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Electric Light Good Vehicles in Singapore – An Economic, Environmental, and Operational Review

Mok Wei Yang[1]; Christopher Tan [2]; Maria Cecilia Rojas Lopez[3]

Abstract

The study examines the combined economic, environmental, and operational impacts of implementing electric light goods vehicles (eLGVs) in Singapore. Considering existing data and inputs from a specific logistic company in Singapore, lifecycle cost and emissions analyses were conducted comparing electrical and internal combustion engine (ICE) light goods vehicles (LGVs). In addition, a case study using a survey on operations was conducted targeting respondents with eLGVs in their fleet. Based on results, the importance of incentives, lower insurance costs, and global collaboration to promote eLGV adoption in Singapore and other countries are discussed. Findings indicate that, in Singapore's context and considering a 10-years lifecycle, eLGVs are economically advantageous, being approximately 11% cheaper than ICE LGVs. This can potentially reduce costs for companies and the savings are likely to grow with vehicle utilisation. Regarding the environmental impact, although eLGVs exhibit higher greenhouse gas emissions during production, their usage emissions over 10-years lifecycle are approximately 34.5% lower than ICE LGVs and are further reduced with usage, resulting in overall lower emissions. Operational challenges identified relate to eLGVs charging time and infrastructure. Findings contribute to the understanding of factors influencing eLGV adoption, offering insights for Singapore and stakeholders seeking resilient and sustainable transport solutions.

Keywords: Light Goods Vehicles, Electric Vehicles, Sustainability, Resilience, Emission Calculator, Singapore

[1] Singapore University of Social Sciences, email: wymok001@suss.edu.sg
[2] Singapore University of Social Sciences, email: christophertan005@suss.edu.sg
[3] Corresponding author, Singapore University of Social Sciences, email ceciliarojas@suss.edu.sg – ORCiD: https://orcid.org/0000-0002-4718-0649

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1. Introduction

Alternatives to slow down the rising global temperatures are being explored, many of them related to reducing the emission of greenhouse gases (GHG), particularly carbon dioxide (CO_2). In addition, nations are aiming to create resilient economies that can adapt to changes, overcome challenges, and remain viable amidst uncertainties, including those related to energy sources and environmental concerns. Among many alternatives, the usage of electric vehicles (EVs) is rising in popularity in many countries, including Singapore. Singapore is an island nation housing close to 7 million people in an area of 729 km² (DoS, 2022). Despite the high density, the country is recognised for its resilience and sustainable development, including efficient urban and transport layout and greenery (CLC, 2021; Lim & Tan, 2018; Rojas Lopez et al., 2020). The transport layout caters for passenger and logistics transport. Facilitating the movement of people mostly by public transport and cargo mainly using light goods vehicles (LGVs) (LTA, 2023c).

In 2021, Singapore has launched the Green Plan 2030. The plan focuses on advancing sustainable developments in the country. The plan has 5 pillars focusing on City in Nature, Sustainable Living, Energy Reset, Green Economy, and Resilient Future (GreenPlan, 2021). Herein, there is a vision of 100% cleaner energy vehicles, mostly EVs, in the country by 2040. The adoption of EVs aligns with efforts to reduce emissions, promote sustainable energy sources, and enhance Singapore's overall economic and environmental resilience. This study aims to assess and document how the adoption of electric light goods vehicles (eLGVs) in Singapore contributes to building a resilient economy, focusing on economic saving, reduced emissions, and operational adaptability. Considering publicly available data/information and some inputs from a specific company (referred to as Company M hereafter), lifecycle cost and emissions analyses are conducted comparing eLGVs and ICE LGVs. In addition, a survey on operations was conducted targeting respondents who already use eLGVs in their fleet, including Company M. While the survey presents a modest and straightforward case by analysing 25 responses, findings remain pertinent to the field and contribute to the understanding of adopting eLGVs in Singapore.

Much research reports the impact of eLGVs on the environment, cost (economy) and operations individually. This study examines all three aspects together and adds to the literature by discussing the findings in the context of Singapore's densely populated and urbanised areas. In such areas, the usage of green vehicles like EVs is crucial to ameliorate the negative impact of motorised transport. Additionally, the increased demand for logistics and deliveries has made using eLGVs for building a resilient city imperative. The study utilised methods that have been used in the literature and some of the findings are in line with trends in the field.

Notwithstanding, the study serves to document current trends and challenges in the adoption of eLGVs in dense urban areas and can be useful for scholars in sustainable transportation and urban planning. Findings not only help to confirm trends but also allow for discussion on how these can result in policies and points that scholars, researchers, and planners can consider to foster the usage and implementation of eLGVs. Following this introduction, some main findings from the literature related to city logistics and electric vehicles are presented. The parameters for the study, such as the local tax

structure, utilisation rate, fuel and charging price, and some other assumptions, are based on the Singapore context. These are further illustrated in the section following the literature review. The paper then outlines the study methodology and presents the findings. Afterwards, a discussion and recommendations section is included based on the findings. The study concludes with a summary that also highlights limitations and directions for future research.

