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Green Assessment and Improvement Framework for Electric Bus Operational System

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ABSTRACT

In response to the worldwide environmental problem and fossil oil dependency concern, electric bus (EB) has emerged as a promising green transport to alleviate air pollution. However, there is no available method on how to quantify the environmental (green) performance of EB operational system that could provide proper guidance to the bus operators. Thus, this study aims to develop a green assessment and improvement framework for EB operational system which is capable of capturing bus noise, emission, and energy consumption level explicitly in quantifying the respective green index. To do this, the approaches of Gini Index, Analytic Hierarchy as well as Weighted-grading are employed accordingly. The resultant Green Performance Index (GPI) is vital not only to enhance the green performance of EB operational system, but also to tackle the needs and preferences of the bus operators in meeting the demand of passengers. By analysing a study area in Putrajaya (Malaysia), the findings show that the green performance of EB operational system would vary across numerous operational factors, including load factor, bus frequency, and bus type. The results also highlight that the green weightage of energy consumption emerges with the highest value (approximately 69%). Besides that, it was found that the improvement strategy of load factor increment is beneficial to improve the GPI of the bus operator, up to 37.9%. Concisely, it is anticipated that the developed approach as well as the resultant findings would yield useful insights especially to the bus operators to operate EB in a greener and better manner.

Keywords: Electric bus; energy consumption; emission; noise; green performance

INTRODUCTION

In view of the fact that the sector of transportation accounted for more than 25% of worldwide energy consumption, the resultant side effects from the transportation activities, including air and noise pollution, certainly requires attentive concern from the stakeholders (Juan et al. 2016). In particular, the element of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emitted from the sector of transportation emerge as the main contributors to greenhouses gas (GHG) emissions (Ong et al. 2011; Shahid et al. 2014). Besides, the emission from the road transportation was found to result in an acute threat to air quality and global warming. In addition to environmental concern, demand increment for urban transport (including public bus) and the dependency on fossil oil thus highlights the need of using green transport (Song et al. 2018).

Correspondingly, electric bus (EB) has emerged as a promising alternative public transport to stimulate green mobility (Juan et al. 2016; Doucette & McCulloch 2011). With the aid of emerging technology, EB is environmentally-friendly, i.e., it is capable to reduce carbon emission (Jouman 2013; Foltyński 2014). There are numerous types of EB, including battery EB, full cell EB, and hybrid EB. Technically, the operation of EB is highly dependent on the propulsion system (Bayindir 2011; Miles & Potter 2014) and the battery type (Elgowainy 2013). In comparison to internal combustion engine vehicles, EB has several benefits, including silent operation, high tank-to-wheel efficiency, and zero tailpipe emission (Fontaínhas et al. 2016). In addition to the environmental benefits, a viable EB operational system would stimulate the ridership of public transport. However, there are some concerns in operating EB. The three major challenges are limitation of battery capacity, scarcity of charging infrastructure, and long duration for battery charging (Juan et al. 2016; Jing et al. 2016; Brandstatter 2016). To tackle these limitations, a proper-designed EB operational system is certainly required to operate green EB viably. It is also vital to enhance its green performance which would result in a win-win situation to the environment and also the community.

Thus, this paper aims to develop a green assessment and improvement framework for EB operational system, by capturing explicitly three vital components, i.e., energy consumption, emission, and noise of EB. The developed approach is capable of quantifying the green performance of EB by considering a variety of operating characteristics while considering the needs and preference of the bus operator. Besides, it is vital to improve the overall green performance of EB operational system by incorporating numerous beneficial improvement strategies. In addition, the developed approach is beneficial to reveal the effectiveness of the improvement strategies in order to assist the bus operator in providing green EB services.

The remaining of this paper is structured accordingly by discussing the relevant literature review in Section 2 while Section 3 focuses on the formulation of the modelling framework. In order to inspect the applicability of the developed approach, a case study is illustrated and analyzed in detail in Section 4. Lastly, this paper is concluded in Section 5.

LITERATURE REVIEW

There are numerous studies that are relevant to the EB operations. As discussed below, these studies could be grouped by three main environmental factors, namely energy consumption, emission, and noise.

ENVIRONMENTAL ASPECT

Generally, the energy source to operate electric EB is electricity (Van Mierlo 2006) for which the energy efficiency of EB is defined to be the net volume of energy required by the buses to travel one kilometer (Zivanovic & Nikolic 2012; Catenacci et al. 2013). In view of the fact that the energy source could affect the bus performance, it is of utmost important to capture the *energy consumption* in planning a viable EB operational system. In addition to energy storage system (Zivanovic & Nikolic 2012; Catenacci et al. 2013), the energy consumption of EB is highly affected by load factor, topography, number of bus stops, and outdoor temperature. (Boren 2016; Gallet et al. 2018; Perrotta et al. 2014; Bunzel & Baker 2018) evaluated the usage of energy in supporting EB operations. In particular, Gallet et al. (2018) showed that varying driving conditions would consume different energy for different bus routes and operating time. Besides, Bunzel & Baker (2018) highlighted that the energy requirement of EB is influenced by a speed-time profile and environmental parameters (*e.g.*, ambient temperature). Perrotta et al. (2014) also found that the most demanding bus route required a higher level of energy to complete EB operations. Although these studies highlighted that it is crucial to include the operational characteristics of EB, some influential factors (*e.g.*, load factor and bus type) are not considered explicitly in the energy determination. Besides, the existing studies did not deliberate the EB energy consumption for green analysis.

