Future Energy
Open Access Journal
ISSN 2832-0328

August 2023| Volume 02 | Issue 03 | Pages 38-48

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.2.3.5

Future Publishing LLC

Review

The feasibility and analysis of electric taxi vehicles in Singapore: A review

Rehan Khalid, Vishtreet Conjobeeharry, Abdullah Saif Sanai, Chelward T. H. Brown, Hadi Nabipour Afrouzi*, Ateeb Hassan

Faculty of Engineering, Computing and Science, Swinburne University of Technology Sarawak, 93350 Kuching, Malaysia

ARTICLE INFO

Article history:
Received 02 December 2023
Received in revised form
12 January 2023
Accepted 18 January 2023

Keywords:
Electric taxis, Transportation, Feasibility, Analysis, Singapore

*Corresponding author
Email address:
HAfrouzi@swinburne.edu.my

DOI: 10.55670/fpll.fuen.2.3.5

ABSTRACT

Taxi is one of the essential ways of transportation, which contributes to the depletion of non-renewable resources, congestion, emissions of harmful gases, energy consumption, and noise pollution. One way to reduce the environmental pollution caused by the road transportation system is to replace conventional and hybrid vehicles with pure electric-driven powertrains. In fact, EVs were announced as the key element in the sustainable transport strategy in urban areas, but the company operating transport services using vehicle fleets should increase the demand for electric vehicles to spread awareness. This paper reviews the feasibility of EV taxis in Singapore by analyzing the available infrastructure and energy prices. To introduce the electric vehicle in Singapore as an electric taxi, the construction along with the location of charging infrastructure need to be properly planned. Initiatives taken by different countries and the large-scale transition have also been reviewed. Despite the drawbacks of battery electric vehicles (BEVs), such as charging inconvenience and limited range, promising potential for EV taxis has been presented by the technological progress This paper also compared different aspects of the currently used taxis with EV taxis in Singapore. For the augmentation of this transition, improvement of the business model, dissemination of charging infrastructure, and policy support can play a vital role.

1. Introduction

Singapore contributes about 0.14% to global carbon emissions, but considering its relatively small population size, its average yearly emissions per capita is about 8 tons. In 2016, an average of 7,214,000 people used public transport in Singapore daily. Of that, 954,000 people commuted by taxis. The MRT, which is the most frequently used form of public transport, is already powered by electricity. To continue to reduce the emissions of CO_2, the team believes in electric taxis because electric cars have a smaller carbon footprint than ICE cars. In Singapore, currently, transport contributes to 14% of CO_2 emissions, which amounts to about 7 million tons of CO_2 [1]. The dependency of road transport on oil can deplete these non-renewable resources, and the pollution from these conventional vehicles causes different kinds of health problems. This is the reason why there should be an alternate way of lowering carbon emissions and dependency on oil. The usage of biofuel, electric powertrains, and improved versions of current vehicles are the three solutions that can be considered to tackle this issue. As the number of people is increasing, zero carbon emissions and dependency on oil seem like a long-term effort. For this situation, EV is the solution that satisfies the conditions. Only an electric motor powered by a battery and charged when not in use is the simple principle of operation for EVs. They are quite efficient, have a high acceleration, and can be charged at low-cost overnight [2]. These vehicles are operated with the help of batteries that can store high energy and, at the same time, need a large amount for the charging requirements with the use of a grid or renewable resources. During peak hours, it's not recommended to charge the batteries, which in the end, impacts the life of the transformers [1]. As the industry and the Government greatly boosted the development of EVs, these vehicles are thought to be prevalent soon. The notion of replacing general petroleum cars with EVs includes the following reasons: 1) EVs make zero emissions of carbon dioxide, which fits the green trend in saving the environment, 2) The energy efficiency of EVs is high, 3) Lower running and maintenance costs. Different sectors have shared the effort, and 95% of the emission is expected to reduce by the road transport sector. With these rising numbers, it is imperative that sustainable alternatives to transport need to be explored. The first company to launch electric taxis in Singapore is HDT Singapore Holdings. In 2016, Land Transport Authority (LTA)

awarded the Taxi Service Operator License for ten years. In early 2017, they launched their first hundred taxi cars on the road. Their fleet is composed of BYD e6 cars only, which is a fully electric cars. HDT taxi was on a trial basis for eight years. This pilot project is part of Singapore's EV Phase 2 Testbed, which is in collaboration with the LTA and the Economic Development Board (EDB). This trial is performed to study the viability of the electric taxi in the Singaporean land transport network. They needed to increase their fleet up to eight hundred cars, as required by the authorities. The company fulfilled this requirement by adding two hundred vehicles every year for the next four years after their establishment. By July 2022, it is expected to have this requirement fulfilled. HDT partnered with Grab company and provided thirty cars that were to be used for e-hailing services. Further research is still in-process in Singapore, by the Research & Development center and in collaboration with local research institutes [3]. The second taxi company to launch electric taxis is ComfortDelGro. In July 2018, two Hyundai Ioniq Electric was released for trial by the company. Then, in January 2019, they introduced two units of the newer Hyundai Kona Electric for trial. The Hyundai Kona Electric has a 64-kWh lithium polymer battery and offers a longer range than that of the Ioniq Electric. The trial will evaluate the roadworthiness of the vehicle, like the electricity cost, maintenance, mileage, and battery durability. The purpose of this article is to review the feasibility of EV taxis in Singapore and evaluate whether the transition from taxis to EV taxis is economically, environmentally, socially, and ethically feasible. The current situation, types of public transport, energy prices, and measures that should be taken to supplant conventional taxis (IC and hybrid) with EV taxis will be reviewed. Previously, many researches have been done on the technical aspects of EVs, but the feasibility and commercialization are hardly addressed. Therefore, the review of the feasibility of EV taxis is substantial.

