ELECTRIC MOTORCYCLE DEMONSTRATION PROJECT, MALAYSIA

IKI INTERNATIONAL CLIMATE INITIATIVE

A Study on the Implementation of a 50-Unit Electric Motorcycle
Field Trail Vehicle Performance
User Assessment
Total cost of Ownership Analysis

FOCUS APPLIED TECHNOLOGIES

JUNE 2024

This report was funded through the German International Climate Initiative (IKI). The development of this report has been supported by the UNEP Global Electric Mobility Programme.

DISCLAIMER

COPYRIGHT

ACKNOWLEDGEMENTS

The authors would like to express our appreciation to those who have contributed to this report including Associate Professor Dr. Theo Yew Heng of the University Sains Malaysia (USM) for administering the allocation of electric motorcycles to end users, Malaysian Automotive Institute of IOT and Robotics (formerly MAI) as well as the hard-working staff of both UNEP and Focus Applied Technologies. A special thanks is extended to the staff of Malaysian Green Technology Corporation (MGTC) who have been of immense help throughout the development of this publication.

UN environment programme

ELECTRIC MOTORCYCLE DEMONSTRATION PROJECT, MALAYSIA

A Study on the Implementation of a 50-Unit Electric Motorcycle Field Trail
Vehicle Performance
User Assessment
Total cost of Ownership Analysis

Dr. Horizon Gitano-Briggs
Chief Technology Officer
Focus Applied Technologies

Nurul Shafina Khairudin
Financial Analyst
Focus Applied Technologies

PROJECT CONTEXT

The United Nations Environment Program (UNEP) is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system and serves as an authoritative advocate for the global environment. Its mandate is to coordinate the development of environmental policy consensus by keeping the global environment under review and bringing emerging issues to the attention of governments and the international community for action.

The Sustainable Mobility Unit, under UNEP's Industry and Economy Division, promotes sustainable, low and zero emissions transport. UNEP is implementing the Global Electric Mobility Program, supporting over 60 low and middle-income countries to shift to electric mobility for improved air quality and climate change mitigation. We do so via various Programs and projects like the Used Vehicles Project, the Global Fuel Economy Initiative, the Electric Mobility Program, Non-motorized Transportation Program, and the Partnership for Clean Fuels and Vehicles project etc.

The purpose of this study is to assess the current condition of electric 2- and 3-wheelers in Malaysia, analyze the related governmental policies, and, together with various government representatives, develop a set of progressive policy measures in order to maximize the utilization of electric 2- and 3-wheelers in the future. Key to this is an assessment of the CO_2 impact of various levels of electric vehicle adoption, which helps serve to emphasize the importance of taking concrete, long-term actions in order to maximize the benefits of this clean, efficient technology.

CONTENT

INTRODUCTION

This work was performed in 2024 as part of the UNEP Global Electric Mobility Program. The main goals of the work were to develop a comprehensive demonstration plan, assess the performance and acceptability of the vehicles for a variety of users and compile a set of recommendations to inform similar projects in the future, including a guide for selecting an appropriate vehicle based on local needs and resources. Additionally, results were used to develop a Total cost of Ownership analysis, contrasting conventional motorcycles, fixed battery electric motorcycles, and battery swapping electric motorcycles.

ELECTRIC – ICE COMPARISON AT A GLANCE

Compared to conventional engine powered vehicles EVs have some unique advantages, and several disadvantages:

EV ADVANTAGES

- Zero "tail pipe" emissions
- Lower maintenance costs
- Better lifetime cost*

EV DISADVANTAGES

- Higher purchase cost
- Limited Range
- Range degradation with age
- Longer re-charge time

* Depends on fuel price

BACKGROUND

Electric Vehicles (EVs) have been around since the 1890s and were fairly popular in the early 1900s[1]. Their initial popularity was due in part to low vibrations, smell, and noise and being much easier to operate than the Internal Combustion Engine (ICE) vehicles of the day. However, EVs started to lose their popularity when the development of highways in the early 20th century exposed the inability of EVs to be driven the longer ranges being demanded. Concurrently the ICE vehicles steadily improved in technology, taking over the market. The low price of petroleum and proliferation of petrol stations also made ICE vehicles cheaper and more convenient to operate over long distances contributing to the decline of EVs.

The combustion of fossil fuels over the last several centuries, however, has led to local degradation of air quality, a large increase in global CO_2 levels and petroleum reserve depletion. One component in rectifying the environmental damage is to convert from ICE vehicles to EVs. While electric vehicles tend to be somewhat more efficient (well to wheels) than ICE vehicles, they are also more amenable to powering from lower carbon energy sources such as solar, wind, hydro, geothermal and nuclear[2]. To that end the United Nation Environmental Program (UNEP) has initiated a study on EVs focusing on electrical two and three wheelers across South-East Asia to identify factors and issues that may help boost the market share of EVs in these countries.

In Malaysia awareness of the importance of Electric Vehicles has been increasing since the government committed to a 45% reduction of greenhouse gas emission by 2030 relative to the emission intensity on 2005 in parallel with Paris Climate Accords[3]. The current number of EVs in Malaysia, however, is still very low in part due to the low cost of automotive fuels, which are currently subsidized. With a view towards reducing the fuel subsidies the Malaysian government is interested in exploring transportation alternatives, especially for the lower economic population who are highly dependent to 2-wheelers. The Malaysian government has been pro-active in establishing tax breaks and significant subsidies for the purchase of electric motorcycles. The high purchase price of fixed battery EVs, low range per charge, and long charging duration are the biggest concerns for perspective EV owners. Despite

[1] A good review is available from: https://en.wikipedia.org/wiki/History_of_the_electric_vehicle
[2] "Electric vehicles typically have a smaller carbon footprint than gasoline cars, even when accounting for the electricity used for charging" https://www.epa.gov/greenvehicles/electric-vehicle-myths
[3] https://climatepromise.undp.org/what-we-do/where-we-work/malaysia#:~:text=Key%20highlights%20from%20the%20NDC,being%20conditional%20on%20external%20support

government tax breaks and other incentives most of the EVs on the market are still expensive, and users generally consider EVs only suitable for short-distance trips due to their limited range[4,5]. Additionally, charging facilities in Malaysia, including home charging facilities and charging along highways, is currently insufficient to meet the larger EV demand[6]. Finally, many 2-wheeler owners do not have access to charging near their designated parking area, making charging of electric motorcycles especially difficult.

Putting the negatives aside, electric vehicles can still provide substantial benefits. EVs cost significantly less to operate than ICEs due to the cost of fuel and maintenance. Additionally, EVs can be charged almost anywhere where there is electrical power and are not limited to charging stations. Although the range of current EVs is still fairly limited, progress in battery technology is constantly improving, reducing battery cost and charging time. With larger numbers of EVs on the market, the investment in charging infrastructure makes more and more sense, and vehicle costs should come down with increased sales volumes. Current EVs are already suitable for shorter trips, such as urban commuting and first/last mile connectivity to public transport systems. Increasing the number of EVs in Malaysia could significantly help the government attain its CO_2 emissions reduction target.

The goal of this work is to propose revisions of policy and regulations to help aid the proliferation of 2- and 3-wheeled electric vehicles in Malaysia to reduce environmental impact, improve energy efficiency and improve the quality of life, especially for those of modest economic means, which are disproportionately dependent on small 2-wheeled vehicles.

PHASE 1 REPORT

This report is a follow-on report to a study entitled ***"Light Duty Electric Vehicle Proliferation in Malaysia"*** completed in December 2023, which targeted understanding the conventional and electric 2- and 3-wheeler market in Malaysia in order to determine the appropriate actions to encourage their adoption.

Malaysia, consistent with other ASEAN countries, classifies Electric 2-Wheelers (E2W) into 3 categories and has advanced standards addressing the safety and performance and compatibility requirements of each category:

E-Bicycle: Those with top speeds of less than 25kph (Malaysian Standard 2415)
E-Scooter: Those with top speeds of 25-50kph (Malaysian Standard 2688)
E-Motorcycle: Those with top speeds in excess of 50kph (Malaysian Standard 2314)

Malaysia has four domestic manufacturers of electric 2-wheelers (Eclimo, Roda Prestasi, Legatus and Voltron), the first three focusing on E-motorcycles for domestic consumption and Voltron focusing on the export market of E-bikes and scooters. Additionally, there are a number of legitimate importers (AZ bikes, Treelectric, Zesparii, Blue Shark and Ryde EV) who specify and buy in product from China for sale in the local market and are focused mostly on E-motorcycles.

The current E2W fleet in Malaysia consists of approximately 150,000 units, with an annual growth rate of about 8%-12%. These are overwhelming (90%) E-scooters, with a few bicycle class (8%), and very few motorcycle class vehicles. Domestically produced vehicles amount to only about 1000 units with the rest being imported from China. While the local manufacturers and legitimate importers comply with the relevant

[4] Noel, L., de Rubens, G. Z., Kester, J., & Sovacool, B. K. (2020). Understanding the socio-technical nexus of Nordic electric vehicle (EV) barriers: A qualitative discussion of range, price, charging and knowledge. Energy Policy, 138, 111292. https://doi.org/10.1016/j.enpol.2020.111292
[5] Zhu, J. (2016). Analysis of the New Zealand specific electric vehicle adoption barriers and government policy. http://hdl.handle.net/10063/6190
[6] https://www.eco-business.com/news/electric-dreams-what-is-needed-to-accelerate-ev-growth-in-malaysia/#:~:text=According%20to%20Datuk%20Hanafi%20Sakri,much%20smaller%20population%20and%20size

standards *none* of the directly imported models do. Some of the importers "cheat" by achieving bicycle type certification, then importing and selling scooter class vehicles. A simple search of "Electric motorcycle sales Malaysia" brings up dozens of different models mostly in the 700 - 3000RM price range.

Significantly, the models succeeding in the field are *not* comparable to conventional motorcycles in terms of performance: the E-scooter class which is selling relatively well typically has a top speed of around 40kph and a maximum range of 30 to 60 kilometers. It is used more like a bicycle than a motorcycle, and accumulates around 1,500 km per year on average, as opposed to conventional motorcycles which attain around 9,000km per year. The annual range of conventional motorcycles depends on their engine displacement with the range increasing by approximately 70km per cubic centimeter of engine displacement. That is, a 100cc motorcycle will accumulate about 7,000km per year, whereas a 150cc (the most common displacement these days) motorcycles accumulate closer to 10,500km per year.

EXECUTIVE SUMMARY

Fifty units of TailG BOLD model electric motorcycle donated by TailG were used for a demonstration project in Malaysia. The units were distributed to a wide range of users, including “low”, “medium” and “high” demand users, who then operated the vehicles for a number of months, and provided their feedback on the vehicle’s utility, contrasting it with their combustion motorcycles. Additionally, the electric motorcycles were subject to chassis dynamometer testing, and some were instrumented with data loggers, which continuously recorded various operation parameters (such as speed, voltage and current) during operation.

The study resulted in a number of significant findings. One of the first things noted was that although the vehicle is specified to have a 70kph top speed, and while the speedometer of the vehicle reads up to 70kph, the maximum road speed is only 60kph when fully charged and drops to 45kph when nearly depleted. This considerably interferes with the vehicle’s usefulness for long trips. Another observation of special importance is the fact that riders prefer to have a vehicle range of four times their typical daily distance traveled.

The average energy consumption of electric motorcycles was about 35km/kWh giving emissions of 22gCO_2/km, which compares favorably to a combustion motorcycle’s emissions of 48gCO_2/km. The on-road use showed that aggressive drivers tend to accelerate faster, decelerate harder, and operate at higher speeds than less aggressive riders. This resulted in significantly higher energy consumption per kilometer travel for the aggressive riders. Additionally, it was noted that trip average speed corelates strongly with trip distance: shorter trips are performed at much lower speeds than longer trips.

The vehicles were universally praised for their quiet, simple operation and fuel cost savings, with low demand users well satisfied with their performance. Medium demand users felt that the top speed was unacceptably slow for trips of more than a few kilometers. The vehicles range of around 80km was sufficient for those with daily average driving ranges of less than 20km. Higher demand users wanted speeds of closer to 100kph, and a vehicle range in excess of 120km (at 70kph), so this vehicle was not well suited to their needs.

The ride height was deemed too high for female riders, and it was noticed that females tended to use the vehicles at much lower speeds than the males, relating both to their shorter trip distance and different mode of use. Younger male riders operated the vehicle very close to top speed for much of the time.

Although the electric motorcycle used in this study was a volume production version, several basic quality problems were noted including battery failures, disturbingly loud knocking noises from the suspension, front suspension failures, and multiple electrical/lighting failures. Importantly, the batteries appeared to be degrading significantly than expected.

The Total Cost of Ownership (TCO) was analyzed and contrasted with both combustion vehicles and battery swapping electric motorcycles. At current prices the fixed battery electric motorcycle is the most expensive to purchase but gave a long-term cost of ownership just below the combustion motorcycle. As fuel prices rise, however, the fixed battery electric motorcycle will be significantly less expensive to own and operate. Battery swapping was analyzed, and in general gave the highest total cost of ownership, but with a much lower initial purchase price than the fixed battery electric motorcycle. The situation of the battery swapping system provider was also analyzed, and resulted in the conclusion that, as the service providers initial capital outlay is quite high, and the return on investment will take a relatively long time in a rather uncertain market, the service providers economic prospects are fairly risky.

Several recommendations were developed to encourage battery swapping by reducing the relative cost of battery swapping compared to conventional vehicles. Major factors include increasing the price of fuel, reducing the price of electricity provided for battery charging stations, and allowing battery swapping stations to use public locations at little or no cost. Secondary factors include tax incentives for battery swapping service providers and hosting battery swapping sites, short term subsidies for purchasing electric vehicle batteries, subsidizing battery swap station purchase and even establishing plan for 2nd life battery usage and recycling.

A number of recommendations were formulated to inform similar projects. Significant among these is that the demonstration vehicle must be carefully matched to the real-world needs of the target market segment. Manufacturer's stated top speeds and ranges may be suspected, as they are occasionally found to be erroneous, or only achievable under special conditions (e.g. top speed with fully charged battery, or range measured at 30kph). It is therefore recommended to either pre-test the target vehicle, or to specify a vehicle with significant overhead, for example by specifying a top speed of 15kph greater than expected. Finally, given the number of failures of vehicle components, it is important to have a local distributor stocked with spare parts to ensure the vehicle's viability throughout the study period.

PROJECT OVERVIEW

As part of the UNEP's efforts to encourage the cleanest and most efficient transportation systems possible, the UNEP is supporting an electrical mobility project in Malaysia consisting of 50 units of electric motorcycles. The vehicles are part of a larger donation from the Chinese manufacturer TailG, which has contributed to similar projects in other countries, with varying degrees of success.

The goals of this demonstration project are to assess the performance and suitability of the vehicles to a range of real-world users in Malaysia, and contrast that with conventional combustion vehicles. From previous studies it has been observed that some electric vehicles, especially the smaller, less expensive Electric-2 Wheelers (E2Ws), cannot perform up to the expectations of demanding customers. We therefore assigned test vehicles to users at differing demand levels (low, medium and high). Data was collected from customers via surveys and interviews to assess their level of satisfaction with the vehicle's performance, range, handling and overall quality. We also enquired to the user's daily routine (e.g. where they go, how far, when and where they charge, etc.). Apart from user feedback the vehicle's performance was evaluated intermittently throughout the study to determine things like top speed, acceleration, current draw and power. This will assist us in evaluating vehicle and battery degradation over time. Finally, a selected number of vehicles in each use group (low, medium and high) were instrumented with vehicle data loggers which continuously measure and record the vehicles speed, voltage, current, Global Positioning System (GPS) location and hill climb. This data provided extensive and accurate information on the vehicle usage patterns, range, speeds etc. At the end of the study period the bikes will be transferred to users who wish to keep them.