In order to evaluate the generated GHG *emission* from EB operations, the assessment of Well-to-Wheel (WTW), comprising two stages, namely Well-to-Tank (WTT) and Tank-to-Wheel (TTW), is required. WTT measures the GHG emission at both production and distribution process while TTW measures the GHG emissions during the usage process. In overall, the WTW assessment shows that battery EB has a great tendency to reduce GHG emission. Besides, He et al. (2018) showed that there is a closed relation between the WTW and energy consumption of EB for which the energy consumption would proportionally affect the WTW emission of CO2 and air pollutants. Dreier et al. (2018) also showed that TTW energy consumption that could influence GHG emissions, may vary up to 77% across operating routes, times, and bus types. Besides, it was found that EB could contribute to GHG emission reduction by adopting the best electricity distribution loss and charging efficiency (Song et al. 2018).

Besides, EB was found to produce lesser *noise* and vibration. This happened mainly due to the lack of mechanical parts. Compared to diesel buses, EB emits a lower noise level, *i.e.*, up to 8 dBA for exterior cruising stage especially with a bus speed below 50 km/h (Volvo 2016). Notably, it is important to note that the bus noise could generate numerous consequences including annoyance, sleep disruption, hypertension, myocardial infarction, and stroke (Münzel et al. 2014). Specifically, noise pollution is recognized as a critical health problem that is far harder to treat than air pollution. (Ross & Staiano 2007; Boren 2019) compared the noise level generated by diesel and EB. Their findings showed that the noise level of EB would be affected by bus speed for which engine noise will dominate for diesel buses when speeds are low (Ross & Staiano 2007). Besides, Boren (2019) showed that the EB operations could contribute not only in reducing noise pollution, but also contributing to a significant saving on energy consumption as well as zero emissions during the bus operation.

Concisely, the above-mentioned existing studies highlighted that there are numerous components that ought to be captured explicitly in assuring a viable EB operational system. Nevertheless, there is limited study that examines the overall green performance of EB operations explicitly. Furthermore, none of the existing studies from (Gallet et al. 2018; Perrotta et al. 2014; Bunzel & Baker 2018; He et al. 2018; Dreier et al. 2018; Ross & Staiano 2007; Boren 2019) considered the needs and preferences of the bus operator towards the mentioned environmental factors. Therefore, it is of utmost importance to have a proper-developed approach in quantifying the green performance of EB in order to assure a better and greener EB operational system.

GREEN ASSESSMENT

Green assessment has been applied for urban development in order to assure environmental sustainability. However, there is lack of environmental assessment of the transportation sector, especially on electric bus. In particular, for the air transportation sector, Teoh (2015) developed a green fleet index for airlines in order to assess the environmental performance of aircraft. By considering the attribute of aircraft emission, fuel consumption, and noise. She used the Gini index to examine the green performance of the airline. Focusing on the highway and pavement project, Boclin & Mello (2006) adopted a fuzzy logic approach as the decision support method to evaluate the relevant environmental impact. Besides, Soares et al. (2018) applied the Gini index to examine the emission concentration of CO_2, by considering the income and availability of technology in a particular country. However, it is merely a reference to identify the overall CO_2 emission of the country.

In order to quantify the green performance of EB operational system, Analytic Hierarchy Process (AHP), with the ability to deal with uncertainty, (Saaty & Tran 2007) is employed to quantify the green weightage, i.e., the weightage for green index. AHP was first introduced by Saaty (1977) to rank several actions by examining numerous predetermined criteria. As a multiple criteria decision-making approach, the AHP is capable to allow the respective judgments to vary by a fundamental scale of 1-9. Conceptually, the scale of 1 indicates equal importance while the scale of 9 represents the absolute importance, and the scale of 2, 4, 6, and 8 reflect the corresponding intermediate value between the two subsequent judgements (Saaty 1977, 1980). In particular, AHP has the competency to detect the vagueness in the multi-criteria decision making when there is a variation of judgment.

AHP has been used by Wen & Lin (2011) to quantify the qualitative indicator of the service quality of the highway passenger transport while Boujelbene & Derbel (2015) applied AHP to evaluate the performance of the public transport operator in order to identify the best performing public transport operator. Besides, Zhang & Chen (2008) adopted AHP to evaluate the integration degree of the road transportation system of the city cluster in Wuhan (China). In addition, Ignaccolo et al. (2017) found out that AHP is suitable to tackle the complicated transportation decision which considered multi-stakeholder with multi-criteria perspective.

