondents (on the scales from 1 to 9) in both decisional criteria (in Section 2 of the survey) and environmental factors for each decisional criteria (in Section 3 of the survey) can be identified specifically in making decisions for electric bus fleet planning and operation. After conducting the survey, the consistency test was carried out on the entire pairwise comparison matrix. It was observed that there was some inconsistency in the findings. The decision maker's preferences were uncertain due to a lack of knowledge, time to concentrate on the problem at hand, preference information gathering inexperience, or ambiguity in the dimensions of sustainability attributes (Forman, 1990).

Figure 3.4 shows the summary of the personal information (i.e., gender, age, and position) of all the respondents. In total, 32 respondents took part in the survey, which consisted of 75% males and 25% females, with an age range of 25 years old and above 54 years old. The percentage of respondents for the age groups of 25–34 and 35–44 is equally high (i.e., 37.5%). Besides, the respondents hold different positions in two sectors, which are the industry and academic sectors. The industry sectors consist of transport planning, construction, consultancy, and transport providers, while the academic sector covers academicians from different universities. In terms of positions for industry sectors, there are respondents from management level (i.e., decision makers) and executive level who usually do the ground work or survey. As for the academic sector, the respondents' positions ranged from lecturer to assistant professor with an engineering background.

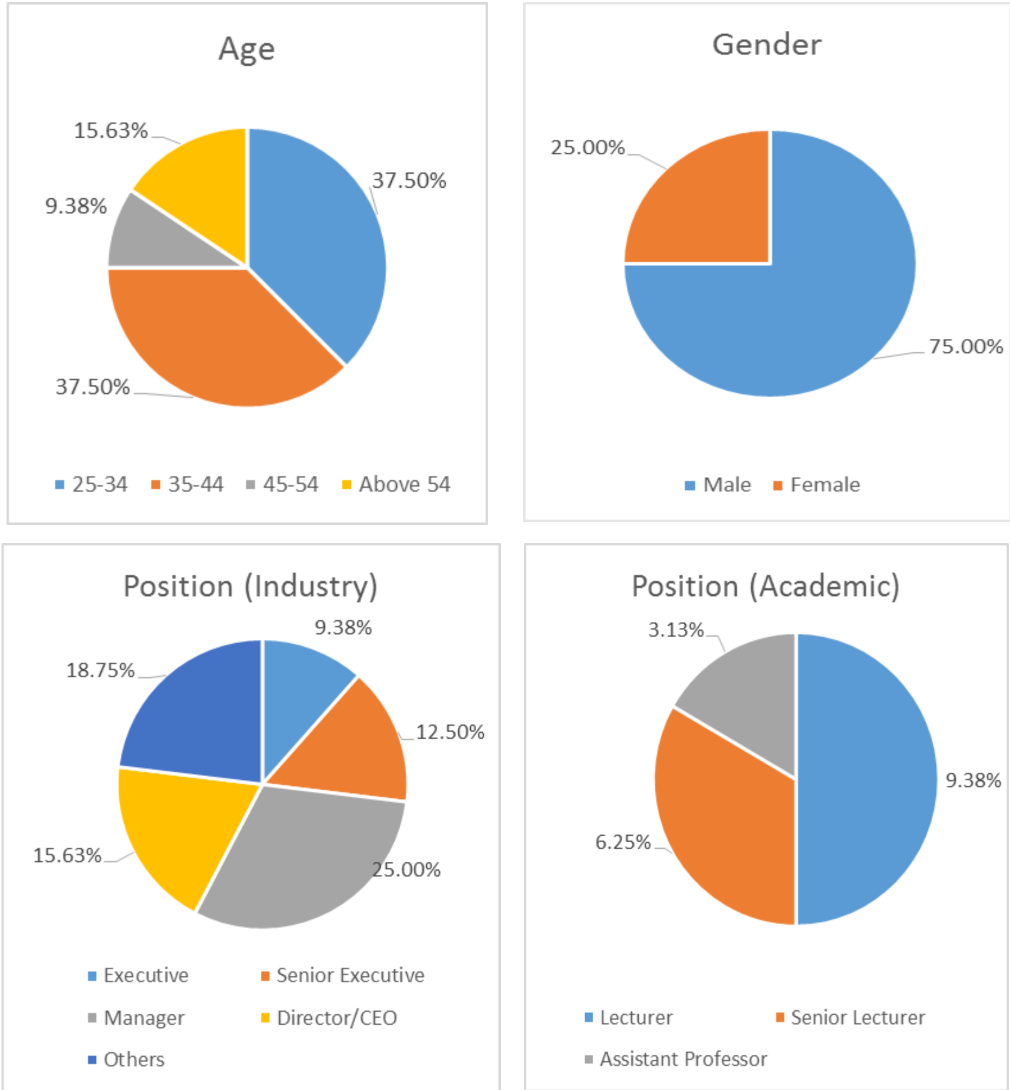


Figure 3.4: Summary of socio demographic and personal information of the respondents (N=32)

3.3.4 An Illustrative Example

This section exhibits how to deploy the proposed AHP modelling framework to quantify the weightage of environmental factors in electric bus fleeting planning and operation.

For **Phase 1** (to establish judgment matrix for decisional criteria):

Step 1: Determine the decisional criteria, F_k

For the electric bus fleet planning and operation purposes, four primary decisional criteria, namely the government policy/subsidy enforcement, (GP), the bus technical features (BT), financial cost (FC) and passengers' feedback (PF), are identified (Lin et al., 2017; Song et al., 2020; Wang et al., 2014; FCH-JU, 2012; Munim and Noor, 2020).

Step 2: Establish judgment matrix for s decisional criteria

The decisional criteria matrix, U can be presented as follows:

$$U = \begin{bmatrix} 1 & 4.58 & 9 & 1 \\ 0.22 & 1 & 3.79 & 0.22 \\ 0.11 & 0.26 & 1 & 0.11 \\ 1.00 & 4.61 & 9 & 1 \end{bmatrix}_{4x4}$$

The judgment matrix U is formed with the aid of the simulated data (adjusted geometric mean) compiled from Table 3.4.

Step 3: Calculate the largest eigenvalue

The maximum eigenvalue, λ_{max} of the matrix U can be computed by adopting the Equation (3.13) as shown below:

$$\lambda_{\max} = \sum_{c=1}^{n} u_{cd} \frac{Av_c}{Av_d} = 4.06$$

It is noticed that the largest eigenvalue, $\lambda_{max} \geq n$ (matrix size is 4), and hence the pairwise comparison matrix is consistent (Saaty, 1980).

Step 4: Carry out consistency test

The consistency index, CI and random consistency index RI can be measured as below:

$$CI = \frac{4.0557 - 4}{4 - 1} = 0.0186$$

$$RI = \frac{1.98(4 - 2)}{4} = 0.99$$

Then, the consistency ratio, *CR* can be evaluated (using the *CI* and *RI* computation) as follows:

$$CR = \frac{0.0186}{0.99} = 0.0188$$

Since the value of *CR* is less than 0.1, it said to be consistent.

As shown in Table 3.4, the collected judgments from the respondents of the survey are compiled appropriately in terms of geometric mean. Compared with the average, the geometric mean is suitable for the aggregation of individual judgment (Aczél and Alsina, 1986). In Table 3.4, the resulted geometric mean (generated from the survey) is ranging from 3.79 to 5.18. When the value is 3.79 at the column of BT (Bus technical features) vs FC (Financial cost), this indicated that BT is 3.79 times more important than FC in electric bus fleet planning and operation. The geometric mean has a range of 1–9 (taken from the fundamental scale) and illustrates how important one decisional criteria is compared to another.

The pairwise comparison matrix was first formed by the resulted geometric mean and the consistency test was done to check is there any inconsistency answers provided by the respondents. The CR (Consistency Ratio) was computed by dividing Consistency Index (CI) by RI (Random Index). The resulted CR is more than 0.1 (i.e., 10%), which indicates there is inconsistency in the matrix. Therefore, the matrix adjustment is required. From the matrix adjustment, the adjusted geometric mean (i.e., from 5.18 to 1.00, 4.34 to 9.00 and 4.07 to 9) was obtained as showed in Table 3.4. There were 3 adjustments done in Table 3.4 for the comparison between decisional criteria (GP and PF, GP and FC, PF and BT).

Table 3.4: Relative Comparison for Decisional Criteria

Respondent	Decisional Criteria					
	GP vs PF	GP vs BT	GP vs FC	PF vs BT	PF vs BT	BT vs FC
1	1	1	1	7	6	9
2	7	7	7	3	3	3
3	1	3	2	1	1	1
4	9	6	2	3	1	3
5	5	6	6	6	4	7
6	1	1	1	5	5	5
7	9	3	7	3	2	6
8	4	4	4	8	8	3
9	4	5	6	4	3	7
10	9	8	6	6	6	6
11	9	7	8	5	3	4
12	9	6	7	1	2	2
13	5	4	1	7	1	1
14	6	6	7	9	6	1
15	8	9	9	8	8	8
16	3	2	2	9	9	3
17	1	1	1	5	3	1
18	9	7	7	7	7	7
19	9	9	9	9	7	7
20	9	5	3	1	1	1
21	8	8	8	7	7	8
22	5	5	5	3	7	7
23	9	9	9	9	9	9
24	8	5	6	4	3	3
25	8	8	5	2	8	2
26	7	8	8	6	8	8
27	5	4	3	5	3	6
28	6	6	6	6	6	6
29	5	4	5	6	6	6
30	7	7	7	4	5	6
31	5	3	7	7	6	5
32	5	3	3	5	3	1
Geometric mean	5.18	4.58	4.34	4.61	4.07	3.79
Adjusted geometric mean	**1.00**	4.58	**9.00**	4.61	**9.00**	3.79

**Note: GP: Government policy /subsidy enforcement, PF: Passengers' feedback /respond, BT: Bus technical features, FC: Financial cost*

In the decision criteria matrix, the geometric mean (which is also the judgment values in the matrix) is re-examined to check the range of values that can be improved. The checking will begin with the first row of the judgment matrix of the relationships among the decisional criteria. Each change in the geometric mean value is used to calculate a new CI. When the CR is less than 0.1, the adjusted geometric mean was used to form a pairwise comparison matrix (decisional criteria) before being applied in the weightage computation.

For **Phase 2** (to establish judgment matrix of environmental factors for each decisional criteria):

Step 1: *Determine environmental factors,* y_p

Three environmental factors, namely energy consumption (EN), emission (EM) and noise (N) are considered when making decision in the electric bus planning and operation. Energy consumption is essential for electric buses to operate for which each bus will be equipped with the battery which mainly act as storage for the electric energy. When the energy is low, the charging of battery is needed (Song et al, 2018). During the charging process, there is emission waste gaseous produced from the electricity supply (Song et al, 2018). Thus, the emission (EM) is one of the identified environmental factors. Besides, the bus noise (N) is produced during the electric bus operation, specifically when the bus is speeding, idling or on constant speed (Boren, 2019).

Step 2: Establish judgment matrix of environmental factors for each decisional criteria

As mentioned earlier, there are altogether three environmental factors (energy consumption, emission and noise) and four decisional criteria (government policy/subsidy enforcement (GP), the bus technical features (BT), the financial cost (FC) and the passengers' feedback (PF)) used for the electric bus fleet planning and operation purposes. From the conducted survey, whose data (geometric mean and adjusted geometric mean with a range of 1–9) was compiled in Table 3.5-3.8, the geometric mean and adjusted geometric mean demonstrate how many times more important environmental factors are when considering each decisional criteria. With the results obtained, the pairwise comparison matrix of government policy/subsidy enforcement (GP), R_{GP} is presented as follows:

$$R_{GP} = \begin{bmatrix} 1 & 4.22 & 8 \\ 0.24 & 1 & 4.02 \\ 0.13 & 0.25 & 1 \end{bmatrix}_{3x3}$$

And, the judgment matrix of bus technical feature $R_{BT,}$ financial cost R_{FC} and passengers' feedback R_{PF} are computed as follows:

$$R_{BT} = \begin{bmatrix} 1 & 3.49 & 8 \\ 0.29 & 1 & 4.31 \\ 0.13 & 0.23 & 1 \end{bmatrix}_{3x3}$$

$$R_{FC} = \begin{bmatrix} 1 & 3.56 & 8 \\ 0.28 & 1 & 4.00 \\ 0.13 & 0.25 & 1 \end{bmatrix}_{3x3}$$

$$R_{PF} = \begin{bmatrix} 1 & 3.38 & 8 \\ 0.3 & 1 & 4.46 \\ 0.13 & 0.22 & 1 \end{bmatrix}_{3x3}$$

Table 3.5 presented the relative comparison among the environment factors (energy consumption, emission and noise) for the decisional criteria of GP with the geometric mean. However, upon carried out the consistency test, the value of Consistency Ratio (CR) obtained is 0.1995 which is not consistent (as the value of CR > 0.1). Hence, the modification and re-examine in the judgment matrix of environmental factors for PF needs to be conducted on the connection among the environment factors. This is to see if any range of value can be improved or corrected due to inconsistency and the inspection will begin at the first row of the judgment matrix. After the matrix adjustment is completed, the adjusted geometric mean is determined to form the pairwise comparison matrix (as presented in Phase 3).

Table 3.5: Relative Comparison of Environmental Factors for Government Policy/Subsidy Enforcement (GP)

Respondent	Government policy /subsidy enforcement (*GP*)		
	Energy consumption vs Emission	Energy consumption vs bus noise	Emission vs bus noise
1	1	1	1
2	7	7	3
3	2	6	9
4	6	3	5
5	6	7	6
6	5	5	1
7	6	9	9
8	3	8	8
9	3	1	3
10	9	7	7
11	9	8	5
12	1	1	2
13	3	1	1
14	7	1	1
15	9	9	9
16	8	3	8
17	1	1	5
18	9	9	9
19	9	8	8
20	5	5	1
21	7	8	9
22	1	1	1
23	9	9	9
24	1	1	1
25	7	7	5
26	8	5	8
27	7	8	8
28	6	6	6
29	5	6	6
30	5	5	5
31	4	5	5
32	1	1	3
Geometric mean	4.22	3.78	4.02
Adjusted geometric mean	4.22	**8.00**	4.02

For the judgment matrix of environmental factors for BT, the adjusted geometric mean is in Table 3.6, which is extracted from the matrix adjustment. The consistency test was done on the original judgment matrix before the matrix adjustment was conducted, in which the resultant value of CR was 16.65%, which is more than 0.1 (i.e., 10%). Therefore, an adjustment of the matrix is required to carry out the check on the geometric mean of the relationship among the environmental factors for BT and to see if any inconsistent value in the judgment matrix can be improved. Consequently, the adjusted matrix has contributed 3.43% (0.0343) of the CR value.

Table 3.6: Relative Comparison of Environmental Factors for Bus Technical Features (BT)

Respondent	Bus technical features (*BT*)		
	Energy consumption vs Emission	Energy consumption vs Bus noise	Emission vs Bus noise
1	2	3	3
2	7	7	3
3	1	8	9
4	2	6	7
5	7	7	7
6	1	1	1
7	7	9	9
8	3	8	8
9	4	2	2
10	9	7	7
11	8	7	7
12	1	1	1
13	4	2	3
14	1	1	1
15	8	8	9
16	6	2	8
17	1	1	5
18	8	8	7
19	8	8	8
20	5	3	1
21	6	6	9
22	1	1	1
23	9	9	9
24	1	1	6
25	7	8	5

Table 3.6 (Continues)

Respondent	Bus technical features (*BT*)		
	Energy consumption vs Emission	Energy consumption vs Bus noise	Emission vs Bus noise
26	4	5	4
27	1	7	7
28	6	6	6
29	6	5	5
30	5	5	5
31	6	3	6
32	2	2	2
Geometric mean	3.49	3.82	4.31
Adjusted geometric mean	3.49	**8.00**	4.31

Similar to Table 3.6, there is an adjusted geometric mean in Table 3.7, which involves the comparison between energy consumption and noise. This indicates that there was a matrix adjustment executed. The adjustment was conducted by re-examining the geometric mean of the link between the environmental factors and FC (beginning from the first row of the judgment matrix) and finding any possible range of value to improve. As a result, the value of CR achieved from the adjusted matrix is 2.82% (0.0282), which meets the consistency requirement.

Table 3.7: Relative Comparison of Environmental Factors for Financial cost (FC)

Respondent	Financial cost (*FC*)		
	Energy consumption vs Emission	Energy consumption vs Bus noise	Emission vs Bus noise
1	3	3	4
2	7	7	3
3	1	8	9
4	7	7	5
5	7	6	6
6	1	1	1
7	7	9	8
8	3	8	8
9	4	4	2
10	9	7	7
11	7	8	5

Table 3.7 (Continues)

Respondent	Financial cost (*FC*)		
	Energy consumption vs Emission	Energy consumption vs Bus noise	Emission vs Bus noise
12	1	1	1
13	3	3	2
14	1	1	1
15	8	9	9
16	8	6	1
17	1	1	5
18	8	8	8
19	8	8	8
20	5	3	1
21	7	8	9
22	1	1	1
23	9	9	9
24	1	1	6
25	7	7	5
26	2	4	7
27	1	8	7
28	6	6	6
29	5	5	5
30	5	5	5
31	5	5	6
32	2	2	2
Geometric mean	3.56	4.20	4.00
Adjusted geometric mean	3.56	**8.00**	4.00

As for the PF, the relative comparison of environmental factors is shown in Table 3.8. As shown in Table 3.8, the geometric mean (from 4.04 to 8.00) was adjusted accordingly. The reason for the adjustment is that the CR value exceeded 0.1 (which is 0.1512). As a result, the new CR value (after matrix adjustment) obtained is 3.4% (i.e., 0.034). The adjusted geometric mean was attained after the re-analysis of the relationship between environmental factors and PF was done.

Table 3.8: Relative Comparison of Environmental Factors for Passengers' feedback/respond (PF)

Respondent	Passengers' feedback/respond		
	Energy consumption vs Emission	Energy consumption vs Bus noise	Emission vs Bus noise
1	2	3	3
2	7	7	3
3	1	8	9
4	2	5	6
5	7	7	7
6	1	1	1
7	6	9	9
8	3	7	8
9	4	4	2
10	9	7	7
11	8	6	5
12	1	2	2
13	2	3	2
14	1	1	2
15	8	8	8
16	6	2	9
17	1	1	5
18	8	8	8
19	9	8	8
20	3	5	1
21	5	5	9
22	1	1	1
23	9	9	9
24	1	1	6
25	7	7	5
26	6	7	5
27	1	4	6
28	6	6	6
29	5	5	6
30	5	5	5
31	7	5	7
32	2	2	2
Geometric mean	3.38	4.04	4.46
Adjusted geometric mean	3.38	**8.00**	4.46

Step 3: Calculate the largest eigenvalue

The largest eigenvalue, λ_{max} of the judgment matrix (size matrix = 3) for GP, BT, FC and PF can be computed as follows:

$$\lambda_{\max,GP} = \sum_{c=1}^{n} u_{cd} \frac{Av_c}{Av_d} = 3.0639$$

$$\lambda_{\max,BT} = \sum_{c=1}^{n} u_{cd} \frac{Av_c}{Av_d} = 3.0450$$

$$\lambda_{\max,FC} = \sum_{c=1}^{n} u_{cd} \frac{Av_c}{Av_d} = 3.0372$$

$$\lambda_{\max,PF} = \sum_{c=1}^{n} u_{cd} \frac{Av_c}{Av_d} = 3.0449$$

As shown above, the largest eigenvalue λ_{max} for all the judgment matrix of environmental factors for each decisional criteria are near to the matrix size (i.e., 3), this signifies that the judgment matrix is consistent.

Step 4: Carry out consistency test

To measure the degree of consistency for the judgment matrix of environmental factors for each decisional criteria, a consistency test is performed. The resultants CR are listed as below:

CR for government policy/subsidy enforcement (GP) = 0.0484

CR for the bus technical features (BT) = 0.0341

CR for financial cost (FC) = 0.0282

CR for passengers' feedback (PF) = 0.0340

It could be seen that all values of CR are less than 0.1 (i.e., 10%), this indicates that the all the judgment matrices are consistent.

For **Phase 3** (to quantify the weightage of environmental factors):

The weightage for the respective environmental factors is presented in Table 3.3. The total weightage is 1 (i.e., 100%) for the GPI, which consists of the weightages of energy consumption, emission, and noise. By applying Equation

3.19, the weightage for each respective green index for each decisional criteria can be computed. Table 3.9 shows the resulted weightage for all decisional criteria with respective to each environmental factors as well as the overall weightage for all environmental factors, which consists of weightage for energy consumption (W_{EN} = 0.6909), weightage for emission (W_{EM} = 0.2382) and weightage for bus noise (W_{BN} = 0.0709). Comparatively, it could be seen that the energy consumption has the highest weightage, which is approximately 69% and noise has the lowest weightage (i.e., 7%). This indicates that energy consumption is prioritised (compared to emissions and noise) by the respondents in quantifying the GPI for electric bus fleet planning and operation.