All the collected data was analyzed, and compared to similar data from conventional vehicles with the intention of evaluating the following:

- **What was the energy consumption/km, CO2 emissions/km, of the various use groups?**
- **What are the performance requirements of the different use cases (speed, acceleration, range)?**
- **How suitable are the project vehicles for the various use cases?**
- **What users, routes, locations are the best fit for this vehicle, and how much battery capacity would be required for other user's needs.**
- **For each use case what would the "optimum" battery capacity be (ie. smaller and less expensive for low demand users, larger for high demand users)?**
- **How satisfied were the users in each group with the E-motorcycle compared to conventional?**
- **What were the advantages they liked?**
- **What were the disadvantages they did not like?**
- **What other aspects could enhance/degrade the acceptability of E-mobility (eg. charging time, charging availability, top speed, range, weight…) based on their experience?**
- **How successful was the overall project, and what are recommendations to inform similar projects in the future?**

This data will be contrasted with "equivalent" ICE 2-wheeler data and Battery Swapping E2Ws in a follow-on study via **Malaysian Green Tech Corp (MGTC).**

Roles of Various Partners

PARTY (PIC and Organization)	*ROLE*
Dr. Horizon Gitano Focus Applied Technologies (FAT)	• Overall Project Coordinator, Data collection and Analysis, Report writing
Yeonju Jeong UNEP	• Providing major project objectives and majority funding, and coordinating with international partners for dissemination of project results
Malaysian Green Tech Corp (MGTC)	• MGTC is interested in getting the data from this study and combining it with their parallel study of Battery Swapping E-Motorcycles. • MGTC will be providing funding for covering the Data Loggers including installation/removal and "down time" compensation required for the same.
TailG (China)	• Vehicle Donor company and manufacturer.
Ni-Hsin (Malaysia)	• Local Assembler/Distributor of the E-motorcycles. • This model (Bold) has already passed VTA and is for sale in Malaysia. • Ni-Hsin will license and insure the bikes for the 12-month duration of the study. • For the duration of the study Ni-Hsin will be responsible for the vehicles timely repair in the event of field failures. • At the end of the study period Ni-Hsin will sign over the vehicles to end users at USM's discretion.
Associate Professor Dr. Teoh Yew Heng University Sains Malaysia (USM)	• USM is the single point "customer" for the vehicle for the duration of the study. They will track the Vehicles and users and allocate vehicles to the users on a permanent basis at the end of the study period. • They will also be allowed to publish study results at the end, as approved by UNEP.

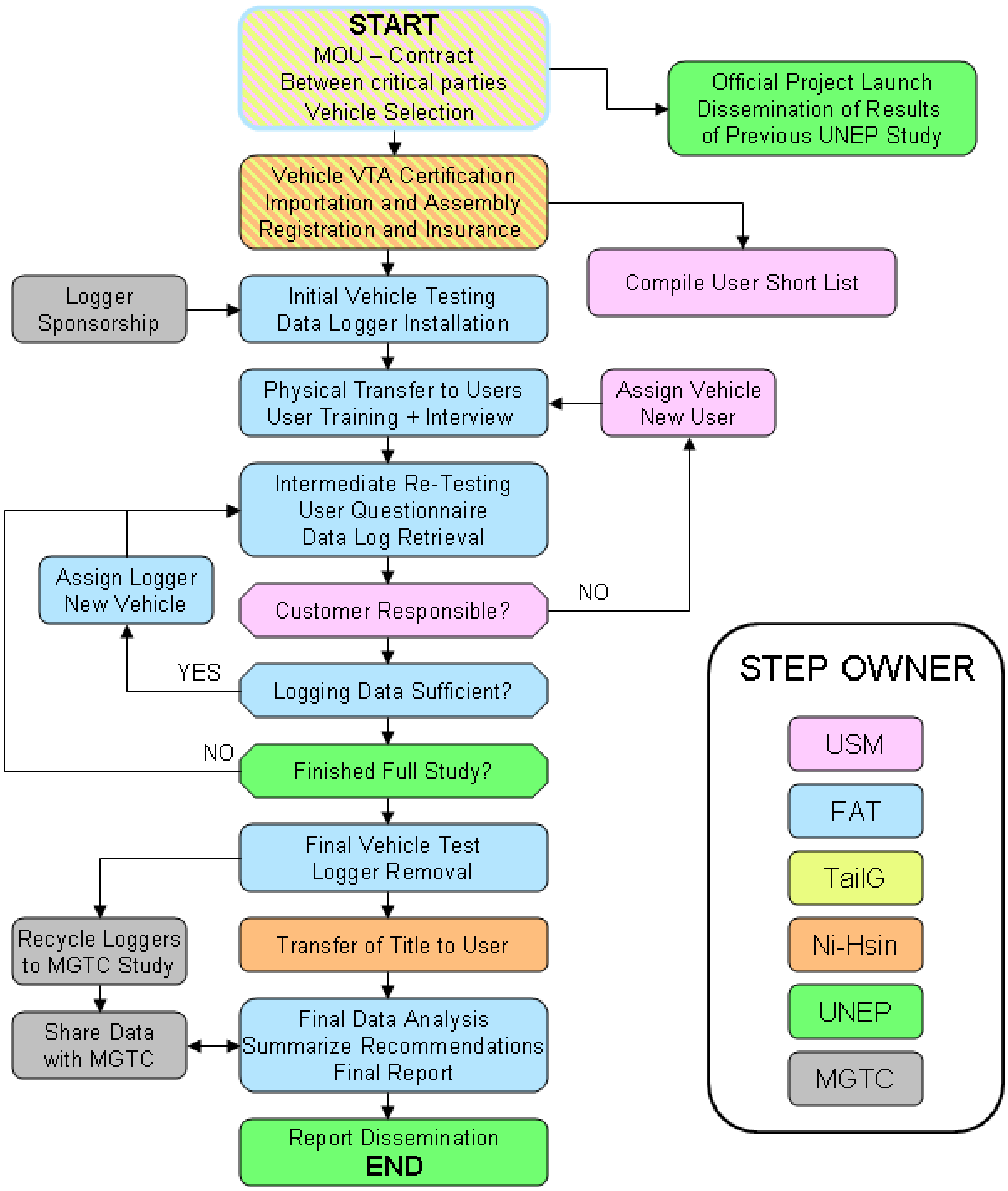
General Demonstration Plan

The vehicles were allocated by the University Science Malaysia (USM) to a variety of 2-wheeler users. The users operated the motorcycles as their own vehicle for the duration of the test, taking it on their daily routine which consisted of such things as commuting to work, going to school, fetching groceries from the market, transporting children to school, delivering parcels, going to job sites, and even leisure activities. Charging was expected to take place at home for most users, however the vehicles were also charged wherever a standard power receptacle is available, such as at work, at depots or guard houses. Tracking where charging was performed was one of the goals of this study. The vehicles were tested by Focus at the beginning and end of the test period, and in some cases intermittently during the study. Users were similarly questioned on their travel habits at the beginning, and in some cases during the study. They were asked for their feedback on the vehicle's performance, how satisfied they are with it in their use case, how often and where they charge, and what other factors affect the desirability of the vehicle, both positive and negatively.

Selected vehicles were equipped with a vehicle data logger, taking high-resolution data on the individual trips (for comparison to the user reported data). Trips were analyzed for distance travel, time, average and maximum speeds, acceleration/braking rates and energy consumption. Trip statistics were compared to the vehicle performance and contrasted between the various use groups. This was analyzed to determine what vehicle performance would be required for each user group separately.

Project Flow

The major project steps are shown below along with each step's main responsible partner.



Production, approvals, licensing and insurance were all handled by TailG/Ni-Hsin. USM was responsible for the allocation and tracking of vehicles, and determining which users are eligible to receive the vehicles at the end of the study. MGTC expressed an interest in getting the data and comparing it with similar data from their study of Battery Swapping Electric Motorcycles and conventional motorcycles. Focus was responsible for the daily operation of the study, collecting data, surveying riders, and inspecting vehicles. At the end of the study Focus analyzed the data, and prepared a report highlighting the vehicle usage patterns, applicability/acceptability of the electric motorcycles to various users, as well as analyzing what other factors affect the viability and acceptability of electric motorcycles. This included battery capacity and price optimization, as well as feedback on things such as parking, charging and even social factors gathered from the users.

Detailed Project Steps

PHASE 1 (first 6 months)		
PIC/DATE	**STEP**	**DETAILS**
USM, TailG, FAT	MOU	A Memorandum of Understanding has been signed between the relevant parties specifying the responsibilities in the project, including vehicle ownership, licensing, registration and insurance
FAT	Vehicle Selection	TailG BOLD model selected[7]: 70kph, 100km range, 72V 44Ah Lithium Battery, 7-hour charge 91kg curb weight, Dual disk brakes, Step-trough frame, 160kg load
TAILG	VTA Certification	BOLD model has passed VTA and is for sale in Malaysia
USM	User List	USM has compiled the list of end users
TAILG	Vehicle Build	Vehicles imported NOV ’23, built at Ni-Hsin plant (KL) DEC ‘23
FAT	Logger Install	Focus was present during vehicle build to install loggers in selected vehicles, as well as perform initial testing.
TAILG	Customer Service Ctr.	17 distributor service centers are active and stocked.
USM, TAILG, FAT	Vehicle Allocation	USM assigned vehicles to the designated end-users. Vehicles were delivered by Ni-Hsin in batches as produced. The focus has instructed users on project requirements and making initial surveys of the users and their intended use of the vehicles.
FAT: Q1-2 ‘24	Data Logging	Focus has been intermittently downloading the data logs from logging vehicles, and re-survey the users for their feedback.
USM: Q1-2 ‘24	User Reallocation	Vehicles were reallocated to new users (as required) by USM. In general, vehicles will only be reassigned to another user if the initial user is negligent, or abusive of the vehicle.
FAT: Q1-2 ‘24	Logger Reallocation	Once sufficient data was logged (~100 trips) some loggers were reassigned to a different vehicle by Focus.

[7] https://ebixon.com/ebixon-bold/

PHASE 2 (second 6 months)		
PIC/DATE	**STEP**	**DETAILS**
USM: Q2-3 ‘24	User Reallocation	Continued reallocation as required
FAT: Q2-3 ‘24	Logger Reallocation	Continued Logger reallocation as required
FAT, MGTC: Q2-3 ‘24	Logger Transfer to MGTC	As logged data became sufficient, the loggers were transferred to MGTC for use in their studies (Battery Swapping EV’s and ICE 2Ws)
FAT: Q3 ‘24	Final Test	Focus performed a final vehicle test and interview with the users
USM, TailG: Q3 ‘24	Ownership Transfer	USM will determine which users have faithfully complied with their data reporting responsibilities and will instruct Ni-Hsin to transfer the ownership of the vehicles to these users if they desire.
FAT: Q3 ‘24	Analysis and Report	Focus analyzed all data and prepared a final report on the project. All data will be shared with USM and MGTC for use in their studies.
UNEP: Q3 ‘24	Dissemination	UNEP provided the report publicly at the end of project workshop with critical stakeholders.

GLOBAL PERSPECTIVE

There is great interest in EVs globally, with a lot of attention focused on battery swapping in urban areas and along commuting corridors. Electric 2-wheelers have long been used in China, however recently they have become increasingly common in other regions as well. E-bicycles are popular in Europe where they augment the existing culture of bicycling for commuting and pleasure. In Southeast Asia E-scooters, E-motorcycles and even electric 3-wheelers are becoming more common every year.

One of the major impediments to greater EV uptake is the cost of the battery, which may constitute 25% to 40% of the vehicle's cost (ICCT 2021, Frost & Sulivan 2022). One solution to this is to sell the EV without the battery, thereby reducing the upfront cost, and then "rent" batteries from battery swapping stations, rolling the battery cost into the charging fees over a longer period. This solution also addresses one of the main drawbacks of EVs, namely the long recharging time. For users without access to charging points near vehicle parking, for example high rise apartment or flat dwellers, it also simplifies vehicle charging (Honan 2023).

Battery swapping is a major challenge for larger vehicles, such as passenger cars, due to the large size and weight of the batteries. Electric 2-wheelers (E2W[8]), however, are much more amenable to battery swapping due to their relatively small size and lower performance. In fact, many E2W manufacturers are already incorporating removable and/or swapable batteries into their designs[9].

USA

In the United States, the biggest use of battery swapping in 2-wheelers is for delivery bicycles in large urban centers, especially New York city, Figure 1, where around 60,000 bicycle deliverers work. Several companies including PopWheel, and Swobbee are providing battery swapping, and Swiftmile has developed fast-charging bike racks for delivery bikes[10].

Figure 1 : Delivery E-Bike rider in New York. ***Image: MIT Technology Review***

[8] We will use the term "Electric 2-Wheelers" for all classes, including E-Bicycles, E-Scooters and E-Motorcycles, when referring to them in general. When referencing only a specific group, we will use that groups name, for example E-Motorcycles

[9] https://www.wired.com/story/battery-swapping-tech-gives-electric-motorcycles-an-edge/, Ben Purvis, Oct 2022

[10] https://www.technologyreview.com/2024/03/21/1089976/battery-swapping-ebikes/, Casey Crownhart, March 2024

Africa

Several electric motorcycle batteries swapping programs have recently been developed in Africa[11]. Motorcycles are becoming more popular in Africa, the vast majority of which are used as taxis, called “boda bodas” or as good delivery vehicles[12].

Figure 2 : Battery Swapping is taking off in Africa. ***Images: Left Spiro, Right CLEMENT DI ROMA/AFP via Getty Images***

Spiro, operating in several countries in Africa, recycles old combustion motorcycles, and provides an incentive of about 344$ towards the purchase of a new electric motorcycle for each recycled combustion unit. The new electric motorcycle owners then pay a daily subscription of around 2$ which pays off the outstanding balance on the E-motorcycle, and allows them access to battery-swap stations, where they can quickly switch out depleted batteries for fully charged ones. Spiro’s battery swapping stations have historically been manned by workers physically handling the batteries, but they have recently announced a move towards automated swapping stations.
Ampersand is another company offering electric motorcycles and battery swapping stations in Kenya and Rwanda, and Uber has also announced that it will begin electric motorcycle services in Kenya as well.

Roam, a Swedish-Kenyan mobility company, formerly known as Opibus, converts combustion motorcycles to electric propulsion and recently opened East Africa’s largest electric motorcycle assembly[13]. Kofa, a Ghanaian company focusing on battery swap networks, is working with China’s TAILG to develop battery swapping motorcycles and stations[14]. Ecobodaa, selling electric motorcycles for about 1,500$ in Kenya, has plans to expand though East Africa, and claims that delivery riders who spend about 6.10$ per day on fuel for combustion motorcycles, will only be spending around 2.50$ for battery swaps each day. Kenya, and many East African countries (including Uganda and Tanzania) have an advantage in that a large part of their electric power comes from renewables, mostly hydroelectric[15].

Indonesia

Indonesia has recently become very active in electric motorcycles, with several domestic designs in production. The national government has been providing subsidies of about 460$ for the purchase of electric motorcycles with greater than 40% local content[16]. Indonesia has also begun making inroads with electric motorcycle battery

[11] https://electrek.co/2024/02/19/are-africas-latest-electric-motorcycle-battery-swapping-gains-outpacing-the-world, Micah Toll Feb, 2024
[12] According to the FIA Foundation, there were 5 million motorcycles in sub-Sahara Africs in 2010, rising to 27 million in 2022, around 80% of which are used in the motorcycle taxi industry.
[13] https://edition.cnn.com/2023/09/04/africa/spiro-battery-swap-africa-electric-bikes-spc-intl/index.html, Nell Lewis, October 2023
[14] https://cleantechnica.com/2023/10/19/kofa-tailg-partner-to-deploy-200000-electric-motorcycles-5000-battery-swap-stations-in-africa-by-2030/, Remeredzai Joseph Kuhudzai, 2023
[15] https://www.reuters.com/business/autos-transportation/battery-swapping-spurs-kenyas-electric-motorbike-drive-2022-12-26/, Ayenat Mersie, December 2022
[16] https://www.pwc.com/id/en/media-centre/infrastructure-news/january-2024/moderate-target-for-electric-motorcycles.html.

swapping, including developments by Swap (PT Swap Energi) with over a thousand stations, and Oyika, NFCX, WDP, Pertamina, Alessa, and Gesits are also active in Indonesia[17].

“Swap”, Figure 3, has highly automated swapping: batteries placed on the BSS stand are recognized by the station, and a charging slot opens allowing insertion of the depleted battery, then a recharged battery slot opens up offering a fully charged one in return. Pricing is based on kilometers traveled, with limited time validity (typically 30 to 60 days). Costs range from 1.25$ for 100km to 5$ for 500km.