In summary, the afore-mentioned studies are remarkable for green assessment. However, it is apparent that there is a lack of concrete study that analyzes the environmental performance for EB operational system. In contrast to Teoh et al. (2020), this paper incorporated AHP to quantify the green weightage, by considering the needs and preference of the transportation experts explicitly. It is anticipated that the inclusion of this element in the proposed framework would yield insightful findings which are more realistic and viable in operating a greener EB operational system.

A BRIEF OVERVIEW ON ELECTRIC BUS APPLICATIONS IN MALAYSIA

In accordance with the Green Technology Application for the Development of Low Carbon Cities (GTALCC) project, Malaysia had its very first battery EB trial in the state of Malacca in the year 2014. This EB is able to carry 60 passengers (The Star 2015). It is equipped with an iron-phosphate battery which requires about five hours to fully recharge. And, the maximum speed of this EB is 76 km/h and it is capable of travelling up to 180 km.

In the year 2015, the government of Malaysia introduced the Stage Bus Service Transformation Program (SBST) to improve the bus services in the country (Chan 2015). Under SBST, Kuala Terengganu emerged as the first city to transform the conventional bus as EB services (Timbuong 2018). The total of the involved bus route is 236 km. In the same year, Bus Rapid Transit (BRT) was operated in Sunway, Selangor (Menon 2015), with a fleet of 15 EBs. The average speed of BRT is 45 km/h for a total of 5.4 km for the bus route. The ridership of BRT for the year 2019 was reported as 16 444 (Bernama 2019).

The Putra NEDO EV Bus project was implemented in the year 2017 in Putrajaya, Malaysia. This 3-year pilot project started with four EBs (operated by Nadi Putra), with 12-meter in length. It can travel up to 30 km after fully charged. The battery of this EB has a long lifespan, low temperature performance and fast charging (requires only 10 minutes for a full charge) (Toshiba 2017). In the year 2018, there are a total 10 EBs deployed in Putrajaya (Nair 2018) for which the targeted number of EB is 150 by the year 2025 (Abd Majid 2017). Nadi Putra has offered free bus service in Putrajaya (starting November 2020) by operating a total of 37 diesel buses and three Putra NEDO EV buses. This project covers 12 bus routes which aims to help citizens who are greatly affected by the pandemic (Halim 2020).

Besides, Universiti Teknologi Malaysia (UTM) turned out to be the first university in Malaysia to use EB in the year 2018 in the campus (Ahmad 2018). This EB, which can go up to 88 km per drive, is equipped with a rechargeable battery which requires 20 minutes to be fully charged.

More recently, a Memorandum of Understanding (MoU) was signed in March 2020 between The Malaysian Green Technology, Climate Change Centre and Malaya Green Builder Energy Sdn Bhd (Azman 2020). This MoU aims to acquire 100 EBs to support the public transit system as well as to transform the cities into low carbon cities through foreign direct investments.

In March 2021, the first free public EB (e-Bus) was launched by The Sarawak Tourism, Arts and Culture Ministry (Bernama 2021). The e-Bus service provides convenient and free transportation alternatives in the city of Kuching, Sarawak, with a total of four buses. The operating bus can ferry up to 26 seated passengers and it is able to operate up to 300 km on a full charge

METHODOLOGY

LIST OF NOTATIONS

The following presents the list of notations used for the developed approach.

cap	Bus capacity
C	Bus resistance coefficient
Cat^n	Cumulative value of operating routes in n category (in percentage)
CE^y_n	Cumulative value of environmental factor in n category (in percentage)
Dr	Length of bus route r
e_i	GHG emission factor of electricity mixes i
E_y	Environmental factor
f	Bus friction force
g	Gravity acceleration
F_{EB}	Bus frequency
i	Type of electricity mixes
j	Type of green index
l	Electricity loss of power transmission system
LF	Load factor of bus
m	Total mass of bus
P_0	Baseline sound pressure
P_{ref}	Reference sound pressure
P_y	Increased sound pressure during acceleration
P_z	Sound pressure during constant speed
Q_{EB}	Bus quantity
r	Bus route
S_j	Green score (score of green index j)
T_{EB}	Bus operating time
t	Duration of time that a person is affected by bus noise
V_{EB}	Bus speed
W_j	Green weightage (weightage of green index j)
ε	Number of bus stops
γ	Number of accelerations during bus movement
a	Angle of inclination of road
∂	Charging efficiency of battery
ρ	Air density
U	Judgment matrix of decisional criteria
R	Judgment matrix of environmental factor