Table 3.9: The Evaluation of Environmental Factor in Fleeting Planning and Operation

Environmental factor	Decisional criteria				Weightage, W_j
	Government Policy /Subsidy enforcement (GP)	Bus Technical Feature (BT)	Financial Cost (FC)	Passengers' feedback (PF)	
Energy consumption, *EN*	0.7067	0.6829	0.6890	0.6775	0.6909
Emission, *EM*	0.2220	0.2462	0.2384	0.2522	0.2382
Noise, *N*	0.0713	0.0709	0.0726	0.0703	0.0709
Total	1.0000	1.0000	1.0000	1.0000	1.0000

3.4 Improvement Strategies

A benchmark scenario (Nadi Putra, a bus company in Putrajaya, Malaysia) is analysed by using the existing data input (without enforcing any enhancement strategy) collected in the year 2015. This benchmark scenario consists of 10 bus routes located in Putrajaya, Malaysia. The electric bus capacity for all the bus routes is 63 passengers per bus. As for the electric bus energy storage, all the buses are furnished with a 300kWh battery capacity and use the same type of charging facility, which could take up to 8 hours to charge, namely slow charging.

As presented in Table 3.10, there are five improvement strategies that were examined with the aim of improving the Green Performance Index (GPI) in comparison to the benchmark scenario. Each improvement strategy emphasises on different operational aspects based on the findings of the previous studies (i.e., load factor adjustment (Carrese et al., 2013; Yu et al., 2015), bus frequency variation (Hoonsiri et al., 2020; Titos et al., 2015), fleet planning (Bogdan et al., 2020; Borén, 2019), bus speed (Zhou et al., 2016; Abbasi, 2018) and charging facility (Zhou et al., 2016; Abbasi, 2018), the better result of the GPI can be achieved. Using a different strategy is also helpful to reveal the effectiveness of each proposed improvement strategy on the respective environmental factor as well as the overall green performance in terms of GPI.

Table 3.10: The outlines for benchmark scenario and improvement strategies

Scenario/Strategy	Remarks
Benchmark scenario	Existing data input (without any improvement strategy)
Strategy 1	Increase load factor
Strategy 2	Adjust bus frequency
Strategy 3	Fleet planning
Strategy 4	Reduce bus speed
Strategy 5	Change charging facility

Strategy 1 focuses on increasing the load factor for those bus routes with low passenger demand (e.g., below 50% of load factor). The load factor will vary depending on the nature of the bus route, but in practice, it should be between 30% and 40% for large buses and up to 65% for particularly busy bus routes.

However, 50% of the load factor is considered an average and relaxed environment, which is able to meet the passenger comfort level (Shen et al., 2016). Consequently, this strategy identified the bus routes with a load factor of less than 50%), so that some efforts could be made accordingly with the aim of increasing their load factor to 50%. Increasing the load factor is important, particularly for bus operators and the environment, because higher load factors and energy consumption result in lower pollutant per passenger (Yu et al., 2016; Carrese et al., 2012).To maintain high demand (load factor) for bus routes, bus operators must employ some appealing marketing strategies, such as offering a lower bus fare, bus fare seasonal rebates, and good bus service (e.g., punctuality).

As for **Strategy 2**, the suggestion is to adjust the bus frequency by implementing two techniques, namely bus frequency reduction or removal, if necessary. This is to be done on bus routes with a low load factor (e.g., 10%). For the identified bus routes, the load factor is increased to 50% when the bus frequency is reduced. Besides, for those bus routes with a very low load factor (i.e., 10%), the bus frequency is removed. This is important for green performance because fewer pollutants (i.e., noise and emissions) are emitted with a higher load factor and lower frequency.

For **Strategy 3**, fleet planning (in terms of using different bus capacities) is proposed in order to cater to different degrees of demand level. A smaller electric bus is suggested for serving the bus routes with a low load factor (i.e., below 50%). Smaller bus capacity is needed to cater fewer passengers and this is also important to the green performance as a smaller bus may produce lesser pollutants (i.e., energy consumption, emission) as the bus weight is reduced. As for load factor, since a smaller bus capacity is used for the designated bus routes, the load factor is expected to be increased accordingly (e.g., up to 50%).

In **Strategy 4** (reduce bus speed), the bus route with the highest energy consumption, emission, and noise in the benchmark scenario could be identified, so that a much better driving behaviour (in terms of controlling the bus speed) can be recommended in order to produce less energy consumption, emission, and noise. When the average bus speed is less than 35 km/h, the energy usage varies significantly (Neaimeh et al., 2013). The bus speed for these bus routes (which have the highest energy consumption) was reduced appropriately. With a lower bus speed, the engine propulsion is expected to produce less noise (Boren, 2019). When there is a higher load factor and a lower bus speed, the environmental benefit increases because the emission and energy consumption levels decrease (Zhou et al., 2016).

Strategy 5 applies different types of charging facilities for the bus route with the highest energy consumption, emission, and noise in the benchmark scenario. In the benchmark scenario, a slow charging facility (which takes up to 8 hours) was used for all bus routes. In this strategy, the fast charging facility (which takes around 10 minutes for 80kWh) is deployed on the designated bus routes. This strategy is important as when the charging duration is reduced, fewer emissions are produced from the electricity generation. Besides, by using fast charging facilities (with a shorter charging duration), the number of buses can be reduced as each bus could perform more trips to cater to the demand of passengers in accordance with the bus schedules.

3.5 Summary

Electric bus environmental (green) performance assessment is important in bus fleet planning and operations. In order to quantify the green performance, each influential environmental factor with different amounts of pollutants (noise, energy consumption, and energy) is being evaluated in terms of the green index (i.e., Green Energy Index, Green Emission Index, and Green Noise Index). A weighted-grading approach is adopted as an essential reference, and the resultant grade reveals the achievement of the greenest performance, for which different grades indicate different levels of green performance.

To integrate all the green indices (GEI, GMI, and GNI) in terms of GPI, two methodologies (weightage based on focus of prior studies and AHP) are presented. The GPI plays an essential role in indicating the overall environmental performance of the entire bus operating network. Various improvement strategies could be implemented with the intention of enhancing not only the performance of the individual environmental factors but also the GPI. The usefulness of the improvement strategy could also be known accordingly.

In order to have a better and greener performance, the electric bus operators could incorporate enhanced strategies into the planning stage. Instead, with a greener performance in the early stages of planning, it is anticipated that the operational system of an electric bus could produce a higher profit margin (through cost savings) for the electric bus operators. Concisely, the proposed approach is beneficial not only to the environment but also to the stakeholders (including bus operators and passengers).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Description of Case Study

Putrajaya, Malaysia has been targeted to be a green city as one of the efforts by the Malaysian government to promote low carbon cities (Putrajaya Corporation, 2012). Therefore, Putrajaya has been chosen as the study area, aiming to explore the feasibility of replacing the existing conventional bus fleet (powered by natural gas) with electric buses.

Nadi Putra, a bus company, was founded in 1999 and is one of the subsidiaries of Putrajaya Corporation. Nadi Putra public buses are able to cater to a larger number of passengers per trip, where the maximum number of passengers for a long bus (12 m long) is 63 people, and 40 people for a mini bus (7 m long). All buses use the same type of charging facility, namely slow charging, which requires 8 hours to fully charge. All electric bus routes (ten in total) are based on 12m long electric buses, each outfitted with a 300kWh capacity titanium-ion battery.

The study area of Putrajaya is displayed in Figure 4.1. The bus network in Putrajaya is furnished with 10 bus routes. There are three terminals functioning as departure points for all the buses and final stops before the daily operation ends. These terminals were also designed as charging stations, providing overnight charging and charging after finishing a trip. All buses are assumed to use the same type of charging station. Specifically, slow charging takes 8 hours to fully charge.

In this study, a benchmark scenario is scrutinised by using the operational data collected in the year 2015 as well as the data inputs that were compiled accordingly from Chong (2016), Song et al. (2018), Borén (2019), Gallet et al. (2018), The Engineering Toolbox (2004), Teoh et al. (2018), and Auto-Che (2020). The appropriate data inputs (to compute energy consumption, emission and bus noise) were compiled in order to demonstrate the applicability of the suggested framework in quantifying the green performance of electric bus operation.

Apart from the benchmark scenario, a few improvement strategies focusing on various operational areas are used to improve the GPI result. The data inputs used in the improvement strategies are derived from the data inputs of the benchmark scenario to calculate the GPI. Some data inputs altered as different aspects (such as changes in load factor, bus frequency, fleet planning, bus speed, or charging facility) are adopted for improvement. The data inputs listed in the table for each improvement strategy (in the following section) are those that differ from the benchmark scenario.

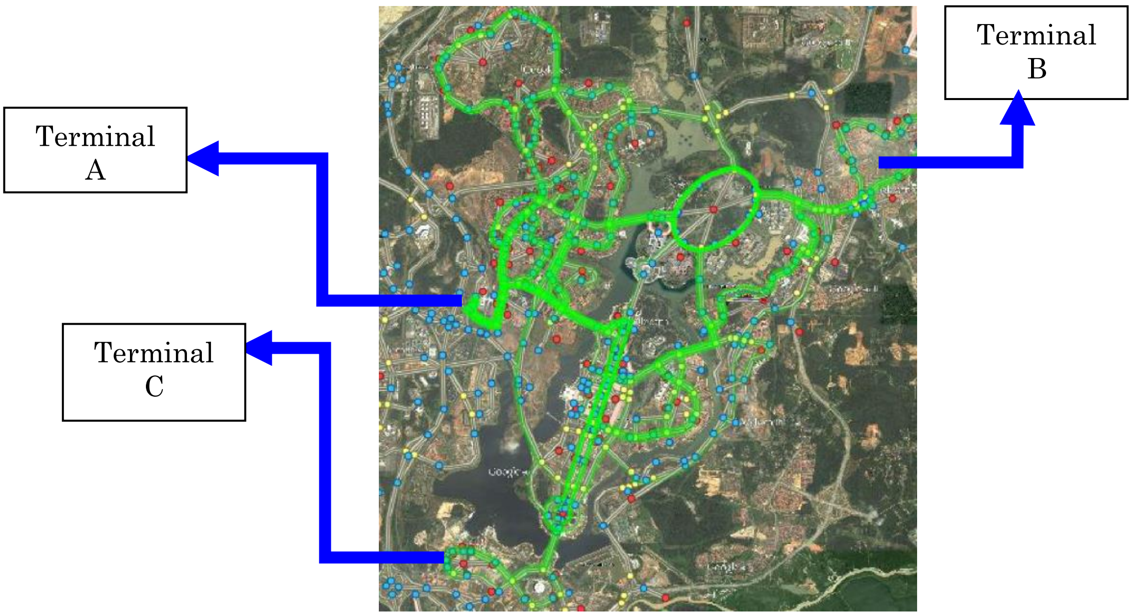


Figure 4.1: The Study Area of Putrajaya (Chong, 2016)

4.2 Benchmark Scenario

The benchmark scenario is designed as per the existing bus routes provided by Nadi Putra. In total, there are 10 bus routes (an average of 17 buses for each route), with a bus capacity of 63 passengers. The daily operating hours are from 6.30am until 12.30am (18 hours), with a headway of 15 minutes.

4.2.1 Energy consumption

Table 4.1 shows the data input to compute the energy consumption for each operating bus route. In table 4.1, the bus weight considers the curb weight of the bus and the total passenger weight (which is approximated to be 65kg per passenger). The same type of bus is operated for all bus routes, and hence the technical specifications, including the frontal areas, resistance coefficients, and friction forces of the bus, remain the same for all operating bus routes.

Table 4.1: Data input for energy consumption (benchmark scenario) (Chong, 2016; Teoh et al., 2018; The Engineering Toolbox, 2004; Auto-Che, 2020; Gallet et al., 2018)

Bus route, *r*	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Average
Bus capacity, *x*	63	63	63	63	63	63	63	63	63	63	63
Average bus speed, *V* (km/h)	55	55	45	45	45	40	40	40	55	45	46.5
Bus route length, *D* (km)	28.59	22.86	23.2	21.87	24.6	22.86	29.13	26.57	32.7	25.88	25.83
Bus operating time per bus route, *T* (hour)	0.52	0.42	0.52	0.49	0.55	0.57	0.73	0.66	0.59	0.58	0.56
Friction force of bus, *f*	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Angle of inclination of the road, $\propto$ (^{0})	3	3	3	3	3	3	3	3	3	3	3.0
Total mass of the electric bus, *m* (kg)	13110	13519	15567	15771	15771	16181	16181	15976	13110	14543	14972.7
Acceleration of gravity, *g* (m/s^2)	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Resistance coefficient of the bus, *C*	0.4666	0.4666	0.4666	0.4666	0.4666	0.4666	0.4666	0.4666	0.4666	0.4666	0.4666
Frontal area of the bus, *a* (m^2)	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93	6.93
Density of air, ρ (kg/m^3)	1.1839	1.1839	1.1839	1.1839	1.1839	1.1839	1.1839	1.1839	1.1839	1.1839	1.1839
Bus frequency, *h*	3	4	4	3	3	3	3	3	3	3	3
Bus quantity, *q*	18	14	14	16	17	16	19	17	19	19	17
Load factor, *LF* (%)	10	20	70	75	75	85	85	80	10	45	55.5
Number of passengers, *b*	6	13	44	47	47	54	54	50	6	28	35

The summary of energy consumption is listed in Table 4.2 and was computed by using Equation 3.5. Table 4.2 shows that bus route R1 has shown the lowest energy consumption, which is 753.03kWh, while bus route R7 has the highest energy consumption, at 7932.53 kWh. This is mainly due to the bus route R7, which has the longest bus operating time compared to other bus routes. Although the bus operating time for R1 is not the lowest, the low bus mass and shorter travelling distance have caused the lowest energy consumption for bus route R1.

Table 4.2: Summary of the energy consumption for each bus route

Bus route, *r*	Energy consumption of bus route, E_r (kWh)
R1	753.03
R2	1240.88
R3	5022.78
R4	5138.80
R5	5780.27
R6	6225.12
R7	7932.53
R8	6724.57
R9	861.29
R10	3368.48
Total	**43047.80**

4.2.2 Emission

All the inputs used for calculating emissions are listed in Table 4.3. The same battery type and charging facility are used on all bus routes, which produce the same charging efficiency. Three types of GHG emission factors are considered as electricity generation consists of various resources.

Table 4.3: Data input for emission (benchmark scenario) (Chong, 2016; Teoh et al., 2018; Song et al., 2018)

Bus route, r	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Average
Bus capacity, x	63	63	63	63	63	63	63	63	63	63	63
Electricity loss of the power transmission system, l (%)	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17
Charging efficiency of the battery in percentage, ∂ (%)	94	94	94	94	94	94	94	94	94	94	94
GHG emission factor, e_1 (kg CO_2eq/kWh)	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
GHG emission factor, e_2 (kg CO_2eq/kWh)	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
GHG emission factor, e_3 (kg CO_2 eq/kWh)	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Bus frequency, h	3	4	4	3	3	3	3	3	3	3	3
Bus quantity, q	18	14	14	16	17	16	19	17	19	19	17
Load factor, LF (%)	10	20	70	75	75	85	85	80	10	45	55.5
Number of passengers, b	6	13	44	47	47	54	54	50	6	28	35
Energy, E_r (kWh)	251.01	321.71	1302.20	1522.61	1819.71	1844.48	2791.08	2117.00	303.05	1185.21	1345.80

The summary of emissions that were computed by using Equation 3.7 is listed in Table 4.4. Among all the bus routes, bus route R1 has shown the lowest emission, which is 186.15 kg CO_2eq, while bus route R7 has the highest emission, with 16667.69 kg CO_2eq. This is primarily due to the bus route R7, which has the highest energy consumption, and hence the emissions, which are produced from the electricity generation, will increase proportionally as well. The same concept is applied to bus route R1, which has the lowest energy consumption and results in the lowest emission level.

Table 4.4: Summary of the emission for each bus route (benchmark scenario)

Bus route, r	Total of emission, EM_r^{WTW} (kg CO_2eq)
R1	186.15
R2	613.49
R3	8691.35
R4	9527.25
R5	10716.53
R6	13080.10
R7	16667.69
R8	13298.40
R9	212.91
R10	3747.06
Total	**76740.93**

4.2.3 Bus Noise

Various inputs for noise calculation are listed in Table 4.5. Different bus speeds may vary the sound pressure. Moreover, the number of accelerations is inclusive of the bus's acceleration when the bus passes by a bus stop, a traffic light or a roundabout. …

Table 4.5: Data input for noise (benchmark scenario) (Borén, 2019; Teoh et al., 2018)

Bus route, *r*	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Average
Bus capacity, *x*	63	63	63	63	63	63	63	63	63	63	63
No of bus stop, ϵ	29.0	22.0	23.0	26.0	23.0	26.0	24.0	25.0	38.0	24.0	26
Number of acceleration, γ	31	25	31	29	33	34	44	40	36	35	34
Bus route length, *D* (km)	28.59	22.86	23.2	21.87	24.6	22.86	29.13	26.57	32.7	25.88	25.83
Bus operating time per bus route, *T* (min)	31.19	24.94	30.93	29.16	32.80	34.29	43.70	39.86	35.67	34.51	33.70
Average bus speed, *V* (km/h)	55	55	45	45	45	40	40	40	55	45	46.5
Reference sound pressure, P_{ref} (Pascal)	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
Increased sound pressure during acceleration, P_y (Pascal)	0.072500	0.072500	0.044200	0.044200	0.044200	0.029000	0.029000	0.029000	0.072500	0.044200	0.04813
Baseline sound pressure, P_0 (Pascal)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sound pressure during constant speed, P_z (Pascal)	0.037000	0.037000	0.037000	0.037000	0.037000	0.037000	0.037000	0.037000	0.037000	0.037000	0.03700
Time duration that a person is affected by the noise from a bus, *t* (second)	5	5	7	7	7	10	12	10	5	4	7.2
Bus frequency, *q*	3	4	4	3	3	3	3	3	3	3	3
Bus quantity, *h*	18	14	14	16	17	16	19	17	19	19	17
Load factor, *LF* (%)	10	20	70	75	75	85	85	80	10	45	55.5
Number of passengers, *b*	6	13	44	47	47	54	54	50	6	28	35

By applying Equation 3.9, the summary of noise for all bus routes is shown in Table 4.6. The three bus routes with the highest noise are R6, R7 and R8 and these bus routes are fulfilled with the highest demand. As for the three lowest noise bus routes, R1, R2 and R9 have the lowest load factor.

Table 4.6: Summary of the noise for each bus route (benchmark scenario)

Bus route, *r*	Total noise per bus route, L_r (dba)
R1	792.43
R2	1582.69
R3	5498.91
R4	5888.66
R5	5894.87
R6	6659.60
R7	6700.38
R8	6278.61
R9	793.18
R10	3502.50
Total	**43591.85**

4.2.4 Green Index

Figure 4.2 shows the results of GEI, GMI and GNI. GNI approached nearer to the line of equality compared to GEI and GMI. This indicates that the green performance in terms of bus noise is better where the resulted bus noise level is lower.

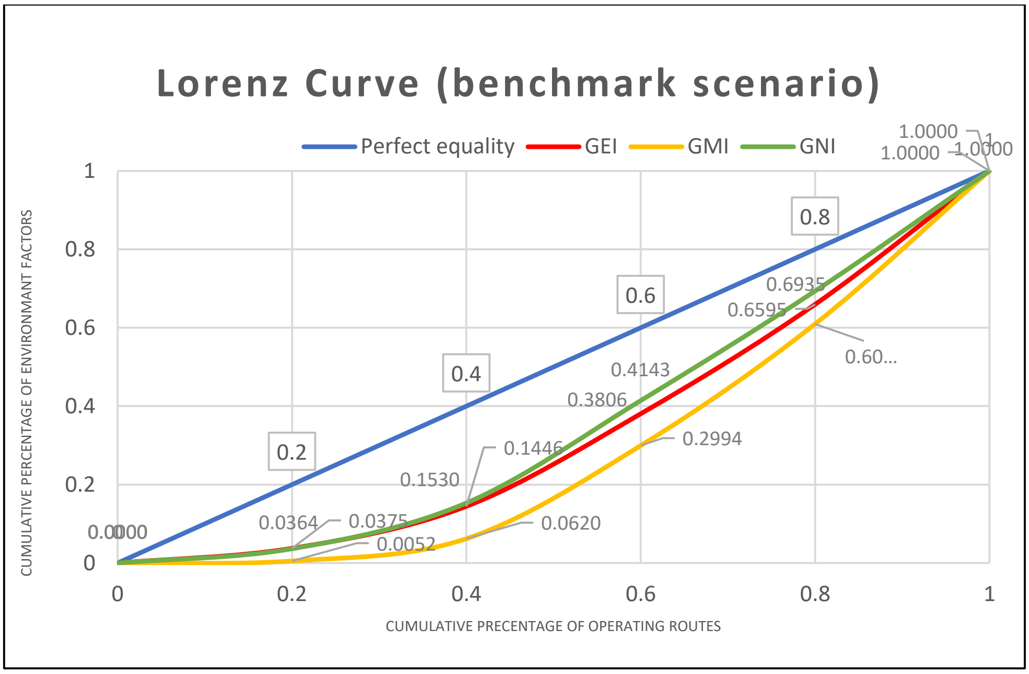


Figure 4.2: The results of GEI, GMI and GNI for benchmark scenario

The summary of the green indexes (score and grade) with different weightages is shown in Table 4.7. Three sets of weightage are applied and each set is used to compute GPI. Although all the grades of GPI fall under the same category (grade IV), Set 3 yields the best result for GPI at 2.8867. This shows that the bus operator could apply the weightage of Set 3 to get the best result for GPI.