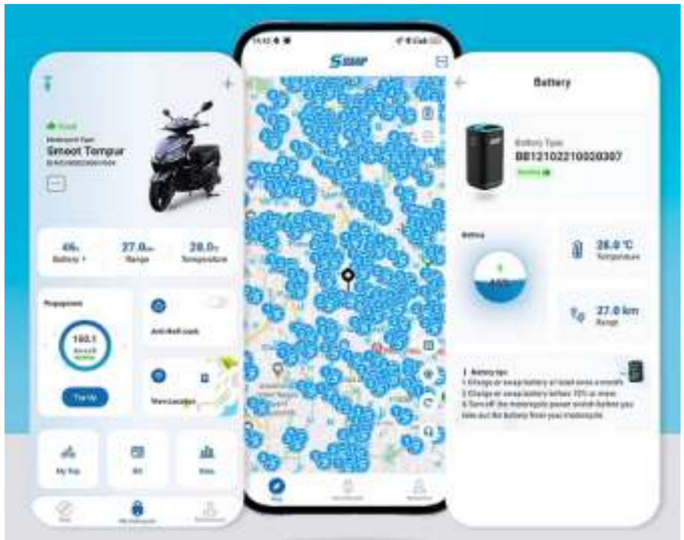


Figure 3 : Swap has an extensive system of battery swapping stations in Indonesia. ***Image: Swap***

The State-Owned Electric Company (PLN) is encouraging EV charging by offering charging companies a preferential electricity tariff of 0.05$ per kWh. The government has also been investing in EV manufacturing and research and development[18]. Farasis Energy, another Indonesian company, has partnered with Chinese companies Yugu, Zhi Zu, China Tower, and Mengniu in introducing a “Standard Electric Motorcycle Battery” which allows rapid charging at a 5C (5 times the batteries rated amp hour capacity), capable of taking a battery from 10% to 80% State Of Charge (SOC) in just 15 minutes potentially competing with battery swapping stations[19].

Singapore

Gogoro, the Taiwan Battery Swapping System (BSS) giant, has entered Singapore focusing on delivery riders because “delivery riders ride more than six-times the distance as consumer riders”[20]. Another BSS project, Mo Batteries, which was to launch a battery swapping system for electric motorcycles in 2024 recently decided to exit the field stating that “*Due to high costs and the complexity of setting up the business to be commercially viable, Mo Batteries will not proceed to launch a battery swapping service for electric motorcycles in 2024 as planned.*” underscoring the difficult position of BSS service providers[21].

[17] https://www.tycorun.com/blogs/news/top-battery-swap-company-in-indonesia
[18] https://bolt.earth/blog/ev-landscape-in-indonesia
[19] https://taiwannews.com.tw/news/5677660
[20] https://electrek.co/2023/03/23/gogoro-battery-swapping-electric-scooters-singapore/, Micah Toll, Mar 2023
[21] https://www.straitstimes.com/singapore/transport/s-pore-company-drops-plan-to-launch-electric-motorcycle-battery-swop-service

Taiwan

Taiwanese brand Gogoro is one of the largest battery swap service providers, and is operational in several locations globally, with its swap system now available in nine countries including Taiwan, China, India, Indonesia, the Philippines, Korea, Japan, Singapore and Israel (Honan 2023). Gogoro currently has stations in over 3000 locations and services ten brands (apart from their own electric motorcycles) for a total of 47 compatible models. In 2021 Gogoro sold almost 72,000 electric scooters in Taiwan, proving that they can succeed as a battery swap service provider as well as an electric vehicle provider.

However, Gogoro is not the only BSS system provider in Taiwan. Kymco, the largest motorcycle manufacturer in Taiwan, has recently introduced their Ionex Energy Battery Swap Station and is working with various E-motorcycle manufacturers to co-develop electric 2-wheelers for use with their BSS stations.

China

China has been the biggest producer and user of electric 2-wheelers for a long time. They have a number of BSS providers for both cars and 2-wheelrers including Nio Power, Immotor, Altun, HELLO, Zhizu, China Tower, TYCORUN, IMMOTOR, Yugu, Qishi, TENWIN, Mambike, 51Charge, Meituan, Yaeda, and Haojue. Of special interest is the fact that HELLO claimed to need only 12 charging slots for almost 100 users.

India

India has a large number of domestically designed electric motorcycles in development, and several BSS providers including Bounce Infinity, Sun Mobility and Yulu Bikes for 2-wheelers, and Sun Mobility for cars. An analysis in India determined that most private motorcycle users travel around 40km per day, and that over a 5-year period a Battery Electric Vehicles (BEV[22]) with "point" charging (that is direct charging of the vehicle or battery at home, or public charging point) is the lowest cost option for those traveling below 100km per day (ICCT 2021). Above 100km, the battery swapping system makes better financial sense.

Regional Cooperation

A number of international cooperative projects have sprung up around Southeast Asia, frequently combining a vehicle manufacturer and a battery or BSS service provider. Gojek, the Indonesian ride hailing and delivery company, is working with Selex, a Vietnamese startup that makes electric vehicles and battery networks already used by Grab and Lazada, to provide Gojek drivers using Selex bikes with home chargers and free access to Selex's battery swapping stations. Gojek will also be sourcing EVs from Dat Bike in Vietnam and is investing in Electrum in Indonesia, which looks to produce up to 1 million electric motorbikes a year[23].

Gogoro recently signed a 1.5 billion USD deal with Maharashtra state in India to build vehicles, batteries, and charging stations there (Honan 2023). The magnitude of this investment helps to highlight confidence in the growth of small electric vehicle demand in the near future.

[22] Also known as a "Fixed Battery" Electric Vehicle. While it may in fact have removable batteries, it is not setup for battery swapping.
[23] https://asia.nikkei.com/Business/Automobiles/Indonesia-s-Gojek-ties-up-with-Vietnam-EV-battery-swap-startup

Other Regions

While our emphasis is predominantly in Southeast Asia, there are a number of EV Battery swapping companies developing and deploying systems globally, including Swobbee (Germany), Raido (Lithuania), Origem and Voltz Motors (Brazil), and Zynch and Citio (Mexico). None of these, however, has attained the market penetration of the E2W swapping stations of East Asia. This is because motorcycles are considered a primary transportation mode in this region, especially for delivery and ride sharing[24].

E2W BSS Standards

One thing that can greatly improve the prospects of battery swapping is the establishment of standards covering the batteries, connections, chargers and vehicle requirements. Setting up swapable EV battery standards, however, is rather difficult as each manufacturer wishes to keep their technology options open, whereas complying to a standard is seen as limiting their future ability to adapt to new technologies or designs. Despite this difficulty, several electric motorcycle battery standards exist. Gogoro uses a 9.8kg battery, and the capacity has increased from 1.3kWh to 1.6kWh with further increases on the horizon. The batteries are not sold separately and until recently were not allowed for home charging. The Japanese giants (Honda, Yamaha, Suzuki, and Kawasaki) came up with a 1.3kWh battery, weighing 10.2kg, which takes 4 to 5 hours to charge and costs about 600 USD each.

In September 2021, the Swappable Batteries Motorcycle Consortium (SBMC) was set up to develop small EV battery standards for Europe. The SBMC is focusing on 48V batteries of up to 2 kWh, with a target weight of below 12 kg. However, the 48 Volt target is a major weakness compared with the current standard of 72V used in many other systems. Malaysia set up its own Swapable Battery System Consortium in May 2024 with the NanoMalaysia[25] and Motorcycle and Scooter Assemblers and Distributors Association of Malaysia (MASAAM) designated as coordinators of the Consortium. There are currently at least three electric motorcycles in Malaysia with the potential for battery swapping including those distributed by Ni-Hsin, BlueShark and Ryde EV (Oyika).

Safety Standards

The main safety standard relating to swapable batteries is the UNR136 which is recognized by Malaysia as the relevant safety standard. This covers such items as labeling, insulation, hi-pot testing, finger ingress, water ingress, leakage and gas accumulation, shock/vibration testing, impact penetration, short circuit, overload, over charging protection, etc. Removable batteries have special limits on mechanical shock and vibration in anticipation of accidentally being dropped more frequently than fixed batteries.

For BSS swapping stations various other safety standards apply, however these are the typical electrical appliance standards mandated for similar equipment.

Malaysian Situation

Currently there are two Electric Motorcycle Battery Swapping Service providers just getting started in Malaysia: BlueShark and RydEV/Oyika. Blue shark is a Malaysian subsidiary of Sharkgulf Technologies Group of China and will be assembling a range of electric 2-wheelers in Malaysia for the Southeast Asian market, as well as possibly for

[24] "Strategic Analysis of the Global Electric Two- and Three- Wheeler Battery Swapping Market", September 2022 https://www.businesswire.com/news/home/20220929005708/en/Global-Electric-Two--and-Three--Wheeler-Battery-Swapping-Strategic-Analysis-Report-2022-Rising-Fuel-Cost-Intro-of-Battery-Swapping-Standards-and-Collaborations-to-Ensure-Transformational-Growth---ResearchAndMarkets.com

[25] Nano Malaysia is a government linked company under the Minister of Science, Technology and Innovation entrusted with nanotechnology commercialization activities

Latin America[26]. They have begun sales of their R1, Figure 4, and R1 Lite models in Malaysia, both of which allow for battery swapping at their stations. BlueShark vehicles can be purchased with batteries for home charging, or without batteries for use with their battery swap stations.

Figure 4 : BlueShark R1 is a step-through frame electric motorcycle with under-seat batteries. *Image: CarSifu.my*

Ryde EV is a business of Yinson Holdings Berhad, headquartered in Malaysia, and will be introducing several models of E2Ws including E-scooters and E-Motorcycles, Figure 5, which allow for battery swapping. The batteries are provided by Oyika, and Yinson is planning on servicing all kinds of surface transportation with electric propulsion, even including boats, internationally. Ryde EV includes road tax and vehicle maintenance in some of the battery swapping packages.

Figure 5 : Ryde EV Ryver is a step-through frame electric motorcycle with under-seat batteries. *Image: RydeEv*

[26] https://www.nst.com.my/business/2022/03/778096/epmb-inks-partnership-china-based-sharkgulf-technologies-cis-pride-silver

Selected specifications for the various models are shown in Figure 6. Top speeds are generally quoted with fully charged batteries, and thus the actual top speed may be significantly lower at any given time. Vehicle range, likewise, is subject to variation. Typically, ranges are quoted, as shown here, at relatively slow speeds. For reference a new conventional 125cc motorcycle can be bought for around 5,500RM, and will have a top speed of 110kph and full tank range of 200km.

Company	***BlueShark***	***BlueShark***	***RydeEV***	***RydeEV***
Model	R1 Lite	R1	Ryder	Hyper
Top Speed (kph) claimed	80	90	65	90
Power	NA	5kW	2kW	4kW
Range (claimed)	100km @ 40kph	100km @ 40kph[27]	72.5 @ 45kph	72.5 @ 45kph
Cost (RM) sans batteries	7,190	9,390	8,500	10,500
Cost (RM) with batteries	12,600	14,800	-	-

Figure 6 : Selected vehicle specifications and costs for Malaysian BSVs.

Overall Observations

Upon reviewing electric motorcycle battery swapping implementation globally, several "best practices" become apparent related to the battery, battery swapping station, electric motorcycle and costing schemes.

Electric Motorcycles

Typical daily vehicle ranges are around 30 to 60km per day, whereas delivery riders drive about 3.5 times further, achieving 120 to 200km per day (ICCT 2021, Feng & Lu 2022 and Gitano 2023). Electric motorcycles generally have energy capacities of 2.9 to 3.3kWh, and consume about 2.8kWh per 100km, for an electric "mileage" of 36.5km per kilowatt hour. Electric motorcycle batteries are expected to last over 5 years, and 100,000km (ICCT 2021). While charging time is not a major impediment for many users, lower demand electric motorcycle owners without access to charging points near parking, and delivery riders, who consume their batteries charge much faster, cannot afford to wait for batteries to charge. Thus, delivery riders, and other high-demand users are the target market segment for battery swapping electric motorcycles.

Battery Swapping Electric Motorcycle

Consumer demand for greater power and range tend to drive vehicles towards higher top speeds and greater battery capacity. One of the fundamental limitations of motorcycle battery swapping is that the battery weight is constrained to what a user can conveniently lift and insert into a BSS station, typically around 10kg. This is significantly smaller than the battery in fixed battery vehicles[28]. For higher powers and ranges this necessitates the use of multiple removable batteries. Currently, most Battery Swapping Vehicles (BSVs[29]) on the market utilize two batteries.

[27] https://www.carsifu.my/bike-reviews/blueshark-r1-urban-ride-on-a-charge
[28] https://www.marketsandmarkets.com/Market-Reports/battery-swapping-market-2482807.html
[29] Battery Swapping Vehicles are electric vehicles designed for battery swapping, and have removable batteries.

MOTORCYCLES VERSUS SCOOTERS

The term "Electric Vehicles" generally brings up images of Tesla and BYD, that is cars, however the fact is that in Southeast Asia there are several orders of magnitude more electric 2-wheelers than 4-wheelers on the road. Estimates for Malaysia, for example, have around 200,000 E2Ws on the road, and less than 2000 electric cars. When it comes to electrification of 2-wheelers, the emphasis is generally on "motorcycles", i.e. those 2-wheelers which can achieve top speeds in excess of 50kph. While not necessarily equivalent to combustion motorcycles, these electric motorcycles are assumed to be capable of taking over the bulk of the functions of combustion motorcycles. It should be remembered, however, that electric scooters, that is smaller, lighter, electric 2-wheelers with top speeds of 25 to 50kph, currently outnumber electric motorcycles by a factor of about 10 in Malaysia and satisfy the travel needs for many "low end" consumers, with limited budgets and requirements. These E-Scooters typically cost 250 to 500 USD and can achieve ranges around 35km. They are popular with elderly people, mothers taking children to school, or fetching groceries from a local market, scrap collectors, and immigrant workers.

E-Motor vs E-Scooter

"While electric motorcycles are high-performance marvels, they have also come in for deserved criticism of their limited range, heavy weight and long charging times. Conversely, its lowly cousin, the urban scooter, has proven to be the better two-wheeler to electrify in the short term. Scooters weigh much less than motorcycles but essentially accomplish the same task, while also providing superior utility and ease of use. They don't have the high-performance expectations of full-size motorcycles, trading speed for a lower price and increased practicality."

https://www.forbes.com/sites/billroberson/2024/01/28/it-works-for-scooters-can-battery-swapping-work-for-electric-cars/?sh=5ff1ba737fad, William Roberson Jan 2024

There is a very good reason why electric scooters are so popular, and electric cars have yet to gain market share: energy storage cost. Simply put, the energy required by a vehicle is proportional to the mass of the vehicle, the expected range, frontal area and the square of its speed. Larger vehicles, like cars, require much more energy storage in order to achieve their desired speeds and ranges. This in turn necessitates a large, expensive battery making the electric car a much more difficult economic proposition[30]. Electric motorcycles are currently slightly more expensive than conventional motorcycles, but electric scooters are less expensive than motorcycles and have the added advantage of market segment monopoly: there are no competing technologies in this performance segment.

BSS Batteries

Early adopters of battery swapping systems settled on 48V as the standard battery voltage. More recent systems have tended towards 72V for their higher power capabilities. All BSS systems currently use lithium batteries, and while various chemistries are to be found in the field, Lithium Iron Phosphate batteries appear to be the most popular.

Initial energy densities of around 1kWh has shifted towards 1.5kWh per battery[28], however announcements have come out indicating capacities of 1.7kWg to over 2kWh per battery. Battery weights average 10 to 12kg for ease of handling, and are removed vertically from the vehicles, typically from under the seat.

[30] "Battery Swapping Systems: From a Business-oriented Analysis to a Practical Case Study" Masters Thesis POLITECNICO DI TORINO, Andrea Comelli 2020

Parameter	Units	TYCORUN	Japan	Gogoro	TailG	BlueShark	Oyika
Models/Brands		Many	Honda, Yamaha, Kawasaki	Many	Bold, Torq	R1, R1 Lite	Okla, TailG, Viar, Niu, Gesits
Cost	USD		610	25/month	455	682	625
Nom Voltage	V	48	50	50	72	48	60
Capacity	Ah	50	26.1	34	22	30	28.8
Energy	Wh	2500	1314	1700	1500	1440	1728
Discharge Max	A	50			50	60	
Cycle life		800			1000	2000	2000
Weight	kg	14	10.2	9.8	11	12	
Product Size	liters	8.5	8.3		6.8		
Charge Time	h				7	3.5	4.5

Figure 7 : Comparison of various swapping capable electric motorcycle batteries

Battery Swapping Stations

Extensive studies have been carried out on electric motorcycle battery swapping stations analyzing factors contributing to their success or failure. Demand for batteries peaks between 10:00 and 22:00, and most (>80%) of users are willing to accept a battery that is charged to 90% or greater. Most batteries are returned with significant charge remaining, thereby reducing the required charging time from the maximum (Feng & Lu 2022). Several important factors should be considered for a successful BSS Station (Huang 2019, Frost and Sullivan 2022), including:

1. **Each BSS station should only service a small number of different batteries (e.g. 1 or 2 models)**
2. **The stations should be located strategically, preferably where people already stop (e.g. Supermarkets, fuel stations)**
3. **If possible, the station should use off-peak charging to reduce costs and improve grid stability**
4. **Batteries must be carefully maintained to prolong the battery life, and to ensure customers trust that the battery they receive is as good as the one they returned**
5. **Battery weight and slot position play a role in user satisfaction**

Battery swap costing

While a "pay per swap" option is available with some battery swapping stations, the prevailing sales model is subscription-based charging, where users sign up for a monthly fee allowing them some number of swaps. A summary of swap costing schemes is shown in Figure 8. Swap in Indonesia, offers distance-based charging from 1.25$ per 100km to 5$ per 500km. Many BSS providers target a base level of 12-18 swaps per month for private electric motorcycle owners. Battery swap costing varies considerably, with Immotor charging 5-10$/month, Gogoro charging 20 to 30$ per month, and Ryde EV costing almost 100$ per month for some models (Honan 2023). The Ryde EV cost, however, also includes road tax and maintenance[31].