GREEN ASSESSMENT AND IMPROVEMENT FRAMEWORK

In order to quantify the green performance of EB operational system in terms of Green Performance Index (GPI), the developed green assessment and improvement framework is displayed in Figure 1. As displayed in Figure 1, it could be seen that numerous environmental factors can be captured in obtaining the respective Green Index (GI). This can be done by adopting Gini Index Approach. Specifically, the developed framework is able to quantify three major green indexes, namely Green Energy Index (GEI), Green Emission Index (GMI), and Green Noise Index (GNI) that correspond respectively to the environmental factor of energy consumption, emission, and noise of EB. Subsequently, Analytic Hierarchy Process (AHP) is applied to determine the respective weightage for the green index (i.e., green weightage) and Weighted-grading Approach is then employed to integrate the obtained green indexes (together with the respective green weightage) to quantify the green indicator, namely GPI. Besides, various improvement strategies can be adopted to enhance a greener performance for the entire EB operational system. In other words, GPI is playing a vital role, not only to reveal the green performance, but also to provide insightful recommendations for implementation purposes, by evaluating the effectiveness of the respective improvement strategy.

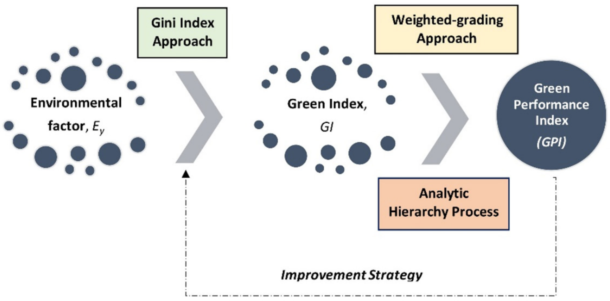

FIGURE 1. The Green assessment and improvement framework

FORMULATION OF GREEN INDEX

In order to obtain the respective GI, the Gini Index Approach is employed by borrowing the idea from the concept of Gini coefficient (index), which ranges from the fundamental scale of zero to one. Conceptually, the operations of EB that do not produce excessive pollutants would tend to result in a smaller value of variance (and average too). This would also yield a higher level of equality with a smaller value of Gini coefficient. In other words, the value of Gini coefficient which is getting closer to the value of zero would indicate a greener performance (due to lesser pollutants with a smaller value of variance and average). On the other hand, the Gini coefficient, that is approaching the value of one, denotes a poorer environmental performance. Therefore, if the EB operators could reduce the amount of energy consumption, emission and noise for the operating routes by incorporating effective improvement strategies, the EB operating network (with a lesser amount of energy consumption, emission, and noise) would attain a smaller value of variance, average, as well as Gini coefficient. Thus, Gini Index Approach is adopted to quantify the respective green index accordingly. Practically, a greener performance could be achieved by incorporating numerous improvement strategies (Teoh 2015; Teoh et al. 2020). Correspondingly, the GI of the respective environmental factor could be determined as below:

$$GI = 1 - \sum\left(CE_y^n + CE_y^{n-1}\right)\left(Cat^n - Cat^{n-1}\right) \tag{1}$$

Notably, *GI→0* signifies that the green level of the EB operational system is getting better by producing fewer energy consumption, emission, and noise while *GI→1* indicates a poorer performance of green level with more energy consumption, emission, and noise.

By having Eqn. (1) in place, the Green Energy Index (GEI) can be determined accordingly as follows:

$$GEI = 1 - \sum\left(E_r^n + E_r^{n-1}\right)\left(Cat^n - Cat^{n-1}\right) \tag{2}$$

for which the daily energy consumption level of EB, E_r for the operating bus route *r*, can be computed as indicated by Eqn. (3). Notably, Eqn. (3) is a modified formula of the total energy consumption from Bunzel and Baker (2018) by adding the component of bus load factor (*LF*), bus operating time (T_{EB}), bus frequency (F_{EB}) and bus quantity (Q_{EB}) in order to capture the EB daily operations as realistic as possible.

$$E_r = \sum LF\left((f\cos\alpha + \sin\alpha)mg + \frac{1}{2}CA\rho(V_{EB})^2 V_{EB}T_{EB}\right)F_{EB}Q_{EB} \text{ for } \forall j \tag{3}$$

Similarly, the Green Emission Index (GMI) can be determined as follows:

$$GMI = 1 - \sum\left(M_r^n + M_r^{n-1}\right)\left(Cat^n - Cat^{n-1}\right) \tag{4}$$

where the daily emission level of EB, M_r can be computed from Eqn. (5) as stated below. Eqn. (5) is modified from Song, et al. (2018) by adding the component of bus load factor (LF), bus frequency (F_{EB}) and bus quantity (Q_{EB}).

$$M_r = \sum LF\left(\sum \frac{E_r e_i}{\partial \times (1-l)_i}\right)F_{EB}Q_{EB} \tag{5}$$

By modifying the total noise formula of Boren (2019), the daily noise level of EB, L_r can be expressed by Eqn. (6). Subsequently, the Green Noise Index (GNI) can be computed as below.