2. Feasibility of Electric Taxi Vehicles in Different Countries

2.1 Feasibility of EV Taxis in Malaysia

The current conditions in Malaysia are not favorable for an electric taxi fleet. Electric taxis require many charging points to be viable in a city. In Malaysian cities, there are not many places where electric vehicles can be charged. There are only 257 charging points in the whole country. Most of these charging points are found in the states of Kuala Lumpur and Selangor. Each charging point would serve an average of 74 km^2 in Selangor and 5 km^2 in Kuala Lumpur. This is a decent number. The situation is far worse in other states like Sabah, with zero charging points, and Sarawak, with only 4 charging points for an area of 120 000 km^2. Finally, there is not much support from the Malaysian Government like tax breaks. So, to drive an electric vehicle it would cost as much (or more) as any internal combustion engine. Moreover, the buying cost of a conventional car is very affordable to the crowd; for example, the cheapest petrol car in Malaysia, a Perodua Axia, manufactured in Malaysia itself, costs only RM 24,000, whereas a Nissan Leaf, currently imported from Japan and sold in Malaysia at RM 188,888, will not appeal and be feasible to the taxi owners or companies, due to their income or salary, and the high initial buying cost [3]. Economy-wise, Malaysia does not have a huge hand in generating electricity from renewable sources of energy, and electricity is mostly generated by burning coal, and coal is imported from foreign countries, so shifting to electric taxis will have a huge impact on the economy when it comes down to the decision of buying more coal. Another point to note is that conventional cars are locally manufactured, so the cost of import, shipping, excise duty, and others are rather inexistent or very less, as compared to the electric cars, which are all imported to be used as electric taxis. To make the shift happens, electric cars should be locally manufactured to make them more accessible to the taxi population.

2.2 Feasibility of EV Taxis in South Korea

Unprecedented efforts have been made by South Korea in the transition of commercialization of conventional vehicles to EV taxi services. On 6th September 2013, a pilot test of Electric vehicle taxis was inaugurated in Daejeon city. This was the first test of its kind that was performed for the analysis of the feasibility of EV taxis before introducing it to the commercial level. The vehicles adopted to perform the test were three SM3 ZE's (Renault- Samsung Motors). In 2014, as a result of this test, about 500 IC taxis were replaced by Electric taxis [4]. According to the results of a study performed by Baek, Kim & Chang 2016 on the feasibility of EV taxis, there is a possibility of real mileage higher than the calculated for EV taxis. This is because in the pilot test, the vehicles that were considered were not sharing charging infrastructure and were operated independently by the companies. The feasibility of EV taxis would be even higher if the selected cars were provided access to localized charging stations. Moreover, the average value of the benefit to cost analysis (B/C) enhanced to 0.7 and consequently making the EV taxis feasible. Following is the formula that was used to calculate the B/C ratio for EV taxis:

$$\frac{B}{C} = \frac{\Sigma_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\Sigma_{t=0}^{n} \frac{C_t}{(1+r)^t}} \quad (1)$$

Where B_t is the benefit in the year t, C_t is the cost in the year t, r is the discount ratio, and n is the project duration.

2.3 Feasibility of EV Taxis in Canada

Another study was performed by Darcovich [5] using real-time driving data and running battery life simulations on the appraisal of the feasibility of EV taxis. Performance targets for the EV simulations were obtained from the driving patterns of single and double-shift gasoline taxis. The data obtained from this study depicted that driving distance is set to 151 km/day for single shift and 298km/day for a double shift to get the results. As per the simulation results, 89% of the reference driving was met by a single-shift taxi in a 6-year period. Whereas there was a need of mid-shift charging in double shift. The only drawback is the loss of revenue by a small percentage of distance, but it can easily be compensated by decreasing the operational costs. Moreover, it was observed that degradation of battery is excited by the annual driving distances as compared to charging speed. In

conclusion of this study, EV taxis for both single and double shifts were economically and operationally feasible [5].

2.4 Feasibility of EV taxis in China

Beijing, the capital of China, has the largest fleet of EVs with registration of around 46000 taxis. In 2011, the authorities in Beijing decided to reduce carbon and other harmful emissions by introducing electric taxis. A program was introduced by the authorities to increase the purchase and usage of electric cars around the city by co-financing approximately 370 euros per month on the purchase. With this, nearly 10% of the city's parking is being selected only for electric vehicles by the Beijing anti-pollution drive. The same process is followed in another city Shenzhen, where in 2010 only 40 taxis were used, then increased to 800 in 2013 [6]. In 2010, Tokyo did an experiment with switchable batteries in EV out for three months before implementing it. For this test, three Nissan Rogue were converted to electric vehicles to examine how long it travels on a full battery and how long it takes to swap the battery with a fully charged one. After successfully completing the experiment, it was applied in Tokyo's electric taxi company, which saves time for charging, as the typical mileage of one taxi is around 300 km daily.

2.5 Feasibility of EV Taxis in Europe

The great number of charging stations in Oslo is the main reason for having a high number of electric vehicles. These visible stations reduced the anxiety of people getting worried about the lack of charging facilities. In 2014, 1000 more charging stations were built of which 700 for public and 300 for private usage. Then in 2015, the expansion of this project was carried out by adding 400 more stations for public use of the climate and environment funds. Moreover, the people were given the exemption of VAT of (25%) on any new vehicles, no fee for first-time registration, allowed to drive in any lanes, including the one reserved for taxis and buses, free from toll roads, can park their vehicles for free at any spot in public parking. Development of a strategy for sustainable transport, the environmentally friendly solution provided, was implemented by the Poznan city authorities, which increased the number of vehicles still 6000 around the Polish roads [7]. In 2008, a company known as a Better place in Europe proposed the development of electric vehicles, by providing the services and network necessary for it and to eliminate the barriers which stop the development of EVs on a national scale. However, in 2013, because of this action taken by Better place, the range of services and infrastructures offered was wide. Installation of a network of charging stations was carried along with embedded energy monitoring, route planning system, and support, which calculates the vehicle range and guides the driver to the available spot for charging. Then finally, the network software was designed that monitor the battery and its need in order to anticipate energy demand, have real-time communication with the grid operators, and implementation of intelligent charging to avoid peak time and offset the intermittency of renewable energy sources. Car clubs were introduced to mainly urban drivers, where they can borrow the EVs on display if needed and pay for that time. This facilitated the urban driver without paying insurance and maintenance of the car, but to use irregularly. This technique was adopted from a car show known as Yélomobile in La Rochelle, France, which was carried in 1999 for a monthly subscription or €7/h for BEVs. Along with this, the second option was also introduced of renting a car for appropriate range, and during the trip their vehicle can be swapped with BEV.

Local policies came into action, which have a crucial weight in the expansion of BEV, after the car show developed at a city scale. The buyers were granted 25% of the vehicle's cost or a max of 5000 pounds from the Government. Other positive steps taken by the local policies provided the EVs a great advantage, like the road tax reduction which is based on the amount of carbon emissions produced. Increase in diesel and petrol tax, which brought the people towards EVs. Parking fee reduction according to the driver's habits is beneficial for some users. Some preferential parking spots having charging points is implemented. Around 30,000 charge points have been installed in 11000 different locations around UK. Alone in London, 5000 rapid charging stations are there, which allow fleet operators, taxi drivers, and freight to quickly charge. Nevertheless, planning is done for an additional 2700 charging stations near the residential area in London to facilitate drivers who cannot charge at their homes. Now, after providing people with benefits, the growth of EVs went from 3586 in 2013 all the way to 37092 in 2016.