Table 4.7: Summary of Green Index with different weightage for benchmark scenario

	Green Index	Score (S_j) Set 1	Set 2	Set 3
Energy Consumption	0.3111	1.2000	1.0500	1.0000
Emission	0.4095	0.9320	0.8155	0.7767
Noise	0.2811	0.6660	0.9990	1.1100
Green Performance Index (GPI)	-	2.7980	2.8645	**2.8867**
Grade of GPI	-	IV	IV	IV

4.3 Strategy 1 (increase load factor)

Bus routes with low demand (with a load factor of less than 50%) are identified. These bus routes are R1, R2, R9, and R10. Bus routes R1 and R9 with the lowest load factor (10% in the benchmark scenario) have increased to 50%, while the increment in load factor is from 20% (in the benchmark scenario) to 50% for the bus route R2. As for bus route R10, 45% of the load factor (in the benchmark scenario) has increased to 50%. It is estimated that the overall green performance of bus operations would be improved by having a higher load factor (Carrese et al., 2013; Yu et al., 2015).

4.3.1 Energy consumption

In Table 4.8, the bus mass has increased for the bus routes R1, R2, R9 and R10 due to the changes in the number of passengers (for increased load factor). When there is an increase in load factor, the number of passengers will be increased as well. Therefore, it will change the total mass of the bus. Table 4.8 presents the affected data input when compared with the data input of the benchmark scenario. The other inputs remain as outlined in the benchmark scenario.

Table 4.8: Data input for energy consumption (Strategy 1)

Bus route, r	Total mass of bus, M (kg)	Load factor, LF (%)	Number of passengers, b
R1	14748	50	32
R2	14748	50	32
R3	15567	70	44
R4	15771	75	47
R5	15771	75	47
R6	16181	85	54
R7	16181	85	54
R8	15976	80	50
R9	14748	50	32
R10	14748	50	32
Average	15443.7	67	42

Remark: number of passengers = bus capacity x load factor

Table 4.9 shows the summary of the resulting energy consumption for all bus routes. Bus route R2 has shown the lowest energy consumption, which is 3377.15kWh, while bus route R7 has the highest energy consumption, at 7932.53kWh. This is mainly due to the fact that bus route R7 has the longest bus operating time compared to other bus routes, but bus route R2 has the shortest bus operating time.

Table 4.9: Summary of the energy consumption for each bus route (Strategy 1)

Bus route, r	Energy consumption for bus route, E_r (kWh)
R1	4223.65
R2	3377.15
R3	5022.78
R4	5138.80
R5	5780.27
R6	6225.12
R7	7932.53
R8	6724.57
R9	4830.83
R10	3794.63
Total	**53050.34**

4.3.2 Emission

When calculating emissions, one of the data inputs is energy consumption. When there are adjustments to the load factor (together with the number of passengers) for bus routes R1, R2, R9, and R10, it results in different energy consumptions. Therefore, Table 4.10 shows the inputs that are different from the benchmark scenario. Other inputs (i.e., charging efficiency) remain as in the benchmark scenario.

Table 4.10: Data input for emission (Strategy 1)

Bus route, *r*	Load factor, *LF* (%)	Energy, E_r (kWh)	Number of passengers, *b*
R1	50	1407.88	32
R2	50	875.56	32
R3	70	1302.20	44
R4	75	1522.61	47
R5	75	1819.71	47
R6	85	1844.48	54
R7	85	2791.08	54
R8	80	2117.00	50
R9	50	1699.74	32
R10	50	1335.15	32
Average	67	1671.54	42

Table 4.11 presents the summary of emissions for each bus route. Bus routes R6, R7, and R8 have revealed the top 3 highest emissions, while bus route R2 shows the lowest emissions. This is due to the top 3 highest emission bus routes that have consumed the most energy and the lowest emission bus routes having utilised the least energy.

Table 4.11: Summary of emission for each bus route (Strategy 1)

Bus route, *r*	Total of emission, EM_r^{WTW} (kg CO_2eq)
R1	5220.39
R2	4174.12
R3	8691.35
R4	9527.25
R5	10716.53
R6	13080.10
R7	16667.69
R8	13298.40
R9	5970.86
R10	4690.13
Total	**92036.81**

4.3.3 Bus Noise

Various inputs for noise calculation are listed in Table 4.12. The number of passengers has increased for the bus routes R1, R2, R9, and R10 due to the increment in load factor. The data inputs that are not listed in Table 4.12 are the same as in the benchmark scenario.

Table 4.12: Data input for noise (Strategy 1)

Bus route, *r*	Load factor, *LF* (%)	Number of passengers, *b*
R1	50	32
R2	50	32
R3	70	44
R4	75	47
R5	75	47
R6	85	54
R7	85	54
R8	80	50
R9	50	32
R10	50	32
Average	67	42

The summary of noise for each bus route is listed in Table 4.13. Bus route R10 has shown the lowest noise, which is 3891.663dba, while bus route R7 still obtained the highest noise at 6700.38dba. Compared with bus routes R1, R2 and R9, bus route R10 produces the least noise. This is due to the low bus speed and sound pressure measured even though the load factor and the number of passengers have increased accordingly. As for bus route R7, even with low sound pressure, this bus route takes a longer time to complete a trip, causing a lengthier duration on the road. This is why bus route R7 produces the highest noise level.

Table 4.13: Summary of the noise for each bus route (Strategy 1)

Bus route, *r*	Total noise per bus route, L_r (dba)
R1	3962.16
R2	3956.73
R3	5498.93
R4	5888.66
R5	5894.87
R6	6659.60
R7	6700.38
R8	6278.61
R9	3965.91
R10	3891.66
Total	**52697.51**

4.3.4 Green Index

Figure 4.3 shows the results of GEI, GMI, and GNI. GMI stayed farther from the line of equality, which indicates the bus produces more pollutants (emissions) compared to GEI and GNI.

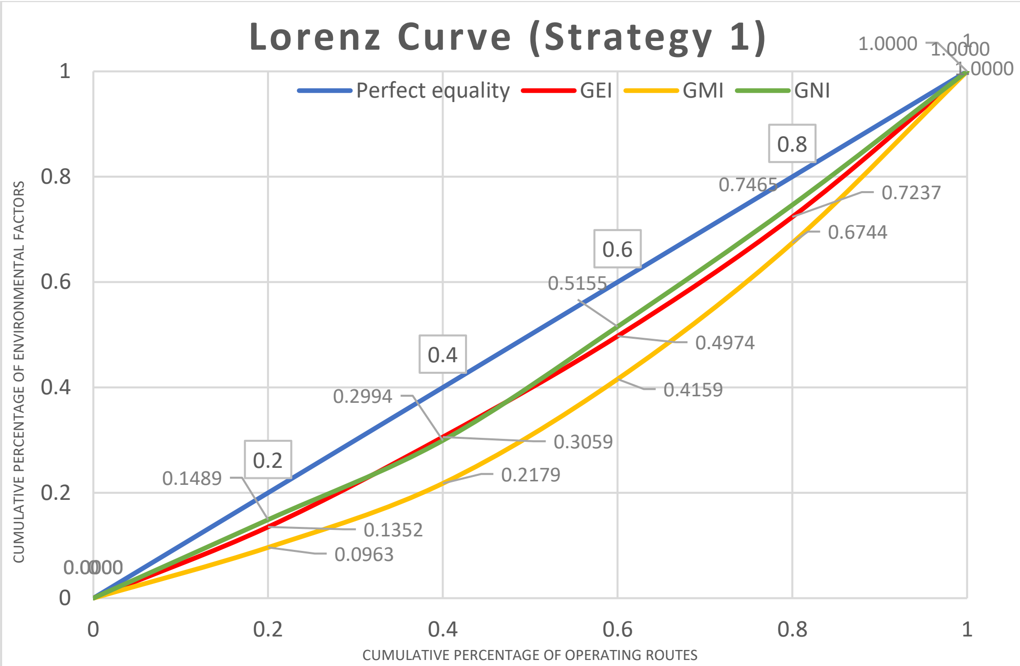


Figure 4.3: The results of GEI, GMI and GNI for Strategy 1

The results of different weightages applied to Strategy 1 are shown in Table 4.14. All three sets of weightage have obtained the same grade, which is I. Among the sets of weightage, Set 3 has shown the best result for GPI, where the weightage is the highest of the three sets of weightage.

Table 4.14: Summary of Green Index with different weightage for Strategy 1

	Green Index	Score (S_j)		
		Set 1	Set 2	Set 3
Energy Consumption	0.1351	1.6000	1.4000	1.3333
Emission	0.2382	1.4680	1.2845	1.2233
Noise	0.1159	0.8000	1.2000	1.2000
Green Performance Index (GPI)	-	3.8680	3.8845	**3.8900**
Grade of GPI	-	I	I	I

Figure 4.4 shows the improvement level for Strategy 1. By increasing the load factor, GNI has shown the greatest improvement with 58.77%, followed by GEI with 56.57% and GMI, which improved by 41.84%. As for the weightage, 3 sets of weightage have shown promising improvement, ranging from 34.76% to 38.24%. Among the three sets of weightage, Set 1 has shown the best result for the

improvement level. This indicates that when compared with the benchmark scenario, Set 1 has improved the most. However, the results in Table 4.15 show that Set 3 in Strategy 1 yields the best GPI (i.e., 3.8900 with grade II) and is recommended as it showed the greenest performance.

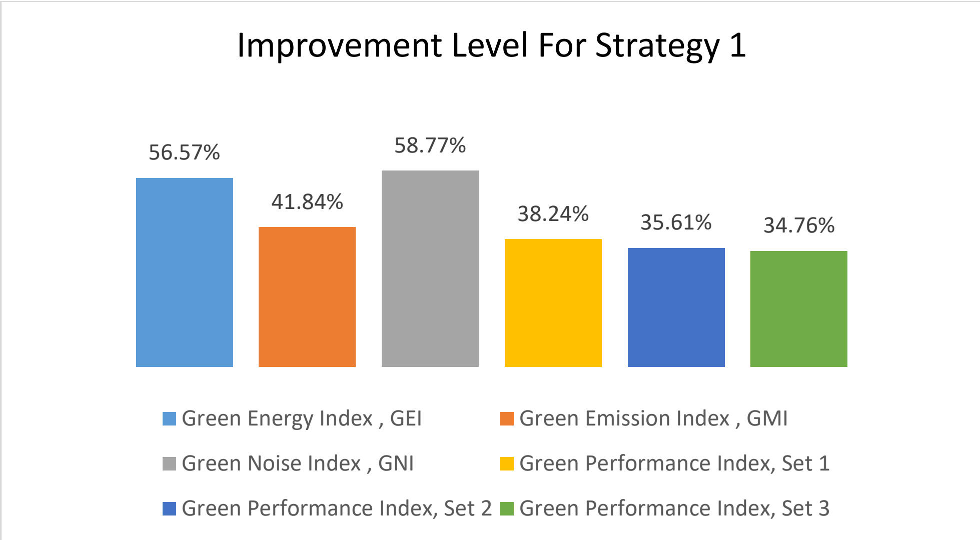


Figure 4.4: Improvement level for Strategy 1

4.4 Strategy 2 (adjust bus frequency)

In the benchmark scenario, four bus routes, i.e., R1, R2, R9, and R10, are identified as the low-demand bus routes due to their load factors, which are lower than 50%. The bus routes R1 and R9 are removed due to a very low load factor (only 10%), and it may not be profitable for the bus operator. Besides, the bus frequency of the benchmark scenario is reduced from 4 to 1 for R2, and hence the load factor is possibly increased from 20% to 50%. Similarly, the 45% load factor (in the benchmark scenario) is increased to 50% for bus route R10, and the bus frequency is reduced from 3 (in the benchmark scenario) to 1.

4.4.1 Energy consumption

Adjustment of bus frequency for this strategy involves frequency removal and reduction. As shown in Table 4.15, there are only eight bus routes (R2, R3, R4, R5, R6, R7, R8 and R10) as two bus routes (i.e., R1 and R9) with the lowest load factor (in the benchmark scenario) are removed. As for the reduction of bus frequency, it has been reduced from 4 to 1 for bus route R2 and from 3 to 2 for bus route R10. However, the demand for bus routes R2 and R10 has increased by 50%. The adjustment of load factors has caused changes in bus weight and the number of passengers. Other inputs remain as in the benchmark scenario.

Table 4.15: Data input for energy consumption (Strategy 2)

Bus route, *r*	Total mass of the electric bus, *m* (kg)	Bus frequency, *h*	Bus quantity, *q*	Load factor, *LF* (%)	Number of passengers, *b*
R2	14748	1	14	50	32
R3	15567	4	14	70	44
R4	15771	3	16	75	47
R5	15771	3	17	75	47
R6	16181	3	16	85	54
R7	16181	3	19	85	54
R8	15976	3	17	80	50
R10	14748	1	19	50	32
Average	15618	3	17	71	45

The summary of energy consumption for all the bus routes is listed in Table 4.16. The bus route R7 remains with the highest energy consumption, which is 7932.53 kWh, due to the fact that this bus route has the longest bus travelling time with a high load factor. The bus frequency has been reduced on bus route R2, and this bus route has shown the lowest energy consumption, which is 875.56kWh.

Table 4.16: Summary of the energy consumption for each bus route (Strategy 2)

Bus route, r	Energy consumption for bus route, E_r (kWh)
R2	875.56
R3	5022.78
R4	5138.80
R5	5780.27
R6	6225.12
R7	7932.53
R8	6724.57
R10	1335.15
Total	**39034.80**

4.4.2 Emission

All the inputs, which varied from the benchmark scenario, are shown in Table 4.17. The bus routes for R2 and R10 have increased in load factor but reduced in bus frequency. Other inputs (i.e., charging efficiency) still remain.

Table 4.17: Data input for emission (Strategy 2)

Bus route, r	Total mass of the electric bus, m (kg)	Bus frequency, h	Bus quantity, q	Load factor, LF (%)	Number of passengers, b
R2	14748	1	14	50	32
R3	15567	4	14	70	44
R4	15771	3	16	75	47
R5	15771	3	17	75	47
R6	16181	3	16	85	54
R7	16181	3	19	85	54
R8	15976	3	17	80	50
R10	14748	1	19	50	32
Average	15618	3	17	71	45

Table 4.18 displays the summary of the emissions for all bus routes. Bus routes R2 and R10 showed the lowest emissions. Low energy consumption on bus routes R2 and R10 may have a significant impact on emissions. The bus route R7 has the highest emissions, followed by bus routes R8 and R6. These three bus routes have the highest load factors of all others.

Table 4.18: Summary of the emission for each bus route (Strategy 2)

Bus route, r	Total of emission, EM_r^{WTW} (kg CO_2eq)
R2	1082.18
R3	8691.35
R4	9527.25
R5	10716.53
R6	13080.10
R7	16667.69
R8	13298.40
R10	1650.23
Total	**74713.73**

4.4.3 Bus Noise

Different inputs for noise calculation (different from the benchmark scenario) are listed in Table 4.19. The bus frequency has been reduced from 4 to 1 for bus route R2 and from 3 to 1 for bus route R10, but there is an increment in load factor (up to 50%) for bus routes R2 and R10.

Table 4.19: Data input for noise (Strategy 2)

Bus route, r	No of acceleration, γ	Time duration that a person is affected by the noise from a bus, t (second)	Bus frequency, q	Load factor, LF (%)	Number of passengers, b
R2	25	5	1	50	32
R3	31	7	4	70	44
R4	29	7	3	75	47
R5	33	7	3	75	47
R6	34	10	3	85	54
R7	44	12	3	85	54
R8	40	10	3	80	50
R10	35	4	1	50	32
Average	34	7.2	2	67	45

The summary of noise for all bus routes is listed in Table 4.20. Bus route R2 and bus route R10 have shown the lowest noise, which is 1025.82dba and

1369.29 respectively, due to a reduction in total bus trips for both bus routes. When the bus performs fewer trips, the noise generated will be reduced as the frequency of the bus being on the route is reduced.

Table 4.20: Summary of the noise for each bus route (Strategy 2)

Bus route, r	Total noise per bus route, L_r(dba)
R2	1025.82
R3	5498.93
R4	5888.66
R5	5894.87
R6	6659.60
R7	6700.38
R8	6278.61
R10	1369.29
Total	**42032.29**

4.4.4 Green Index

Figure 4.5 shows the results of the GEI, GMI, and GNI for Strategy 2. GNI approached the line of equality the closest, followed by GEI and GMI. This indicates that the bus produces more pollutants (emissions) compared to other pollutants (noise and energy consumption) in this strategy.

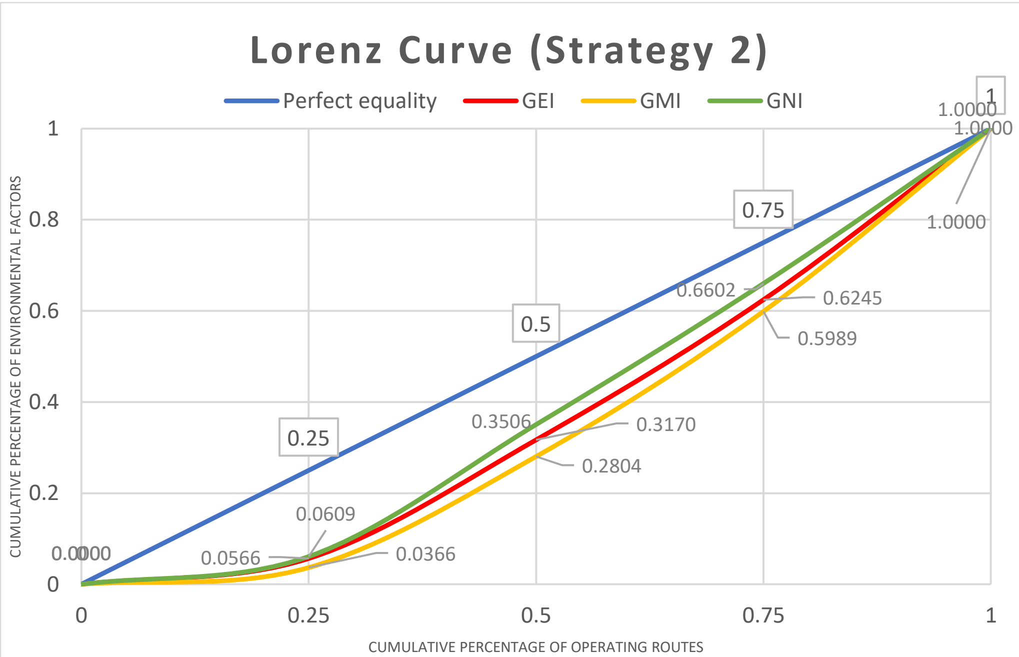


Figure 4.5: The results of GEI, GMI and GNI for Strategy 2

Table 4.21 shows the summary of the Green Index with different weightages. All the three sets of weightage obtained the same grade, which is III, but with different scores. Among three sets of weightage, Set 3 has shown the highest score for the GPI.

Table 4.21: Summary of Green Index with different weightage for Strategy 2

	Green Index	Score Set 1	Score Set 2	Score Set 3
Energy Consumption (S_{EN})	0.2509	1.4680	1.2845	1.2233
Emission (S_{EM})	0.2920	1.3320	1.1655	1.1100
Noise (S_{BN})	0.2347	0.7340	1.1010	1.2233
Green Performance Index (GPI)	-	3.5340	3.5510	**3.5567**
Grade of GPI	-	II	II	II

The improvement level for Strategy 2 is presented in Figure 4.6. GMI has the highest percentage of improvement (i.e., 28.69%), followed by GEI with 19.34% of improvement and GNI with 16.50% of improvement. Among the three sets of weightage in terms of improvement level (when compared with the benchmark scenario), Set 1 has produced the greatest result (i.e., 26.30%), which reveals the most improved set. Nevertheless, Set 3 is the best weightage computation set for Strategy 2 as it presents the best GPI and is therefore recommended. Set 1 revealed the lowest GPI score, even with the highest improvement level.

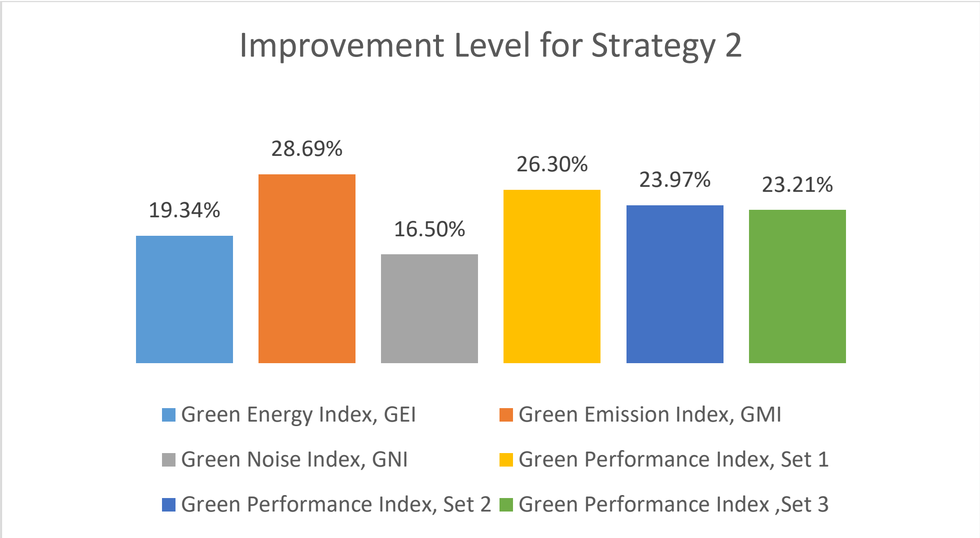


Figure 4.6: Improvement level for Strategy 2

4.5 Strategy 3 (fleet planning)

In the benchmark scenario, four bus routes (R1, R2, R9, and R10) are identified as low-demand bus routes with less than 50% load factors. Thus, the bus capacity of the benchmark scenario is reduced from 63 to 40 for the selected bus routes, which are R1, R2, R9, and R10. With a smaller bus capacity, the load factor of these bus routes (in the benchmark scenario) could be increased by implementing this strategy. For bus routes R1 and R9, the load factor was increased from 10% (benchmark scenario) to 50%. As for bus route R2, the load factor was increased from 20% to 50%, and the load factor for bus route R10 was increased from 45% to 50%.