$$L_r = \sum_{\forall r} LF\left(10\log\left[\frac{V_{EB}}{D_r}\int_0^{\frac{D_r}{V_{EB}}} \frac{P_0^2\left(\frac{D_r}{V_{EB}}\right) + \left(P_y + P_0\right)^2(\varepsilon+\gamma)t}{P_{ref}^2}\,dt\right] + 10\log\left[\frac{V_{EB}}{D_r}\int_0^{\frac{D_r}{V_{EB}}} \frac{P_z^2}{P_{ref}^2}\,dt\right]\right)F_{EB}Q_{EB} \tag{6}$$

$$GNI = 1 - \sum\left(L_r^n + L_r^{n-1}\right)\left(Cat^n - Cat^{n-1}\right) \tag{7}$$

ANALYTIC HIERARCHY PROCESS (AHP) MODELLING FRAMEWORK

In order to quantify the GPI, it is necessary to determine the green weightage of each green index for which a higher weightage indicates a higher priority (or concern) on the respective green index. In practice, there are multiple decisional criteria, such as government policy (including subsidy enforcement), financial cost, bus specification, and passengers' feedback that could greatly affect the operational and environmental performance of EB. Thus, AHP, a multi-criteria decision-making approach, is adopted to quantify the green weightage. With the aid of AHP, the judgement of the bus operators towards the environmental factors and decisional criteria could be captured by utilizing the fundamental scale of 1-9 (Saaty 1977, 1980). As displayed below, Figure 2 shows the proposed AHP modelling framework (with three phases) to quantify the green weightage. As shown in Figure 2, the first phase (Phase 1) plays the role to establish the judgement matrix for the relevant decisional criteria while Phase 2 works out the judgement matrix of the environmental factors for each decisional criteria. As depicted in Figure 2, a survey can be carried out accordingly to compile the judgment matrices, by considering the needs and preference of the bus operators, and the last phase (Phase 3) computes the green weightage as outlined below.

$$\text{Green Weightage}, W_j = \sum U^*_c R^*_c \text{ for } \forall j \qquad (8)$$

where U^*_c denotes the average of row c of the normalized matrix U while R^*_c denotes the average of row c of the normalized matrix R. Subsequently, the resultant green weightage will be applied to quantify the GPI.

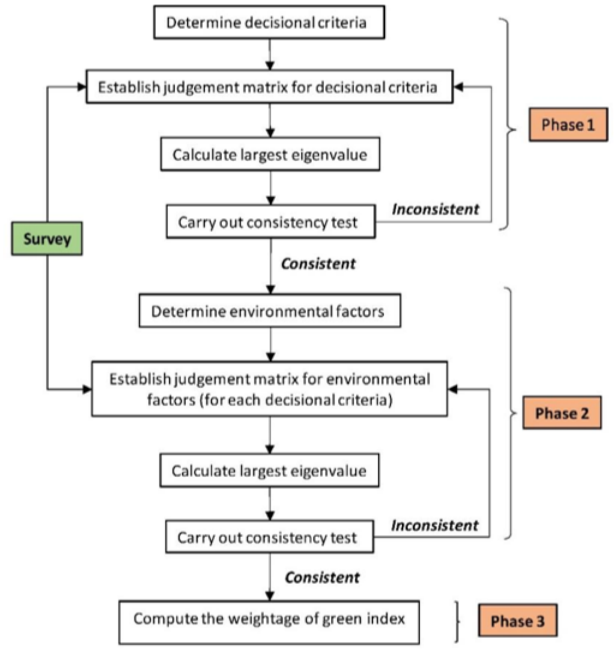

FIGURE 2. Analytic Hierarchy Process (AHP) modelling framework

GREEN PERFORMANCE INDEX (GPI)

The GPI, as the green indicator for the EB operational system, could be determined as follows:

$$GPI = \sum W_j S_j \text{ for } \forall j \qquad (9)$$

for which W_j refers to the resultant green weightage obtained from the AHP modelling framework while the green score, S_j could be obtained from the designated Weighted-grading Approach (WGA) as shown in Table 1. WGA has altogether eight grades, from grade I to VIII, for which grade I (with a score of 4.00) represents the best (greenest) environmental performance while grade VIII (with a score of 0.00) shows the worst green performance.

AN ILLUSTRATIVE CASE STUDY

Putrajaya, Malaysia has been targeted as a *Green City* in accordance to the efforts by the government of Malaysia in reducing the emission of CO_2 by 60% (Putrajaya Corporation 2012). Therefore, Putrajaya was chosen as the study area. Nadi Putra, a bus company which was founded in the year 1999, is one of the subsidiaries of Putrajaya Corporation. Nadi Putra operates two types of public bus, namely a 12-meter long type (for 63 passengers) and a 7-meter long minibus (for 40 passengers). There are altogether 10 operating routes and the EB is equipped with a 300 kWh capacity titanium-ion battery. To support the operations of EB, there are three terminals which function as the departure point, final stop, as well as the charging stations. Besides that, it is assumed that all buses use slow charging facilities that require eight hours to get fully charged.