[31] https://soyacincau.com/2023/09/10/rydeev-malaysia-electric-motorcycle-oyika-swappable-battery/10-Sept 2023

Region	Africa	China	Global	Indonesia	Malaysia	Malaysia
Company	Ecobodaa	Immotor	Gogoro	Swap	Ryde EV	BlueShark
Cost per Swap	1.25$					0.44$
Cost (Low)		5$/month	20$/month	1.25$/100km	68$/month*	13.4$/month
Cost (High)		10$/month	30$/month	5$/500km	98$/month*	31.6$/month

* Ryde EV costs include road tax and maintenance

Figure 8 : Comparison of battery swap costings from various regions.

Multiple analyses have indicated that "point charging" is most practical for average users traveling below 40 to 100km per day, with battery swapping being the best option for users traveling in excess of 120km/day (ICCT 2022).

According to the ICCT, for private vehicle owners BEVs are the least expensive, followed by BSVs, while ICE 2-wheelers have the highest total cost of ownership after 5 years of ownership, depending on local fuel prices. For delivery riders, BSVs are slightly less expensive than BEVs, and much cheaper to own than ICE 2-wheelers (ICCT 2021). Greater standardization of swapable batteries and expected battery improvements and cost reductions will increase BEV financial attractiveness and improve BSS profitability as well (Setiawan 2023).

Issues With Battery Swapping

As battery swap stations should be located in "high traffic" areas, their space rental is likely to be relatively expensive. For the same reason, battery swapping is likely to be most useful only in dense urban centers, with rural customers forced to rely on fixed battery EVs. The battery standardization required for BSS success can potentially stifle innovation for vehicle manufacturers as they are locked into a given battery specification for potentially many years. Perhaps most damning, however, is the long-term cost of battery swapping[32]. As the end customer is paying for at least one battery in addition to the one used in their vehicle, as well as the BSS cost, maintenance and service provider profit, battery swapping EVs will always cost more in the long run than fixed battery EVs. To cover the large up-front cost of the inventory of batteries and charging stations, BSS service providers require a large amount of capital, which will only get repaid slowly, over a number of years. With rapid changes in technologies and markets, this makes their financial prospects especially risky, requiring service providers to charge relatively high rates.

Government Policy

EV subsidies are expected to be more effective than electricity subsidies or battery subsidies in increasing EV ownership (Setiawan 2023). National governments are often slow to respond to the rapid changes in technologies, and it has been pointed out that local governments can play a role in encouraging the use of E2Ws, and implementation of BSS, such as allowing electric motorcycles and scooters on various roads, installing public charging points and providing space and regulatory support for battery swap stations.

Malaysia is actively supporting the purchase of electric vehicle market in a number of ways including the recently announced rebate for purchases of qualifying electric motorcycles, reduced road tax and licensing fees, and

[32] Gogoro has been criticized for being too "profit making" to compete, and for not allowing home charging. https://plugincaroo.com/2016/10/17/tork-vs-ather-vs-gogoro/

manufacturers tax incentives[33]. Other governments have encouraged EVs via preferential charging schemes for night-time charging, or lower electricity tariffs for EV charging[34].

Battery Recycling

As the batteries in most BSVs are actually owned by the BSS service provider, they will have much greater potential to either re-use the batteries in a 2nd life product or recycle the batteries owing to the large volume of uniform product available.

Trends And Best Practices

While our review covers a wide geographic area, with varying levels of development, 2-wheeler and EV penetration, several "best practices" and trends are readily discernable[35].

- Battery swapping is much faster than battery charging.
- Batteries should be highly standardized to prevent multiple incompatible systems running in parallel.
- Battery swap stations must be safe for users, batteries, and passersby.
- Swapping stations must be placed in convenient locations, within a short distance of normal commutes.
- The batteries should have a convenient weight, and height for ergonomic insertion /removal to/from the vehicle and charging station.
- The unlocking/opening of charging slots should be as automated as possible. Payment services should likewise be highly automated.
- Charged batteries should always be available to prevent users from having to wait for batteries to charge.
- Battery charging and discharging must be carefully controlled to ensure long battery life, and assure users that they will always receive a battery with an acceptable range per charge.
- Users like the predictability of "pre-ordering" batteries from selected stations, allowing them to ride up and swap batteries with the foreknowledge that the battery will be fully charged and waiting.
- The most advanced systems allow "hot swapping" of batteries, without the need to switch off between swaps.
- BSVs are less expensive to purchase than BEVs, however the long-term cost is greater for BSVs.
- Battery swap providers must be reputable, with good "up time" and readily available customer service.
- Batteries are constantly improving, increasing capacity and reducing costs.

[33] GUIDELINES FOR GREEN TECHNOLOGY TAX INCENTIVE, MGTC
[34] https://bolt.earth/blog/ev-landscape-in-indonesia
[35] https://batteryswapcabinet.com/electric-motorcycle-swappable-battery/

DEMONSTRATION OF DATA COLLECTION AND METHODOLOGY

The demonstration vehicle assembly began in December 2023 at the TailG distributor Ni-Hsin in Kuala Lumpur, Malaysia, Figure 9, and went smoothly as Ni Hsin had previously built out about 60 units of this same model. The vehicles were tested on dynamometer provided by Focus Applied Technologies as an "End of Line" Quality Check test confirming acceleration, top speed, regenerative braking and speedometer readings. At this time, it was noticed that the vehicle displays approximately 16% higher speed than the actual road speed: when the wheel speed is 60kph the display will read 70kph. As the vehicle was chosen in part for its stated top speed of 70kph, it was a major disappointment to discover that the actual top speed was only 60kph.

Figure 9 : Assembly of the donation vehicles at Ni Hsin, Kuala Lumpur, December 2024. ***Image: Author***

The Vehicle Data Loggers were mounted inside the battery box area under the seat as shown in **Figure 10**. An installation manual was prepared to facilitate the installation of the loggers, **Figure 11**, some of which were installed by Ni Hsin. Installation went smoothly, and only required about 30 minutes per bike. These are powered by the vehicle's 12V system, and actively record any time the bike's key is switched ON. Every key-ON event trigger recording of a sequentially numbered log file, so there will be one data file per trip. GPS, which requires a few seconds to begin recording, also supplies the date, so data can be analyzed on a per-trip or per-day basis.

Figure 10 : Logger (gray box at top) installed in battery bay. The two batteries can be seen in the foreground.

Figure 11 : Logger installation manual developed especially for this project.

After installation the data logger operation was confirmed via observation of the SD Card status LEDs (which blink every 200ms indicating recording taking place) and short tests where the vehicle’s motor was operated while lifted on the center stand of the motorcycle.

Data Collection

A number of methods of data acquisition were performed including basic vehicle inspection, user data and surveys, individual vehicle data logging and vehicle performance (dyno) testing.

Basic Vehicle Information

All vehicles underwent basic vehicle inspection including the following data collection:

- **Vehicle Information: VIN, ODO, Plate Number, Location, Date**
- **Visual Inspection: Check tires, seat, wiring, frame**
- **Functional Inspection: Lights, Horn, Breaks, Power, Display**
- **Battery Level, Battery voltage**
- **Acceleration: 0-50 kph time**
- **Top Speed**
- **Charger Functionality**

User Reported Data and Surveys

Users were asked for some basic demographic information including their weight, age, gender, annual income. They were also surveyed about their typical vehicle use including distance traveled (km/day, week, month or year), purpose of trips (school, work, deliveries), urban/suburb/rural setting, and road type used (Express way, Federal Highway, State Highway, Local Road, or unpaved). We asked about their typical Load (# pax[36] or cargo + operator weight), range, speeds, throttle (i.e. wide open or not), # trips, charging duration and times, hill climb and acceleration, breaks, lighting, vehicle satisfaction. Finally, at the end of the test period we asked them to suggest what were the best/worst aspects of the vehicle, and what could be done to make it a more acceptable vehicle for their needs.

USER SURVEY QUESTIONS

Use Info	: Age, sex, Weight, Annual household Income, # Pax in house
Travel Area	: Urban, Rural, Sub-Urban, Inter-Urban
Road Surface	: Expressway, Fed/state Highway, Local Road, Mini Tar, Unpaved
Typical Load	: #pax, cargo weight
Destinations	: Work, School, Store, Agricultural plot, Office, Delivery, Job Site, Leisure
Vehicle	: Bike, Motorcycle (specify cc), Car, other

TRAVEL SURVEY QUESTIONS

Trip	: Range, speeds, Throttle (i.e. wide open or not), # of trips per day or week Hilly or Flat, acceleration and breaking (Hard, Medium or soft)
Charging	: Days between charges, charging time of day, duration, location, Range per charge

OVERALL VEHICLE SATISFACTION

Problems	: Quality, Functionality, Charging, Range, Charging, Performance, Stability, Other
Highlights	: Cost of Operation, Ease of Use, Maneuverability, Sound, Torque, Other
Have you had any	: Accidents? Maintenance? Rate this vehicle compared to your normal vehicle.

[36] Pax is a common abbreviation for "people"

Apart from the surveys, we asked them to track some basic information during the test period including how often they charge, where they charge and for how long. They were asked to note their travel range on a weekly or monthly basis and note any problems that have with the vehicle (i.e. ran out of charge, problem finding charging, breakdowns, accidents, etc.).

Vehicle Data Logging

While user feedback and data are very useful sources of information, users are not well equipped to accurately report many aspects of their vehicle usage. For this reason, selected vehicles have a Vehicle Data Logger installed for some period of time (targeting two months per vehicle). The data loggers are compact, rugged Vehicle Data Loggers, which incorporate 10Hz GPS, and are commonly used in vehicle and transportation studies. They are equipped with Battery Voltage Probes and High Current Clamp-type sensors.

Parameters to log include:

- **Vehicle Speed**
- **Distance Traveled**
- **Time of Day**
- **Battery Voltage**
- **Motor Current**
- **Barometric Pressure (for high-resolution hill climb)**
- **GPS location and speed**

Individual vehicles were logged for around 2 months to accumulate 100 – 500 trips per vehicle, and individual trips were analyzed for several statistics including: Max/Average Range, Speed, Power, Battery SOC, acceleration/deceleration.

Dynamometer Testing

A few vehicles were subjected to extensive testing on a chassis dynamometer. This is to carefully track the vehicles' performance over time and as a function of battery cycles and degradation. Data measured included:

- **Current and Torque vs Speed (Wide Open Throttle)**
- **Cruise Current as a function of speed**
- **Full Charge Range on World Motorcycle Test Cycle (WMTC1-2) drive cycle**

This provides detailed information about vehicle performance and range degradation.

Launching Event

The initial project agreement was signed as a Memorandum of Understanding (MOU) between the TailG (as the vehicle donors), Ni Hsin (as the vehicle assemblers and maintenance), University Science Malaysia (as the vehicle allocation and partner) and Focus Applied Technologies (for vehicle data logger and analysis). This took place on 25 November 2023. Subsequently, an official handing over ceremony, Figure 12, took place on December 27th at a Ni Hsin associated café in Kuala Lumpur.

Figure 12 : Vehicle handover ceremony. L to R: Associate Professor Dr. Teoh Yew Heng (USM), Dr. Horizon Gitano (Focus), Mr. Khoo and Norhaidi Chen Dan (Ni Hsin), Associate Professor Dr. Mohd Wira Mohd Shafiei (USM) and Mr. Rizvi Abdul Halim (Ni Hsin)

This project met with broad interest and resulted in several publications. *The Edge*, a financial news organization, focused on the collaborative nature of the project, and its contribution towards the Malaysian government's commitment to the National Low Carbon Cities 2030 initiative[37]. *Business Today* mentioned that the study was aiming to assess the viability of the electric motorcycles to perform useful work in the Malaysian environment[38]. USM's own engineering website had the most comprehensive coverage, which mentioned USM's role in the project noting its dedication to actively contributing to sustainable transpiration solutions[39].

[37] https://theedgemalaysia.com/node/686319
[38] https://www.businesstoday.com.my/2023/12/27/ni-hsin-hands-over-50-ev-bikes-to-usm-for-research/
[39] https://www.eng.usm.my/index.php/en/berita2/news/969-usm-spearheads-electric-mobility-initiative-in-malaysia-with-50-e-bikes

Data Logging and Dynamometer Results

One of the more unique features of this study is the intensive data collection performed on the vehicles and their users. Data collection was performed in three main ways, namely user interviews and surveys, extensive vehicle testing both on the road and chassis dynamometer, and on-the-road vehicle data logging. Collection of this data allowed us to investigate different sociological aspects of the vehicle's usage, vehicle "fit for use" evaluation for different use case scenarios, and extensive vehicle performance, endurance and reliability information.

Individual Trip Analysis

Data loggers were placed in the battery box for protection from weather and connected to the battery for voltage and current measurements, the throttle position signal, and the wheel speed, measured from one of the hall sensors in the hub motor for vehicle speed. In addition, the loggers carried an internal barometric pressure sensor, for hill climb measurement, and a 10Hz Global Positioning System (GPS) module for location information. While most of the useful information comes from analysis of a large number of trips, detailed inspection of individual trip data gave some interesting insight to the vehicles and their usage, as well as general instrumentation issues.

One of the things noticed early on is that GPS, while being very convenient and popular for vehicle studies, is not very good at tracking a vehicle's dynamic speed.

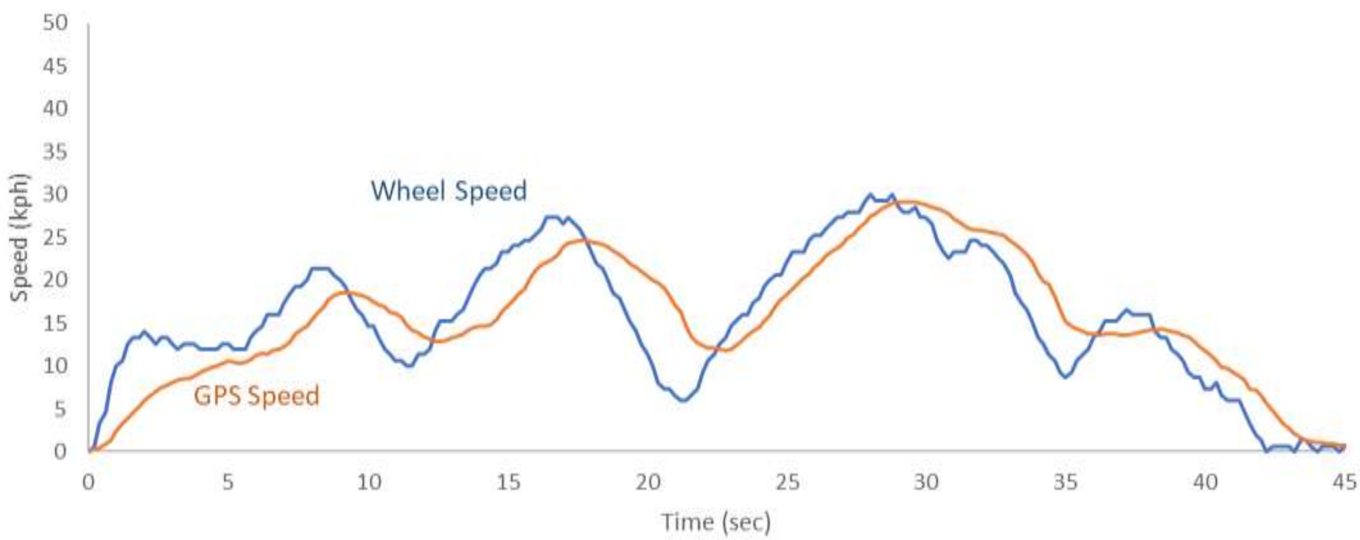


Figure 13 : GPS speed and actual wheel speed versus time during part of a trip

As can be seen in Figure 13, GPS (orange) is fairly slow to respond to speed changes, and lags behind the actual wheel speed (blue) during both acceleration and slowing. For studies investigating things like driver aggressiveness (for example the quick acceleration at the start of the trip) GPS is insufficient, and actual wheel speed should be used. Also, for an accurate estimate of distance travel we used the wheel rotations measured by the data logger.