4.5.1 Energy consumption

In Table 4.22, the bus mass is reduced for bus routes R1, R2, R9 and R10 as a smaller bus is used on these bus routes. With a smaller bus, the bus specification, like the frontal area of the bus, has been reduced from $6.93m^2$ to $4.88m^2$. The smaller bus has a different weight and mass compared to the benchmark scenario.

Table 4.22: Data input for energy consumption (Strategy 3) (Auto-Che, 2020; Gallet et al., 2018)

Bus route, *r*	Bus capacity, *x*	Bus operating time per bus route, *T* (hour)	Total mass of the electric bus, *m* (kg)	Frontal area of the bus, *a* (m^2)	Load factor, *LF* (%)	Number of passengers, *b*
R1	40	0.48	4110	4.88	50	20
R2	40	0.38	4370	4.88	50	20
R3	63	0.52	15567	6.93	70	44
R4	63	0.49	15771	6.93	75	47
R5	63	0.55	15771	6.93	75	47
R6	63	0.57	16181	6.93	85	54
R7	63	0.73	16181	6.93	85	54
R8	63	0.66	15976	6.93	80	50
R9	40	0.55	4110	4.88	50	20
R10	40	0.43	5020	4.88	50	20
Average	54	0.53	11305.7	6.11	55.5	38

Table 4.23 displays the summary of energy consumption for all bus routes. The bus route R2 ranked the lowest in energy consumption, with the recommendation of using a smaller bus capacity with lower bus mass. In Table 4.23, the top 3 energy consumers are the bus routes R6, R7, and R8, which have the highest number of passengers (highest load factor).

Table 4.23: Summary of the energy consumption for each bus route (Strategy 3)

Bus route, *r*	Energy consumption for bus route, E_r (kWh)
R1	1508.95
R2	1206.53
R3	5022.78
R4	5138.80
R5	5780.27
R6	6225.12
R7	7932.53
R8	6724.57
R9	1725.88
R10	1345.74
Total	**42611.2**

4.5.2 Emission

All the inputs (which are different from the benchmark scenario) used for calculating emissions are listed in Table 4.24. The bus type for bus routes R1, R2, R9, and R10 has changed to a smaller bus, but the charging efficiency of the battery remains the same as long as the same battery type and charging facility are used. The application of smaller buses has caused changes in the bus capacity as well as the number of passengers.

Table 4.24: Data input for emission (Strategy 3)

Bus route, *r*	Bus capacity, *x*	Load factor, *LF* (%)	Energy, E_r (kWh)	Number of passengers, *b*
R1	40	50	502.98	20
R2	40	50	312.8	20
R3	63	70	1302.2	44
R4	63	75	1522.61	47
R5	63	75	1819.71	47
R6	63	85	1844.48	54
R7	63	85	2791.08	54
R8	63	80	2117	50
R9	40	50	607.25	20
R10	40	50	473.5	20
Average	54	67	1329.36	38

The summary of emissions for each bus route is listed in Table 4.25. The total emissions for Strategy 3 are 79134.11kg CO_2eq. Bus route R7 has the highest emissions, followed by bus route R8. The prolonged bus travel time and the highest energy consumption have caused the highest emissions for bus routes R7 and R8. The lowest emissions are produced by bus route R2 which has the lowest energy consumption with low bus quantity and a shorter bus operating time.

Table 4.25: Summary of the emission for each bus route (Strategy 3)

Bus route, r	Total of emission, EM_r^{WTW} (kg CO_2eq)
R1	1865.05
R2	1491.26
R3	8691.35
R4	9527.25
R5	10716.53
R6	13080.10
R7	16667.69
R8	13298.40
R9	2133.17
R10	1663.32
Total	**79134.11**

4.5.3 Bus Noise

Table 4.26 presents the data input (which is different from the benchmark scenario) for the noise calculation. The bus capacity for bus routes R1, R2, R9, and R10 has been reduced to 40, but the load factor of these bus routes has increased to 50%.

Table 4.26: Data input for noise (Strategy 3) (Borén, 2019)

Bus route, r	Bus capacity, x	Time duration that a person is affected by the noise from a bus, t *(second)*	Load factor, LF (%)	Number of passengers, b
R1	40	4	50	20
R2	40	4	50	20
R3	63	7	70	44
R4	63	7	75	47
R5	63	7	75	47
R6	63	10	85	54
R7	63	12	85	54
R8	63	10	80	50
R9	40	4	50	20
R10	40	4	50	20
Average	54	6.9	67	38

The summary of noise for all bus routes is listed in Table 4.27. With smaller bus capacity, the bus routes R1, R2, R9, and R10 have shown the lowest noise, which is less than 4000dba. As for bus routes R6, R7, and R8, they have achieved the top three noise levels as these bus routes cater to the highest load factor and the lowest bus speed.

Table 4.27: Summary of the noise for each bus route (Strategy 3)

Bus route, r	Total noise per bus route, L_r (dba)
R1	3942.43
R2	3935.98
R3	5498.91
R4	5888.66
R5	5894.87
R6	6659.60
R7	6700.38
R8	6278.61
R9	3946.85
R10	3891.66
Total	**52637.98**

4.5.4 Green Index

Figure 4.7 shows the outcome of GEI, GMI, and GNI. The GEI and GMI appear to be further away from the line of equality, whereas the GNI approaches it. This indicates that the bus operation produces less noise and has a better green performance in terms of bus noise.

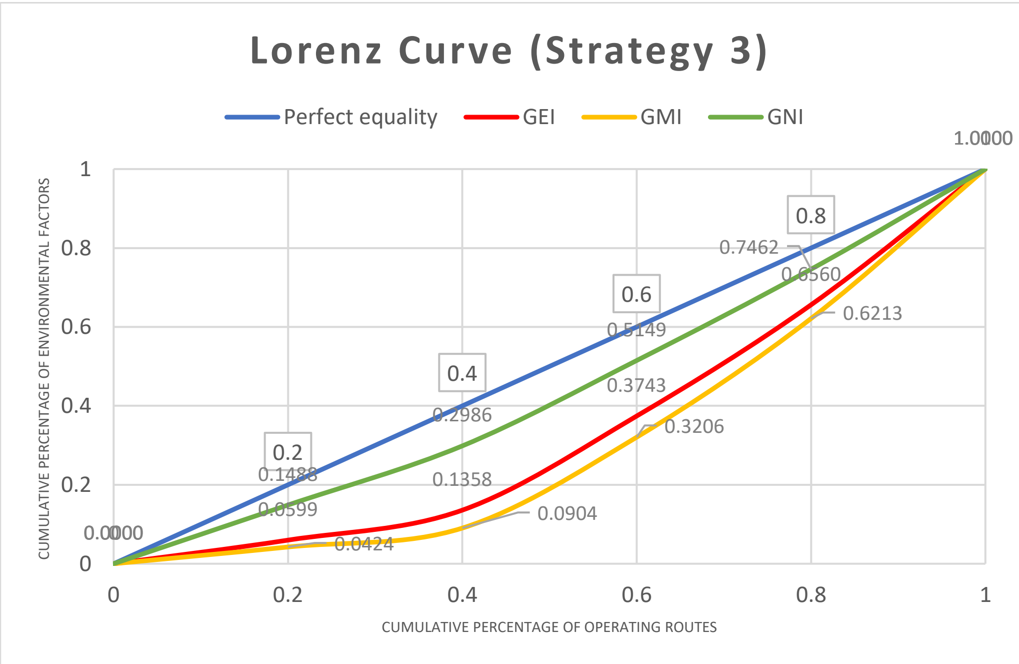


Figure 4.7: The results of GEI, GMI and GNI for Strategy 3

The summary of the Green Index with various weightages is shown in Table 4.28. Three sets of weightage are applied and each presents a different score of GPI, but all fall under the same grade, which is III. Set 3 shows the best score of GPI among the other sets.

Table 4.28: Summary of Green Index with different weightage for Strategy 3

	Green Index	Score (S_j) Set 1	Set 2	Set 3
Energy Consumption	0.3096	1.2000	1.0500	1.0000
Emission	0.3701	1.0680	0.9345	0.8900
Noise	0.1166	0.8000	1.2000	0.8900
Green Performance Index (GPI)	-	3.0680	3.1845	**3.2233**
Grade of GPI	-	III	III	III

In Figure 4.8, GNI has shown the highest percentage of improvement, which is 58.53%. The high percentage of improvement levels for GNI reveals that by using a smaller bus, one is able to improve the noise level when compared with the benchmark scenario.

GEI has an improvement of less than 1%. This indicates that the total energy use required for a smaller bus capacity is almost the same as for a bigger bus. Even if the bus capacity is reduced, the bus will still need to perform more trips to cater to passengers' needs, which requires more energy to complete the bus operation.

GMI has a slightly higher improvement level. This happened due to the increment in load factor and a smaller bus (with a lighter weight) equipped with a smaller battery size, which requires frequent charging in order to obtain sufficient energy for its operation. Frequent charging (with slow charging) will emit more emissions during the charging process.

As for the selection of weightage, Set 3 is recommended as it showed the highest percentage of improvement, which also gave the best score of GPI for Strategy 3.

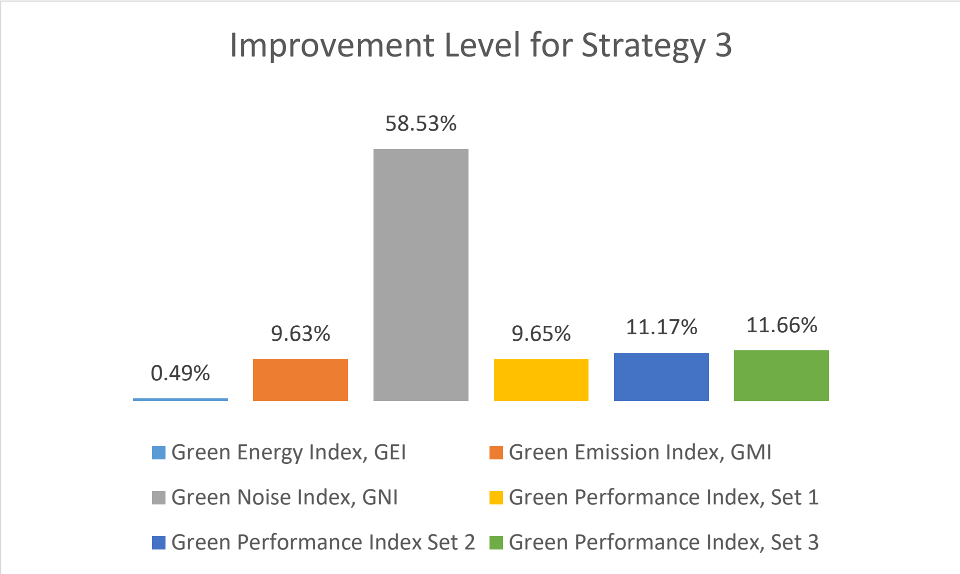


Figure 4.8: Improvement level for Strategy 3

4.6 Strategy 4 (reduce bus speed)

In the benchmark scenario, bus routes R6, R7, and R8 showed the highest energy consumption, emissions, and noise for the bus operation. Thus, the bus speed in the benchmark scenario is reduced from 40 km/h to 30 km/h for bus routes R6, R7, and R8. The average bus speed for all bus routes is reduced from 46.5 km/h to 43.5 km/h. For this strategy, there is an impact on the bus quantity due to the longer travelling and charging times that will require more buses to service the schedules. For bus route R6, the bus quantity is increased from 16 (benchmark scenario) to 17. As for bus route R7, the bus quantity has increased from 19 (benchmark scenario) to 21 and the 17 buses (benchmark scenario) have increased to 18 for bus route R8.

4.6.1 Energy consumption

In Table 4.29, the bus speed has been reduced for bus routes R6, R7, and R8 (which showed the highest energy consumption in the benchmark scenario). The bus speed is reduced from 40 km/h to 30 km/h (which is less than 35 km/h). The bus quantity has increased for these bus routes due to the longer bus travel time.

Table 4.29: Data input for energy consumption (Strategy 4)

Bus route, *r*	Average bus speed, *V* (km/h)	Bus operating time per bus route, *T* (hour)	Bus quantity, *q*
R1	55	0.52	18
R2	55	0.42	14
R3	45	0.52	14
R4	45	0.49	16
R5	45	0.55	17
R6	30	0.76	17
R7	30	0.97	21
R8	30	0.89	18
R9	55	0.59	19
R10	45	0.58	19
Average	43.5	0.63	17

The summary of energy consumption for all bus routes is listed in Table 4.30. With the reduction of bus speed, the bus routes R6, R7, and R8 remain at the highest energy consumption. An increase in bus volume could be one of the causes. Besides, bus routes R1 and R9 have the lowest energy consumption, as the bus mass for these two routes is the lowest.

Table 4.30: Summary of the energy consumption for each bus route (Strategy 4)

Bus route, r	Energy consumption for bus route, E_r (kWh)
R1	753.03
R2	1240.88
R3	5022.78
R4	5138.80
R5	5780.27
R6	6194.98
R7	7894.13
R8	6691.61
R9	861.29
R10	3368.48
Total	**42946.3**

4.6.2 Emission

All the inputs for emission calculation (varying from the benchmark scenario) are listed in Table 4.31. The charging efficiency of the battery remains the same for all bus routes as long as the same charging facility is used. The bus quantity is increased, as the travelling time takes longer while the bus speed is reduced.

Table 4.31: Data input for emission (Strategy 4)

Bus route, r	Bus quantity, q	Energy, E_r (kWh)
R1	18	251.01
R2	14	321.71
R3	14	1302.2
R4	16	1522.61
R5	17	1819.71
R6	17	1835.55
R7	21	2777.56
R8	18	2106.62
R9	19	303.05
R10	19	1185.21
Average	17	1342.52

Table 4.32 presents the summary of emission for all the bus routes. As there is a correlation with energy consumption, bus routes R6, R7, and R8 have the highest emissions. On the other hand, the load factor for R6, R7, and R8 is the

highest. The least amount of emissions is produced from the bus route R1, whereby the bus route R1 has a low load factor and the lowest energy consumption.

Table 4.32: Summary of the emission for each bus route (Strategy 4)

Bus route, *r*	Total of emission, EM_r^{WTW} (kg CO_2eq)
R1	186.15
R2	613.49
R3	8691.35
R4	9527.25
R5	10716.53
R6	13016.79
R7	16587.01
R8	13233.22
R9	212.91
R10	3747.06
Total	**76531.75**

4.6.3 Bus Noise

Table 4.33 shows the input (which varies from the benchmark scenario) for the noise calculation. The number of buses has increased for bus routes R6, R7, and R8 due to the reduction in speed and prolonged bus operating time. The reduction in bus speed has caused changes to the bus operating time as well as the number of accelerations.

Table 4.33: Data input for noise (Strategy 4)

Bus route, r	No of acceleration, γ	Bus operating time per bus route, T (min)	Average bus speed, V (km/h)	Increased sound pressure during acceleration, P_y (Pascal)	Bus quantity, h
R1	31	31.19	55	0.0725	18
R2	25	24.94	55	0.0725	14
R3	31	30.93	45	0.0442	14
R4	29	29.16	45	0.0442	16
R5	33	32.8	45	0.0442	17
R6	72	45.72	30	0.00175	17
R7	82	58.26	30	0.00175	21
R8	78	53.14	30	0.00175	18
R9	36	35.67	55	0.0725	19
R10	35	34.51	45	0.0442	19
Average	64	37.63	43.5	0.03996	17

The summary of noise for all bus routes is listed in Table 4.34. Bus routes R6, R7, and R8 have the highest total noise, even though the bus speed has been reduced, but the bus quantity has increased. The bus route R1 produced the lowest noise as this bus route has a low load factor and operates at a higher speed.

Table 4.34: Summary of the noise for each bus route (Strategy 4)

Bus route, r	Total noise per bus route, L_r(dba)
R1	792.43
R2	1582.69
R3	5498.91
R4	5888.66
R5	5894.87
R6	6569.14
R7	6607.03
R8	6204.63
R9	793.18
R10	3502.50
Total	**43334.07**

4.6.4 Green Index

The results of GEI, GMI, and GNI are presented in Figure 4.9. GNI approached nearer to the line of equality, and this shows that the bus produces fewer pollutants (noise) compared with GEI and GMI.

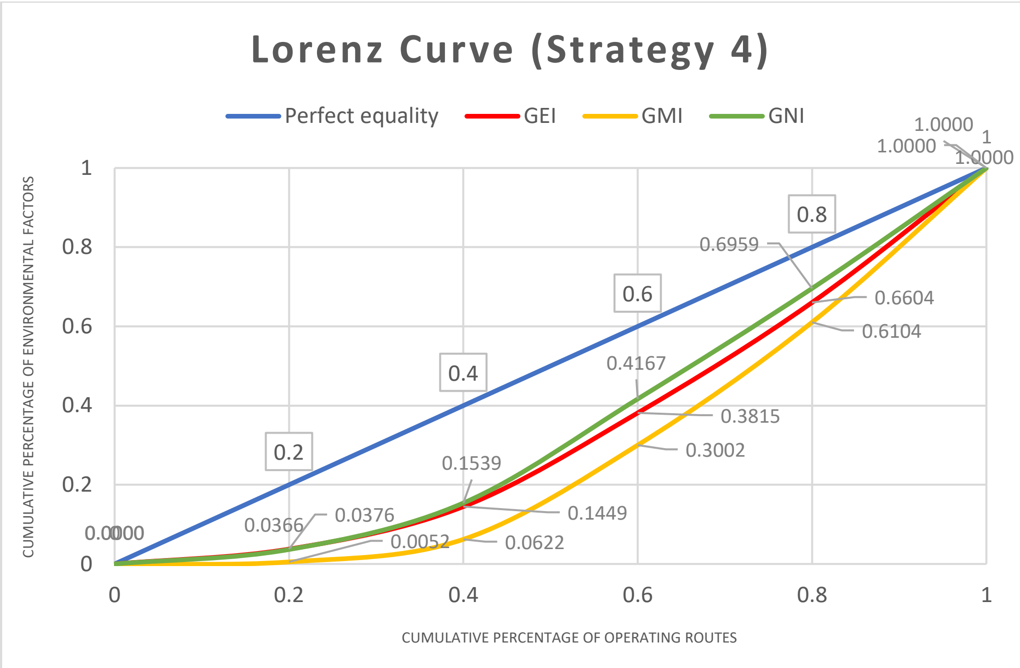


Figure 4.9: The results of GEI, GMI and GNI for Strategy 4

Table 4.35 presents the summary of the Green Index with different weightages. Three sets of weightages are applied. Even though each set of weightage falls under the same grade, which is IV, a different score is obtained. Set 3 showed the best result, with the highest score for the GPI.

Table 4.35: Summary of Green Index with different weightage for Strategy 4

	Green Index	Score (S_j) Set 1	Set 2	Set 3
Energy Consumption	0.3102	1.2000	1.0500	1.0000
Emission	0.4088	0.9320	0.8155	0.7767
Noise	0.2787	0.6660	0.9990	1.1100
Green Performance Index (*GPI*)	-	2.7980	2.8645	**2.8867**
Grade of *GPI*	-	IV	IV	IV

In Strategy 4, GNI has shown the highest percentage of improvement, which is 0.86%, followed by GEI with 0.28% of improvement and GMI with only 0.18% of improvement, as shown in Figure 4.10. The GEI, GMI, and GNI show minimal improvement as compared with the benchmark scenario. Even if there is a reduction in bus speed, it has caused the bus travelling time to become longer. Consequently, an increment in bus quantity was incurred in order to perform daily bus operations and cater to passengers' needs. Therefore, the amount of energy, emissions, and noise produced by Strategy 4 is reduced slightly compared with the benchmark scenario. Consequently, the resultant GPI reveals the same score and grade, and thus it shows no improvement (when compared with the benchmark scenario) in all sets of weightage. Set 3, with the highest GPI score, is recommended as the best set for the weightage calculation of GPI in Strategy 4.