2. Literature Review

Globally, the transport sector is reported to produce over 36% of the total CO_2 emissions, with most emissions coming from land transport – cargo and passenger (Ritchie et al., 2020; Sanguesa et al., 2021a; Statista, 2021). The usage of motorised vehicles in land logistics (cargo) is very common and has increased in recent years with the increased demand for products, online shopping, and home deliveries (Juan et al., 2016; Rojas Lopez et al., 2023; Yan et al., 2023). In city logistics, it is common to use vehicles with a laden weight between 3,500 and 7,000 kg, known as light goods vehicles (LGVs). Vehicles with a maximum laden weight of up to 3,500 kg are used in North America, Europe, and Singapore (LTA, 2023c; Singh & Mutreja, n.d.). In efforts for sustainability and resilience, some countries and companies have shifted from internal combustion engine (ICE) LGVs to eLG.

Electric vehicles (EVs) first appeared in the 19th century, and in recent years, there has been much research and efforts to adopt their usage in land transport, including logistics (INL, 2015; Sanguesa et al., 2021b). Known are green vehicles, EVs – including eLGVs, can contribute towards environmental sustainability and energy resilience by helping to reduce GHG emissions and dependency on fuels (Juvvala & Sarmah, 2021; Sanguesa et al., 2021a; Tabuchi & Plumer, 2021). In addition, EVs operate much quieter than internal combustion engine (ICE) vehicles; hence, they also contribute to reducing noise pollution (Aboazoum, 2022). EVs can also help to reduce costs. Although the upfront cost can be higher than an ICE, operational and maintenance costs are generally lower (Barkenbus, 2020; Leijon & Boström, 2022; Scorrano et al., 2021).

Research has indicated that the actual environmental impact of EVs depends on the mining of raw materials for lithium-ion batteries used in EVs, methods for electricity charging, and battery recycling procedures. In general, due to mining minerals required for the battery, more GHG are produced during EVs manufacturing as compared to ICE vehicles. The upfront higher carbon footprint can reach an emission breakeven point in EVs useable lifetime as emissions from usage are much lower (Aboazoum, 2022; Lienert, 2021). EV emissions relate to the power grid's carbon emissions; hence, the source of energy also affects how green an EV can be. The greener the energy sources, the greener the EVs (Barkenbus, 2020; EIA, 2022; Leijon &

Boström, 2022). It should be noted that several ways to measure and calculate emissions from EVs have been proposed and these can lead to different results (Neubauer et al., 2015; Saxena et al., 2015; Zimakowska-Laskowska & Laskowski, 2022).

Furthermore, there are some challenges related to the adaptation of EVs. Purchasing cost, vehicle range anxiety, limited selection of vehicles, difficulty finding technicians, and charging infrastructure/speed/price are often mentioned (Aboazoum, 2022; Leijon & Boström, 2022; Sanguesa et al., 2021b). Noticing that the challenges are mostly financial and operational challenges. Regarding range, the range of the EVs is affected when the battery capacity falls below 70% or, in some cases 80% of its capacity (Sanguesa et al., 2021b; Tabuchi & Plumer, 2021). This means that batteries must be retired or updated somewhere between that range. Research and industry reports have also indicated that EV battery degrades 1% to 2.5% per year (Han et al., 2019; Neubauer et al., 2015; Saxena et al., 2015). Therefore, the battery degradation is expected to most likely not exceed 25% at the end of the 10-year period. In view of the advantages of research and development, this degradation is expected to be even lower in the coming years (Adany et al., 2013; Neubauer et al., 2015).

3. Singapore Overview

Around 95% of Singapore's energy is generated from the cleanest form of fossil fuel, natural gas (Andres, 2023). The remaining 5% consists of more renewable energy alternatives, such as solar and regional power grids, with efforts to increase their usage further. By 2030, Singapore aims to generate a minimum of 2 gigawatt-peak of solar energy deployment (annual electricity need of 350,000 households) (GreenPlan, 2021). The country, committed to resilience and sustainable developments, is also moving towards becoming a car-light nation and minimising fuel dependency. Since 1990, to control the vehicle population, car owners have been required to pay for a Certificate of Entitlement (COE). The COE give rights to own and use a specific vehicle in Singapore for 10-years, after which a new COE should be obtained, or the vehicle scrapped. The COE cost works on a bidding system and applies to all types of vehicles (EVs and ICE vehicles). As of June 2023, the COE for prices ranges from SGD 121,000 to SGD 82,223 for different vehicles and SGD 10,000 for motorcycles (LTA, 2023b). As of June 2023, SGD 1 = USD 0.76 or EUR 0.67.

In Singapore, LGVs are pick-up trucks, vans, and small trucks, the majority of which (79%) are less than 10-years old. These are typically used for transporting and distributing consumer items, commonly involving a single collection point with multiple drop points (LTA, 2023c, 2023a). Most of them are diesel-propelled ICE vehicles. However, the population of eLGVs has grown exponentially from 97 units in 2020 to 1894 units in 2022 (LTA, 2023a). Moving towards sustainable transportation is a crucial step towards achieving the aimed sustainability and resilience in the country. There are government regulations and incentives to promote vehicles with lower carbon emissions. As part of the Singapore Green Plan 2030, there is a vision of 100% cleaner energy vehicles by 2040. For this, public buses and taxis are already being electrified, and EVs charging points have been installed, with the goal of having over 60,000 EVs charging points available at public and multi-story carparks by 2030 (GreenPlan, 2021). As of 2023, most businesses in Singapore do not have parking premises and may need charging stations; hence, operators often rely on public charging infrastructure.