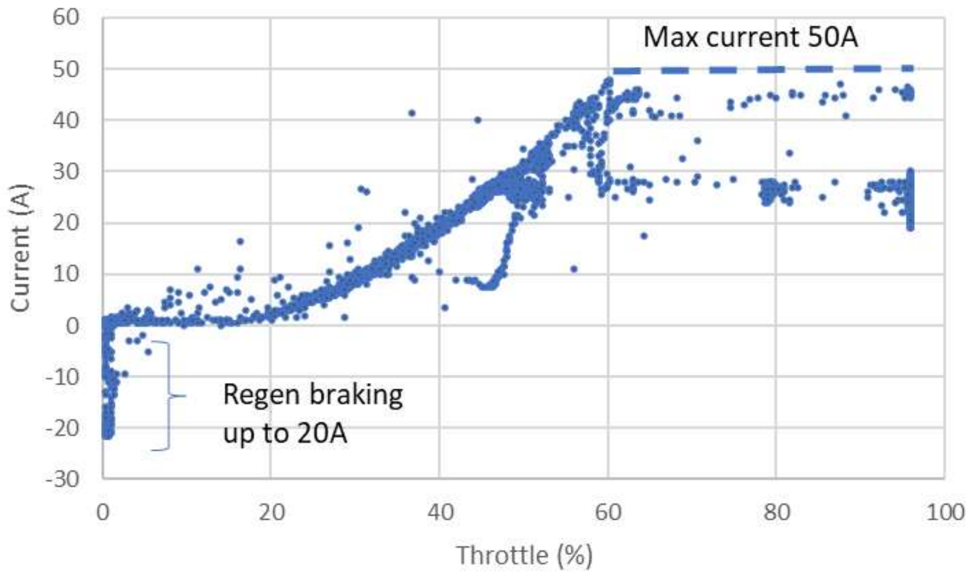


Figure 14 : Current versus Throttle Position from a random trip

In Figure 14 we can see the current as a function of throttle position (0 being "idle", and 100 being "Wide Open Throttle"). The current increases approximately proportional to the square of the throttle and is limited to 50A by the Battery Management System (BMS). At higher speeds the current is reduced, despite applying full throttle, as the motor generates a voltage in opposition to the battery voltage, as explained further below. Braking is performed when the throttle is closed and the brakes are applied, and results in negative currents (ie. regenerative braking) charging back the battery. The maximum regen braking current is limited to 20A, again limited by the BMS.

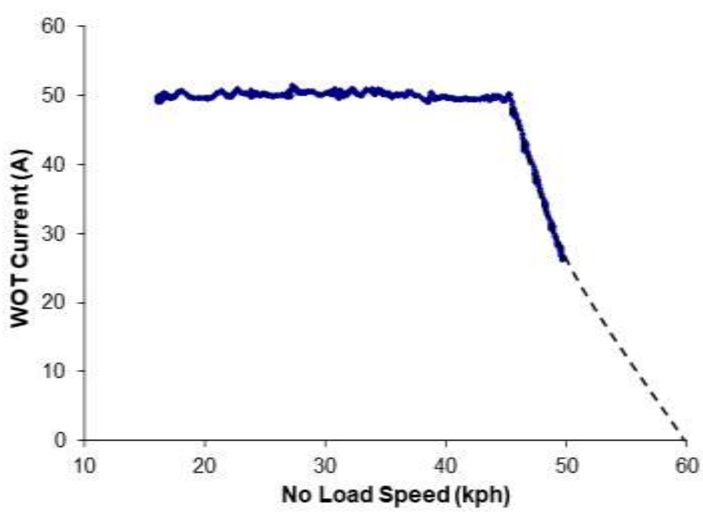


Figure 15 : Wide Open Throttle current versus Speed (unloaded) on the dynamometer

The maximum current draw of 50A is clearly shown, Figure 15, during Wide Open Throttle operation on the dynamometer. Below speeds of about 46kph the BMS limits the current to 50A. Above this speed the Back Electromotive Force (BEMF) produced by the motor reduces the current draw. Extending this BEMF dominated region it can be seen that at speeds over 60kph the motor current will drop to zero, and the motor will no longer give any torque. This is called the "no-load" speed of the motor and represents the speed at which the motor produces a BEMF equal to the batteries voltage, which is the maximum speed of Brushless

Direct Current (BLDC) motors common on lower capacity EVs[40]. With a fully charged battery this no-load speed will be about 60kph, whereas near depletion the top speed drops to around 45kph.

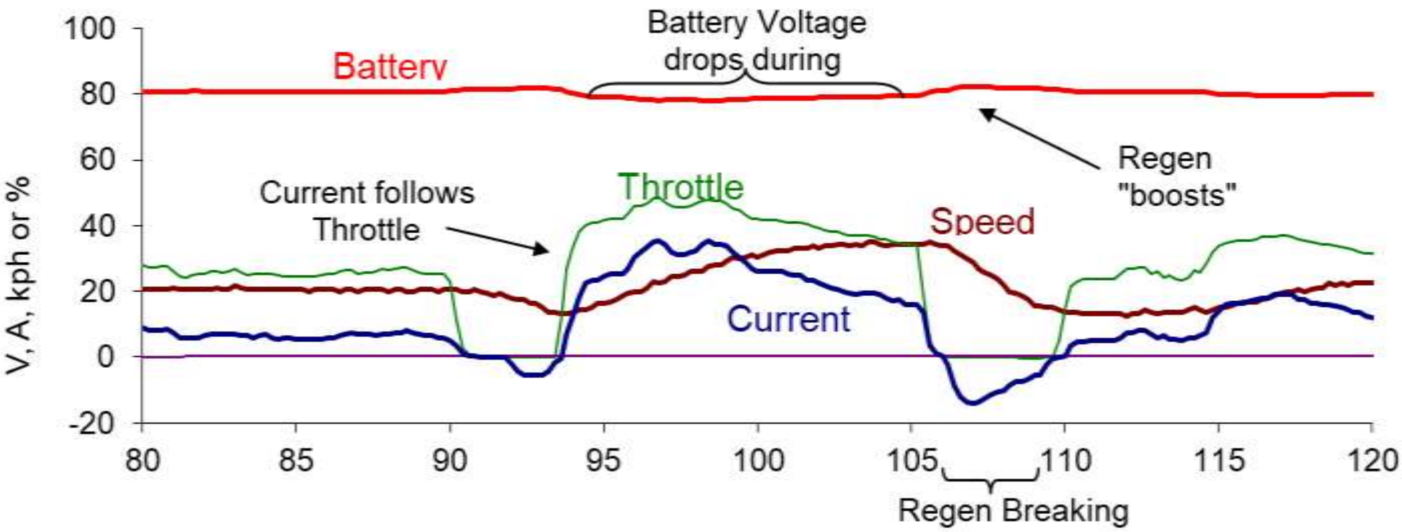


Figure 16 : Various factors captured during part of a single trip

In Figure 16 the Throttle – Current correlation can be seen: as the throttle is changed, the current changes appropriately. Battery voltage drops with heavy loading and increases slightly with regenerative braking (negative current) during the period 105-110 seconds. The maximum regen current is limited to 20A, but this can only be achieved at speeds above35kph, below that speed the current drops off with speed.

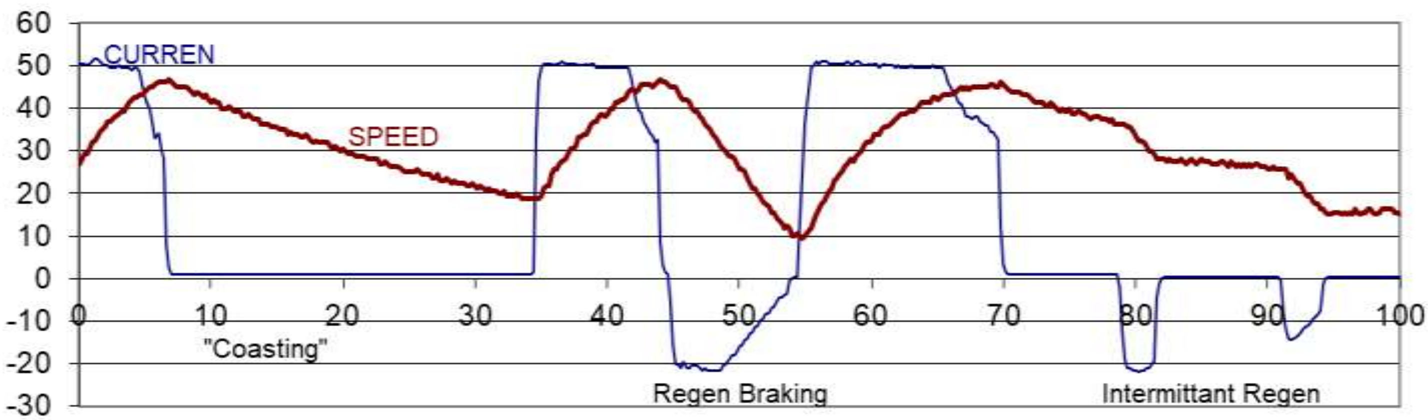


Figure 17 : Coasting versus Regenerative braking.

Regenerative braking is initiated by the brake light switch. If the throttle is released, but the brakes are not actuated, and the vehicle will “coast” down, with a gradual deceleration as seen in Figure 17 where, from about 10 to 35 seconds, the throttle was released for coasting. The vehicle subsequently accelerated, then at about 45 seconds the brake lever was pressed just enough to turn on regen braking without causing the frictional brakes to engage. A significant regen current rapidly decelerates the vehicle from 45 to 50 seconds. The vehicle was subsequently accelerated again, and then from 70 seconds onwards regen braking was intermittently triggered, each time resulting in relatively rapid deceleration of the vehicle.

[40] For a more complete explanation see: https://things-in-motion.blogspot.com/2019/05/understanding-bldc-pmsm-electric-motors.html

On some EV models, regen braking is triggered any time the throttle is reduced below a given level. This can lead to difficulties in controlling the vehicle speeds at low speeds, however the TailG model used in this study had good “drivability” in part from the brake light triggered regenerative braking.

Multiple Trip Analysis

Thousands of individual trips were logged by 20 vehicle operators. Each trip was then summarized for trip distance and duration, average and maximum speeds, total energy consumption etc. This was then used to investigate how different operators used their vehicles.

1. Rider Speed Histograms

One of the first things noticed is that different users operated their vehicles at very different speeds. Figure 18 shows the probability of operation at each speed for a number of different users. For most riders there is a “peak” in the curve around their typical cruise speed. As the vehicle is limited to a max speed of about 60kph, the probability drops off to zero above this speed. Most drives contain a large amount of time at or near stop speed, however we have eliminated the “tail” that pops up near zero kph for clarity.

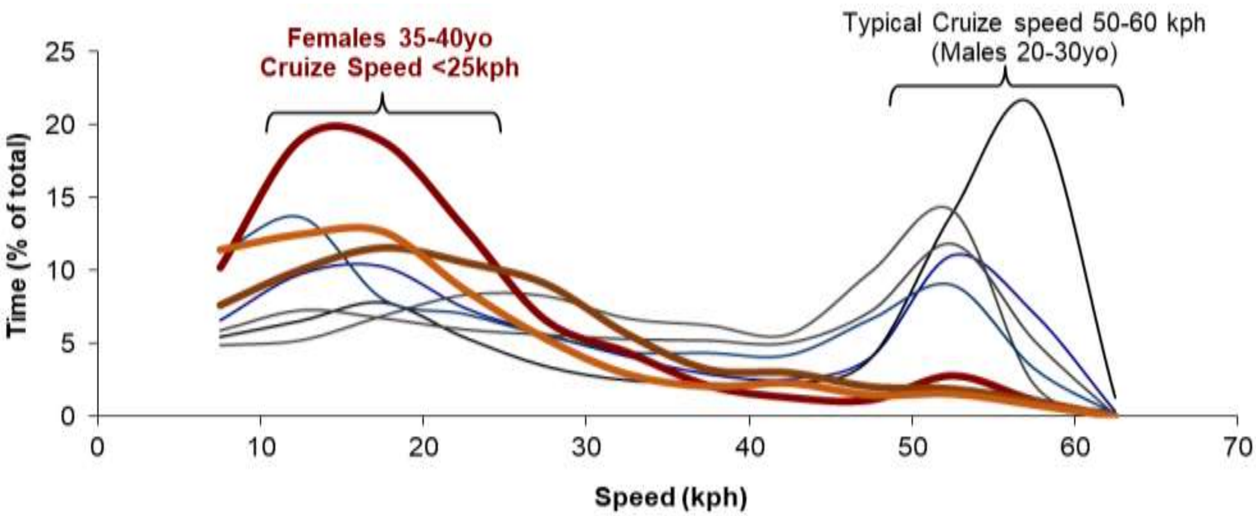


Figure 18 : Speed Probability distributions of several riders

It can be noted that the female riders typically operate at much lower speeds (<30 kph) with very little time spent above that. The young men in this sample, on the other hand, exhibit peak probabilities at much higher speeds (50-60kph), limited only by the top speed of the vehicle. In general, the males were using the motorcycles for slightly longer trips and wanted higher speeds to reduce the duration of the trip. Many of the women mentioned that, while they understood that the motorcycles couldn’t achieve speeds in excess of 60kph, this was not a problem for them. The men, however, wanted more speed. This matches with similar studies performed on cars (Rietveld 1999).

The differences in “cruise speed” is related to several factors, including trip distance and purpose. The speed versus trip distance trend can be seen in Figure 19, the plot of average cruising speed vs trip distance taken from over 2000 trips by the various riders.

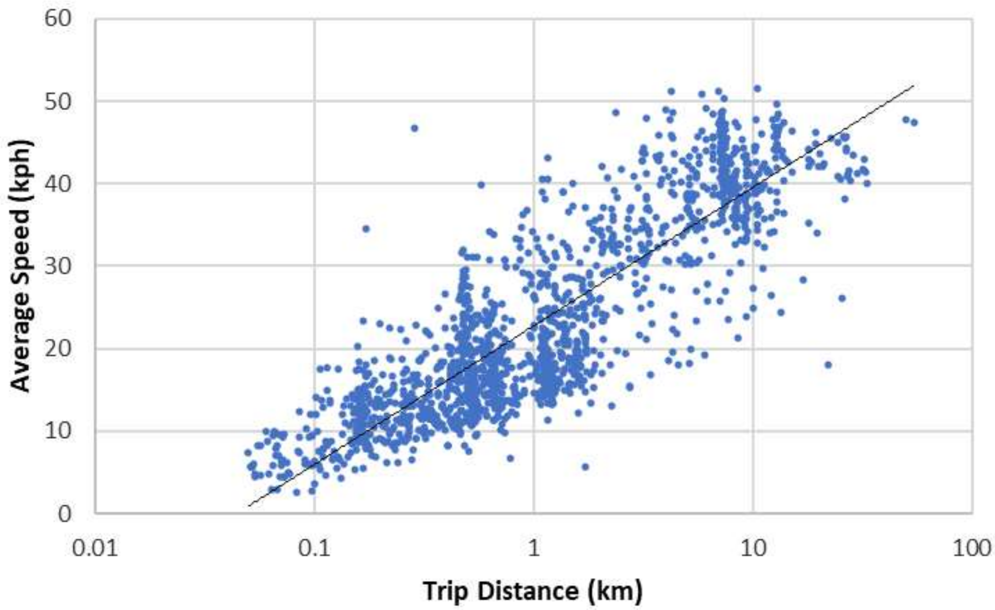


Figure 19 : Trip Average (non-zero) speed versus Trip Distance

For trips below 2 km there is a very strong trend toward lower cruising speeds. This is related to the fact that vehicles have limited acceleration, and require some time, and thus distance, to build up greater speeds. On shorter trips, therefore, they will be limited to lower average speeds. As the trip length grows, however, the average trip speed trends toward the vehicles' maximum speed, with 50km trips coming in at almost 50kph, in other words the rider kept the vehicle at full throttle almost the whole time. This is related to the trip duration: a 2km trip is so quick that the time required is inconsequential, even at only 20 kph. However, a 50km trip will take an hour even at 50kph, thus the operators will run at higher speeds to reduce the time required for the trip. Again, the increase in trip speed with longer trip distance has been noted in other automotive studies (Rietveld 1999).