The strategy for Norway was different, as approximately 73% of the population lives in row houses, detached or semi-detached houses, and family house, charging opportunity is available for them, and thus from the data, it was not considered important to build infrastructure for charging station, but planning is done to provide a high-speed charging facility which is more relevant, but not important from selling point of view. A one-year membership is awarded in the EV association, mostly to those who are among the EV purchasers. Norway has placed some tools and policies in hand to speed up the growth and make space in taxi companies for electric vehicles. These were the seven different roles, excluding the infrastructure of charging stations, which motivated the people to buy EVs; exemption from VAT, exemption from purchase tax, exemption from road tolling, free ferry tickets, bus lane access, reduction in the fee of vehicle's license and free parking. Around 11,500 electric vehicles were registered in Norway during the first three months of 2019, which is added to the previous count of 200,000. Although charging points were not needed, more than 10000 charging points were built to provide people with an additional benefit. From these charging points, 400 are rapid and semi-fast charging points [8].

A study was performed by Bischoff & Maciejewski on a transition of Berlin taxis to BEV's fleet. According this study, it will take substantial effort to make this transition using the infrastructure that is currently available and requires executive and fiscal support. As per this study, there is a need for the installation of one 50-kW level 3 or 4 chargers for ten taxis. It was also concluded that peak energy consumption and usage of the charger would occur in Winter term operations. As per the driver's viewpoint, this state of the art technology can only be efficient if concessions are given for the battery life by reducing the energy costs expressively, and finally by subsidizing the service [9].

3. Feasibility Analysis in Singapore

3.1 Public transport in Singapore

Singapore is a city-country, which is situated below Malaysia, and houses 5.3 million inhabitants [10]. It has among the best public transport in the World. They offer a wide array of public transportation, from buses, taxis, LRT to MRT. Buses are the most convenient option for public transport, as they can cover every part of the island, compared to the transit services, which operate on rails that run in high traffic and certain neighborhoods only. MRT is also widely used as a mode of public transportation since it can transport a large crowd at one time and avoid road traffic congestion. It is also faster than buses and taxis because they do not run on roads; they have their own rail tracks built underground or overhead, and they only stop at their stations, and they have a higher traveling speed than buses. The downside of MRT is that its network is not extensively spread across the island and is only available in popular and frequented areas. Figure 1 shows the average passenger trips per day by the different modes of public transportation for 2016. In 2013, the Singaporean Land Transport Authority (LTA) focused in the public transportation sector, and according to their study, 63 % of all peak-hour trips were made by public transport [10].

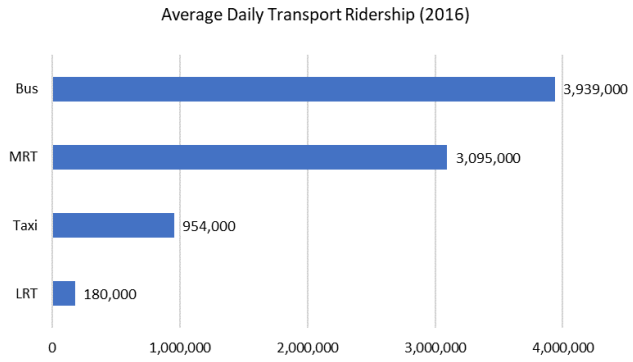


Figure 1. Average daily transport ridership [11]

However, same as every country got its own taxi network to serve as public transportation, Singapore has also its taxi service. Taxis are very popular across the globe because it provides transport service to the population with greater speed, comfort, privacy, ease, and convenience. Its advantage over bus is that it does not run on a fixed route, so it can pick and drop the customers at any requested location or at their doorstep. They operate 24 hours and overnight. Taxi drivers are very professional and experienced drivers, as they have a different driving test compared to a normal driver, and they are familiar in the region. They know the roads and the traffic conditions on the tip of their fingers. Some taxi companies offer different types of vehicles, from standard passenger cars to luxurious cars and limousines, and disability, wheelchair-accessible and pet-friendly vehicles [12]. According to Statista (2020), there are 18,542 taxi vehicles registered and circulating around Singapore for 2019 [13]. Taxis represent 3 % of the vehicle population in Singapore and are responsible for about 15 % of the overall mileage driven. The need for electric taxis is to reduce carbon dioxide emissions and go towards an environment-friendly form of public transportation [10]. Nowadays, there is an increased in popularity in ride-hailing services, like Grab and GoJek. This type of transport makes use of an online platform, like a website or a smartphone application to connect the passenger and the driver in the vicinity. Unlike taxi services, where they use taxi registered, licensed, and regulated vehicles and drivers, this service operates by local drivers using their own personal vehicles. This cuts the costs of registration, license and insurance occurred with a registered taxi vehicle, and it is convenient to both drivers and passengers. It provides a cheaper fare compared to traditional taxi service. Even with the introduction of ridesharing/hailing or e-hailing services, taxis still play an important role in modern society. Taxis are the go-to transport for elderly and disabled persons, especially for those who are not exposed to smartphones and the internet. Some tourists still prefer taxis as they can negotiate with the taxi drivers for tours and visits around the island and ask for recommended hotels and eating places. In that sense, it is more convenient for tourists who want this kind of traveling experience. Some data for the densities of taxis per person and the flag-down and mileage fees for the first kilometer in the different cities are shown in Figure2.

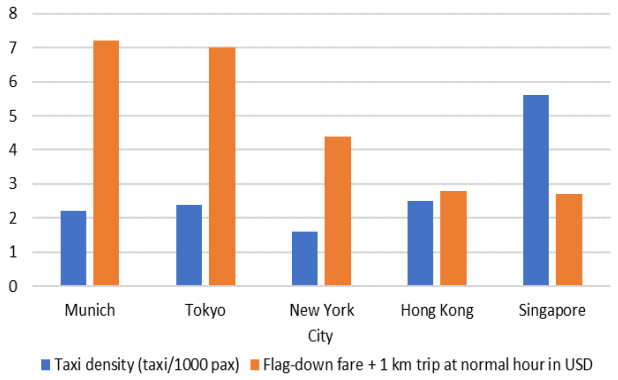


Figure 2. Taxi density and flag-down fares for different cities [10]

From the above chart, Singapore has the highest taxi density and the lowest flag-down and first 1 km fares among the other cities listed. This is because the Land Transport Authority required 65 – 70 % of the taxi fleet to be on the road back in 2013. In 2014, they changed the law. They required 70 % of the taxi fleet to drive 250 km per day, which required around 8 to 9 hours per day, six days per week.