4. Methodology

A combination of approaches was utilised to investigate the economic, environmental, and operational aspects of eLGVs to build a resilient economy in Singapore. Some of these have been used in the literature to measure the cost or emission of ICE vehicles and EVs in different countries. For the cost and environmental segments, existing data was collected from government web pages, vehicle dealers, and other reliable data sources in Singapore. In addition, a survey was conducted to gather information on the operational segment. The survey targeted existing eLGV owners and operators whose companies have adopted eLGVs in their fleets. Table 1 gives an overview of the information gathered and the related sources. In view of most LGVs in Singapore being less than 10-years old and the COE requirements, a lifespan of 10-years is used for the calculations. This is also appropriate in view of the battery's relatively minimal degradation (likely to not exceed 25%) at the end of the 10-year period.

For the economic and environmental factors, a total of 6 LGVs were considered and compared for this study using a lifecycle analysis. For ICE LGVs, Toyota HiAce, Nissan NV350 and Hyundai Starex (all diesel) were considered, and for eLGVs, Opel Vivaro-E, Foton Iblue V6, and Higer H5F were considered. These 6 vehicles have similar capacities for transporting and distributing consumer items (maximum laden weight of 3,500kg), and are commonly available in Singapore.

Table 1. Information gathered for this study.

Economic	Sources
Ownership Cost	
Vehicle price	Vehicle dealers' webpages
Certificate of Entitlement (COE)	Official webpage (https://www.motorist.sg/coe-results)
Road tax Additional Flat Component (AFC) Commercial Vehicles Emissions Scheme (CVES)	Singapore Land Transport Authority webpage (https://www.lta.gov.sg/content/ltagov/en.html)
Operation Costs	
Insurance	Company M records
Maintenance	National Environment Agency webpage (https://www.nea.gov.sg/)
Propulsion	Suppliers' webpages
Environment	**Sources**
Production stage GHG emissions	Power grid emissions (https://www.spgroup.com.sg/home); and
Operation stage GHG emissions	Energy Market Authority webpage https://www.ema.gov.sg/index.aspx)
Operational	**Sources**
Benefits of eLGVs adoption	Survey
Challenges of eLGVs adoption	Survey

By factoring in the costs presented in Table 1, the total ownership cost is calculated as shown in Equation (E) 1. Similarly, to obtain the operational cost, the insurance, maintenance, and propulsion (fuel or electricity) costs are added together (see Equation 2). Noticing that specific calculations are used for the annual propulsion costs, as shown in Equation 3. Literature has suggested that the factors considered in the calculation can indeed affect the adoption (or purchase) of EVs and these have been compared with ICE vehicles (Liu et al., 2021; Palmer et al., 2018; Wu et al., 2023). In the current study, the factors have been tailored and calculated based on the local context. The total ownership and operational costs are added together for the lifecycle cost analysis.

Ownership Cost = Vehicle Price + COE + Road tax + AFC + CVES (E1)

Operational Costs = Insurance + Maintenance + Propulsion (E2)

$$Propulsion\ Cost = EC_M \times cost\ of\ fuel/energy \quad \text{(E3)}$$

where:

*EC = fuel/energy consumed (**litres** for diesel vehicles or **kWh** for electric propulsion) or*

$$EC = \frac{M \times FC}{100}$$

M = annual mileage travelled (km)

FC = fuel/energy consumption rate (l/100km or kWh/100km)

For the Lifecycle Environmental Analysis, the focus was placed on the GHG emissions during the production stage and operations for both types of vehicles. The disposal stage of the vehicles is also known to affect the GHG emissions. However, the end-of-life handling of ICE and EVs and their impacts are not considered in this study due to the dispersity of the data in the Singapore Context at the time of the study. For the production stage, emissions are calculated differently for ICE and EVs. This study considers vehicle weight (VW) and the average manufacturing emission factor (MEf) for ICE vehicle production. This is taking reference from existing literature and using an average MEf for different types of vehicles (Hawkins et al., 2013; Pero et al., 2018). On the other hand, for EVs, the battery weight (BW) is deducted from the VW, and the battery capacity (BC) and battery emission factor (BEf) are considered as presented in Equations 4 and 5, respectively.

On the other hand, usage emission is calculated based on tailpipe emission per mile travelled (see Equation 6) and EC time power grid CO2 factor (see Equation 7) for ICE and EVs, respectively. This approach has previously been used by researchers (Pero et al., 2018; Zimakowska-Laskowska & Laskowski, 2022).

ICE Production Carbon Emission = Gross_VW x MEf (E4)

EV Production Carbon Emission = [(Gross_VW − BW) × MEf] + (BC × BEf) (E5)

where:

BW = Battery capacity x Battery Weight Factor

ICE Usage Carbon Emission = Tailpipe emissions × M (E6)

$$EV\ Usage\ Carbon\ Emission = EC \times Power\ Grid\ CO_2\ factor \quad \text{(E7)}$$

An ' expected lifecycle emissions calculator ' is developed using the mentioned variables and equations related to the environmental analysis. The calculator allows inputting critical variables (e.g., expected mileage, energy efficiency for different EV models, and grid factor) and returns expected GHG emission figures, helping companies compare various types of vehicles easily.