The difference in speed also has ramifications for energy consumption: at higher speed more energy is lost to aerodynamic drag, thus we expect to see a drop in the km/kWh as trip average speed increases.

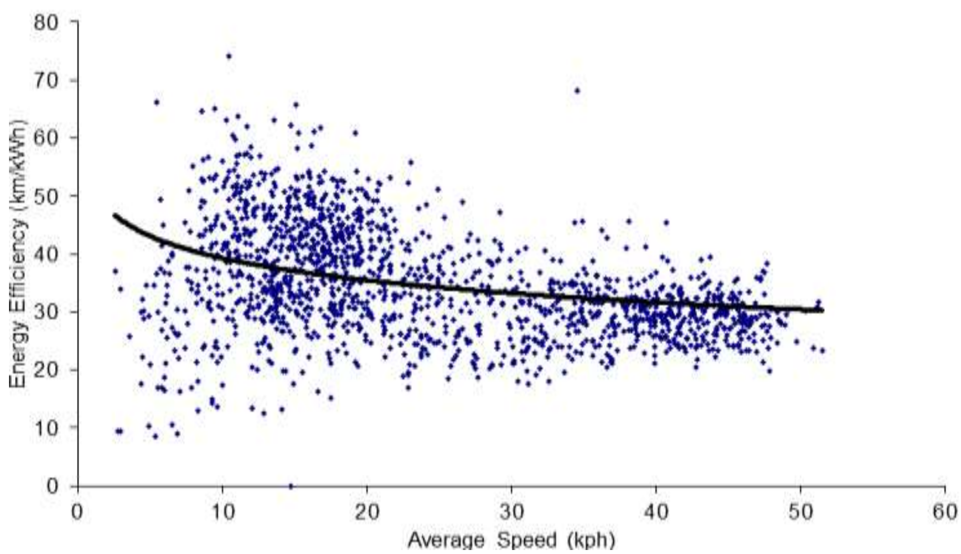


Figure 20 : Individual trip Energy Efficiency versus Trip Average (non-zero) Speed

Despite significant scatter, the data of Figure 20 shows a distinct trend, with lower speed trips of around 10kph achieving about 40km per kWh of energy, whereas trips at 50kph get closer to 30km per kWh. The scatter is caused by uncontrolled factors, such as hill climb, weather conditions, load, and driver aggressiveness.

Driver aggressiveness can be accessed via the acceleration and deceleration rates, as well as driving speeds, with more aggressive drivers exhibiting higher values in all areas. We can investigate the correlation between acceleration and deceleration by plotting the average acceleration rates vs average deceleration rates. As shown in Figure 21 there is a clear correlation: riders who brake aggressively tend to accelerate aggressively as well.

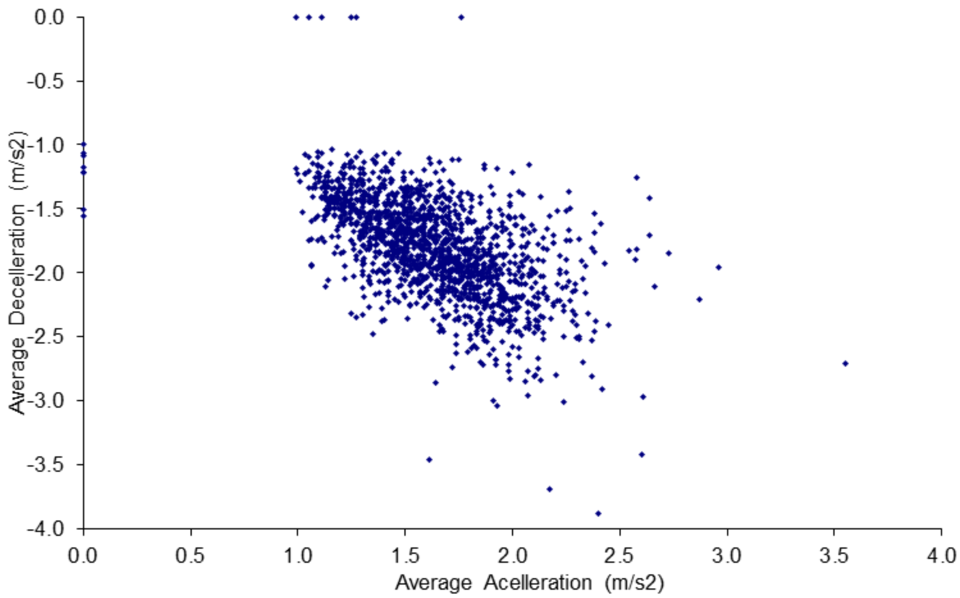


Figure 21 : Trip Average Deceleration versus Trip Average Acceleration

Another step is to see if there is a collation between cruising speed and rider acceleration. As shown in Figure 22, riders with high average acceleration rates also tend to have exhibit higher average speeds and visa-versa.

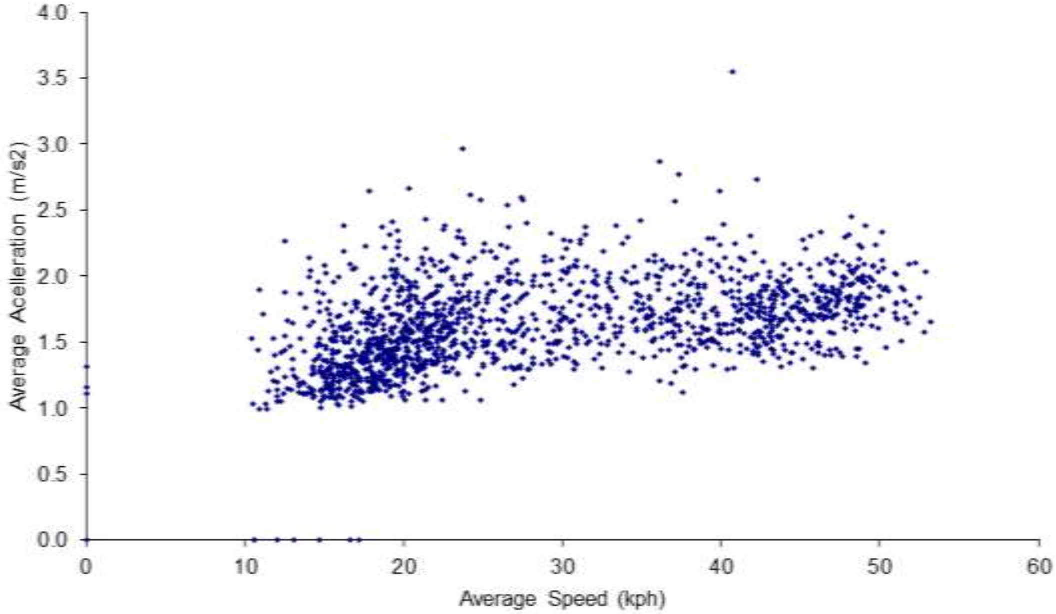


Figure 22 : Trip Average Acceleration versus Trip Average (non-zero) Speed

One final aspect to investigate is the ramifications of driver aggressiveness on Vehicle Efficiency (km/kWh). As can be seen in Figure 23, more aggressive drivers, as judged by high acceleration rates, achieve lower efficiencies, getting fewer kilometers of travel per kilowatt hour of energy[41].

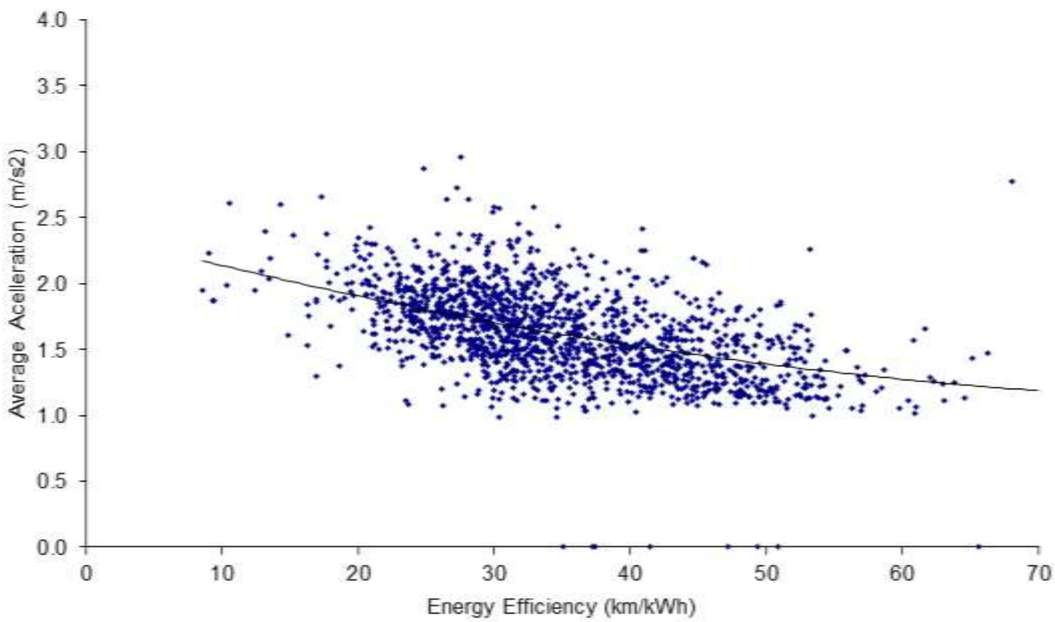


Figure 23 : Trip Average Acceleration versus Trip Energy Efficiency

From the data we can see that riders with high average acceleration close to 2 m/s^2 will get close to 20km/kWh, whereas less aggressive drivers with average acceleration rates around $1.5m/s^2$ will get closer to 45km/kWh.

[41] Driver aggression is mentioned as a significant factor in reducing EV range here: https://www.vyro.com.au/content/electric-vehicle-range-city-vs-highway-driving

2. Dynamometer Testing

Further verification of efficiency and range was carried out on the dynamometer. The chassis dynamometer was calibrated to give the same current draw versus speed as travel on the road. In Figure 24 we can see the battery voltage and current versus time when operating on the dynamometer at a constant speed of 10, 20, 30, 40 and 50kph on a single battery pack. Every time the speed is increased, the current in similarly increased, and the duration of the battery is reduced. It can also be seen that, at high current draws, the battery terminal voltage is much less than low current draws, even on a fresh battery.

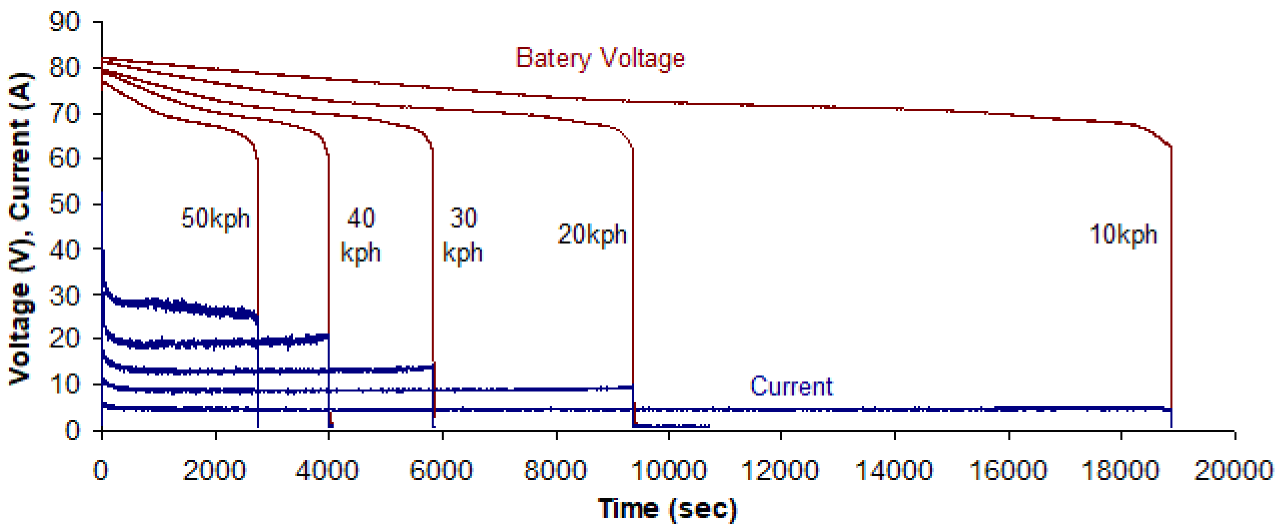


Figure 24 : Battery current and Voltage versus time at different speeds on the dynamometer

Converting this to a maximum achievable range versus speed, we get the data shown in Figure 25. The maximum (2 battery) range of about 115km is achieved at a speed of only 10kph, and the range drops off at an increasing rate with speed with 50kph travel only achieving about 80km range. This underscores the need to specify the speed or drive cycle used when stating the vehicles range per charge.

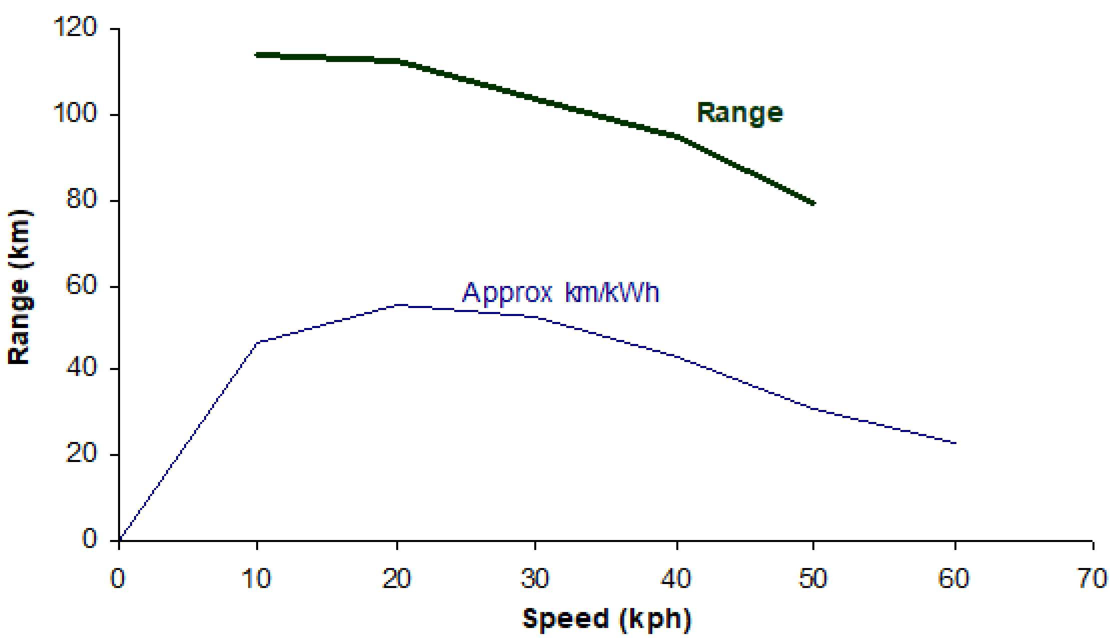


Figure 25 : Range versus cruise speed on the dynamometer

It is interesting to note that the kilometer per kilowatt hour is actually maximized at 20kph. Below this point the trip takes so long that a relatively large amount of energy is being spent running the lights and other accessories, decreasing the achievable kilometers per kilowatt hour.

The vehicle achieved a range of 87.8km using the standard World Motorcycle Test Cycle, however as it was incapable of achieving speeds over 52kph during the test, this cannot be considered a valid range on that test. Some users reported ranges of up to 80km with fully charged batteries, making this the upper limit of the vehicles real-world range, and corresponding to what it would achieve at 50kph.

In the course of battery testing, it was also noticed that the factory provided charger is exceptionally inefficient. Whereas most electric motorcycle chargers are around 85 to 95% efficient, the unit provided with this mode was about 45% efficient and gave off significant heat during battery charging. This is significant as it throws off battery charging costing by a factor of two.