TABLE 1. Weighted-grading approach for Green Performance Index (GPI)

Green Index	Green Score	Grade
0.00 – 0.20	4.00	I
0.21 – 0.25	3.67	II
0.26 – 0.30	3.33	III
0.31 – 0.35	3.00	IV
0.36 – 0.40	2.67	V
0.41 – 0.45	2.33	VI
0.46 – 0.50	2.00	VII
0.51 – 1.00	0.00	VIII

For analysis purposes, the following data inputs were compiled accordingly (Song et al. 2018; Gallet et al. 2018; Boren 2019; Muthuvel et al. 2013; The Engineering ToolBox 2004; Teoh et al. 2018):

1. Bus capacity, $cap = 63$
2. Angle of inclination of road, $\alpha = 30$
3. Gravity acceleration, $g = 9.8\text{m/s}^2$
4. Bus resistance coefficient, $C = 0.4666$
5. Bus friction force, $f = 0.008$
6. Air density, $\rho = 1.1839\text{kg/m}^3$
7. Electricity loss of power transmission system, $l = 3.17\%$
8. Charging efficiency of battery, $\partial = 94\%$
9. GHG emission factor, $e_l = 0.76\text{kg } CO_2\text{eq/kWh}$

10. GHG emission factor, e_2 = 0.71kg CO_2eq/kWh
11. GHG emission factor, e_3 = 0.78kg CO_2eq/kWh
12. Reference sound pressure, P_{ref} = 2 x 10-5 Pascal
13. Baseline sound pressure, P_0 = 0.02 Pascal
14. Sound pressure during constant speed, P_z = 0.037 Pascal

Besides that, Table 2 presents some other data input used to quantify the energy consumption and noise of the bus. As presented in Table 3, a benchmark scenario is analyzed by using the operational data collected in the year 2015 as well as the above-mentioned data inputs. Three improvement strategies were outlined with the aim to improve the GPI.

TABLE 2. Data inputs

Bus route, r	Min	Max	Average
Bus speed, V_{EB} (km/h)	40	55	46.5
Length of bus route, D_r (km)	21.9	32.7	25.84
Bus operating time, T_{EB} (hour)	0.42	0.73	0.56
Total mass of bus, m (103 kg)	13.1	16.2	14.98
Bus frequency, F_{EB}	3	4	3.2
Bus quantity, Q_{EB}	14	19	16.9
Load factor, LF (%)	10	85	55.5
Number of bus stops, ϵ	22	38	26
Number of accelerations during bus movement, γ	25	44	33.8
Increased sound pressure during acceleration, P_y (10^{-4} Pascal)	290	725	481.3
Duration of time that a person is affected by bus noise, t (second)	4	12	7.2

Source: Boren (2019); Teoh et al. (2018); Auto-Che (2020)

As indicated in Table 3, Strategy P focuses on load factor increment for the bus routes with a relatively low level of passengers' demand (below 50% of load factor). By increasing load factor, it is anticipated that the amount of emitted pollutants per passenger would be lesser and the EB operating network would be greener (Carrese et al. 2012). Strategy Q aims to adjust the bus frequency from two aspects, namely frequency reduction and removal (if necessary). This could be done on the bus routes with a low load factor (e.g., below 50%). For the identified bus routes, the bus frequency may be reduced while aiming to increase the load factor (up to 50%). The restructure of the bus frequency from these aspects is vital in view of the fact that fewer bus frequencies may produce less pollution (Titos et al. 2015). For Strategy R, fleet planning (in terms of using different bus capacity) is proposed in order to accommodate varying demand levels. A smaller size of EB could be used to serve the bus routes with a low load factor (i.e., below 50%). It is anticipated that the operations with smaller buses would produce less pollution mainly due to the reduction of the total mass of bus (Teoh et al. 2020).

TABLE 3. The outlines for benchmark scenario and improvement strategies

Scenario	Description
Benchmark	Existing operational data (without improvement strategy)
Strategy P	Load factor increment (up to 50% for certain bus routes)
Strategy Q	Bus frequency adjustment and load factor increment (for certain bus routes)
Strategy R	Fleet planning and load factor increment (for certain bus routes)

RESULTS AND DISCUSSION

GREEN INDEX

Figures 3 and 4 display the resultant Green Index and the corresponding improvement level. The results show that Strategy P, with an average improvement level of 52.4%, outperforms the other improvement strategies. For the Green Index in terms of GEI, GMI and GNI, the results also show that Strategy P yields the greenest performance. Comparatively, the impact of Strategy P is more than double the effect of Strategies Q and R. Besides that, Strategy R, with an average improvement level of 22.9%, is slightly better than Strategy Q that improved 21.5%. This could be explained by a greater impact of GNI that improved 58.5%.