Finally, an online questionnaire was created and distributed for the operational review. Several logistics and delivery companies were reached and eLGV owners or operators whose companies have adopted eLGVs in their fleets were invited to complete the survey in their own available/free time. The survey was created following university ethical guidelines and possessed less than minimal risk to respondents. No personal data or identifiable information was collected in the survey to safeguard confidentiality and anonymity and gender/religious neutral vocabulary was utilised throughout. Survey data is analysed using descriptive statistics and by classifying open-ended responses by theme. The gathered information helped identify the operational advantages and limitations of adopting eLGV, and recommendations are given accordingly.

5. Findings

5.1 Economic Aspects of Adoption of EVs.

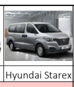
Related to LGVs ownership costs in Singapore, it was noted that the vehicle listed prices for LGVs are exclusive of COE and include the first six months of road tax, registration fees, and net carbon emissions scheme taxes.

Moreover, all the vehicles under consideration fall under the same COE category of goods vehicles and buses (Category C) (LTA, 2023b). Hence, the cost of COE is excluded from this comparison. For the Road Tax, ICE LGVs are subject to SGD 213 (diesel) and SGD 170 (petrol) bi-yearly (every 6 months), and eLGVs are subject to SGD 170 biyearly plus an Additional Flat Component (AFC) of SGD 190 annually (LTA, 2023d). Finally, the Commercial Vehicle Emission Scheme (CVES) for LGVs is banded based on their tailpipe emissions. Bands go from A (less emission) to C (most emission) and vehicle owners receive a one-time incentive or surcharge.

Band A vehicles (<123g/km CO2 emissions) receive an incentive of SGD 15,000, Band B vehicles (between 123g/km and 216g/km CO2 emissions) receive an incentive of SGD 5,000, and Band C vehicles (>216g/km CO2 emissions) are subject to a surcharge of SGD 15,000 (MOT, 2023). The total ownership cost is calculated using Equation 1. As seen in Table 2, the average ownership cost of the ICE LGVs is SGD 62,980, and the eLGVs are SGD 61,973.

Related to the operation costs, it was found that the cost of insurance for LGV varies. Based on Company M's records, the cost of insurance for an ICE LGV is approximately SGD 1,500 annually and between SGD 1,800 and SGD 2,000 annually for an eLGV (an average of SGD 1,900 was used in this study). It has been indicated that the average maintenance cost for an ICE LGVs is close to 8.75 cents/km and 5.05 cents/km for an eLGV (EERE, 2021). This indicates that eLGVs could reduce maintenance costs by approximately 40%, which is in line with previous research findings indicating that the average cost of repair and maintenance is lower on an EV than on an ICE vehicle (Aboazoum, 2022; Henry, 2021). To obtain the propulsion cost, the diesel and battery charging price rates and the LGVs mileage in Singapore were obtained and used in Equation 3. As of April 2023, the diesel price was SGD 1.78/litre (SmartEnergy, n.d.), and the average cost of battery charging was SGD 0.52/kWh (max SGD 0.56/kWh; min 0.45/kWh) (Low, 2022). It has been indicated that LGVs travel approximately 30,000km every year (Chan, 2023; PanPacific, 2021; Tan, 2014). Using Equation 2, operational costs were calculated. Similar to ownership costs, operational costs are also found to be overall lower for eLGVs as shown in Table 2.

Table 2. Lifecycle Cost Analysis.

						
	Toyota Hiace	Nissan NV350	Hyundai Starex	Opel Vivaro-E	Foton Iblue V6	Higer H5F
	Diesel (ICE)			Electric		
Ownership Costs						
Vehicle price	$ 54,900	$ 45,900	$ 50,999	$ 72,500	$ 69,800	$ 73,800
COE						
Roadtax (10 years) First 6-months paid by dealer * Diesel: $213 every 6 months * Electric: $170 every 6 months	$ 4,047	$ 4,047	$ 4,047	$ 3,230	$ 3,230	$ 3,230
Additional Flat Component * Diesel: NA * Electric: $190 per year - 1s year paid by dealer (Total 10 years)				$ 1,710	$ 1,710	$ 1,710
Carbon Vehicle Emissions Scheme Banding	*C*	*C*	*B*	*A*	*A*	*A*
CEVS	$ 15,000	$ 15,000	-$ 5,000	-$ 15,000	-$ 15,000	-$ 15,000
Total Ownership Cost	**$ 73,947**	**$ 64,947**	**$ 50,046**	**$ 62,440**	**$ 59,740**	**$ 63,740**
Average		$ 62,980			$ 61,973	
Operating Costs						
Annual Insurance Cost	$ 1,500	$ 1,500	$ 1,500	$ 1,900	$ 1,900	$ 1,900
Annual Maintenance Cost * Diesel: 8.37c /km * Electric: 5.05c /km	$ 2,511	$ 2,511	$ 2,511	$ 1,515	$ 1,515	$ 1,515
Tank/Battery capacity (L / kWh)	*70*	*65*	*80*	*75*	*50*	*50*
Mileage per full tank/charge (km)	*843*	*765*	*920*	*330^*	*195^*	*235/260**
*Fuel/Energy consumption *Diesel: litres/100km *Electric: kWh/100km*	*8.3^*	*8.5^*	*8.7^*	*22.7*	*25.8*	*20.3*
*Annual Fuel/Energy Consumed (30,000 km) *Diesel: litres *Electric: kWh*	*2,490*	*2,550*	*2,610*	*6,818*	*7,728*	*6,088*
Annual Propulsion Cost	$ 4,432	$ 4,539	$ 4,646	$ 3,564	$ 4,040	$ 3,183
Total Operating Cost (10 years)	**$ 84,432**	**$ 85,500**	**$ 86,568**	**$ 69,793**	**$ 74,547**	**$ 65,978**
Average		$ 85,500			$ 70,106	
Lifecycle cost	$ 158,379	$ 150,447	$ 136,614	$ 132,233	$ 134,287	$ 129,718
Average		$ 148,480			$ 132,079	
^World Harmonised Light Vehicle Test Procedure (WLPT); *New European Driving Cycle (NEDC) - average taken						