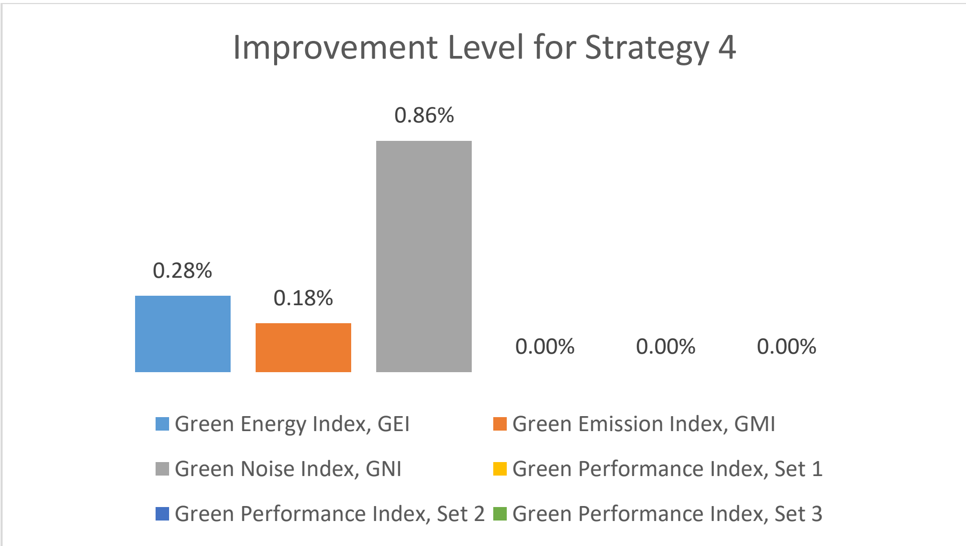


Figure 4.10: Improvement level for Strategy 4

4.7 Strategy 5 (change charging facility)

In the benchmark scenario, a slow charging facility is utilised for all bus routes. The slow charging can take up to 8 hours, while the fast charging takes around 10 minutes for 80 kWh. Fast charging could achieve a higher charging efficiency, which is approximated to be 98%, compared to the charging efficiency of slow charging, which is only 94%. Three bus routes, R6, R7, and R8, with the highest energy consumption, emissions, and noise have been chosen to change their charging facility. The charging facility that is proposed to be used is fast charging. When the charging duration is shortened, the number of buses can be reduced as each bus can perform more trips to meet the demand of passengers. The bus quantity is reduced from 16 (benchmark scenario) to 5 (strategy 5) for bus route R6 and the bus frequency is increased from 3 (benchmark scenario) to 11 (strategy 5) as more trips can be made by the same bus. The bus quantity is reduced from 19 (benchmark scenario) to 10 (strategy 5) for bus route R7, and the bus frequency is increased from 3 (benchmark scenario) to 5 (strategy 5) as more trips can be made by the same bus. The bus quantity is reduced from 17 (benchmark scenario) to 7 (strategy 5) for bus route R8 and the bus frequency is increased from 3 (benchmark scenario) to 8 (strategy 5) as more trips can be made by the same bus.

4.7.1 Energy consumption

In Table 4.36, the bus frequency for bus routes R6, R7, and R8 has increased, but the bus quantity has been reduced due to the reduction in bus charging duration (as the fast charging facility is used).

Table 4.36: Data input for energy consumption (Strategy 5)

Bus route, r	Bus frequency, h	Bus quantity, q
R1	3	18
R2	4	14
R3	4	14
R4	3	16
R5	3	17
R6	11	5
R7	5	10
R8	8	7
R9	3	19
R10	3	19
Average	5	17

Table 4.37 shows the summary of the energy consumption for all bus routes. Bus routes R1 and R9 showed the lowest energy consumption, while bus routes R7 and R8 had the highest energy consumption. Although the charging facility has changed to fast charging for bus routes R7 and R8, there is no impact on the energy consumption as the amount of energy required for the bus operation is still the same as applied in the benchmark scenario.

Table 4.37: Summary of the energy consumption for each bus route (Strategy 5)

Bus route, *r*	Energy consumption for bus route, E_r (kWh)
R1	753.03
R2	1240.88
R3	5022.78
R4	5138.80
R5	5780.27
R6	6225.12
R7	7932.53
R8	6724.57
R9	861.29
R10	3368.48
Total	**43047.80**

4.7.2 Emission

Table 4.38 shows the input (which varies from the benchmark scenario) for the emission calculation. Due to applying the fast changing facility, the charging efficiency of the battery was increased to 98% for bus routes R6, R7, and R8. With a shorter charging duration, there are changes in the bus frequency and bus quantity for the bus routes R6, R7, and R8.

Table 4.38: Data input for emission (Strategy 5) (Song et al., 2018; Chong, 2016)

Bus route, r	Charging efficiency of the battery in percentage, ∂ (%)	Bus frequency, h	Bus quantity, q	Energy, E_r (kWh)
R1	94	3	18	251.01
R2	94	4	14	321.71
R3	94	4	14	1302.2
R4	94	3	16	1522.61
R5	94	3	17	1819.71
R6	98	11	5	213.79
R7	98	5	10	822.63
R8	98	8	7	386.93
R9	94	3	19	303.05
R10	94	3	19	1185.21
Average	95.2	5	17	812.89

The summary of emissions for each bus route is shown in Table 4.39. Bus route R5 has the highest emissions because it uses a slow charging facility, which causes the emissions generated by electricity production to be higher due to the longer charging duration. Besides, the bus routes R6, R7, and R8 have presented fewer emissions than the bus routes R3, R4, and R5 as the fast charging facility is deployed on bus routes R6, R7, and R8. The reduction of the charging duration could lead to lower emissions from electricity supply and generation. This happens when the bus spends a shorter time completing the charging process and thus produces fewer emissions.

Table 4.39: Summary of the emission for each bus route (Strategy 5)

Bus route, r	Total of emission, EM_r^{WTW} (kg CO_2eq)
R1	186.15
R2	613.49
R3	8691.35
R4	9527.25
R5	10716.53
R6	4646.75
R7	8881.87
R8	5669.16
R9	212.91
R10	3747.06
Total	**52892.52**

4.7.3 Bus Noise

The input for noise calculation (which varies from the benchmark scenario) is as listed in Table 4.40. The bus quantity is reduced for bus routes R6, R7, and R8 and each bus can perform more trips for the bus operation.

Table 4.40: Data input for noise (Strategy 5)

Bus route, *r*	No of acceleration, *γ*	Bus frequency, *q*	Bus quantity, *h*
R1	31	3	18
R2	25	4	14
R3	31	4	14
R4	29	3	16
R5	33	3	17
R6	34	8	5
R7	44	8	10
R8	40	8	7
R9	36	3	19
R10	35	3	19
Average	34	5	14

Table 4.41 shows the summary of noise for all the bus routes. The bus routes R6, R7, and R8 showed the highest noise levels, even though there was an upgrade in charging facilities (from slow charging to fast charging). When the fast charging facility is applied to the designated bus routes, the bus operation time (inclusive of charging time) is reduced due to the shorter charging duration. However, each bus will need to perform more trips to fulfil the passengers' demands as per the bus schedule. This indirectly creates a reduction in bus quantity with an increment in bus frequency per bus. With these changes, the total number of trips performed by the buses remains as in the benchmark scenario, and there is no significant impact on the bus noise level.

Table 4.41: Summary of the noise for each bus route (Strategy 5)

Bus route, r	Total noise per bus route, L_r(dba)
R1	792.43
R2	1582.69
R3	5498.91
R4	5888.66
R5	5894.87
R6	6659.60
R7	6700.38
R8	6278.61
R9	793.18
R10	3502.50
Total	**43591.85**

4.7.4 Green Index

The results of GEI, GMI, and GNI are shown in Figure 4.11. In this figure, the GMI stays farther from the line of equality, which indicates that more pollutants (emissions) were produced by the bus during the bus operation compared with GEI and GNI.

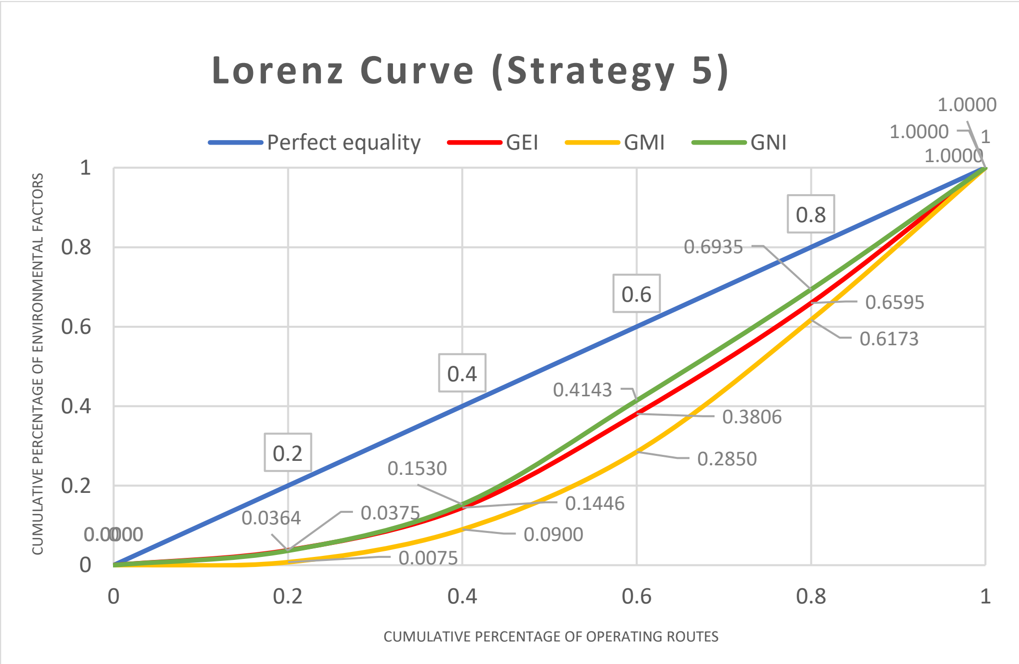


Figure 4.11: The results of GEI, GMI and GNI for Strategy 5

The summary of the Green Index with various weightages is shown in Table 4.42. Three sets of weightage are applied in this strategy. With this strategy, the grade for all sets is the same (grade IV), but Set 3 has shown a better score (3.000) than the others, which could provide a better GPI result.

Table 4.42: Summary of Green Index with different weightage for Strategy 5

	Green Index	Score (S_j)		
		Set 1	Set 2	Set 3
Energy Consumption	0.3111	1.2000	1.0500	1.0000
Emission	0.4001	1.0680	0.9345	0.8900
Noise	0.2811	0.6660	0.9990	1.1100
Green Performance Index (GPI)	-	2.9340	2.9835	**3.0000**
Grade of GPI	-	IV	IV	IV

Figure 4.12 shows the improvement level for Strategy 5. However, there is no improvement for GEI and GNI. This is because fast charging does not have any direct impact on the energy consumption and noise levels as the total number of trips for buses remains the same as in the benchmark scenario.

However, as for GMI, which is the only one with an improvement of 2.31%, the waste gaseous emission is not direct from the bus tailpipe but generated during the electricity supply. The shorter the charging duration, the less waste gaseous emissions are generated during the charging process (from the energy resources).

As for the weightage in terms of improvement level compared with the benchmark scenario, Set 1 has shown the highest percentage (i.e., 4.86%) of improvement and produced the best result for Strategy 5. This was followed by Set 2 with 4.15% of improvement, and Set 3 only obtained 3.93% of improvement. As a result, Set 3 presented the best GPI in weightage computation and was recommended in Strategy 5.

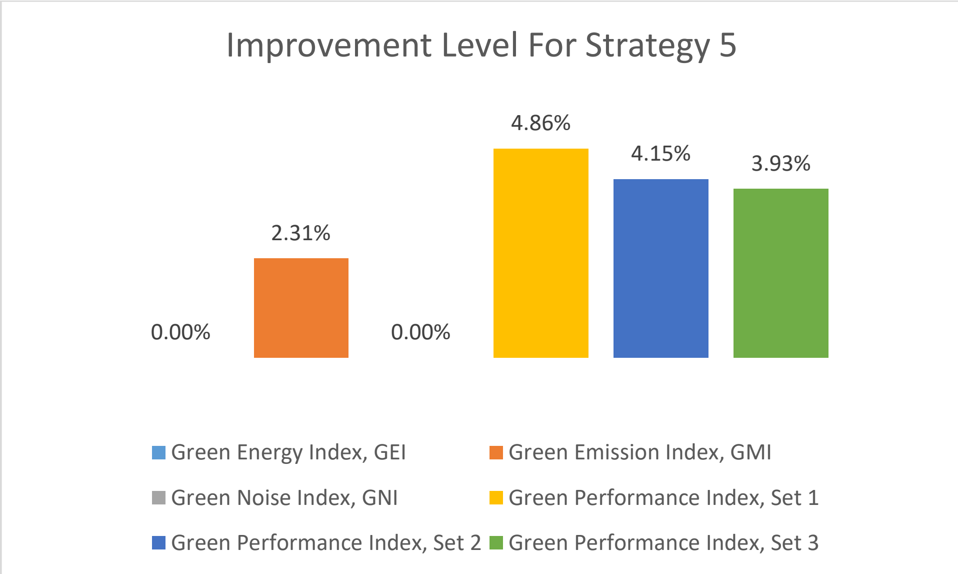


Figure 4.12: Improvement level for Strategy 5

4.8 Comparative and Improvement Analysis (Without AHP)

The summary of energy consumption, emission and noise levels for the benchmark scenario and all improvement strategies is shown in Tables 4.43, 4.44, and 4.45.

In Table 4.43, **Strategy 1** has the highest total energy consumption, while Strategy 2 has the lowest total energy consumption. For Strategy 1, the load factor has been increased for four selected bus routes (i.e., R1, R2, R9, and R10). This has shown that by increasing the load factor (a higher number of passengers) could lead to more energy consumption. However, the findings (discussed further below) show that increasing the load factor would result in a greener performance for the entire bus operational system.

In terms of **Strategy 2**, there is a reduction in the number of bus routes, with only eight remaining in operation (bus frequency eliminated) as a result of the load factor on the selected bus routes being too low (e.g., only 10% load factor). Four bus routes with the lowest load factor have been identified: R1, R2, R9, and R10. In this strategy, the bus routes with the lowest load factor (10%), which are R1 and R9, were eliminated. As for bus routes R2 and R10, the bus frequency has been reduced and the load factor has increased to 50%. All these adjustments have caused Strategy 2 to produce the lowest energy consumption.

Besides, **Strategy 3** showed a lower total energy consumption compared with the benchmark scenario for which four bus routes (R1, R2, R9, and R10) were selected to use smaller buses for the bus operations. The overall result of Strategy 3 in terms of the total energy consumption (see Table 4.43) shows that fleet planning is useful in producing a greener performance (with lower energy consumption).

Table 4.43: Summary of energy consumption for benchmark scenario and improvement strategies

Bus route, r	Energy consumption for bus route, E_r (kWh)					
	Benchmark scenario	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
R1	753.03	4223.65	-	1508.95	753.03	753.03
R2	1240.88	3377.15	875.56	1206.53	1240.88	1240.88
R3	5022.78	5022.78	5022.78	5022.78	5022.78	5022.78
R4	5138.80	5138.80	5138.80	5138.80	5138.80	5138.80
R5	5780.27	5780.27	5780.27	5780.27	5780.27	5780.27
R6	6225.12	6225.12	6225.12	6225.12	6194.98	6225.12
R7	7932.53	7932.53	7932.53	7932.53	7894.13	7932.53
R8	6724.57	6724.57	6724.57	6724.57	6691.61	6724.57
R9	861.29	4830.83	-	1725.88	861.29	861.29
R10	3368.48	3794.63	1335.15	1345.74	3368.48	3368.48
Total	**43047.80**	**53050.34**	**39034.80**	**42611.2**	**42946.3**	**43047.80**

Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Strategy 4 has considered the adjustment of bus speed for selected bus routes (i.e., R6, R7, and R8). In the benchmark scenario, these three bus routes showed the highest energy consumption in comparison to other bus routes. The bus speed for these bus routes has been reduced from 40 km/h to 30 km/h, and this reduction has resulted in a depletion in energy consumption. This shows that the bus speed reduction (Strategy 4) can have some impact on improving the green performance of the bus operating network.

For **Strategy 5**, it is interesting to see from Table 44 that the total energy consumption is the same as the benchmark scenario. The charging facility has changed from slow charging to fast charging in Strategy 5. Nevertheless, the total energy consumption needed for the bus operations remains the same. This strategy has shortened the battery charging duration for selected bus routes. It has indirectly affected the quantity of buses and bus frequency. When the charging duration is shorter, it causes a reduction in the bus operating time, but a higher bus frequency for each bus is required in order to fulfil the bus schedule. With the increment of bus frequency per bus, the number of buses needed for operation is reduced. However, the total trips for all buses is the same as in the benchmark scenario, which results in the same energy consumption.

Table 4.44 presents the total emissions for the benchmark scenario and the improvement strategies. For Table 4.44, Strategy 1 has the highest total emission, followed by Strategy 3, which has the second highest. In **Strategy 1**, the load factor is increased for the selected bus routes, and this has caused higher total emissions. As the energy consumption correlates with the emission, the total emission is greatly influenced by how much energy is generated. Although smaller bus capacity is used in **Strategy 3**, the load factor has been increased for the selected bus routes, and this has led to the total emission level being higher than the benchmark scenario. However, the findings in terms of GPI (as presented in Table 4.46 and to be discussed in a later section) indicate that both strategies (Strategy 1 and 3) are, in fact, greener than the benchmark scenario.

Strategy 2 and Strategy 4 have shown a slightly better result in terms of emissions compared with the benchmark scenario. The changes in bus frequency and load factor in **Strategy 2** have slightly reduced the emissions. As for **Strategy 4**, the reduction in bus speed is applied and reveals its slight impact on the reduction in emissions. The energy consumption in both strategies was reduced when compared with the benchmark scenario. This indicates that even if there is a slight reduction in energy consumption, the emissions generated during the charging process are affected as well. Furthermore, both strategies use slow charging, which results in a longer charging time and potentially higher emissions.

For **Strategy 5**, although the energy consumption is the same as the benchmark scenario, the emission level is lower and ranked the lowest among all strategies. This could be explained by the deployment of fast charging facilities (for Strategy 5), as when the completion of charging is done in a shorter period, the emissions (from electricity generation) will be reduced.

Table 4.44: Summary of total emission for benchmark scenario and improvement strategies

Bus route, r	Total emission, EM_r^{WTW} (kg CO_2eq)					
	Benchmark scenario	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
R1	186.15	5220.39	-	1865.05	186.15	186.15
R2	613.49	4174.12	1082.18	1491.26	613.49	613.49
R3	8691.35	8691.35	8691.35	8691.35	8691.35	8691.35
R4	9527.25	9527.25	9527.25	9527.25	9527.25	9527.25
R5	10716.53	10716.53	10716.53	10716.53	10716.53	10716.53
R6	13080.10	13080.10	13080.10	13080.10	13016.79	4646.75
R7	16667.69	16667.69	16667.69	16667.69	16587.01	8881.87
R8	13298.40	13298.40	13298.40	13298.40	13233.22	5669.16
R9	212.91	5970.86	-	2133.17	212.91	212.91
R10	3747.06	4690.13	1650.23	1663.32	3747.06	3747.06
Total	**76740.93**	**92036.81**	**74713.73**	**79134.11**	**76531.75**	**52892.52**

Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

In Table 4.45, it shows the summary of the total noise level for the benchmark scenario and all improvement strategies. **Strategy 1** has revealed the highest noise level among the other strategies. The load factor in Strategy 1 will increase the weight of the bus. This weight increment has raised the sound pressure level, which indicates high noise level generation.

Strategy 3 has the second highest noise level. The increment of trips required for the smaller bus is necessary to meet the bus schedule. Hence, more frequent trips tend to produce more noise during the bus operation.

The noise level for **Strategies 2** and **4** has decreased compared to the benchmark scenario. The low noise level has resulted from the discount of bus extent (due to bus route elimination) and bus frequency in Strategy 2. As for Strategy 4, it shows that the reduction in bus speed has caused a drop in the noise level compared to the other strategies.

There is no change in noise level for **Strategy 5** when compared with the benchmark scenario due to the modification of the charging facility, which reduced only the charging time. With the reduction of bus quantity but an increment of bus frequency per bus on selected bus routes, the total trips performed by the buses remains the same as in the benchmark scenario.

Table 4.45: Summary of total noise for benchmark scenario and improvement strategies

Bus route, r	Total noise per bus route, L_r(dba)					
	Benchmark scenario	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
R1	792.43	3962.16	-	3942.43	792.43	792.43
R2	1582.69	3956.73	1025.82	3935.98	1582.69	1582.69
R3	5498.91	5498.93	5498.93	5498.91	5498.91	5498.91
R4	5888.66	5888.66	5888.66	5888.66	5888.66	5888.66
R5	5894.87	5894.87	5894.87	5894.87	5894.87	5894.87
R6	6659.60	6659.60	6659.60	6659.60	6569.14	6659.60
R7	6700.38	6700.38	6700.38	6700.38	6607.03	6700.38
R8	6278.61	6278.61	6278.61	6278.61	6204.63	6278.61
R9	793.18	3965.91	-	3946.85	793.18	793.18
R10	3502.50	3891.66	1369.29	3891.66	3502.50	3502.50
Total	**43591.85**	**52697.51**	**42032.29**	**52637.98**	**43334.07**	**43591.85**

Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Additionally, the comparison between the benchmark scenario and all improvement strategies was carried out by evaluating the improvement level for each strategy. The summary of the comparison is shown in Table 4.46. For the GPI, the resultant grade ranges from I to IV. It could be seen that **Strategy 1 (increase load factor)** has shown the greatest improvement level, i.e., 34.76%–38.24%, and this strategy increased the grade of GPI from V (benchmark scenario) to II (Strategy 1). These findings signify that increasing load factor (Strategy 1) is effective in improving the green performance of the bus operations and could serve as the most desirable strategy for the bus operators.