In particular, when Strategy P is implemented for every 1% of load factor increment, it is noticeable that the average improvement level would increase by 5% and the corresponding GPI would improve about 3.3%. For Strategy Q, the average improvement level would increase by 2% for the green indexes while the GPI would improve about 2.3% for the adjustment of the service frequency (in terms of the reduction of bus frequency). For Strategy R (via fleet planning), the results show that there is an average improvement level of 3% for all indexes while GPI would improve about 0.5% for every reduction of bus seat. Besides, it could be seen that Strategy P yields a significant improvement with 58.8% for GNI. This strategy is, in fact, quite comparable with Strategy R that improved 58.5%. This shows that both Strategy P (load factor increment) and Strategy R (fleet planning) could reduce the noise level significantly.

GREEN WEIGHTAGE

In order to capture the needs and preference of bus operators towards the EB operational system, a survey was conducted in August 2020 by collecting the relevant feedback from the industry and academic experts. There are 3 sections in the survey which consists of respondents' personal information (Section 1), judgment comparison among the decisional criteria (Section 2), and judgment comparison among the environmental factors for each decisional criteria (Section 3). In particular, four decisional criteria (*i.e.*, government policy, bus specification, financial cost, and passengers' feedback) and three environmental factors (*i.e.*, energy consumption, emission, and noise) were considered in the survey. In total, there were 32 respondents participating in the survey (with 75% male and 25% female).

With the aid of AHP modelling framework, the resultant green weightage is presented in Table 4. As shown in Table 4, it could be seen that the green weightage of energy consumption emerges with the highest value (approximately 69%) while the green weightage of noise has the lowest value (about 7%). This indicates that green concern on energy consumption is prioritized (compared to emission and noise) by the survey respondents in quantifying the GPI for the EB bus operational system.

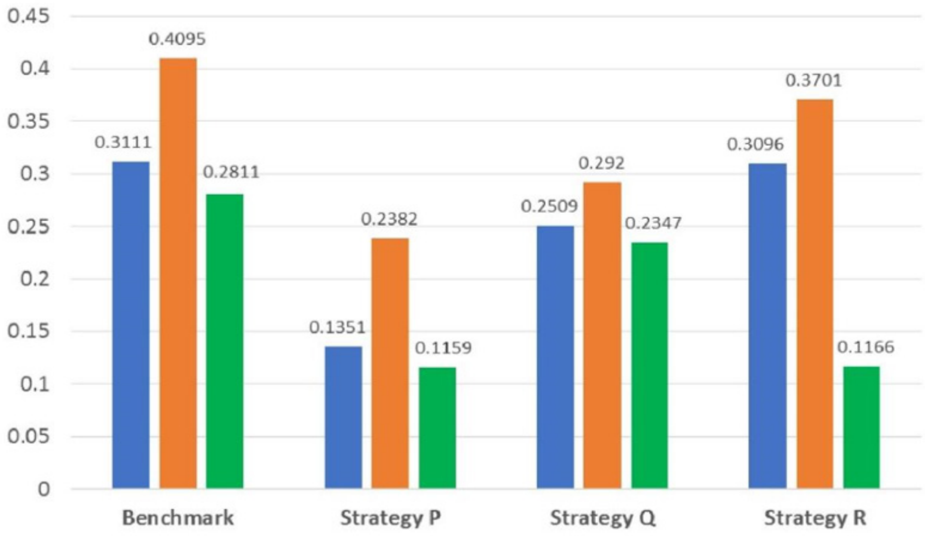

FIGURE 3. The resultant Green Index

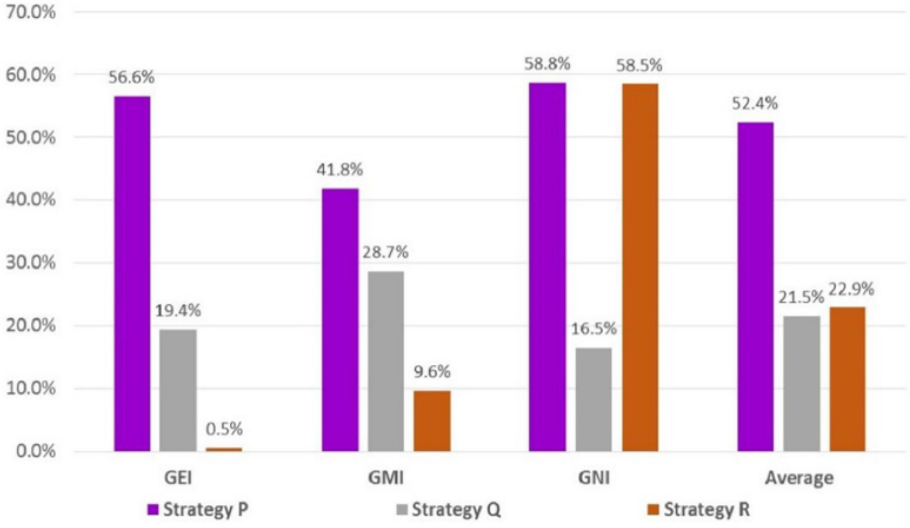

FIGURE 4. The improvement level of Green Index

GREEN PERFORMANCE INDEX (GPI)