Combining the ownership and operational costs, the tabulation for the lifecycle cost analysis shows that the three eLGVs fared better than the ICE counterparts. The 3 ICE LGVs averaged SGD 148,480, approximately 12% more than the eLGVs' average lifecycle cost of SGD 132,079. This indicates that the cost savings achieved through eLGV adoption costs can improve a company's financial stability and flexibility during economic fluctuations, which are in line with the concept of creating a resilient economy. It should be noted that the literature presents mixed findings related to EV costs compared to ICE vehicles in different countries or even different cities. These are largely related to different taxes and incentives/rebates as well as gasoline and electricity costs (Das & Bhat, 2022; Liu et al., 2021; Palmer et al., 2018; Verma et al., 2021; Wong et al., 2010).

5.2 Environmental Aspects of Adoption of EVs.

At the production stage, the main difference between an ICE vehicle and an EV is the lack of an engine and the presence of large battery packs and an electrical motor in an EV. To manufacture a vehicle, the overall GHG emission is estimated to be around 5 kg CO2-eq/kg (Hawkins et al., 2013). Moreover, a 2017 study indicated that the GHG emission from battery production and manufacturing, including mining and refining, is between 150 and 200 kg CO2-eq/kWh (IVL, 2017). For this study, the midpoint of 175kg CO2-eq/kWh was considered. It should be noted that this emission could be further improved, in 2019, it was indicated that GHG emissions could be between 61-106 kg CO2-eq/kWh if clean, renewable energy is used to manufacture the batteries (IVL, 2019). Moreover, it was found that EVs typically achieve an average energy density of 0.154kWh/kg, as the cooling system and structure add weight but not capacity. Hence, the corresponding battery weight factor (average battery mass per kWh) is close to 6.5kg/kWh (Benveniste et al., 2018; Muelaner, 2022). Using the mentioned data and equations 4 and 5, the emissions from the production of the vehicles were calculated. From Table 3, it can be seen that the emissions from the production of eLGVs are more than double that of the ICE LGV, where most of the increase is from the production of the battery packs. This is in line with previous studies findings.

During the useful life of vehicles in general, emissions are mainly related to the mileage done by vehicles. Considering the mentioned average millage of LGV in Singapore (30,000km) and using equations 6 and 7, the useful life emissions were calculated. As presented in Table 3, the average emissions from the ICE LGVs useful life are around 61,700kg, while eLGVs are around 27,905kg. Combining the production and the useful life emissions, the overall lifecycle emissions were obtained. The eLGVs emit an average of 46,027kg, while the ICE LGVs emit an average of 70,242kg. This indicates that eLGVs are much greener, with an overall 34.5% less emissions than the ICE LGVs. Lowering carbon emissions through eLGV adoption is a step towards building an economy that is better equipped to handle possible environmental challenges and reduce the impacts of transport in climate change. Similar to costs, environmental findings comparing EVs and LGVs are mixed. Overall, there is a consensus on EVs having lower usage emissions than ICE vehicles (Kumar & Alok, 2020; Pero et al., 2018; Zimakowska-Laskowska & Laskowski, 2022). However, the emissions or pollutants related to the vehicles' manufacturing and disposal (which was not considered herein) process can be relatively high. This is mainly due to the chemicals and metals required (Barkenbus, 2020; Muelaner, 2022). In addition, there are also debates on the source of energy used to power EVs and how this affects overall emissions (Aboazoum, 2022; IVL, 2017; Sanguesa et al., 2021).

Table 3. Lifecycle Emissions Analysis.

						
	Toyota Hiace	Nissan NV350	Hyundai Starex	Opel Vivaro-E	Foton Iblue V6	Higer H5F
	Diesel (ICE)			Electric		
Emissions from Production						
Gross_VW (Unladen weight) (kg)	*1660*	*1800*	*1665*	*2025*	*1950*	*1900*
Tank/Battery capacity (L / kWh)	*70*	*65*	*80*	*75*	*50*	*50*
Estimated Battery weight				488.4	327.1	327.1
Emission from Production (kg)	8,300	9,000	8,325	7,683	8,115	7,865
Additional emission from Battery (kg)				13,125	8,790	8,790
Total Production Emissions (kg)	**8,300**	**9,000**	**8,325**	**20,808**	**16,905**	**16,655**
Average	8,542			18,123		
Emissions from Useful Life						
Fuel/Energy consumption per 100km * Diesel: litres/100km * Electric: kWh per 100km	8.3	8.5	6.5	23.3	24.1	19.2
Annual Fuel/Energy Consumed (30,000 km) *Diesel: litres, *Electric: kWh	2490	2550	2610	6818	7728	6088
CO_2 Emission *Diesel: g/km, *Electric: g/kWh	218	222	177	405.7	405.7	405.7
Annualised CO_2-eq Emissions (g) (30,000km mileage)	6,540,000	6,660,000	5,310,000	2,766,136	3,135,125	2,470,098
Annualised CO_2-eq Emissions (kg)	6,540	6,660	5,310	2,766	3,135	2,470
Total Useful Life Emissions - 10yrs (k	**65,400**	**66,600**	**53,100**	**27,661**	**31,351**	**24,701**
Average	61,700			27,905		
Lifecycle Emissions (kg)	73,700	75,600	61,425	48,469	48,256	41,356
Average	70,242			46,027		