Strategy 2 (adjust bus frequency) ranked second in respect of the improvement level, i.e., the grade of GPI for this strategy improved from IV (benchmark scenario) to II (Strategy 2). From Table 4.46, it can be seen that all three sets of weightage that were applied in Strategy 2 have revealed the same grade with different scores. Hence, Set 3 (with a score of 3.5567) was shown to be the best set as in weightage selection, which is recommended in Strategy 2.

Strategy 3 (fleet planning) has shown a slight improvement (i.e., 9.65%–11.66%). The grade of GPI has improved from V (benchmark scenario) to III (Strategy 3). Among the three sets of weightage, Set 3 is recommended as it showed the highest score (i.e., 3.2233).

As for **Strategy 4 (reducing bus speed)**, the GPI has the same score as the benchmark scenario. Therefore, it showed no improvement in scores and grades. However, there is some improvement in the GEI, GMI, and GNI, i.e., a 0.86% improvement for GNI (the highest) and the GMI achieved the lowest improvement (0.18%). This indicates that a reduction in bus speed managed to have a slight impact on the improvement level. Among the sets for weightage computation, Set 3 is recommended as it showed the best score in Strategy 4.

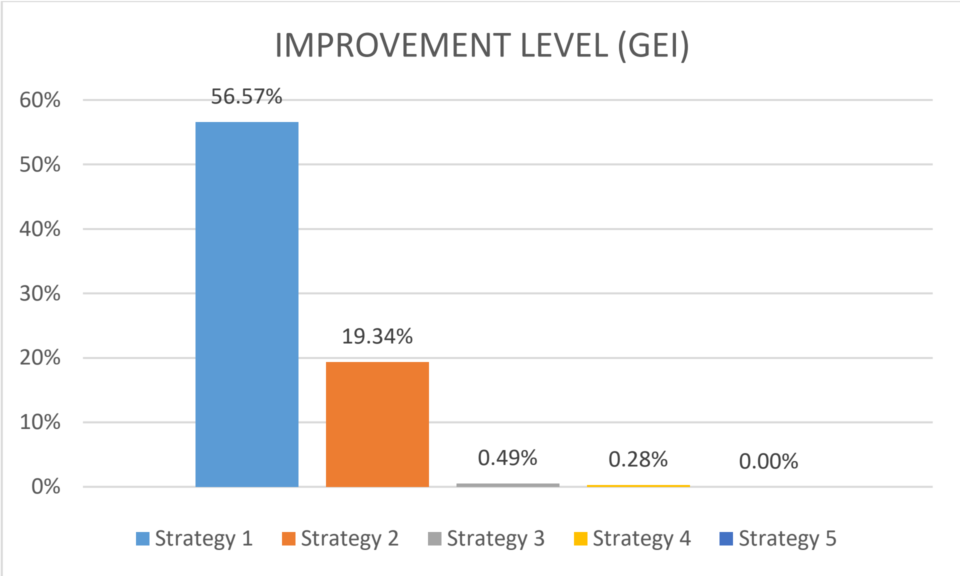
For **Strategy 5 (change charging facility)**, there are some improvements (i.e., 3.93%-4.86%) in the score. Set 3 (Strategy 5) has shown the highest score. This set of weightages is recommended as a better score indicates a better environmental performance. For the individual green indexes, only GMI shows an improvement of 14.59%, while there is no improvement for GNI and GEI when compared with the benchmark scenario. This indicates that the charging duration affects the emissions (during the electricity generation process) but has no impact on the noise and energy consumption.

Figures 4.13–4.15 show the improvement level achieved by using the respective improvement strategy on each environmental factor (energy consumption, emission, and noise). Figure 4.13 shows the improvement level of improvement strategies in terms of GEI. Strategy 1 showed the highest improvement level, with a 56.57% improvement compared to the other strategies. This demonstrates that increasing the load factor has a significant impact on GEI. Strategy 2 (adjust bus frequency) ranked second in Figure 4.13 and shows an improvement level of 19.34%. As for Strategy 3 and Strategy 4, they show slight improvement (less than 0.5%). This indicates when a reduction in bus speed or fleet planning is in place, but it does not have a substantial influence on reducing energy consumption. As for Strategy 5, the resulted GEI is the same as the benchmark scenario, and there is no improvement. This shows that with the application of different charging durations (fast charging), there is no major impact on the GEI as the amount of energy consumption required by the bus is the same as in the benchmark scenario.

Table 4.46: Summary of green indexes and GPI with different weightage

Scenario /Strategy	Green Energy Index, GEI		Green Emission Index, GMI		Green Noise Index, GNI		Green Performance Index, *GPI*					
	Index	Score	Index	Score	Index	Score	Set 1	Grade	Set 2	Grade	Set 3	Grade
Benchmark	0.3111	3.0000	0.4095	2.3300	0.2811	3.3300	2.7980	IV	2.8645	IV	2.8867	IV
Strategy 1	0.1351	4.0000	0.2382	3.6700	0.1159	4.0000	3.8680	I	3.8845	I	3.8900	I
Improvement level (strategy 1)	56.57%	33.33%	41.84%	57.51%	58.77%	20.12%	38.24%		35.61%		34.76%	
Strategy 2	0.2509	3.6700	0.2920	3.3300	0.2347	3.6700	3.5340	II	3.5510	II	3.5567	II
Improvement level (strategy 2)	19.34%	22.33%	28.69%	42.92%	16.50%	10.21%	26.30%		23.97%		23.21%	
Strategy 3	0.3096	3.0000	0.3701	2.6700	0.1166	4.0000	3.0680	III	3.1845	III	3.2233	III
Improvement level (strategy 3)	0.49%	0.00%	9.63%	14.59%	58.53%	20.12%	9.65%		11.17%		11.66%	
Strategy 4	0.3102	3.0000	0.4088	2.3300	0.2787	3.3300	2.7980	IV	2.8645	IV	2.8867	IV
Improvement level (strategy 4)	0.28%	0.00%	0.18%	0.00%	0.86%	0.00%	0.00%		0.00%		0.00%	
Strategy 5	0.3111	3.0000	0.4001	2.6700	0.2811	3.3300	2.9340	IV	2.9835	IV	3.0000	IV
Improvement level (strategy 5)	0.00%	0.00%	2.31%	14.59%	0.00%	0.00%	4.86%		4.15%		3.93%	

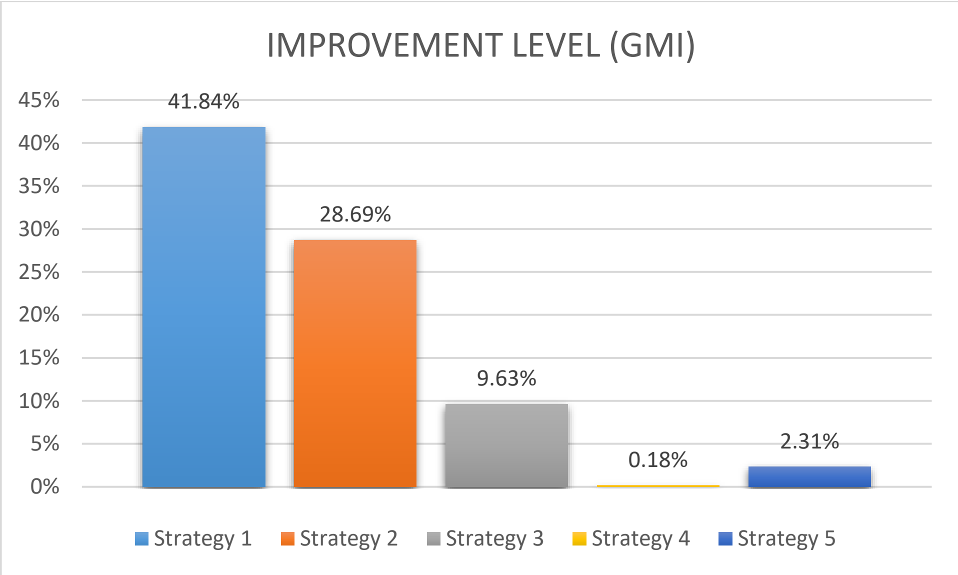
Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility



Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Figure 4.13: Improvement level for GEI

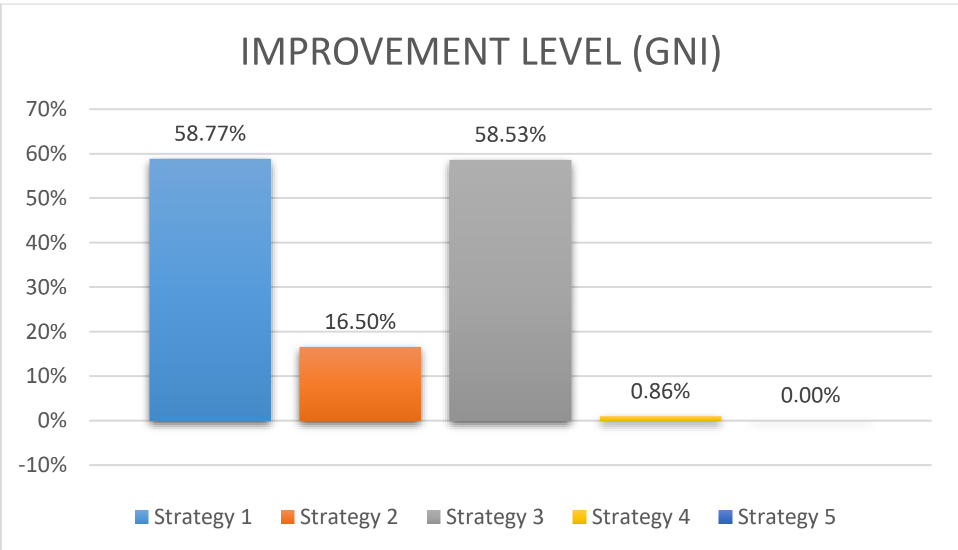
As for GMI in Figure 4.14, Strategy 1 attained the highest improvement level with 41.84%, followed by Strategy 2 with a 28.69% improvement. This demonstrates that increasing the load factor and fleet planning can have a significant impact on emissions. Among all the strategies, Strategy 4 achieved the lowest improvement, which is only 0.18%. This demonstrates that reducing bus speed has little effect on emissions. Strategy 2 and Strategy 5 show a slight increase in improvement level, which is less than 10%. As a result, Strategy 1 would be recommended as it gives the best improvement.



Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Figure 4.14: Improvement level for GMI

For the improvement level of GNI as displayed in Figure 4.15, it shows that Strategy 1 has shown a significant improvement with 58.77%, followed by Strategy 3, which improved by 58.53%. This shows that the load factor increment (Strategy 1) and fleet planning (Strategy 3) can affect the reduction of the noise level.



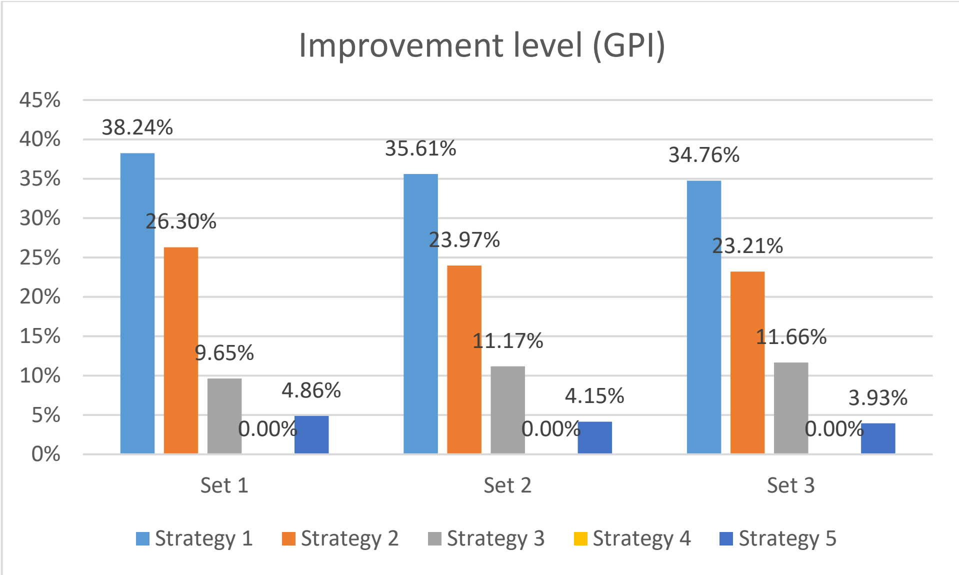
Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Figure 4.15: Improvement level for GNI

As for Strategy 2, with the reduction and removal of bus frequency as well as the increment of load factor in the designated bus routes, it has caused 16.50% of the improvement level. However, Strategy 5 has presented no improvement, and Strategy 4 only has a 0.86% improvement level. This shows that the reduction of bus speed (Strategy 4) and the change of charging facility to fast charging (Strategy 5) do not cause the major changes in the bus noise level.

Figure 4.16 depicts the improvement level for GPI in different weightages to examine the effects of weightage selection in assessing the green performance of an electric bus operational system in terms of GPI. Sets 1-3 showed the highest percentage improvement level, which produced the best result for both Strategy 1 and Strategy 2. However, there is no improvement in the sets of weightage for Strategy 4. For Strategy 3, the improvement level for 3 sets of weightage ranges from 9.65% to 11.66%, followed by Strategy 5, which has a slight improvement in all 3 sets of weightage (i.e., 3.93%-4.86%).

Generally, the findings show that the choice of weightage would produce varying green performances for the respective improvement strategies, and hence the operators should make a wise consideration in evaluating the weightage so that a greener bus operating system can be assured.



Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Figure 4.16: Improvement level for Green Performance Index (GPI) in different weightage

From the results shown in Table 4.47, there is an approximately 4.56% increment for an average improvement level for GEI, GMI, and GNI with every 1% increment of load factor (Strategy 1), which also contributes to an improvement of 3% for GPI. Every reduction in bus frequency (Strategy 2) can lead to an approximate 2.11%-2.39% improvement level for GPI and 1.96% of the average improvement level for green indexes (GEI, GMI, and GNI). As for Strategy 3, it shows that for every reduction of bus seats (fleet planning in terms of bus capacity adjustment), there is an approximate 2.54% average improvement level for all green indexes and a 1.07%-1.30% improvement level for GPI. Although there is no improvement in Strategy 4 compared with the benchmark scenario, with every reduction in bus speed (Strategy 4), there is 0.147% of an average improvement level for all indexes. For Strategy 5, there is an increase of 0.64% for the average improvement level for all green indexes (GEI, GMI, and GNI) and 3.28%-4.05% for the improvement level for GPI with every increment of the battery charging efficiency.

Overall, all the proposed strategies (increasing load factor, adjusting bus frequency, fleet planning, reducing bus speed, and changing charging facilities) have a positive effect on enhancing the green performance. The results are in accordance with the facts revealed by Carrese et al. (2013) and Yu et al. (2015) that the load factor can have a significant impact on the energy consumption and emissions as well as passengers per pollutant. Furthermore, it was demonstrated that bus frequency adjustment plays an important role in energy and emission levels (Hoonsiri et al., 2020; Titos et al., 2015).Bogdan et al. (2020) and Borén (2019) mentioned that bus size and fleet planning are useful in assisting to improve the green performance, which is agreed by the results of the proposed Strategy 3. The results of Strategy 4 show its effectiveness in enhancing green performance, which meets the facts revealed by Zhou et al. (2016) and Abbasi (2018). Besides, Zhou et al. (2016) and Abbasi (2018) also mentioned that the charging duration affects the emission but not the noise, which coincides with the results obtained in Strategy 5.

4.9 Multi-Criteria Analysis with Analytic Hierarchy Process

An Analytic Hierarchy Process is adopted to quantify the Green Performance Index, where the weightage for the respective Green Index can be determined accordingly. Practically, a survey (as discussed in Section 3.3.3) is conducted to provide the relevant input for the AHP method. Table 4.47 summarises the resultant green indexes as well as the improvement level for all improvement strategies.

Among all the strategies, **Strategy 1** (increase load factor) has shown the best result of improvement for GPI with 36.93%. This demonstrates that increasing the load factor is a positive way to improve the environmental performance of bus operations.

Strategy 2 (adjust bus frequency) has shown 25.32% of improvement for GPI which ranked second among the improvement strategies. This is due to an adjustment of bus frequency (in terms of frequency reduction and removal) and increment of load factor (from an average load factor of 55% to 71%) has been carried out in this strategy.

Strategy 3 (fleet planning) only gained 4.49% of its improvement level. In this strategy, a smaller capacity bus is utilised for selected bus routes but with an increased load factor. The amount of energy consumption required for the small bus is almost the same as for the larger bus, which led to less improvement level. This is due to the use of the same bus quantity and bus frequency as in the benchmark scenario. However, the engine propulsion in a smaller bus may not be the same as in a bigger bus, which may generate a lower noise level. This explains why there is a better improvement level for noise (GNI).

Strategy 4 (reduce bus speed) has shown no improvement in GPI, although there is a slight improvement in GMI. With the reduction of bus speed, the bus travelling time became longer, causing a decrease in bus frequency. With these changes, the bus quantity needs to be increased to furnish passengers' needs. However, the total number of bus trips is equal to the benchmark scenarios, implying that the amount of energy consumed, emissions, and noise produced is the same as the benchmark scenario. Energy consumption and emissions are interrelated; therefore, the improvement level for GEI and GMI is similar, which is 0.28% and 0.18%, respectively.

Strategy 5 (change charging facility) has shown a slight improvement level with an approximate 2.83%. The charging facility has changed (from slow charging to fast charging) for selected bus routes (bus routes 6, 7 and 8), while other bus routes still apply slow charging. Table 5.6 shows there is no improvement in energy consumption. This can be explained by the fact that the bus (on a selected bus route) needs to perform more trips when the travelling time is reduced due to the shorter charging duration. However, the increment in bus frequency for each bus reduces the bus quantity, but it does not have an impact on the total trips for all the buses. Therefore, the amount of energy required for whole bus operation is the same as the benchmark scenario. The same idea is applied when determining the noise level of the bus. Nevertheless, the GMI showed improvement as the time spent at the charging facility was reduced with better charging efficiency (from 94% to 98%). As a result, it reduces the amount of waste gaseous emissions from the generation of electricity.