The resultant GPI is shown in Table 5. Comparatively, Strategy P, with the highest score of GPI at 3.9214, shows the best grade of GPI, i.e. grade II. This reveals that Strategy P (load factor increment) is the most beneficial approach in improving the green performance of EB operational system. Besides that, it could be seen that Strategy Q gains the second highest GPI (i.e., 3.5890), at grade III. This reveals that an integrated approach (bus frequency adjustment and load factor increment) is also effective in improving the green performance of electric bus operational system. Although Strategy R generates the same grade of V as the benchmark scenario, it yields a higher score of GPI than the benchmark scenario. This signifies that the bus operator may implement Strategy R (by using smaller capacity of bus via fleet planning) in particular to improve the GNI to a large scale (i.e. up to 58.5% as shown in Figure 4).

TABLE 4. The resultant green weightage

Decisional criteria				Green Weightage
Government policy	Bus specification	Financial cost	Passengers' feedback	
0.7067	0.6829	0.6890	0.6775	$W_{EN} = 0.6909$
0.2220	0.2462	0.2384	0.2522	$W_{EM} = 0.2382$
0.0713	0.0709	0.0726	0.0703	$W_{BN} = 0.0709$

Note: W_{EN} refers to the weightage of Green Energy Index, W_{EM} indicates the weightage of Green Emission Index and W_{BN} denotes the weightage of Green Noise Index.

TABLE 5. The resultant Green Performance Index

Scenario/strategy	GPI	Grade of GPI
Benchmark	2.8638	V
Strategy P	3.9214 (+37.9%)	II
Strategy Q	3.5890 (+25.3%)	III
Strategy R	2.9923 (+4.5%)	V

Concisely, the positive effect of all proposed strategies (increasing load factor, adjusting bus frequency and fleet planning) in enhancing the green performance is in line with the findings of Carrese et al. (2012), Titos et al. (2015), Boren (2019), Teoh (2015) and Teoh et al. (2020). In particular, the resultant findings highlight that the developed framework could assist the bus operator to consider the respective environmental factor in operating EB. Thus, the bus operator would be able to gain a clearer direction especially in implementing a particular improvement strategy to enhance the green performance of EB operations. In accordance with the resultant findings, EB operators may attract more passengers (to increase load factor) by offering attractive discounted or seasonal bus fare. Besides, a reliable and good service of EB, in terms of the punctuality and comfort level, should be provided in order to retain the existing passengers. In addition, the operators may consider to do necessary adjustment on the bus frequency in order to meet the demand of passengers at a desired level. If necessary, heterogeneous EB with varying bus capacity can be incorporated to yield a greener performance. Concisely, the positive effect of all proposed strategies (increasing load factor, adjusting bus frequency and fleet planning) in enhancing the green performance is in line with the findings of Carrese et al. (2012), Titos et al. (2015), Boren (2019), Teoh (2015) and Teoh et al. (2020). In particular, the resultant findings highlight that the developed framework could assist the bus operator to consider the respective environmental factor in operating EB. Thus, the bus operator would be able to gain a clearer direction especially in implementing a particular improvement strategy to enhance the green performance of EB operations. In accordance with the resultant findings, EB operators may attract more passengers (to increase load factor) by offering attractive discounted or seasonal bus fare. Besides, a reliable and good service of EB, in terms of the punctuality and comfort level, should be provided in order to retain the existing passengers. In addition, the operators may consider to do necessary adjustment on the bus frequency in order to meet the demand of passengers at a desired level. If necessary, heterogeneous EB with varying bus capacity can be incorporated to yield a greener performance.

CONCLUSIONS

This paper deals with a green assessment and improvement framework in quantifying the environmental performance of electric bus operational system, by capturing numerous environmental factors, namely energy consumption, emission and noise. To the best of the understanding of the authors, this is the first study that incorporated AHP in performing the green analysis for electric bus. The developed framework should be beneficial to the bus operators to operate electric bus in a greener and better manner. In particular, the findings confirmed that the green performance of the entire EB operational system could be enhanced by incorporating effective improvement strategies. Besides that, the green performance of EB is relatively influenced by numerous components, namely operating route, load factor, bus capacity and frequency. In addition, it is important to note that the determination of green weightage may vary across the needs and preferences of the bus operator. In overall, the findings show that the EB with a greener performance turns out to be a promising alternative that can inspire green mobility.

Thus, future work may focus on how to apply the developed approach in solving EB optimization problems by considering the relevant operational constraints. Besides, further study may capture the element of uncertainty (e.g. traffic condition) accordingly for more relevant operational analysis.

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DECLARATION OF COMPETING INTEREST

None.

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