With the formulas and calculations derived from the study, a calculator to estimate the expected lifecycle emissions of vehicles was derived and presented in Figure 1. Companies can input the vehicle specifications and expected utilisation (annual mileage) to compare the benefits to the environment of different vehicles. Parameters such as vehicle and battery production factor, battery weight factor, and grid emission factors can be amended.

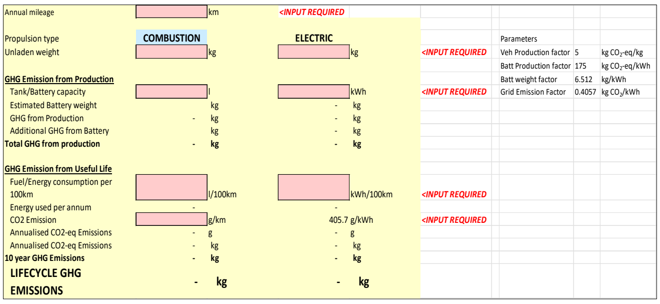


Figure 1. Vehicle emissions calculator.

5.3 Operational Aspects of Adoption of EVs.

A total of 25 respondents, owners or operators whose companies have adopted eLGVs in their fleet, participated in the survey. Noticing that, to the best of the authors' knowledge, there is an absence of specific information on the total number of logistics companies that own or operate electric vehicles in Singapore, limiting the ability to establish an appropriate or most suitable sample size. However, the modest sample size still provides valuable insights into the operational aspects of EVs and contributes to ongoing research in the field.

To gain some understanding of operational issues, respondents were asked about the strategies used for charging the eLGVs. For on-route charging, the operator deploys its fleet to fulfil its tasks, and charging occurs between shifts at on-road locations, such as public charging infrastructure. For the return-to-base strategy, the operator has charging infrastructure at the operation base and vehicles are charged outside their operating hours (Leijon & Boström, 2022). It was found that the majority (13 respondents or 52%) of operators take on a hybrid approach of both on-route and return-to-base charging. This could be related to the flexibility of the hybrid approach whereby the charging schedules are based on situational conditions. Moreover, 6 respondents (24%) reported using the return-to-base strategy. It is probable that these operators have direct or easy access to charging stations. The same number of respondents (6 or 24%) reported using the on-route charging strategy, where charging occurs along the way.

Moreover, respondents were queried on four (4) factors that encouraged EV adoption in the operators' fleet using a 5-points scale as presented in Figure 2. Overall, respondents acknowledged that environmental benefits prompted the adoption of eLGVs (3.76). However, it is observed that there is more focus on financial aspects, such as cost savings (4.20) and government incentives – which are mostly related to economic incentives (4.20). Customer demand was the less popular factor affecting EV adoption (3.44). Answers indicate that, from a business standpoint, economic considerations are the main factor guiding the decision-making process. This is in line with the general trend indicated in the literature. Much research has indicated that, while environmental considerations are relevant (Das & Bhat, 2022; Kumar & Alok, 2020; Sanguesa et al., 2021), the financial benefits or incentives play a critical and often decisive role in incorporating, not only EVs, but newer technologies in general (Adnan et al., 2017; Coffman et al., 2017; He et al., 2022; Patil, 2020; Wu et al., 2023).

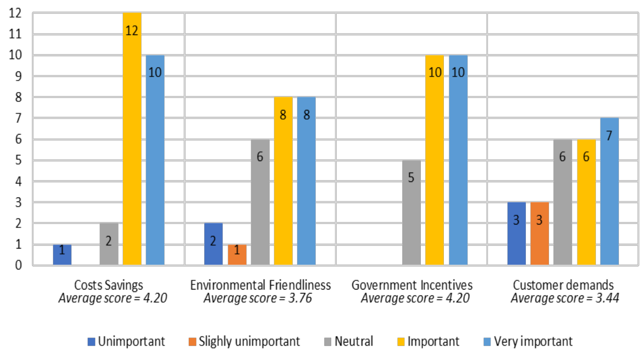


Figure 2. Factors that encouraged EV adoption in the operators' fleet.