3.2 Taxi networks and companies in Singapore

Eight taxi companies operate taxis in Singapore: Comfort Transportation, CityCab, Yellow Top Taxi, SMRT Taxis, Trans-Cab Services, SMART Automobile, Premier Taxis, and Prime Taxi [14]. Figure 3 shows the taxi stops (stands) spread across the whole island. There were 270 taxi stands/stops in the whole island for the year 2013, according to data.gov.sg [15]. Taxi operates by the shift systems. The one-shift taxi has one driver and drives around 347 km in a day. The two-shift taxi has two drivers who cover 260 km each per shift, which totals to 520 km in a day. The two-shift taxis are always on the road and only stopped when needed, that is for refueling, washing,

or changing driver. Table 1 shows the taxi population of different companies up to December 2017 [16].

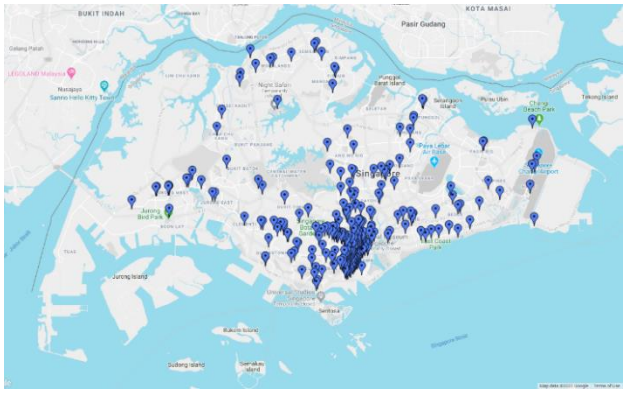


Figure 3. Land Transport Authority (LTA) Taxi Stops island-wide [17]

Table 1. Monthly Taxi Population by Company [16]

Month	Company	No. of Taxis
2017-12	Comfort	9,825
2017-12	CityCab	3,419
2017-12	TransCab	3,686
2017-12	SMRT	3,380
2017-12	Premier	2,055
2017-12	Prime	691
2017-12	Individual Yellow – Top	84

3.3 Energy prices in Singapore

In Singapore, oil and gas prices have been high for many years ago. This is because Singapore needs to import crude oil from overseas. The amount imported is more than it produces in its own country. Also, if the petrol is coming from outside, transportation is required to bring oil to Singapore, which costs money. Singapore has imposed a fuel excise tax on top of the high price of fuel. Singapore's Government strategy is to discourage people from owning a car because of their highly dense population packed in a small area, to avoid traffic congestion and parking problems, and high air pollution in the long run. The oil prices provided by the different companies are listed in Table 2 [18].

Table 2. Singapore Fuel Price Comparison per liter, dated 21st May 2020 [18]

Types of fuel	Caltex	Esso	Shell	SPC	Sinopec
92-Octane	S$1.98	S$1.98	-	S$1.95	-
95-Octane	S$2.02	S$2.02	S$2.02	S$1.99	S$2.02
98-Octane	S$2.52	S$2.39	S$2.41	S$2.33	S$2.39
Others (e.g. V-Power)	-	-	S$2.65	-	S$2.55
Diesel	S$1.70	S$1.70	S$1.72	S$1.64	S$1.70

As it can be seen from the table below, diesel prices are lower than petrol prices, which explains the popularity of diesel cars used as taxis on the island, as the running or mileage costs of a diesel car will be lesser than that of an ICE car. The price for the different EV charging points provided by the different companies in Singapore are listed in Table 3. Every company has a different pricing strategy for its customers [19]. It can also be seen from the table below that the different companies are expanding their charging facilities by increasing the number of charging stations throughout the island. This is a positive approach to push both taxi and private car owners to switch to electric cars. The charging stations will be located in popular and frequented residential and commercial areas, with special thought to the "taxi uncles" who can charge their electric cars while having a drink at the nearest coffee shop and getting some rest.

Table 3. Comparison of different EV charging points in Singapore, dated 29th April 2020 [19]

EV Charging Points	Number of Stations	Price
BlueSG	Over 200 available island-wide; expected to hit 2000 in 2020	A yearly membership fee of S$20 to be paid to become a BlueSG member. For EV charging, S$1 per hour for the first 3 hours, and S$2 an hour after that.
Shell Recharge	10 (including fast charging stations)	S$0.55 per kWh
SP Group	24; expected to hit 1000 with 250 being fast chargers in 2020	Prices are calculated by kWh and are adjusted periodically on prevailing electricity costs.
Greenslots	50	From S$1.50 an hour

3.4 Transition from conventional to EV taxis in Singapore

To differentiate from each other, companies used different cars adapted for different uses and for different choices of customers. Taxis in Singapore used to be petrol and diesel cars before, but diesel cars were in larger numbers. Taxi drivers used to prefer diesel cars because of their efficiency and durability over petrol cars, due to the high amount of driving daily. Also, diesel engines produce more torque, which makes it more drivable in the city. Diesel cars must do lower maintenance, as compared to petrol cars, as diesel engines are tougher. Diesel prices are usually lesser than petrol. Diesel engines produce less carbon dioxide but in the cost of more carcinogenic gases. The trade-off for diesel cars is that they are more expensive to buy than petrol cars. Also, there is a special tax on diesel vehicles in Singapore. Although the maintenance frequency is lesser in diesel cars, its costs are much higher than a gasoline car. The most common diesel cars used as taxis in Singapore were the Hyundai Sonata and the Toyota Crown. With the advent of petrol-electric hybrid cars in the market, taxis, together with the public, got one more type of car to choose from, apart from conventional petrol and diesel, that was dated from years ago. In 2008, there was not a single unit of a hybrid taxi. In November 2017, it was reported to have 4000 hybrid taxis on Singaporean roads, which accounts for approximately 17 % of the taxi car population [20]. The increase in hybrids in Singapore was due to the new rules and regulations set by the Land Transport Authority of Singapore. The new emissions-based taxation scheme provides a rebate of up to S$45,000 for hybrid taxis. Hybrid cars contribute to a cleaner air. With the