User Survey Results

Surveys of vehicle operators were performed before they began running the E-motorcycles, and then several times after they had been riding them. A wide range of comments were received, both positive and negative, but the overall consensus was that as long as you accept the speed and range limitations of the vehicle, it can be a very convenient and useful form of transportation, and significantly reduces the expenditure on fuel.

Figure 26 : Older riders didn't mind the low speeds as they felt safer maneuvering in traffic when slow.

Most participants mentioned that for shorter trips they prefer the EV over a combustion machine. It is lighter and more convenient as there is no shifting or kick starting, and you can be sure you won't have to stop for fuel. For longer trips they preferred a combustion 2-wheeler or even a car, in part for the higher speed, but also as the concern over battery depletion ("range anxiety") grows with trip distance. On shorter trips the lower top speed of the E-motorcycle (approximately 50kph) wasn't a problem. The general consensus of what is considered a "short" trip is about 10km one way. Below 10km most riders prefer the E-motorcycle, whereas if a trip is greater than 20km most riders prefer a conventional motorcycle.

The average daily range (on days that the motorcycle was used) ranged from below 5km to just over 25km for the various users. This can be divided into "low" range users with daily ranges of less than 10km, "mid" range users in the 10 to 20km daily range and "high" range users accumulating more than 20km per day.

If we take the vehicles range to be around 80km (at 50 kph), and a "preferred" daily trip distance of 20km or less, this indicates that riders want a range capability of at least ***four times*** their nominal daily trip distance[42]. As their

[42] Three times the daily range is suggested here: https://www.carmax.com/articles/electric-car-range

average range per day is 20km, about half of the time they will be traveling further than this, however with the “four time the average daily range” margin, they likely won’t have to charge every day. Having to charge every day becomes a convenience problem when, for whatever reason, you simply can’t charge the vehicle on some days, leaving you with insufficient range on the following day.

For the “low” range users, the vehicle would be sufficient with just one battery, as their average daily range is less than 10km, and they will likely be getting more range than 50km from the vehicle due to their relatively slow speeds. With a vehicle range of around 80km the “mid” range users, averaging 10 to 20km per day, are relatively satisfied with the 2-battery vehicle. Higher range users, however, would need not only greater range, but also a higher top speed to be comfortable. Thus, either the motorcycle would be more expensive due to the larger batteries required or require a battery swapping arrangement.

Figure 27 : This urban commuter finds the electric motorcycle more convenient for trips of less than 10km

There was also general agreement, at least among the more demanding riders, that the range per charge decreased fairly rapidly: initially single-battery ranges of 60km were achievable, whereas after 3 months and 1500km of riding the range per charge dropped to around 50km. This is quite significant as the manufacturers stated battery lifetime is 1000 cycles, at which point there should only be a 20% reduction in range. 1500km should only represent around 15 cycles, and already the operators are reporting a degradation of close to 17%.

This helps to emphasize the need for battery life cycle testing of EVs to confirm manufacturers' claims and avoid creating false expectations for the customers.

Some of the delivery riders require over 130km per day, which would take at least three battery charges per day to achieve. As this vehicle can only charge one battery at a time, and a full charge requires around 7 hours, it is essentially incompatible with ranges in excess of 100km per day. One of the major weaknesses of this particular electric motorcycle is the inability to charge both batteries simultaneously, necessitating 7 hours of charging, switching the charger to the 2^{nd} battery, and another 7 hours of charging to fully charge both batteries. Users suggested two potential solutions: (1) a charger which could charge both batteries simultaneously, or (2) keeping a 3^{rd} battery on a charger, essentially creating a home battery swap station. All demanding operators requested faster charge times as well.

In the first few weeks of testing several batteries suffered failures including total lack of functionality, and an inability to charge. Two chargers also failed. Several units had problems with headlights failing, and some of these were traced back to a staple being used as an electrical jumper in the wiring harness. Finally, one bike had a front fork failure (spring retaining cap stripped and ejected). Several bikes were inspected and many of them have loose front fork spring retaining caps, which were tightened. All these items were attended to by the local distributor Ni-Hsin, as warranty claims. Other frequent criticisms include the relatively low speed especially when the batteries are below 50% charge, long time to charge and loud “knocking” sound from the front suspension when traveling over rough roads, and insufficient storage space. Many of the users complained about having to stop the vehicle and raise the seat in order to switch batteries when the initial one is depleted. They would prefer an external, or handlebar mounted switch, or even automated switch over. Finally, users in flats and apartment buildings mentioned that hauling the battery up to their apartment for charging is problematic, especially when both batteries need to be charged.

A lot of positive feedback was also received, notably that the electric motorcycles are convenient, quiet, light and easy to ride, resulting in a more relaxed riding experience. The instant torque was appreciated as it improves the low-speed maneuverability compared to ICE machines and makes it “fun” to ride. There was universal praise for the reduction in fuel consumption, and no longer having to visit the petrol station to fill up.

One rider, who uses the bike extensively for commuting and performing local deliveries on the weekends, noted that it is a more convenient vehicle for the frequent start-stop of deliveries as there is no shifting or stopping/starting of the engine: you just twist and go. It was also noted that the lower “gear” (a simple speed limiter switch) was very useful on sandy roads, helping with the vehicle's stability.

Figure 28 : This delivery rider likes the lack of shifting and kick starting of the electric motorcycle

Most of the women riders, and a few of the men, noted that the seat is a little too high for comfort, Figure 29, making them nervous in low-speed maneuvering, and also that the rear seat doesn't have foot pegs, Figure 30, which causes fatigue in their pillion riders, typically children being transported to/from school. The quiet operation and ease of use, with instant torque, however, was much appreciated.

Figure 29 : Several of the women riders felt that the seat height was too high for comfort.

Figure 30 : The rear seat passenger doesn't have a foot peg, causing leg fatigue on even moderate rides

Demonstration Project Conclusions

Throughout this study a wide range of information was collected, resulting in several clearly discernable conclusions relating to the acceptability of these electric motorcycles, and EVs in general, which are enumerated here.

The electric motorcycles were praised for their ease of use, quiet operation and low operating cost. They were regarded as exceptionally maneuverable at low speeds, owing to a lack of transmission “snatch”, and superior to combustion vehicles for frequent start-stop situations.

The charging time, at 7 to 8 hours per battery, necessitates a total of 14-16 hours to charge both batteries. This was a major complaint among medium and high demand users. This charging time is unusually long for lithium-ion batteries, with some competing models offering charging times of around 4 hours, which would be much more acceptable, especially if both batteries could be charged simultaneously. The charger provided with the motorcycle was very inefficient compared to similar chargers for other vehicles and resulted in an electricity cost of twice what is expected.

The relatively low speed of 45-60kph was considered acceptable for low demand users but was too slow for medium and high demand users, or for trips longer than about 10km one way. The range of 80km at full charge was a problem for people riding greater than 20 km per day.

Aggressive riders tend to exhibit higher average acceleration, and deceleration (braking) of around $2m/s^2$ and top speeds near the maximum of 50-60kph, while achieving lower range per charge. Less aggressive riders accelerated/decelerated closer to $1.5m/s^2$, operated at speeds closer to 20kph, and achieved approximately twice the range per kilowatt hour as aggressive drivers. Middle aged women riders exhibited lower peak speeds, typically 10-30kph, and lower acceleration and deceleration than young men, and achieved more kilometers per kilowatt hour than more aggressive riders. This underscores the need to consider driver aggressiveness in EV range modeling.

Average mileage worked out to be about 35km/kWh, with aggressive drivers getting only about 25km/kWh, and less demanding riders achieving up to 45km/kWh. Given Malaysia’s grid emissions factor 780gCO2/kWh, this results in about 17 gCO2/km for the low demand users, 22gCO2/km for average users, and 31gCO2/km for high demand users. This compares favorably to a typical 120cc conventional motorcycle which emits about 48.3 gCO2/km.

Trip average speed was a strong function of trip distance. Lower demand users typically ran vehicles for 3 km (single trip) or less at speeds below 30kph, whereas more demanding riders tended to run 7km or more per trip at speeds of over 40kph.

Riders prefer to have a vehicle range of at least four times their nominal daily trip distance. Assuming Malaysians use motorcycles for an average of 30km per day, a minimum range of 120km would be sufficient for about half of the population. Given this vehicle’s range of around 80km for two batteries, it is capable of meeting the needs of less than half of the motorcycling population, whereas most of the motorcycling population would require higher top speeds, and significantly greater battery capacity.

Low demand users, with round trips well below 10km, would be satisfied by a single battery model, which can achieve a range of around 50km per charge at their lower speeds of operation. This vehicle would cost significantly less as it only requires half the battery capacity.

The highest demand users are the delivery riders who accumulate up to 200km per day (ICCT 2021, Feng & Lu 2022 and Gitano 2023). Long-distance commuters will also require higher speeds to meet their needs. A top speed of 80-90kph was mentioned, requiring a significantly more powerful vehicle. For a higher demand commuter, a 90kph, 200km vehicle might be appropriate, however this would require approximately four times the battery capacity of this model. For delivery riders, the battery would be unreasonably large and, given current prices, prohibitively expensive, thus necessitating a battery swapping arrangement.

There were several discrepancies between expectations or specifications, and the real-world performance. For one, the specified top speed of 70kph is not achievable, with the maximum recorded speed being 60kph. The battery charger should have an efficiency of around 90%, whereas it was measured to be 45% efficient. Maximum range was stated as over 100km, whereas real-world driving gave a range of about 80km on a full charge. Finally, the battery degradation is apparently much greater than expected, losing about 17% of the initial capacity in 1,500km, whereas we would expect a 20% degradation in about 5 to 10 years of “normal” use (ICCT 2021), being about 30,000 to 60,000km of operation. All of this helps to emphasize the need for product conformity testing under real-world conditions.

Although the demonstration project vehicles were “volume production” units, there were a fairly high rate of failures which the local distributor repaired as the vehicles were all still under warranty. A similar project should have extra units and/or spares to ensure that all vehicles are kept in running condition. Having a good local distributor responsible for the warranty claims is probably the best way to do this.

Due in large part to the detailed data generated by this project, it is viewed as very successful: the data will inform Cost of Ownership calculations, many conclusions can be directly used in comparable EV studies and projects, and customer concerns have been made very clear.

RECOMMENDATIONS FOR SIMILAR DEMONSTRATION PROJECTS

Vehicle Selection

Vehicle fitness-for-use includes many factors, several of which were analyzed in this study. The most obvious factors are the vehicle's speed, power and range. It was noted that users preferred to have vehicles with ranges in excess of four times their daily driving range. It should be recalled that the users will drive more than their average daily distance about half the time, and the maximum range per day could potentially be several times the daily average range. Users frequently stated that the limited range of the electric motorcycle was understood and considered acceptable as long as they have another option, for example a combustion motorcycle, or car, on days when they require a longer distance of travel. Essentially the electric motorcycle was relegated to the "normal" daily drives (e.g. commuting to work, normal shopping trips, or fetching kids from school), and anything greatly in excess of that would be handled by another mode. However, a nominal vehicle range of at least four times the daily average range will allow users to charge their vehicle every two days, and still have an acceptable margin. Different manufacturers state their range on different drive cycles, or with blanket statements such as "Vehicle can achieve up to XXXkm per charge" making this difficult to assess without actual vehicle testing.

Speed is another important user requirement. One of the problems with some electric vehicles is that as the battery discharges, the maximum speed also drops. This does not happen with combustion vehicles: they can travel at the same speed regardless of the fuel level in the tank. It was noticed with the demonstration vehicles that their speedometer exaggerated the actual speed by about 10kph, and stated a top speed of 70kph, whereas the fully charged top speed is actually only 60kph. Additionally, when the battery is nearly empty, the top speed degrades to about 45kph. In some situations, the top speed may not be a critical factor, for example if the vehicle is predominantly used in heavy traffic, or for short hop deliveries, such as urban postal deliveries. However, it was shown that as trip distance grows, the average cruise speed increases significantly. For any intended use both the range and cruise speed should be carefully evaluated. For strict compliance with the original intended use, the electric vehicle should be able to maintain the desired cruising speed even with a nearly depleted battery. As s minimum, however, it may be acceptable to require the electric vehicle to achieve the required top speed with a 50% state of charge, if the users can tolerate some top speed degradation as the battery discharges. Manufacturers will typically state the "top speed" of the vehicle at a fully charged battery voltage. If they are using actual "GPS" speed, and not an exaggerated speedometer reading, this number might be useful for assessing the top speed under partially discharged battery conditions. The batteries used in this study were 72V nominal voltage, with a range of 65V when empty to 84V when fully charged, a swing of about 25%. For "strict" adherence to a desired top speed, you might insist on an actual fully charged battery top speed of about 25% more, e.g. for a top speed of 60kph (on a nearly depleted battery) you would want the vehicle to have a (fully charged) top speed of about 80kph. For a less strict interpretation you might insist on a 15% margin (e.g. top speed of 70kph on full charge for an anticipated typical top speed of about 60kph).

Payload, or carrying capacity are another factor in many situations. Individual commuters may not require much payload capacity beyond their own weight, but in many applications the vehicle is to be used as a taxi, i.e. with one or more passengers, or for deliveries. In these cases, the vehicle should be able to achieve the required range and speed with the normal load including passengers or cargo. Additionally, the vehicle should be capable of supporting the required weight on its frame and wheels. Usually, the maximum payload is specified by vehicle manufacturers.

Other payload related factors resulting from this study were storage space, or lack thereof, and foot pegs. The particular model used in this study had a bench seat suitable for two people, however the pillion rider did not have acceptable foot pegs, causing significant leg strain for passengers on even moderate rides. Many conventional motorcycle models, especially "step-though" frame models, have under-seat storage, and in SE Asia baskets are often added either in front of the steering tube (as in Thailand) or just behind it (as in Malaysia). Many electric motorcycles store batteries under the seat, reducing the available storage space.

Hill climb capability will be important in especially hilly locations. The low-speed torque of many electric motorcycles is quite good, however their hill climbing speed can be greatly reduced, even on fairly low inclines. Relatively few electric motorcycles will specify their hill climbing ability, usually expressed in terms of an angular incline which it can accelerate up from a stop. Again, this may not be directly applicable to the required hill climbing capabilities of a fully loaded vehicle, which might require actual vehicle testing, however, an excess of top speed capability is probably a good proxy for decent hill climb capability.

Additional Recommendations

Ensuring that field demonstration projects work smoothly can be a demanding task, especially when dealing with new technologies. In order to improve the success of such projects, and to maximize the learning that takes place, we have developed a list of recommendations for similar projects in the future. These are listed below.

1. Take baseline data on the existing vehicles in the proposed project market segment. Typical daily ranges and speeds, loads, hill climb and fueling costs are among the most important data to consider. Ask perspective vehicle owners and operators about their concerns and motivations (as related to transportation modes and vehicle choices) before deciding on a project vehicle.

2. Choosing a vehicle which is a good fit for the intended uses. For electric 2-wheelers this will likely include specifying a top speed well in excess of the expected top speed, and a range of at least four times the daily range of existing drivers. The project vehicles should also have sufficient payload capabilities.

3. Be sure to get department of transportation approval for your project vehicles before beginning the project. Coordination with various government agencies should be done from the very start of the project.

4. Ensure that there is a sufficient supply of spare parts, notably batteries, controllers and tires, to keep all the project vehicles running. It is much easier to control this if there is a dedicated service organization to perform all required warranty work over the duration of the project.

5. Formulate the rider experience survey early and use it on pre-existing vehicle users. While user estimates are easy to get, many times they make rather poor assessments of their speeds, ranges etc.

Therefore, it is highly recommended that simple, low-cost data loggers be installed on project vehicles to gather detailed data on travel usage patterns.

*For a more complete list of recommendations, explanations and tools, see our EV Demonstration guide **"LIGHT DUTY ELECTRIC VEHICLE PROJECT IMPLEMENTATION GUIDE"**.*

TOTAL COST OF OWNERSHIP ANALYSIS

In this section we will compare the Total Cost of Ownership (TCO) of a conventional Internal Combustion Engine (ICE) motorcycle, a Battery Electric Vehicles (BEV) motorcycle and a Battery Swapping Vehicle (BSV). We will also analyze the Battery Swapping Service (BSS) TCO for the same period.

The cost of vehicle ownership is much more than the vehicles purchase price; it also includes fees, such as registration and annual road taxes, and insurance costs. Some vehicles are bought via a financing scheme, where the total purchase price of the vehicle includes the financing costs. Additionally, vehicle operation requires the purchase of fuel or electricity for charging, and maintenance of components that wear out in normal operation. Most vehicle owners resell the vehicle before the vehicle's end of life, therefore the resale's value of the vehicle, and how long it will be owned for, will also be important for the TCO calculation.