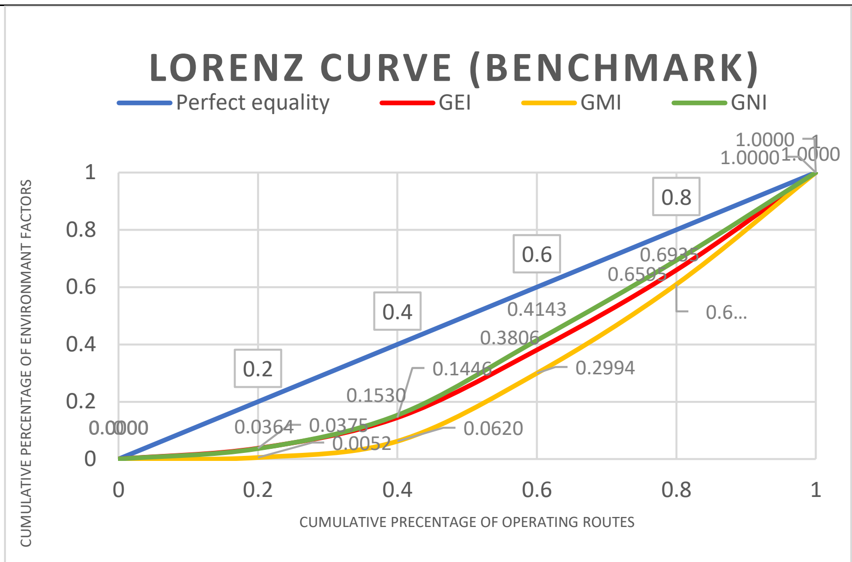
Table 4.47: Summary of improvement level of green indexes for benchmark and strategies

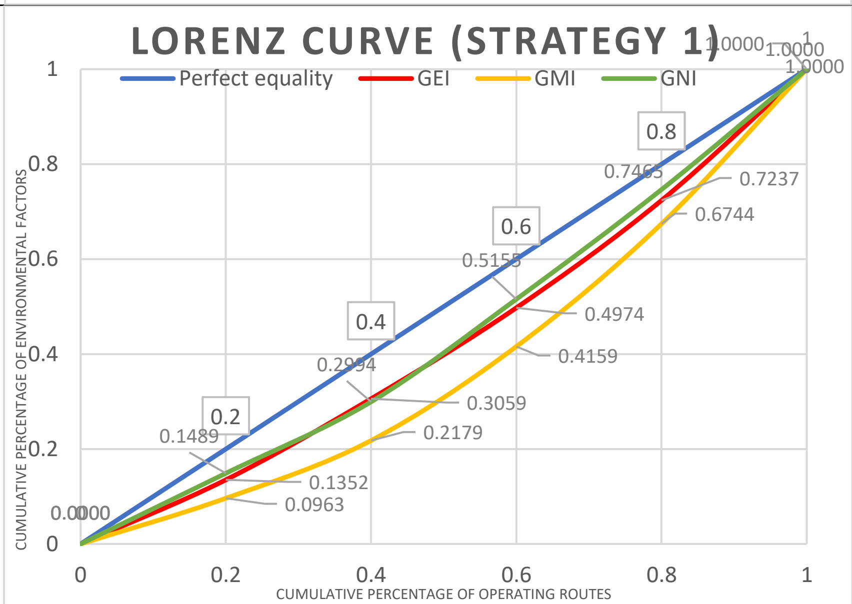
Scenario /Strategy	Green Energy Index, GEI		Green Emission Index, GMI		Green Noise Index, GNI		Green Performance Index, GPI	
	Index	Score	Index	Score	Index	Score	Score	Grade
Benchmark	0.3111	3.0000	0.4095	2.3300	0.2811	3.3300	2.8638	IV
Strategy 1	0.1351	4.0000	0.2382	3.6700	0.1159	4.0000	3.9214	I
Improvement level (strategy 1)	**56.57%**	**33.33%**	**41.84%**	**57.51%**	**58.77%**	**20.12%**	**36.93%**	
Strategy 2	0.2509	3.6700	0.2920	3.3300	0.2347	3.6700	3.5890	II
Improvement level (strategy 2)	**19.34%**	**22.33%**	**28.69%**	**42.92%**	**16.50%**	**10.21%**	**25.32%**	
Strategy 3	0.3096	3.0000	0.3701	2.6700	0.1166	4.0000	2.9923	IV
Improvement level (strategy 3)	**0.49%**	**0.00%**	**9.63%**	**14.59%**	**58.53%**	**20.12%**	**4.49%**	
Strategy 4	0.3102	3.0000	0.4088	2.3300	0.2787	3.3300	2.8638	IV
Improvement level (strategy 4)	**0.28%**	**0.00%**	**0.18%**	**0.00%**	**0.86%**	**0.00%**	**0.00%**	
Strategy 5	0.3111	3.0000	0.4001	2.6700	0.2811	3.3300	2.9448	IV
Improvement level (strategy 5)	**0.00%**	**0.00%**	**2.31%**	**14.59%**	**0.00%**	**0.00%**	**2.83%**	

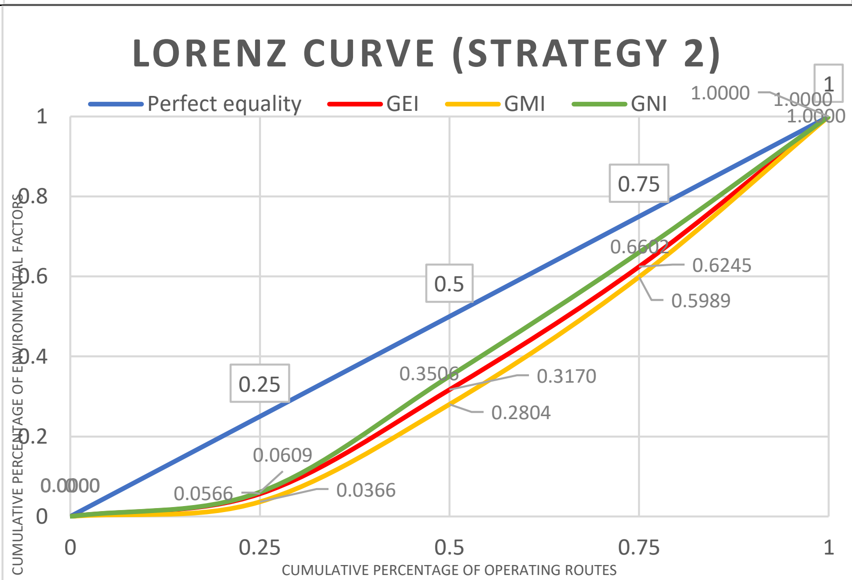
Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Besides, the overall results of GEI, GMI, and GNI for benchmark scenarios and improvement strategies are shown in Figure 4.17.

In the **benchmark scenario**, it can be seen that GNI performed better compared to the GEI and GMI as the line of GNI is approaching the line of equality. This also stated that the green performance of bus noise is better as the noise produced is less.


LORENZ CURVE (BENCHMARK)
Perfect equality
GEI
GMI
GNI
CUMULATIVE PERCENTAGE OF ENVIRONMANT FACTORS
CUMULATIVE PRECENTAGE OF OPERATING ROUTES
0.0000
0.0364
0.0375
0.0052
0.1530
0.1446
0.0620
0.4143
0.3806
0.2994
0.6935
0.6595
0.6...
1.0000
1.0000


LORENZ CURVE (STRATEGY 1)
Perfect equality
GEI
GMI
GNI
CUMULATIVE PERCENTAGE OF ENVIRONMENTAL FACTORS
CUMULATIVE PERCENTAGE OF OPERATING ROUTES
0.0000
0.1489
0.1352
0.0963
0.2994
0.3059
0.2179
0.5155
0.4974
0.4159
0.7465
0.7237
0.6744
1.0000


LORENZ CURVE (STRATEGY 2)
Perfect equality
GEI
GMI
GNI
CUMULATIVE PERCENTAGE OF ENVIRONMENTAL FACTORS
CUMULATIVE PERCENTAGE OF OPERATING ROUTES
0.0000
0.0609
0.0566
0.0366
0.3506
0.3170
0.2804
0.6602
0.6245
0.5989
1.0000

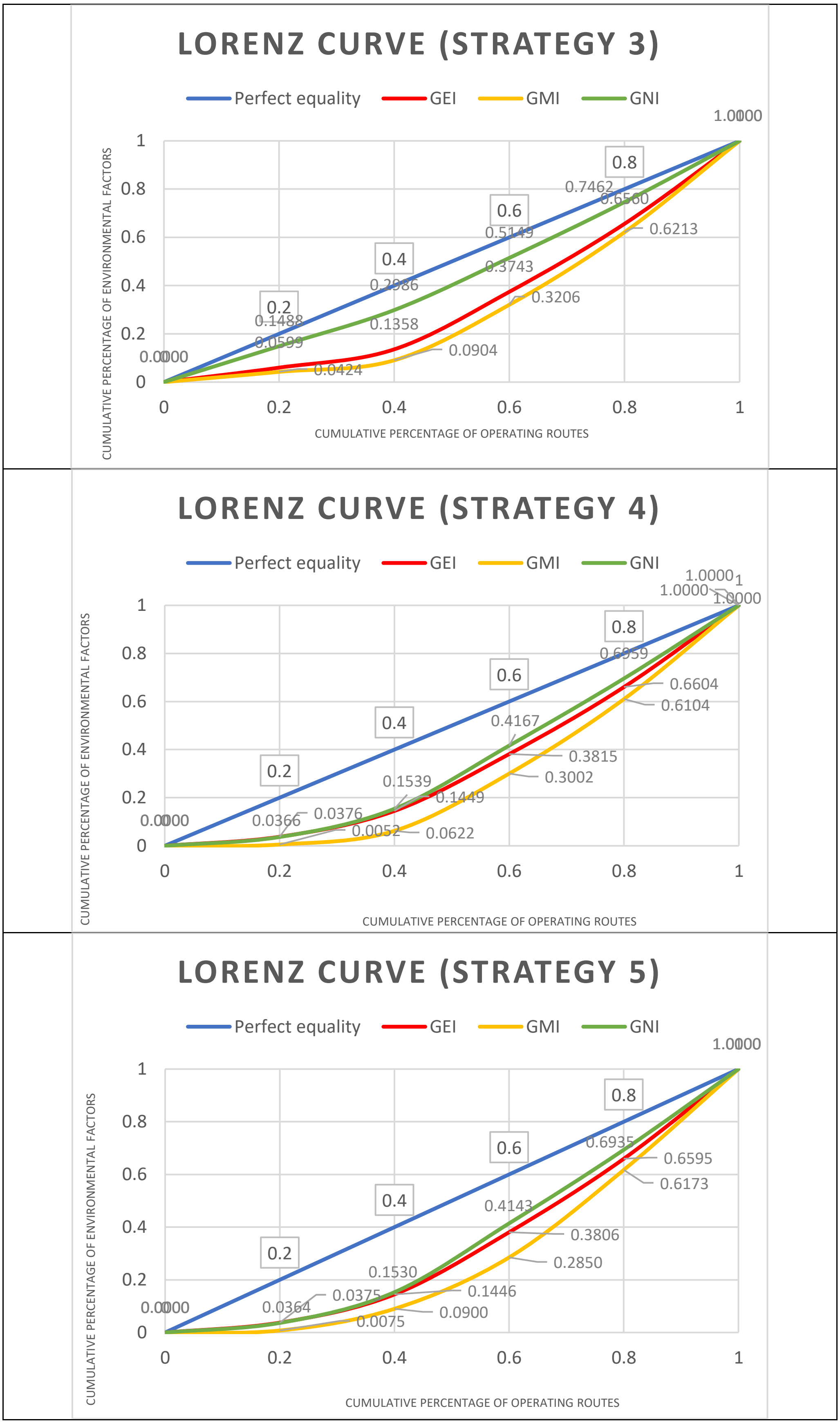


Figure 4.17: The Summary of Lorenz Curve for Benchmark Scenario and Improvement Strategies

Compared with all the strategies, **Strategy 1** showed the lines of GEI, GMI, and GNI closer to the line of equality. This indicates that Strategy 1 (increase load factor) could lead to a greener performance of the bus operation. However, in Strategy 1, GNI and GEI appeared nearer to the line of equality, while GMI stayed farther from the line of equality. This indicates that the bus produces more pollutants (emissions) than GNI and GEI.

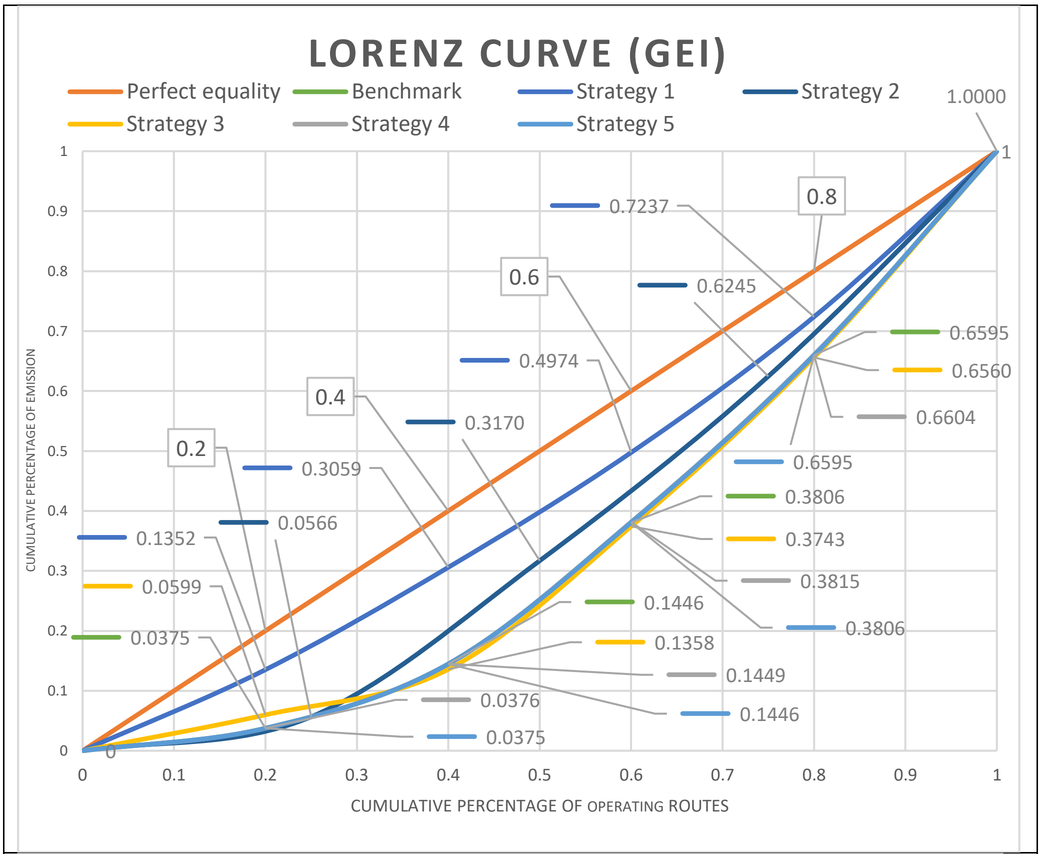
The Lorenz curve for **Strategy 2** shows that GNI is the closest to the line of equality, followed by GEI, and lastly, GMI. This showed that the bus produced more pollutants (emissions) but with less noise during its operation. From the Lorenz curve, **Strategy 3** has revealed that the bus has a better green performance in terms of bus noise than Strategy 2. It is anticipated that when the line gets nearer to the line of equality, it will indicate better green performance of the bus. Still, GMI stayed farther from the line of equality, which means the bus produces more pollutants (emissions) in the bus operation.

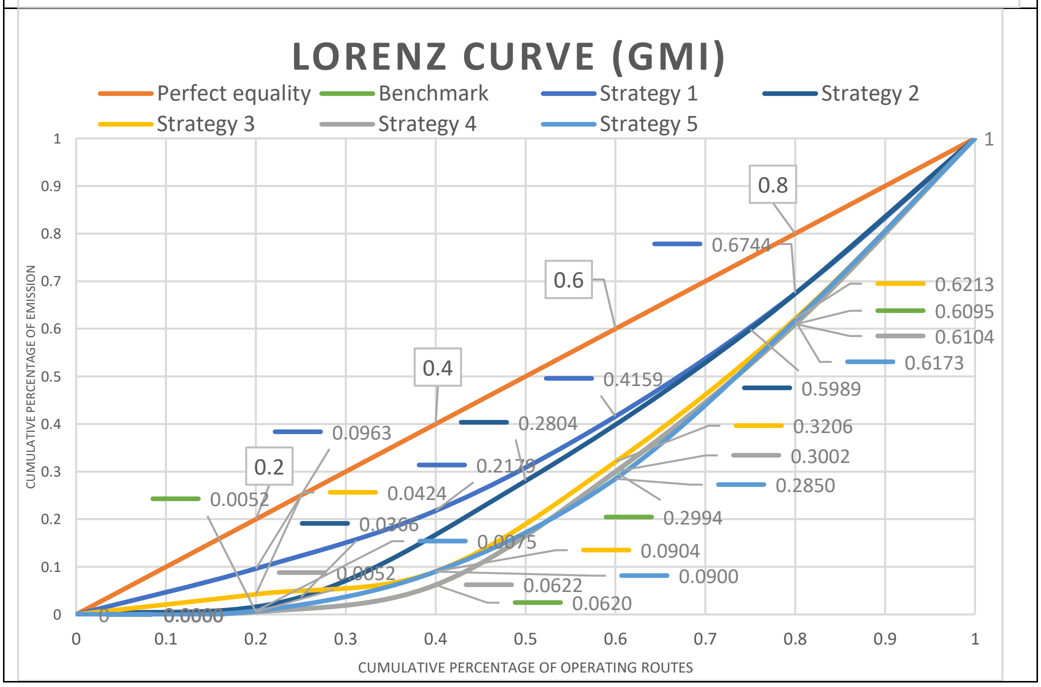
GNI in **Strategy 4** has approached nearer to the line of equality compared with GMI and GEI. This reveals that the bus produced fewer pollutants (noise) but more emissions instead, as GMI stayed farther from the line of equality. Improved charging facilities (fast charging) in **Strategy 5** have contributed to GNI to approach the line of equality, followed by GEI and GMI, for which the bus produced the most pollutants (emissions) compared with noise and energy consumption.

Figure 4.18 presents the summary of the Lorenz curve for all green indexes (GEI, GMI, and GNI) for benchmark scenarios and improvement strategies. From Figure 4.18, Strategy 1 has shown the best strategy in GEI, followed by Strategy 2. However, the lines of Strategy 3-5 seem to stay nearer to the benchmark scenario, which is farther from the line of equality. This explains why Strategy 3-5 has minimal impact in terms of improvement for GEI.

The best strategy for GMI is Strategy 1, followed by Strategy 2, Strategy 3, and Strategy 5. It can be seen that the line of Strategy 1 approaches nearer to the line of equality. As mentioned earlier, Strategy 4 has no improvement, and the line seems to stay nearer to the benchmark scenario and farther from the line of equality.

Besides, Strategy 1 remains as the best strategy for GNI, and Strategy 3 was ranked as the second-best strategy. It can be seen that the lines of Strategy 1 and 3 are approaching one another as well as staying nearer to the line of equality, which indicates better green performance. Both strategies (Strategy 1 and 3) have a high improvement level (i.e., 58.77% and 58.53%, respectively). As for Strategy 2, the line stayed between Strategy 1, 3 and Strategy 4, 5, with an improvement level of 16.50% only. However, the GNI line of Strategy 4 and 5 stayed farther from the line of equality but nearer to the line of the benchmark scenario, which means the noise level for these two strategies is the same as the benchmark scenario.


LORENZ CURVE (GEI)
Perfect equality
Benchmark
Strategy 1
Strategy 2
Strategy 3
Strategy 4
Strategy 5
CUMULATIVE PERCENTAGE OF EMISSION
CUMULATIVE PERCENTAGE OF OPERATING ROUTES
1.0000
0.7237
0.6245
0.4974
0.3170
0.3059
0.0566
0.1352
0.0599
0.0375
0.6595
0.6560
0.6604
0.6595
0.3806
0.3743
0.3815
0.1446
0.3806
0.1358
0.1449
0.0376
0.1446
0.0375


LORENZ CURVE (GMI)
Perfect equality
Benchmark
Strategy 1
Strategy 2
Strategy 3
Strategy 4
Strategy 5
CUMULATIVE PERCENTAGE OF EMISSION
CUMULATIVE PERCENTAGE OF OPERATING ROUTES
0.6744
0.6213
0.6095
0.6104
0.6173
0.4159
0.5989
0.2804
0.0963
0.3206
0.3002
0.2850
0.0052
0.0424
0.2179
0.2994
0.0904
0.0900
0.0052
0.0622
0.0620

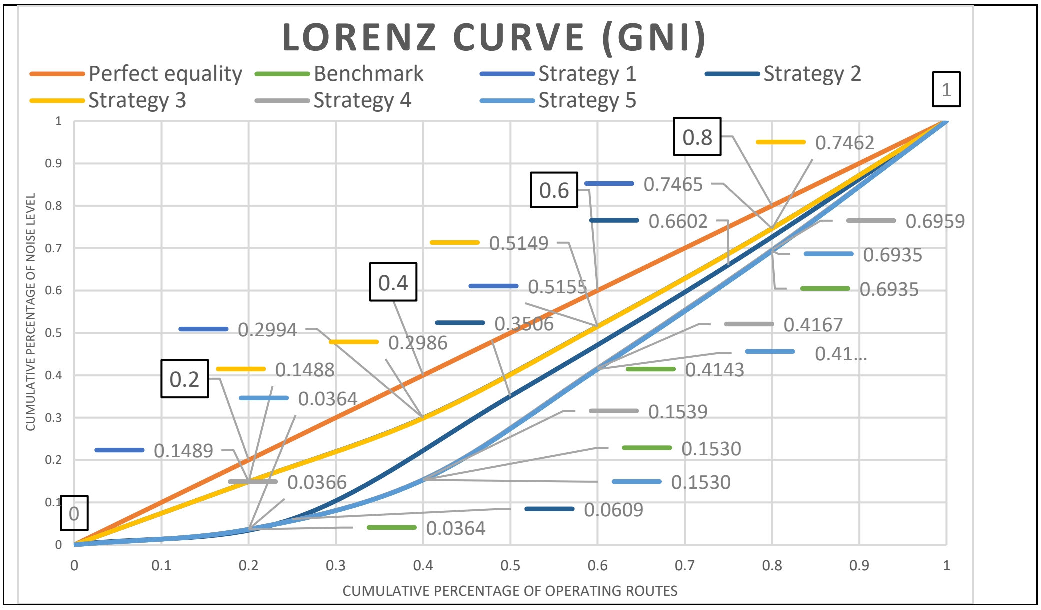


Figure 4.18: The Summary of Lorenz Curve for green indexes for Benchmark Scenario and Improvement Strategies

The summary of GPI for the benchmark scenario and five improvement strategies is shown in Table 4.48. As shown in Table 4.48, the grade of GPI ranges from I to IV, where the grade of I indicates the best green performance and the grade of IV indicates intermediate green performance.

Table 4.48: Summary of GPI for Benchmark Scenario and Improvement Strategies

	Benchmark scenario	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Green Performance Index (GPI)	2.8638	3.9214	3.5890	2.9923	2.8638	2.9448
Improvement level (%)	NA	36.93%	25.32%	4.49%	0.00%	2.83%
Grade of GPI	IV	I	II	IV	IV	IV

Note: strategy 1: increase load factor, strategy 2: adjust bus frequency, strategy 3: fleet planning, strategy 4: reduce bus speed, strategy 5: change charging facility

Strategy 1 shows the highest grade of GPI, which is I, and with the highest score of GPI at 3.9214, Strategy 2 ranks second highest (i.e., 3.5890) with the grade of GPI, II. This reveals that **Strategy 1** (increasing load factor) is the most beneficial approach for improving the green performance of electric bus operations, while **Strategy 2** is also effective in enlightening the green performance of electric bus operations by adjusting the bus frequency as well as increasing the load factor.