advent of technology, the petrol-electric hybrid has improved significantly, since its introduction in 1997, with the launch of the Toyota Prius in Japan. In 2009, Prime Taxi was the first company to launch hybrid taxis in Singapore. They have experimented with hybrids and concluded that the diesel Hyundai Sonata and the new Toyota Prius Hybrid average the same fuel cost per kilometer, which is 8 cents per kilometer. Also, for replacing the batteries, Prime Taxi imports its batteries from its joint company, which costs S$2,200 each, instead of buying them from the authorized dealer Toyota dealer, Borneo Motors, which costs S$5,200 each. Hybrid taxis do not need to pay the annual diesel tax [20]. Singapore reviewed its system of vehicle emissions in January 2018. The new Vehicular Emissions Scheme (VES) is stricter and will be applied to all vehicles registered from 1st January 2018 to 31st December 2020 [21]. With the introduction of this new system, diesel cars have become lesser and lesser in Singapore day by day because of higher running taxes. Considering all these factors, hybrids are the better and the most cost-effective choice for taxis, as compared to the most used diesel and conventional petrol cars. To promote the use of environmentally friendly cars, taxi owners are given 40 % discount on their Additional Registration Fee (ARF). Prime Taxis, being the first one to launch hybrid taxis in Singapore, has most of its fleet converted to hybrid cars today. Then, other companies have followed the pace. Almost, all taxi companies have already switched to hybrid vehicles for their standard or basic service. The most common car for the taxi is the Toyota Prius Hybrid (both 3rd and 4th generation variants) on Singaporean roads. The new hybrid car from Hyundai, the Ioniq Hybrid is also present in a few numbers on Singaporean roads and is being tested by the taxi company ComfortDelGro. With all the positives received from the hybrid taxis in Singapore, most of the taxi companies have already switched to hybrid vehicles due to the high oil prices and lower running costs paid to Singapore Authorities. The Government has done its part to promote a greener and more sustainable approach by pushing taxis to convert to hybrid taxis, and it has been a successful operation. Diesel cars have been decreasing day by day since the rise of hybrid taxis. In early 2020, the last Hyundai Sonata (diesel) retired. But contradictory, for the “taxi limo”, a short form for limousine service, they still use Mercedes-Benz E220 CDI and Bluetec (diesel and petrol respectively), Mercedes-Benz Viano and V220d (diesel) and Toyota Alphard (hybrid) [14]. But it is noted that for the “limo” service, customers are charged at a higher fare than that of the standard or regular taxi service. With the new stricter rules on the island, hybrid taxis do not make any sense since the year 2018, since their running costs have increased significantly, and they have become quite saturated on Singaporean roads. During that period, electric cars also picked up and gained some popularity on the island. Since June 2020, Singapore has been occupied by 11 different electric vehicles of various brands, from which Renault and BMW cars cannot be used as they fall in the coupe or supermini category, which are not suitable for taxi use. The price of the Porsche, Tesla, Jaguar, and Audi cars vary between a range of S$300k to S$550k, which makes it inappropriate for a taxi fleet due to their high price. In Table 4, the electric vehicles that are being used as taxis in Singapore are listed.

The comparison can be made using the table, by which it is clear that using a Hyundai Kona Electric for the taxi fleet is more suitable than any other electric vehicle, due to its maximum range; so it can cover 482 km just by consuming 13 kWh/100km, whereas the BYD e6 can cover only km on a single charge by consuming 19.5 kWh/100km, which means it consumes more electrical power while delivering a lesser range than the Hyundai Kona Electric. Although the charging time is a bit higher than BYD, the range and power consumption of the Kona electric still have a decent value. Two taxi companies are currently testing these electric cars to be used as taxis in Singapore [23].

3.5 Charging infrastructure to cater for EV taxis in Singapore

These electric cars need to be charged to obtain their power source. HDT placed 75 charging points in 10 areas across Singapore in 2016, for their launch on the island. The charging type is the Type 2 charging standard, and it supports semi-fast charging, together with the normal charging of EVs. The number of charging points is expected to rise in the coming years [24]. Apart from charging from HDT charging stations, drivers of Grab and HDT can access SP agreements between the companies. SP Group offers two types of charging: DC charging, which is rated at 50 kW, and AC charging, which is rated at 43 kW. The DC charger charges the EV faster than the AC charger. In total, they have 38 charging points island-wide, half AC and the other half DC chargers (Figure 4) [25]. Their target is to build 1000 charging points by 2020, of which one-quarter of them will be fast DC charging [26]. Their charging power ranges from 22 kW from the older chargers to 350 kW from the new extra high-powered chargers to charge bigger electric vehicles with higher battery capacity and greater driving range. Other companies have set up EV charging stations for the public to use: BYD charging station, Shell Recharge charging points powered by Greenlots available at 10 Shell filling stations throughout the island, Greenlots charging stations, Blue SG charging stations, and Grab charging stations [27]. One shopping mall, City Square Mall, is equipped with its own charging stations in its two parking lots. Few condominiums have installed EV charging points in their parking lots for their residence. In March 2020, it was noted that Singapore counted 1600 chargers, which are accessed by the public.

ComfortDelGro has its own charging facility to cater to its research vehicles, which is the Terra 54 CG charging station. Their own subsidiary company, ComfortDelGro Engineering, partnered with Greenlots to provide the DC fast charging that will be able to charge the EVs in around 30 minutes. They have only two slots for the fast charger so far at this station, and it is open to the public at the cost of S$40 cents per kWh. Taxi drivers can also opt to charge at the headquarters of the company at Braddell and at Komoco Motors in Alexandra, where fast-charging facilities are also available for the taxis of ComfortDelGro.

4. Comparisons

4.1 Economical aspect

Electric vehicle battery is the most expensive component of EV taxis that increases Open Market Value (OMV) and consequently leads to increased taxes, for instance, additional registration fees (ARF) [28].

Table 4. Electric Taxi cars currently in use by different taxi companies in Singapore [22]

Manufacturers	Model	Type	Fast Charging Time (min)	Selling price (S$)	Power consumption (kWh/100km)	Maximum Range (Km)	Taxi Company
BYD	e6	SUV	40	109,888	19.5	400	HDT Taxi
Hyundai	Kona Electric	SUV	54	140,999	13	482	ComfortDelGro
	Ioniq Electric	Sedan	57	148,999	11.7	311	

Figure 4. SP Group high-speed charging network [25]