Respondents were also asked about the operational challenges they faced. They were presented with four (4) common challenges and asked to rank them using a 5-point scale, these are presented in Figure 3. Responses indicate that the availability of charging infrastructure is perceived as the greatest challenge for current EV operators (4.04). At this time, many operators do not have to charge facilities in their compound; hence, they must rely on public charging infrastructure, which can affect their operations. The availability of charging stations (or lack of it) has been previously mentioned in the literature, in many cases related to public charging infrastructure (Coffman et al., 2017; He et al., 2022). Increasing the number of available charging stations has been linked with increased adoption of EVs. Singapore has been taking active steps to increase the number of charging stations, as previously described. Secondly, charging time was also recognised as a common challenge (3.92). The downtime incurred to charge eLGV can result in businesses losing operational opportunities or affecting daily operations. This was followed by the range of vehicles, which was identified to pose occasional challenges to operators (3.33). With EVs, operators must be mindful of route planning based on battery capacity. Finally, the vehicle load capacity, while still a concern, was the less commonly mentioned challenge for EV adoption (3.13). Largely, eLGVs have a slightly lower payload capacity as compared to ICE LGVs.

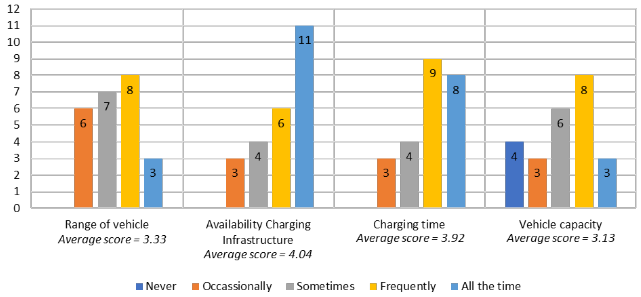


Figure 3. Challenges faced on EV adoption.

Interestingly, however, almost all respondents (22 or 88%) reported that no changes to their operational strategy were made with the adoption of EVs. Respondents who did make changes elaborated on them, and the following was found:

- More effort is invested in eLGVs route planning (due to battery capacity and charging downtime);
- Checks on eLGVs battery levels before the start of operations have been implemented, and
- Changes in eLGVs parking locations (eLGVs need to be parked at business/charging premises for charging while ICE LGVs can – and often are – driven to drivers' homes)

Finally, respondents were asked about their perception of common barriers hindering the wider adoption of eLGVs in the commercial/industrial sector. In line with current challenges, the top 3 reasons include low availability of charging infrastructure, costs, and range of vehicle, with 22, 13, and 11 respondents out of 25 selecting them, respectively. In all, eLGVs, can provide operational flexibility and have the ability to adapt and navigate urban environments, hence contributing to business resilience.

6 Discussion and Recommendations

The economic review of eLGVs vs ICE LGVs using a lifecycle analysis revealed that eLGVs are around 11% cheaper overall than ICE LGVs, considering ownership and operation costs. It should be noted that the ownership cost is only 1.6% cheaper for eLGVs, and the most difference is found in the operating cost (18% cheaper for eLGVs), showcasing a potential alternative to alleviate or overcome economic challenges and fluctuations constantly faced by companies and the logistics sector. Such financial stability and flexibility can help to increase overall business resilience. This is taking into consideration 10-years of usage with minimal battery degradation. Much of the lower ownership cost is related to lower road taxes for EVs, as well as the CVES in Singapore, which favours vehicles with lower emissions by providing incentives. The government can consider further advertising these costs so that people are aware of the financial benefits that adopting an eLGV can bring to their company and shift current modes of transport in support of sustainable choices. Other countries (or cities or states) that are looking at promoting the usage of EVs, should take this learning into consideration and consider revising existing taxes and/or rebates and implementing some that favour the usage of such vehicles. This could motivate people to shift to greener vehicles, leading to several benefits overall.

Moreover, noticing that insurance costs are higher for eLGVs, insurance providers could work towards offering more competitive rates for EVs to encourage their adoption. Also, as indicated by previous research and confirmed in the case of Singapore based on this study, the maintenance costs for EVs are lower. Companies should be made aware of this fact associated with eLGVs so they can be encouraged to add them to their fleet and improve their revenue while demonstrating a strong and adaptable economic strategy. These points apply not only in Singapore but could be considered globally. It is imperative for companies to collaborate and promote the usage of EVs globally. This could be facilitated by providing accessible insurance and highlighting low maintenance of the vehicles.

From the environmental perspective, the lifecycle emission review indicates that eLGVs perform better than ICE LGVs, with 34.5% less emission over a 10-year lifecycle. Highlighting that much more emissions are generated during the production stage of eLGVs (52.9% more than ICE LGVs). However, emission production during eLGVs' useful life is 54.8% less than ICE LGVs' emissions. Shifting to eLGVS can help reduce the company's overall carbon footprint and the country at large, showcasing a larger-scale resilient strategy to handle environmental challenges and mitigate climate impacts. As mentioned, GHG emissions from battery production vary depending on the sources of energy. Singapore is investing in enhancing its environmental resilience by reducing energy/fuel dependence. This is reflected in the development of sustainable energy sources as well as in research efforts to enhance battery production technology. This can potentially result in even lower emissions from eLGVs manufacturing, supporting the country's environmental objectives. Related to useful life emissions, the literature review has indicated that the breakeven point for EVs when using hydraulic energy is close to 14,000km, and close to 127,000km when using coal to produce energy, as in Singapore. Herein, the breakeven point can be shortened with the shift to Singapore towards cleaner energy sources. Nations with greater access to hydraulic energy should leverage this and promote the usage of eLGVs or EVs to reduce traffic-related emissions. The millage considered in this study is 30,000 km per year, with the increasing demand for deliveries, it would not be surprising if overall millage for LGVs is further increased. This mileage might already be higher in larger countries where delivery vehicles travel longer distances. The increased millage would result in even lower emissions from eLGVs as the breakeven point will most likely be surpassed.