From Table 4.48, it should be noted that the benchmark scenario's GPI grade is IV, with a score of 2.8638, and the same grade obtained for Strategies 3-5 (i.e., 2.9923 for Strategy 3, 2.8638 for Strategy 4, and Strategy 5 having achieved 2.9448). Although **Strategy 3** and **Strategy 5** generated the same grade as the benchmark scenario, both strategies gained higher scores in GPI than the benchmark scenario. This showed that Strategy 3 and Strategy 5 have better green performance than the benchmark scenario. For Strategy 3, there is an adjustment in the fleet planning (by using a smaller capacity bus) and an increment in load factor, but the improvement level in GPI is minimal (i.e., 4.49%). In contrast, applying a different charging facility (from slow charging to fast charging) to the selected bus routes has no significant impact on further improving the green performance of the electric bus operation.

Among these three strategies (Strategy 3-5), **Strategy 4** has the same grade and score as the benchmark scenario. This is mainly due to Strategy 4's green indexes, which fall into the same category as the scoring level as the benchmark scenario, although, the resultant GEI, GMI, and GNI of Strategy 4 improved (as displayed in Table 4.49). As a result, Strategy 3-5 has little influence on improving the environmental assessment when compared to the benchmark scenario.

With every 1% increment in load factor in Strategy 1, there is an approximately 4.56% increment for an average improvement level for GEI, GMI, and GNI, which also contributes to an improvement of 3.2% for GPI. As for every decrease in bus frequency (Strategy 2), it can bring up to 1.96% of the average improvement level for GEI, GMI, and GNI, which leads to an approximate 2.3% improvement level for GPI. However, for every reduction of bus seats (Strategy 3), there is an approximate 0.5% improvement level for GPI, which consisted of 2.54% of the average improvement level for all green indexes. As for Strategy 4, every cutback in bus speed brings 0.147% of an average improvement level for all indexes. For Strategy 5, every addition of the battery charging efficiency causes a 2.36% improvement level for GPI, with an increase of 0.64% for the average improvement level for all green indexes (GEI, GMI, and GNI).

4.10 Comparative and Improvement Analysis

Table 4.49 presents the comparison of GPI for the benchmark scenario and improvement strategies when applying different weightages (AHP or without AHP computation). The result of score and grade for both weightages (AHP or without AHP) is approximately similar to one another, ranging from I to IV.

For Strategy 1, the score (AHP) of GPI is the highest compared with the other sets of weightage. However, the grade of GPI remains the same for all the weightage calculations. As for Strategy 2, the score of GPI for all weightages is close to each other, which is in the range of 3.5 with a grade of II.

The grade of the GPI (without AHP) for Strategy 3 seems to be better in both score and grade when compared with the GPI (with AHP). It indicates a greener performance of the electric bus. However, as for Strategies 4 and 5, the grade of GPI is the same for both types of weightage calculations.

Overall, the resulted GPI (with AHP) is more convincing when compared with the GPI computed from Sets 1, 2, and 3. This is due to the data input collected through a survey from different experts, and it is closer to the daily life application.

Table 4.49: Comparison of GPI for Benchmark Scenario and Improvement Strategies (with AHP and without AHP weightage)

Scenario /Strategy	Green Performance Index, GPI (AHP)		Green Performance Index, GPI (Without AHP weightage)					
	Score	Grade	Set 1	Grade	Set 2	Grade	Set 3	Grade
Benchmark	**2.8638**	**IV**	**2.7980**	**IV**	**2.8645**	**IV**	**2.8867**	**IV**
Strategy 1	**3.9214**	**I**	**3.8680**	**I**	**3.8845**	**I**	**3.8900**	**I**
Improvement level (Strategy 1)	36.93%		38.24%		35.61%		34.76%	
Strategy 2	**3.5890**	**II**	**3.5340**	**II**	**3.5510**	**II**	**3.5567**	**II**
Improvement level (Strategy 2)	25.32%		26.30%		23.97%		23.21%	
Strategy 3	**2.9923**	**IV**	**3.0680**	**III**	**3.1845**	**III**	**3.2233**	**III**
Improvement level (Strategy 3)	4.49%		9.65%		11.17%		11.66%	
Strategy 4	**2.8638**	**IV**	**2.7980**	**IV**	**2.8645**	**IV**	**2.8867**	**IV**
Improvement level (Strategy 4)	0.00%		0.00%		0.00%		0.00%	
Strategy 5	**2.9448**	**IV**	**2.9340**	**IV**	**2.9835**	**IV**	**3.0000**	**IV**
Improvement level (Strategy 5)	2.83%		4.86%		4.15%		3.93%	

4.11 Summary

Five improvement strategies and a benchmark scenario were used to compute the GPI and identify the most constructive strategy that can effectively produce a greener performance for the electric bus operation. The findings from the proposed strategies show their effectiveness in enhancing the green performance of electric buses. Different adjustments are made in the improvement strategies. When compared with the benchmark scenario, each result demonstrated an impact on the three environmental factors. Consequently, Strategy 1 is the best strategy in terms of score and grade, and it has performed the best in terms of environmental impact when compared to the other strategies. When the load factor increases (the number of passengers' increases), the pollution per passenger decreases. The load factor adjustment was shown to be beneficial when dealing with the green performance of electric buses.

In addition, two methods for quantifying weightage are used to calculate the GPI. Each strategy would have a different GPI depending on the weightage. The results reveal that the types of environmental factors (energy consumption, emission, and noise) with different weightages would generate varying levels of importance in measuring the GPI.

With the application of AHP, the results of the case study showed that the GPI has been greatly influenced by the decisional criteria (i.e., government policy/subsidy enforcement, bus technical features, financial cost, and passengers' feedback) and the environmental factors, which are closely associated with the respective weightages.

By collecting the responses from industry and academic experts via a survey, various perspectives of judgement can be obtained and further analysed. Moreover, through the survey, more practical and accurate data can be derived, which leads to a better understanding and good reference. The extracted results from the survey are crucial in assisting bus operators to quantify the weightage of the GPI.

Overall, the proposed techniques (raising load factor, altering bus frequency, fleet planning, reducing bus speed, and switching charging facilities) have demonstrated their efficacy in improving green performance. The findings support the findings of Carrese et al. (2013) and Yu et al. (2015) in terms of load factor adjustment; Hoonsiri et al., 2020; and Titos et al. (2015) in terms of the influence of bus frequency variation. Bogdan et al. (2020; Borén, 2019) have found that bus fleet planning is effective in revealing green performance. Zhou et al. (2016) and Abbasi (2018) discovered the impact of bus speed on environmental improvement. The charging duration has no effect on bus noise levels, but it does result in emissions that are consistent with the results of Strategy 5.

GPI acts as a tool in making decisions for electric bus fleet planning and operation as it enables the bus operator to have better guidance and understanding of the environmental assessment so that he can carefully think about various aspects (i.e., economic, environmental, and social).

CHAPTER 5

CONCLUSIONS

5.1 Summary

According to the review of the literature, most previous studies only looked into the environmental performance of electric buses by evaluating the amount of pollutants (energy consumption, noise, and emission). In other words, the environmental aspect of electric buses is neglected in the electric bus fleet planning and operation.

With the newly proposed methodology, this study is able to quantify the environmental performance of the electric bus fleet and operational planning. With the flexibility of the weightages of the green index, the established framework (with the help of the Gini Index Approach and a weighted-grading approach) is adjustable. In the second attempt to measure the weightage, the subjective perceptions (with several significant considerations) of the transportation experts were explicitly included with the use of AHP. Furthermore, this is a straightforward approach in which the elements of the bus energy consumption, emission, and noise formulas can be changed as needed. In addition, since numerous techniques (single or integrated) can be used for improvement purposes, the usefulness (effectiveness) of the various tactics on each environmental aspect can be determined.

An illustrative case study was conducted in order to assess the feasibility of the proposed study. Overall, Strategy 1 (load factor increment) is highly suggested for running a greener and better electric bus operating system since it leads to a greener performance of the bus operation. Furthermore, the results of the improvement strategies are validated by data from previous studies. It was discovered that a variety of criteria, including bus capacity, bus frequency, speed, and charging duration, had a significant impact on the green performance of electric buses. It would provide prudence recommendations for bus operators, given the enormous influence of each element. The findings suggest that the proposed assessment framework will make it easier for bus operators to include environmental factors in the planning and operation of electric bus fleets. Furthermore, the GPI generated can be used as a decision-making tool to help the bus operator have a clearer direction when adopting an improvement strategy in electric bus fleet planning and operation.

With the GPI measurement in place, a more environmentally friendly bus operation can be achieved. As a result, this research is critical for bus operators to consider environmental considerations while planning and operating electric bus fleets. Overall, the data demonstrates that an electric bus with better environmental performance is a promising alternative to stimulate green mobility.

The following are some of the contributions of this study:

1) Development of an assessment framework and decision-making procedure to quantify green performance of electric buses operations.
2) The incorporation of AHP and subjective judgments of transport experts (which included numerous influencing aspects (government policy/subsidy enforcement, passengers' feedback/response, bus technical

features, and financial cost) has significant impacts on electric bus fleet planning.

3) Assessing the environmental (green) performance of electric bus operations can be one of the most important factors for bus operators to consider when making decisions about electric bus fleet and operation planning.

4) Recommendation on various improvement approaches to achieve a greener performance of electric buses by reducing pollutants through ideal electric bus fleet planning and decision-making.

As a result, all of the study objectives outlined in Chapter 1 were met successfully.

5.2 Future works

Future work may focus on the optimization problems of electric buses and the analysis of cost savings for electric bus fleet planning and operation. From the results obtained, the overall green performance for the entire bus network has been attained. By applying and studying the parameters of the electric bus fleet, it will be able to provide a cost analysis for bus operators. Besides, the cost of an electric bus before and after computing the GPI can be studied to acquire greater accuracy and provide a discrete idea for the bus operator. In addition, in terms of social aspects, stakeholders' (i.e., passengers and bus operators) satisfaction could be included in the future study to provide a more comprehensive reference.

Furthermore, road types, different types of electric buses, and traffic conditions can be used as inputs to improve the accuracy of the result. A comprehensive idea inclusive of social, economic, and environmental factors would encourage more bus operators to replace conventional buses with electric buses.

5.3 Research Accomplishment

The list below shows the status of papers that had been succumbed to some recognized journals and conference.

1) Journal:
   - Lay Eng Teoh, Hooi Ling Khoo, Siew Yoke Goh, Lai Mun Chong (2018). Scenario-based electric bus operation: A case study of Putrajaya, Malaysia. International Journal of Transportation Science and Technology, 7(1), 10-25 (impact factor: 2.709).
   - Lay Eng Teoh, Siew Yoke Goh, Hooi Ling Khoo (2021). Green Assessment and Improvement Framework for Electric Bus Operational System. Journal of Engineering, UKM Press (Universiti Kebangsaan Malaysia Publisher), Volume 33, Issue 3, 739-749 (ISSN: 0128-0198).

2) Conferences:
   - Lay Eng Teoh, Siew Yoke Goh, and Hooi Ling Khoo (2020). Environmental assessment and improvement strategies for electric bus operations. The 16th IMT-GT International Conference on Mathematics, Statistics, and their Applications (ICMSA 2020), 23 & 24 November 2020
   - Hooi Ling Khoo, Lai Mun Chong, Siew Yoke Goh (2017). Electric

Bus Operational Design for Sub-urban City Service: A Case Study of Putrajaya, Malaysia. The 12th International Conference of Eastern Asia Society for Transportation Studies, Vol.11, Vietnam.

- Siew Yoke Goh, Lay Eng Teoh and Hooi Ling Khoo (2016). An Overview on the Network Design and Fleet Planning of Electric Bus. The 10th Asia Pacific Conference on Transportation and The Environment (APTE), 8-9 Nov 2016, Petaling Jaya, Malaysia.

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APPENDIX A

THE SUMMARY OF GREEN INDEXES WITH VARIANCE AND AVERAGE

This appendix displays the GI, variance, and average for the benchmark scenario and Strategies 1–5. From the operational aspect, when there is a reduction in the electric bus emissions, energy, and noise (or when the data sets are closer to each other), the variance of the measured data sets and average will tend to be smaller, which will produce a lower Gini Index (approaching zero). However, if the GI value generated is close to one, the current operating network performs poorly in terms of green performance. These variations could be described using the Lorenz curve. This appendix demonstrates that the respective improvement strategy is advantageous in terms of achieving greener performance for electric bus operations, with lower values of variance, average, and GI.

a) Energy consumption

Scenario/Strategy	Green Index	Variance	Average (kWh)
Benchmark	0.3111	6758723	4304.78
Strategy 1	0.1351	1943426	**5305.34**
Strategy 2	0.2509	6289873	3903.48
Strategy 3	0.3096	6543916	4261.12
Strategy 4	0.3102	6697454	4294.63
Strategy 5	**0.3111**	**6758723**	**4304.78**

Remarks:

- **Strategy 1** (increase load factor) has a higher average energy consumption than the benchmark scenario. This happened mainly due to heavier bus weight (higher number of passengers).
- **Strategy 5** (change the charging facility) has produced same result as benchmark scenario. This is due to the adopted fast charging facility in Strategy 5 has shortened the charging time but there is no change in the total bus trips.

b) Emission

Scenario/Strategy	Green Index	Variance	Average (kg CO_2eq)
Benchmark	0.4095	36942251	7674.09
Strategy 1	0.2382	18016346	**9203.68**
Strategy 2	0.2920	30432449	7471.37
Strategy 3	0.3701	32633215	**7913.41**
Strategy 4	0.4088	36624622	7653.18
Strategy 5	0.4001	16500704	5289.25

Remarks:

- **Strategy 1** has a higher average emission than the benchmark scenario. This is due to the energy consumption correlates with the emission and the total emission was greatly influenced by how much of energy generated.
- **Strategy 3** has slightly higher average emission than the benchmark scenario. This happened due to the increment of load factor and smaller bus (with lighter weight) equipped with smaller battery size which requires frequent charging in order to get sufficient energy for operation. Frequent charging (with slow charging) will emit more emission during charging process.

c) Bus Noise

Scenario/Strategy	Green Index	Variance	Average (dba)
Benchmark	0.2811	6037206	4359.19
Strategy 1	0.1159	1428384	**5269.75**
Strategy 2	0.2347	5433936	3931.62
Strategy 3	0.1166	1445783	**5263.8**
Strategy 4	0.2787	5912589	4333.41
Strategy 5	**0.2811**	**6037206**	**4359.19**

Remarks:

- **Strategy 1** has a higher average bus noise than the benchmark scenario. The increment of load factor in Strategy 1 (with heavier bus weight) caused the increment in sound pressure level which generates high noise level.
- **Strategy 3** has slightly higher average bus noise than the benchmark scenario due to the smaller buses needs to perform more trip to meet the bus schedule (which generate more noise).
- For **Strategy 5**, there is no change in the bus noise compared with the benchmark scenario. This is due to the modification of the charging facility which only involves the reduction of the charging time while the total trips performed by all buses are still the same in accordance to the bus schedule.

APPENDIX B

SURVEY OF INFLUENTIAL FACTOR IN ELECTRIC BUS FLEET PLANNING AND OPERATION

Study Objective: to examine the relative importance of influential criteria/factor in electric bus fleet planning and operation.

Section 1: Personal Information

Please tick ✓ the answer that best describe about you.													
1	Gender	Male		Female									
2	Age (years old)	25-34		35-44		45-54		Above 54					
3 a	Sector of working *	Industry											
	Position	Executive		Senior executive		Manager		Director/ CEO		Others			
3 b	Sector of working *	University											
	Position	Lecturer		Senior lecturer		Assistant professor		Associate professor		Professor		Others	
4	Working experience	1-5 years		6-10 years		11-15 years		16 years above					

**Please fill in 1 sector only*

Section 2:

Four important decisional criteria are considered in promoting the electric bus fleet, i.e., government policy/subsidy enforcement, passengers' feedback/respond, bus technical features, and financial cost. The definitions of these factors are stated as follow:

1. Government policy/subsidy enforcement: The adherence to the government/authority's policy for electric bus operations and also government incentive program (such as company tax rebate or subsidy) for the deployment of electric bus.
2. Passengers' feedback/respond: Passengers' feedback on the service quality in riding electric bus (demand aspect).
3. Bus technical features: This considers the operational feasibility of operating electric bus (including bus maintenance, driver capability on handling electric bus, charging facility/time, and battery capacity).
4. Financial cost: Additional cost (e.g., capital, operational) or cost-saving (e.g., energy consumption, maintenance) incurred in operating electric bus.

Using the pairwise comparison method, please indicate your opinion on the relative importance of the following pair of criteria as presented on a score of 1 to 9. Please tick (/) your choice.
Remarks: **1: equal importance, 3: weak importance; 5: strong importance; 7: demonstrated importance; 9: absolute importance while 2, 4, 6 and 8 signify the corresponding intermediate values between two adjacent judgments.**

For example;
Government policy/subsidy enforcement ----> Passengers' feedback/respond has a score of 5. It reads "Government policy /subsidy enforcement factor is 5 times more important than passengers' feedback/respond factor in electric bus fleet planning and operation".

Statement	1	2	3	4	5	6	7	8	9
Government policy /subsidy enforcement ----> Passengers' feedback/respond Government policy /subsidy program enforcement is ___ times more important than passengers' feedback/respond factor in electric bus fleet planning and operation									
Government policy /subsidy enforcement ----> Bus technical features Government policy /subsidy program enforcement is ___ times more important than bus technical features factor in electric bus fleet planning and operation									
Government policy /subsidy enforcement ----> Financial cost Government policy /subsidy program enforcement is ___ times more important than financial cost in electric bus fleet planning and operation									
Passengers' feedback/respond ----> Bus technical features Passengers' feedback/respond is ___ times more important than bus technical features factor in electric bus fleet planning and operation									
Passengers' feedback/respond ----> Financial cost Passengers' feedback/respond is ___ times more important than financial cost factor in electric bus fleet planning and operation									
Bus technical features ----> Financial cost Bus technical features is ___ times more important than financial factor in electric bus fleet planning and operation									

Section 3:
Besides the four criteria as outlined in Section 2, three important environmental factors (i.e., energy consumption, emission, and noise) are considered for **each decisional criteria** in the electric bus fleet planning and operation. The definitions of these factors are as follow:

1. Energy consumption: The total amount of energy used to operate electric buses (unit per year).
2. Emission: The total amount of emission gas (such as carbon dioxide, carbon monoxide) emitted from the fleet of bus (unit per year).
3. Noise: The total amount of noise emitted from the fleet of buses to the environment (unit per year).

Using the pairwise comparison method, please indicate your opinion on the relative importance of the following pair of factors (as presented on a score of 1 to 9) for each decisional criteria. Please tick (/) your choice.

Remarks: **1: equal importance, 3: weak importance; 5: strong importance; 7: demonstrated importance; 9: absolute importance while 2, 4, 6 and 8 signify the corresponding intermediate values between two adjacent judgments.**

For example;
Energy consumption ----> Emission has a score of 2. It reads “Energy consumption factor is 2 times more important than emission factor in electric bus fleet planning and operation”.

(a) By considering the decisional criteria of **government policy/subsidy enforcement**

Statement	1	2	3	4	5	6	7	8	9
Energy consumption ----> Emission Energy consumption is ___ times more important than emission factor in electric bus fleet planning and operation.									
Energy consumption ----> Noise Energy consumption is ___ times more important than noise factor in electric bus fleet planning and operation.									
Emission ----> Noise Emission is ___ times more important than noise factor in electric bus fleet planning and operation.									

(b) By considering the decisional criteria of **passengers’ feedback/respond**

Statement	1	2	3	4	5	6	7	8	9
Energy consumption ----> Emission Energy consumption is ___ times more important than emission factor in electric bus fleet planning and operation.									
Energy consumption ----> Noise Energy consumption is ___ times more important than noise factor in electric bus fleet planning and operation.									
Emission ----> Noise Emission is ___ times more important than noise factor in electric bus fleet planning and operation.									

(c) By considering the decisional criteria of **bus technical features**

Statement	1	2	3	4	5	6	7	8	9
Energy consumption ----> Emission Energy consumption is ___ times more important than emission factor in electric bus fleet planning and operation.									
Energy consumption ----> Noise Energy consumption is ___ times more important than noise factor in electric bus fleet planning and operation.									
Emission ----> Noise Emission is ___ times more important than noise factor in electric bus fleet planning and operation.									

(d) By considering the decisional criteria of **financial cost**

Statement	1	2	3	4	5	6	7	8	9
Energy consumption ----> Emission Energy consumption is ___ times more important than emission factor in electric bus fleet planning and operation.									
Energy consumption ----> Noise Energy consumption is ___ times more important than noise factor in electric bus fleet planning and operation.									
Emission ----> Noise Emission is ___ times more important than noise factor in electric bus fleet planning and operation.									

Thank you for your participation. For additional comments, please email: Phoebe (pgsy80@gmail.com)