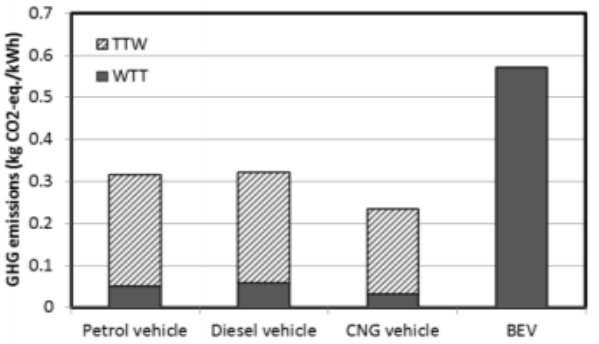
Due to the increase in these taxes, acquisition costs are also subjected to increase, thereby reducing the economic competitiveness of EV taxis. On the other hand, conventional taxi vehicles do not have such expensive components and acquire a relatively cheaper petrol or diesel tank. Therefore, to accelerate the adoption of EV taxis, encouraging policies should be devised by the Government, such as the cost of traction battery should be excluded from the ARF and only applies to the OMV of the vehicle. So far, this exemption was only presented for the BYD e6 in 2016, and the OMV reduced significantly from 47,000 SGD to 17,237 SGD [28]. The overall basis for the feasibility of EV taxis supplanting conventional taxis is the total cost of ownership (TCO). The TCO of conventional and EV taxi for the span of 4 years from 2016 to 2020 was analyzed by Robert [29], and the results depicted that battery electric vehicles incur a rise in maintenance cost as compared to hybrid electric vehicles. It was also found that conventional and EV taxis fell in the same range in 2016, whereas due to incessant decreases in the battery price, EV taxis were primarily cheaper by 2020. Daily rental fee is another impediment to the feasibility of EV taxis. The survey of taxi drivers in Singapore conducted by Kochhan [30] confirms that higher daily rental fee is considered a detriment. This is because it is a fixed cost payable by the driver irrespective of how much he or she is earing in the respective day. Nevertheless, an inconsequential positive correlation was also observed for the approval of high daily rental fee by those drivers that are expected to make two-shift taxis or use relief drivers and cover a higher total daily mileage.

4.2 Environmental aspect

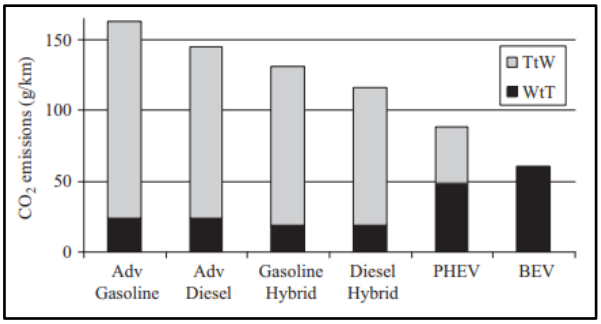
For fossil fuel vehicles, the upstream Greenhouse gases (GHG) emissions per energy content are comparatively lower than that for electricity, as shown in Figure 5(a). Higher upstream efficiencies of diesel, petrol and natural gas production are more responsible for this than the efficiency of electricity generation and distribution. The calculation of total GHG emissions per final energy well-to-wheels (WTW) analysis is based on the specified upstream well-to-tank (WTT) emissions and the specific direct emissions in the vehicle. While the CNG emissions are low, the total emissions from diesel and petrol are on the same level at about 0.3 kg CO_2-eq./kWh. In Singapore, the GHG emissions per energy are maximum for electricity, comprising only upstream emissions. The lower CO_2 emissions of the PHEV and BEV versus the other vehicles are a direct outcome of the higher efficiency of these electrified vehicle concepts and the higher share of non-fossil electricity sources when compared to purely fossil-based gasoline and diesel. Though the high upstream emissions factor remains, the lowest GHG emissions per/km have been obtained compared to diesel, petrol, and CNG cars in BEV taxis. As the final energy demand of the vehicle is relatively lower because of the high efficiency of the electric motor than the conventional engines, it leads to this outcome for BEV taxis. The BEV is clearly the best concept from a CO_2 WTW perspective in 2010 and will maintain this position through 2030. All vehicle concepts reduce their WTW CO_2 emissions from 2010 to 2020 very significantly, which is clearly shown in Figure 5(b) and Figure 5(c). During manufacturing, it has been observed that the amount of emissions caused are lower for petrol vehicle than for diesel vehicle. The similarity between a CNG car and a gasoline car is the engine, as the same engine with smaller adjustments can be used. The differences include the additional natural gas tank and the extra ducting that results in an elevated amount of emissions. During the production of an electric vehicle, the high emissions caused are strongly dependent on the size of the battery or sometimes the use of special lightweight materials, like in the case of an electric vehicle approved (EVA) [31].

4.3 Sustainability

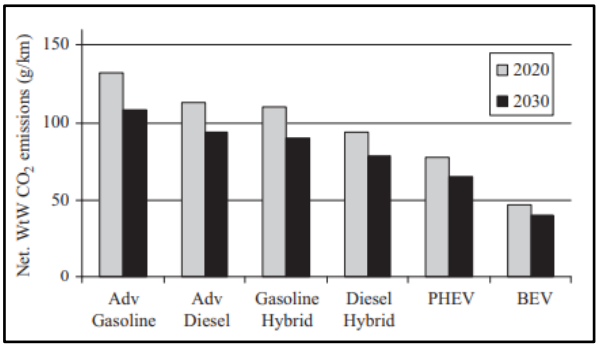
With the increased in EVs in the roads, extra power needs to be generated from the traditional power generation plants, which in turn will lead to a similar ecological impact as using diesel or petrol in conventional vehicles [32].



(a)



(b)



(c)

Figure 5. (a) GHG emissions per kWh final energy (b) WtT CO_2 comparison for 2010 (c) WtW CO_2 comparison for 2020 and 2030 [31]

To address this issue, charging EVs with green energy needs to be adopted. Singapore has its electricity production by using natural gas reported to 95 %. Natural gas is also burnt to produce electricity, but it is cleaner than fossil fuels but is not totally renewable or sustainable. Singapore is going towards grid-connected solar energy to address the issues of natural gas electricity production. EVs have battery packs to store their electrical energy. The issues related to the batteries in the sustainability of EVs are the energy required to manufacture these batteries, and together with its emissions and consequences. 3430 kWh and 7176 kWh of energy is required to make a 25 kWh of lead-acid and NiMH battery, respectively. Also, the batteries of EVs cannot be readily recycled. A large amount of energy is needed to recycle the batteries, or the defective batteries need to be disposed.

4.4 Ethical and social aspects

In general, ethical aspects ensure the community's safety, education, and empowerment for a process. There are certain factors that are well thought-out by the buyer or a user of EV taxis that are as follows:

- Perceived Usefulness
- Service and System Quality
- Perceived trust
- Perceived risk

When it comes to the transition from conventional taxis and preferment of the EV taxi system, the above-described factors play a vital role in forming users' psychological perceptions. It has been found that perceived cost is a negative variable on the other hand, perceived usefulness is a positive variable. Therefore, to promote EV taxis, these factors should be considered as substantial variables, and Singaporean Government should devise strategies and policies for subsidizing taxi drivers' expenses like purchasing, maintaining, repairing, and others. Scientists and researchers should focus on problems that enhance EV taxis' reliability and find solutions for charging infrastructure to increase process efficiency [31].