Findings from the operational review indicated that charging infrastructure is a key concern among operators. This can be related to businesses in Singapore relying on public charging infrastructure and is likely to be alleviated when the 60,000 charging stations are completed in 2030. While charging infrastructure and time were mentioned as relevant concerns, 84% of respondents reported not having made operational changes when introducing eLGVS into their fleets, suggesting companies' adaptability to technologies such as eLGVs. This could be because the range of eLGVs is sufficient for the entire day. An annual mileage of 30,000km over 260 working days a year gives an average of 115km per day. The range of the eLGVs is from 195km per full charge and above, way above the daily average of 115km; hence, the range from a full charge should not impede the day-to-day operations. However, vehicles must be charged during non-operating hours to ensure a full charge for the following day's work. The adoption of eLGVs is not only a sustainable choice, but also a resilient one that can help companies adapt to disruptive trends in the supply chain, regulatory challenges, and shifting consumer preferences towards sustainability – which in the longer term can contribute to the overall resilience of Singapore's economy. This might be different in larger countries, where – as mentioned previously – vehicles might travel longer distances. In such cases, charging during operations or some downtime during the shifts for charging should be taken into consideration. Companies should assess their day-to-day operations and do some additional planning for efficient and uninterrupted EV usage.

On a general level, conducting awareness campaigns to educate individuals and companies about the benefits of owning and operating EVs, especially for logistics, is crucial. More companies, in the local or international context, could follow the example of Company M and integrate eLGVs into their fleet if success stories and testimonials are shared, further supporting resilient adoption. EV owners can showcase the advantages of such vehicles, including the lower lifecycle costs and emissions. Singapore should continue its research and development efforts to enhance the affordability and performance of EVs in general, as well as its components (e.g. batteries). Collaboration with international companies and research centres is of key importance for streamlining the process. By working across borders, the best expertise and resources can be leveraged to achieve goals efficiently. This can help to reduce not only the cost but also the EVs' associated emissions, hence having an overall positive environmental impact. Herein, different stakeholders, including government bodies, vehicle manufacturers, and industry players, need to cooperate to collect data and concerns on eLGVs. Stakeholders should also pool resources to create comprehensive policies and strategies that support the growth of the EV ecosystem, considering specific regional contexts and regulations. The goal should be to develop and promote strategies to encourage the adoption of EVs and address concerns for resilient and sustainable transport advancement in Singapore and globally.

7 Conclusion

The study presents an economic, environmental, and operational review of adopting commercial eLGVs in Singapore. Lifecycle analyses were conducted for the financial (ownership and operating costs) and environmental (production and useful life emissions - propulsion) components, and a survey was conducted on the operational aspects of adopting EVs. The study methodically collects data and presents it in a structured and systematic manner, contributing to scholarly knowledge in the Singapore context related to EVs and eLGVs in particular. The discussion highlights how EVs and eLGVs in specific can contribute to Singapore's resilience and presents possible learning points for other countries looking to build resilience. For the economic and environmental review, three ICE LGV and three eLGVs, all with minimum payloads of 1,000kgs and maximum laden weight of 3,500kg, were compared. Considering Singapore's COE scheme and average life of vehicles, 10-year lifecycle calculations were used, assuming minimal battery degradation for eLGVs. A mileage of 30,000km per year was estimated for the vehicles and analysis under consideration.

Overall, it was found that eLGVs have lower costs (11%) and emissions (34.5%) as compared to ICE LGVs. As of 2023, Singapore offers many incentives and rebates, making eLGVs cheaper. While companies are expected to receive financial benefits for adopting eLGVs, consideration on incentives at the moment of acquiring the vehicle should be taken into consideration. This is particularly important as for the operational factors that encourage the shift to eLGVs, survey participants for this study indicated financial savings as the main factor. For the environmental aspects, while emission is lower for eLGVs, it is critical to note that there is a breakeven point where the eLGVs become "greener" than ICE LGVs. Low utilisation – mileage - of the vehicle can result in overall eLGV emissions being higher than ICE LGV emissions, which is due to the high emission during the production stage of eLGVs. On this line, an emission calculator is presented in this study for companies to compare emissions across different vehicles easily, aiding in the development of effective resilience strategies. On the operational aspects, it was found that the biggest challenge is related to charging infrastructure. Vehicle range due to battery limitations was also mentioned as a concern, yet most operators did not have to change their operational planning.

Based on findings, it is suggested that companies in Singapore should consider switching to eLGVs and maximising their utilisation so more benefits can be derived. In addition, some recommendations to foster the adoption of eLGVs in the country and internationally are given. This research is not without limitations. First, the end-of-the-life emission of vehicles was not considered as sound data regarding the different vehicles was not available/accessible. Then, the emissions from the production of different vehicles vary broadly, while a deemed good average was considered in this study, more in-depth research on production emissions can help to strengthen the results. Future research can investigate including more depth into these two factors so that a standardised methodology for calculating emissions can be established. This could be considered in the local and international context for consistency and comparability of results. Finally, while the survey has helped to shed light on operations, the sample size is limited. Expanding the sample size and conducting a similar survey in other countries shall be considered in future research. Specific contexts and regulations in different countries shall be reviewed, and recommendations presented accordingly.

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