Regulatory measures like service and warranty procedures are sort of a problem for both EV and ICE taxi drivers in Singapore. Moreover, the charging stations for EV taxis and petrol stations for hybrids & ICE taxis are not alike. For instance, in a normal taxi fuelling station, drivers can easily stop and have a lunch or coffee break, unlike charging stations for EV taxis that are sometimes located at eccentric places having fewer facilities in the stations' vicinity. On the plus side, electric cars take longer to charge, which allows the drivers to have longer resting hours, which is beneficial for drivers after a few hours of driving. They can comfortably have their meals and rest. In Shenzhen, China, the facilities for charging electric taxis are well developed, and this city has the largest charging facility for electric taxis in the whole world, which counts 637 fast chargers [33]. With the coming of this facility, there has been a development in terms of socio-economical aspects as well. Businesses like shopping malls have been bult in its vicinity to promote economic development as well as social development. A large community engagement had happened in this locality. The problem that is happening with electric cars is they are getting updated so quickly, as compared to a conventional car, which gets updated in 4 to 8 years. When the new model of the electric car is released, the value of the older model drops constantly, which makes consumers perceive that they have lost their money. To afford the new electric cars with the newer technology and better range efficiency, consumers must pay a way higher price for them. Also, the mindset of most of the population is not in favour of new technology. People usually do not want to take risks and pay such a high amount for a new unknown technology introduced which has not been proven and tested over the years.

5. Discussions

After reviewing different aspects of the electric taxi fleet that have been summarized in the above sections, it can be observed that EV taxis are viable. The driving pattern and the available charging infrastructure are the main constituents of the feasibility of EV taxis. The use of these taxis should be facilitated by short trips blended with good coverage of charging infrastructure.

Table 5. Feasibility assessment of the current and proposed taxi fleet in Singapore

Type of Taxis	Economic	Social	Environmental	Ethics	Sustainability
EV	xx	xxx	xxxx	xxx	xxxx
Conventional (ICE and Hybrid)	xxx	xxx	xx	xxxx	xx

Legend:
x = Adequate, xx = Fair, xxx = Good, xxxx = Excellent

The peak hours must be assisted with supporting mechanisms for the prevention of revenue loss due to charging required at productive hours, and this can be done by fusing charging time with breaks or low-demand hours of the day. Singapore offers the most suitable condition for EV taxis since often braking, low speed, and less range is expected in the city. Singapore's economy is one of the best in the world and it attracts the vast majority of tourists every year. Therefore, these people are more convivial with this type of transition than any other country. Since it is very unlikely for a tourist to own a car, the taxi business is booming there, and foreigners like to explore new options and innovations and have the luxury to afford it. Hence Singapore is ethically an ideal place for this large-scale transition. Table 5 summarizes the feasibility of EV Taxis in Singapore as compared to the current taxi system. The conventional taxi system is cost-effective today, but the difference is not very substantial and can be retrenched by encouraging government policies like withdrawing ARF and other taxes etc. The chart clearly shows that EV taxis are a better choice environmentally because the dwindling sources of fossil fuels and growing environmental consciousness drives researchers and developers toward green energy. Moreover, conventional taxis are ethically preferred because of the already established market, abundant fuel stations, and ample perceived trust. However, EV taxis in Singapore still entail consideration to increase reliability which can be done in numerous ways, as reviewed in section 4.4 and lastly, EV taxis are also feasible as compared to conventional taxis on the basis of sustainability. However, there are some principled adjustments that are required. The imposed challenges can be tackled by taking the concerned authorities and already existing energy bodies on board and spreading energy literacy and the significance of RET's (Renewable energy Targets) among the businessman community and industrialists. Overall, this large-scale transition from a traditional taxi fleet to an EV taxi fleet is totally feasible in Singapore. However, efforts should be made to provide a stable and cost-efficient system for the user. Policies should be formulated by the taxi companies to enhance the user's attitude towards the EV taxi system by endorsing the positive societal factors.

6. Conclusion

In this research paper, the feasibility of EV taxis has been reviewed. The main goal of this research was to review the feasibility of a large-scale transition to electric taxis in Singapore that has been achieved by reviewing the current situation and development in Singapore and then looking into the different aspects conferred to prove why and how electric

The large-scale transition to electric taxis has been feasible in different countries like Berlin, China, South Korea, etc, as reviewed in earlier sections, and so will be feasible in Singapore; however, this transition cannot happen overnight. It will take time to gradually make the switch by increasing the charging facilities, providing incentives and grants to motivate drivers, and slowly phasing out the diesel taxi cars and the rest of the gasoline and hybrid taxi cars. The noteworthy aspects that are deterring the transition to EV taxis in Singapore are Economical and Ethical. However, this can be vanquished by taking the coveted means described in this paper. The decommissioning process has already been started, and it is expected that diesel and gasoline-powered taxi cars will phase out by the end of 2024 and 2030, respectively, and consequently be supplanted with EV Taxis.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] A. M. Andwari, A. Pesiridis, A. K. Kontakiotis, and V. Esfahanian, "Hybrid Electric Vehicle Performance with Organic Rankine Cycle Waste Heat Recovery System," Applied Sciences, 2017. https://doi.org/10.3390/app7050437

[2] Lopes, João A. Peças, Filipe Joel Soares, and Pedro M. Rocha Almeida. "Integration of electric vehicles in the electric power system." Proceedings of the IEEE 99.1 (2010): 168-183. DOI: 10.1109/JPROC.2010.2066250

[3] Arif, "Electric cars are here, but is Malaysia ready for them?," Wapcar, Jun. 12, 2020. https://www.wapcar.my/news/electric-cars-are-here-but-is-malaysia-ready-for-them-2989 (accessed Oct. 12, 2020).

[4] S. Baek, H. Kim, and H. J. Chang, "A feasibility test on adopting electric vehicles to serve as taxis in daejeon metropolitan City of South Korea," Sustainability (Switzerland), vol. 8, no. 9. MDPI AG, Sep. 21, 2016, doi: 10.3390/su8090964.

[5] K. Darcovich, H. Ribberink, C. Michelet, K. Lombardi, and M. Ghorab, "The Feasibility of Electric Vehicles as Taxis in a Canadian Context," in 2019 Electric Vehicles International Conference, EV 2019, Oct. 2019, doi: 10.1109/EV.2019.8892867.

[6] J. Yang, J. Dong, and L. Hu, "Design government incentive schemes for promoting electric taxis in China," doi: 10.1016/j.enpol.2017.12.030.

[7] A. Merkisz-Guranowska and M. Maciejewski, "The implementation of the electric taxi fleet in the city of Poznan, Poland," 2015, doi: 10.2495/UT150191.

[8] K. Y. Bjerkan, T. E. Nørbech, and M. E. Nordtømme, "Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway," Transp. Res. Part D Transp. Environ., vol. 43, pp. 169–180, Mar. 2016, doi: 10.1016/j.trd.2015.12.002.

[9] J. Bischoff and M. Maciejewski, "Electric taxis in Berlin – analysis of the feasibility of a large-scale transition," in Communications in Computer and Information Science, 2015, vol. 531, pp. 343–351, doi: 10.1007/978-3-319-24577-5_34.

[10] Bender, Sebastian, Vinoth Pannirsilvam, Raymond Khoo, Pablo López Hidalgo, Maximilian Tschochner, Pratik Sheth, Sebastian Osswald, Daniel Gleyzes, Heong Wah Ng, and Markus Lienkamp. "Concept of an Electric Taxi-for Tropical Megacities." In CoFAT. 2014.

[11] data.gov.sg, "Public Transport Utilisation - Average Daily Public Transport Ridership." Statista, 2016, Accessed: May 25, 2020. [Online]. Available: https://data.gov.sg/dataset/public-transport-utilisation-average-public-transport-ridership?view_id=3619b55d-d1c2-4891-8b43-97b192bcb0c4&resource_id=552b8662-3cbc-48c0-9fbb-abdc07fb377a.

[12] D. Bennett, "Benefits Of Using A Taxi Service – Bravo Media Inc," Bravo Media Inc, 2017. https://www.elbordonartesanos.com/transport/benefits-of-using-a-taxi-service (accessed Jun. 01, 2020).

[13] J. Muller, "Singapore: size of taxi fleet 2019" Statista, 2020, Accessed: January 17, 2023. [Online]. Available: https://www.statista.com/statistics/953759/size-of-taxi-fleet-singapore/

[14] "Taxi Singapore - Taxi cabs, fares, reservation & booking hot-lines, surcharges and more!" Accessed: Jun. 01, 2020. [Online]. Available: https://www.taxisingapore.com/.

[15] "Commuter Facilities (Bus and Taxi)-Data.gov.sg," 2017.

[16] data.gov.sg, "Monthly Taxi Population by Company," LTA, 2018. .

[17] data.gov.sg, "LTA Taxi Stop," LTA, 2016. https://data.gov.sg/dataset/lta-taxi-stop?view_id=0391327c-ad40-4b9e-9401-5fbf7ac2da8b&resource_id=fb808253-852c-423d-9715-20404eda8c9e (accessed Oct. 11, 2020).

[18] Cheyenne, "Singapore Petrol Price Comparison 2019" Motorist, 2023, Accessed Jan 17, 2023 [Online]. Available: https://www.motorist.sg/article/331/petrol-price-singapore-2019.

[19] Cheyenne, "Singapore Petrol Price Comparison " Motorist, 2023, Accessed Jan 17, 2023 [Online]. Available: https://www.motorist.sg/article/507/petrol-price-singapore-2022.

[20] A. Chan, "Buying an Electric Car in Singapore: A Complete Guide | Singsaver." 2020, Accessed: May 31, 2020. [Online]. Available: https://www.singsaver.com.sg/blog/guide-to-buy-an-electric-car-singapore.

[21] Bawono, A.A. (2022). Electro-Mobility Solution Towards the Ultimate Public Transport System with a Case Study of Singapore. In: Engineered Cementitious Composites for Electrified Roadway in Megacities. Springer Theses. Springer, Cham. https://doi.org/10.1007/978-3-030-88542-7_2.

[22] C. Tan, "Hybrid cabs growing in number". Torque, 2023. Accessed: Jan 17, 2023. [Online]. Available: https://www.torque.com.sg/news/hybrid-cabs-growing-number/.

[23] C. Tan, "Hybrid cabs growing in number". Torque, 2023. Accessed: Jan 17, 2023. [Online]. Available: https://www.torque.com.sg/news/hybrid-cabs-growing-number/.

[24] "Vehicle Emission Schemes | Upfront Vehicle Costs | Buying | One Motoring," One Motoring SIngapore, 2020. https://www.onemotoring.com.sg/content/onemotoring/home/buying/upfront-vehicle-costs/emissions-charges.html (accessed Jun. 01, 2020).

[25] "BYD e6 is an electric crossover that's quirkier than a French car | Torque." https://www.torque.com.sg/reviews/byd-e6-review/ (accessed May 30, 2020).

[26] Huang, Y., & Kockelman, K. M. Electric vehicle charging station locations: Elastic demand, station congestion, and network equilibrium. Transportation Research Part D: Transport and Environment, 78, 102179. 2020 doi: 10.1016/j.trd.2019.11.008.

[27] sg.byd.com, "E6 – BYD SINGAPORE," EAUTO, 2018. https://sg.byd.com/e6/ (accessed Oct. 11, 2020).

[28] G. Teo, "28,000 charging stations for electric cars is possible - but where? Industry players weigh in - CNA," Channel News Asia, 2020.

[29] D.-W.-I. Robert, P. Kochhan, and T. Hamacher, "Techno-Economic Evaluation of Battery-Electric Taxis Technisch-ökonomische Analyse von batterie-elektrischen Taxis."

[30] P. Kochhan, "Techno-economic evaluation of battery-electric taxis". Open Access Repositorium der Universität Ulm und Technischen Hochschule Ulm. Dissertation. http://dx.doi.org/10.18725/OPARU-5128.

[31] A. Kamil, "SP Group rolls out first wave of electric vehicle charging points - TODAYonline," Today Singapore, 2019. https://www.todayonline.com/singapore/sp-group-rolls-out-first-wave-electric-vehicle-charging-points (accessed May 30, 2020).

[32] G. Teo, "SP Group to double electric vehicle charging points to 1,000 by 2020 - CNA," CNA, 2019.

https://www.channelnewsasia.com/news/singapore/sp-group-electric-vehicle-charging-points-1000-by-2020-10863134 (accessed May 30, 2020).

[33] S. C. Kuttan, "Commentary: Why Singapore is ripe for an electric vehicle revolution - CNA." 2019, Accessed: Jun. 01, 2020. [Online]. Available: https://www.channelnewsasia.com/news/commentary/singapore-electric-vehicle-car-sale-models-how-much-price-12051780.