For combustion vehicles, the required numbers are fairly well established: it is commonly known how much is spent on maintenance, and what the likely resale value of a used motorcycle is. As EVs are relatively new, some of the relevant data is not available, and we will have to make some assumptions or extrapolate from ICE numbers. From our surveys and data logging, we have established that lower power vehicles are used for much fewer kilometers per year than higher power vehicles[43]. For comparison we've selected a typical "low cost" 100cc ICE motorcycle and a "medium cost" electric motorcycle for the analysis as these are the closest matching common vehicles[44]. The electric motorcycle used in the analysis is the same model used in the demonstration project, namely the TailG Bold model distributed by Ni-Hsin in Malaysia. This model is comparable to several other E2Ws in the Malaysian market including Treelektrik T70, RydeEV Ryder model, and between the Blue Shark models R1 Lite, and R1[45].

VEHICLE PARAMETERS		*Units*			*Units*
Vehicle Type	**ICE**		**BEV**	**BSV**	
Fuel or Battery Type	Petrol		Li Ion	Li Ion	
Tank or Battery Capacity	4	liter	44	44	Ah
Displacement or Voltage	100	cc	72	72	V
Top Speed	90		60	60	kph
Peak Power	6		3	3	kW
Energy Consumption	55	km/liter	32	32	km/kWh

Figure 31 : TCO Vehicle Performance Parameters

Even the smallest conventional motorcycle will still have a power and range in excess of the "medium cost" electric motorcycle[46], so the vehicles are not 100% comparable, however considering the relative cost of the vehicles we have decided to compromise, and stick with the 100cc motorcycle and 3kW E-motorcycle. As shown in Figure 31 the 100cc motorcycle can achieve a top speed of around 90kph and will get approximately 55km per liter of fuel[47]. The BEV and BSV are the same, with a peak power of 3kW and a top speed of 60kph. Based on data from the demonstration vehicles, they average approximately 32km per kWh. It has been established that higher power vehicles are driven greater distances, and 8000km per year is in the range of what a lower displacement

[43] See page 20 of UNEP Report "LIGHT DUTY ELECTRIC VEHICLE PROLIFERATION IN MALAYSIA"
[44] While smaller 70cc conventional motorcycles exist, they are not very popular in Malaysia. Higher power E2Ws also exist, but they are exceedingly rare in the same market.
[45] Specifications are available in the appendix
[46] Honda EX5, for example, has a 4.3liter tank and gets 50-58km/l, for a range of around 230km, while the E2Ws investigated here have ranges on the order of 100km.
[47] See for example: "Analysis of Motorcycle Fuel Consumption in Malaysia", 2010, by LEE Jih Houh, CHONG Chew Liang, Dr. Horizon GITANO-BRIGGS

motorcycle is likely to achieve in Malaysia[48]. The demo project vehicles accumulated an average monthly mileage of 500km, for a slightly lower annual mileage of 6,000km.

PURCHASE COSTING	***ICE***	***BEV***	***BSV***	
Vehicle Sale Price	1000	1902.75	1268.50	$
EV Subsidy	0	507.40	507.40	$
Financing Cost	200	279.07	152.22	$
Registration	1.06	0	0	$
Total Purchase Cost	1201	1674	913	$

OPERATIONS COSTING	***ICE***	***BEV***	***BSV***	
Fuel Cost	0.433 $/liter	0.071 $/kWh	15.86 $/month	
Charge or Transfer Efficiency	1	0.9	1	
Annual Mileage	8000	6000	6000	Km
Maintenance Cost (annual)	31.87	19.87	17.97	$/year
Road Tax (annual)	0.42	0.42	0.42	$/year

Figure 32 : TCO Vehicle Purchase and Operational Cost. Calculations are enumerated in an appendix.

The vehicle purchase cost, Figure 32, is somewhat complicated as the conventional vehicle is paid for at the market price, whereas E-motorcycles can receive "rebate" from the government. In late 2023 the Malaysian government announced a rebate of up to 2,400RM (507$) on the purchase of electric motorcycles via the "Electric Motorcycle Adoption Incentive Scheme" which significantly reduces the purchase cost of the EV models[49]. Similar with other countries, most 2-wheelers in Malaysia are bought on credit with an average financing cost of about 20% of the purchase price, and financing schemes have also recently been implemented for E2Ws which is included in their costing as well (ICCT 2022).

The conventional 100cc motorcycle costs about 1000$, whereas the BEV is almost twice that price at 1900$ mostly due to the rather expensive battery (ICCT 2021, Frost & Sulivan 2022). The Battery Swapping Vehicle is the same as the BEV but excludes the battery and thus costs only about 1270$. After the EV Subsidy the BEV cost drops to about 1400$, and the BSV drops to 760$, somewhat less than the conventional motorcycle.

Each vehicle in this analysis will have a different "fuel cost": the conventional motorcycle is fueled by petrol, while the BEV motorcycle is charged from a wall socket, and the BSV pays a monthly swapping fee. Malaysia currently has subsidized vehicle fuel which at 0.43$/liter (our base case) costs less than half the ASEAN average, which is about 1.16$/liter. The cells highlighted in green are factors which will be manipulated later in our analysis to compare different scenarios. The residential electricity tariff is 0.071$/kWh, and most users charge at home. Generally an EV battery charger would be assumed to have an efficiency of 80-95%, and our measurements confirm this for other E2Ws, however in the course of the study it was noticed that the chargers provided with the demonstration vehicles are exceptionally inefficient: they produce a lot of heat during charging and measurements show them to be only about 45% efficient[50], thus the energy consumption per charge is over twice the actual battery charge, and this is compensated for in the calculation via the Charge Efficiency as shown in Figure 32. For the base case calculation, we have chosen a more typical charger efficiency of 90%. There are many ways to charge for battery swapping, but one of the most common is to charge a monthly "subscription fee" for some maximum number of battery swaps. One of the E2W BSS service providers in Malaysia charges 20.72$ per month for the first year, and 42.07$ per month thereafter. This would give an average monthly cost of 39.20$/month over 8 years of

[48] See page 20 of UNEP Report "LIGHT DUTY ELECTRIC VEHICLE PROLIFERATION IN MALAYSIA"
[49] As reported in *The Edge*: https://theedgemalaysia.com/node/686070
[50] TailG Charger Measured Power: Input 240VAC, 2A (rms) for 480W, Output: 75VDC, 2.8A for 210W, 45% efficient

ownership, which is our "high" BSS cost value. For the base line case we'll chose a number from another BSS provider, quoted as their "typical" costing of 15.86$/month[51].

Registration and insurance costs are quite low for the conventional bike already, but much higher for larger displacement vehicles, and registration is free for the EVs.

MAINTENANCE				
	ICE	BEV	BSV	
Tires	14.80	14.80	14.80	$
Oil	8.46			$
Filter	1.06			$
Breaks	1.06	1.06	1.06	$
Misc	2.11	2.11	2.11	$
Clutch	1.90			$
Plug	0.37			$
Battery	2.11	0.00	0.00	$
Charger		1.90		$
TOTAL	**31.87**	**19.87**	**17.97**	$

Figure 33 : Annual Vehicle Maintenance Costs.

The vehicle maintenance cost, Figure 33, is different for each of the vehicles. All of the vehicles will have costs associated with replacing worn tires and brakes and miscellaneous expenses, and the ICE vehicle will have additional expenses for engine oil, air and oil filters, spark plug replacement, clutch and 12V battery maintenance. Based on the initial data from the demonstration vehicles and interviews with E2W owners, we know there will be some attrition of both chargers and batteries. Lead acid batteries, common in low cost E2Ws, are subject to rapid degradation and generally must be replaced every 6 months to 2 years. The lithium-ion batteries of the E2W models chosen here are significantly better than the lead acid batteries, but still suffer some degradation and occasional outright failures, though most of the failures are associated with the Battery Management System, which can be replaced relatively inexpensively[52]. Most of the BEV batteries fail in the first few weeks of usage, when the vehicle is still under warranty, therefore we have chosen not to include any battery maintenance cost in the BEV vehicle costing. From our surveys of E2W users it was noted that one of the components' occasionally requiring replacement is the charger, thus an average annual cost for charger replacement has been debited to the BEV costing. The BSS station owner will be responsible for the maintenance of the batteries; thus, this cost is omitted from the BSV vehicle. As generally expected, the ICE vehicle has a slightly higher annual maintenance cost than the electric versions, with the battery swapping vehicle having the lowest cost. This, however, is highly dependent on the quality of the BEV battery: as it is such an expensive component, even a small failure rate will result in a high average maintenance cost. This is borne out in studies of the low-end lead acid BEVs, and we believe it is also applicable to the less expensive Li-ion BEVs as well. This factor is highlighted for further analysis.

[51] BSS subscription costs come from interviews with the Malaysian E2W BSS service providers.
[52] BMS units for the TailG Bold Model (DALY 20S, 50A/20A) costs 28.50$

LIFETIME COST	ICE	BEV	BSV	
Years of Operation	8	8	8	years
Vehicle Purchase Cost	1201	1674	913	$
Vehicle Resale Value	500	698	381	$
Depreciated Vehicle Value	500	977	533	$
Fuel (or Battery Swap) Cost	504	118	1522	$
Total Fees	4.44	3.38	3.38	$
Maintenance	255	159	144	$
TOTAL COST	**1264**	**1257**	**2202**	**$**
Cost per year	158	157	275	$/year
Cost per kilometer	0.020	0.026	0.046	$/km

Figure 34 : Total Cost of Ownership for three models of 2-wheelers.

For the Total Cost of Ownership, we need to assume a duration of ownership, and, if the vehicles are not yet at the end of their useful life, a resale price. Eight years is a fairly typical duration of ownership of a newly purchased vehicle, so we'll use this in the analysis. Conventional motorcycles will depreciate by about 50% over the first 8 years, however as the resale value of E2Ws is not known, we have chosen to apply the same depreciation rate for the E2Ws as well. Taking the purchase price and summing up the operating expenses over the eight years of ownership and subtracting the resale value we can derive the Total Cost of Ownership.

Using the current fuel price in Malaysia, residential charging rates for the BEV with a 90% efficient charger and no battery maintenance cost, and the lower BSS subscription fee, we get the TCO numbers shown in Figure 34. This is essentially the "best case scenario" for the customer, in that all the manipulated cost factors are set to their lowest nominal values. The conventional 100cc motorcycle results in an eight-year total cost of about 1264$, with a very similar BEV cost of 1257$. The BSV is significantly more than the others, coming in at about 2202$.

This is not what is generally expected: it is usually assumed that BEVs will cost significantly less to own and operate in the long run due to the reduced fuel and maintenance cost. In our scenario, however, the fuel cost is low, 0.43$/liter as opposed to an ASEAN average of 1.16$/liter, due to government fuel subsidies. Additionally, although we have chosen a "typical" battery charger efficiency of 90%, we know that the BEV model analyzed here in reality suffers from a very inefficient charger, which will essentially double the energy consumption and increase the actual cost of the BEV. Finally, most analysis assumes that the batteries will last 10 or more years, which is may not the case with the low-cost Li-ion batteries in these products.

The BSV cost is significantly greater than the BEV, as expected, because it includes not only the cost of the batteries, but also cost overhead for the charging station and BSS service provider, as well as their profit margin. For a BEV, there is a one-to-one relationship between the number of batteries and vehicles, however with a BSS system there must always be more batteries than there are vehicles so that customers have access to charged batteries when returning depleted ones, which winds up being an additional cost to the consumers. Again, the cost of the BSV is actually much higher than the ICE motorcycle for all the reasons stated above. This is despite the government providing subsidy of 500$ for the EV versions.

Figure 35 provides a costing breakdown of the various vehicles. The ICE motorcycle has roughly similar expenditures on fuel and purchase price (less resale), with the remaining 20% going towards maintenance. The BEV in this case has a very similar total cost to the ICE, however now the cost is dominated by the purchase cost, at about 78% of the total, with a roughly equal, and low, expenditures for charging and maintenance. The vast majority (78%) of the BSV cost is going towards paying the battery swapping fees, but keep in mind that the total expenditures for the BSV are 75% more than the BEV under this scenario.

It should be noted that while the cost *per year* of the ICE and BEV are about the same, the cost *per kilometer* is actually slightly higher for the BEV. This stems from our assumption that the ICE motorcycle will be used for more kilometers per year than the electric vehicles owing to its greater power and speed. This was seen in our previous study (Gitano 2024) which included analysis of E-scooters: as they were operated for relatively low numbers of kilometers, their cost per kilometer was substantially higher than ICE vehicles, however because their overall costs were lower, the resulting cost per year was significantly less. These lower power E-scooters wound up being the choice of consumers who required relatively low annual mileages.

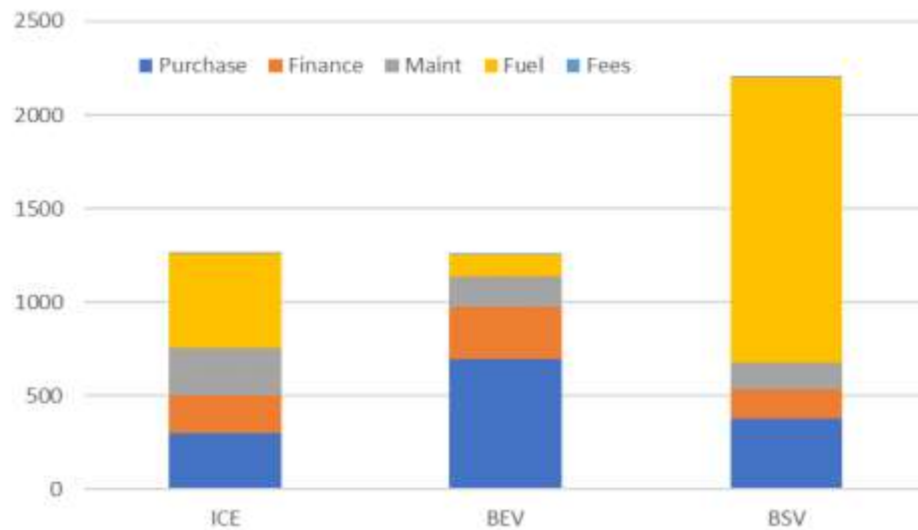


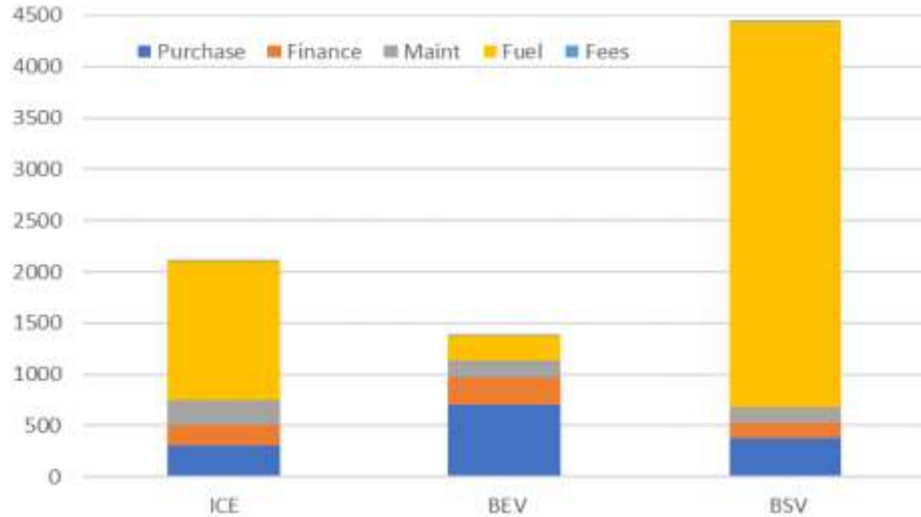
Figure 35 : Costing breakout assuming 0.43$/liter fuel, 90% BEV charging efficiency, and 16$/month BSV fee

Alternative Scenarios

Looking back at the analysis there are several things that stick out, strongly influencing the relative cost of the EVs compared with the ICE version. First is the low fuel cost: at 0.43$/liter there simply isn't much incentive to go electric. The Malaysian government has already announced plans to begin reducing fuel subsidies starting in 2024, therefore we should look into a scenario where fuel is closer to the ASEAN average price of 1.16$/liter longer term[53]. A second issue is the grossly inefficient charger used in the TailG Bold model which we will use in this second scenario[54]. Finally, we will pick the higher monthly subscription fee, which we regard as more realistic[55].

[53] As mentioned in *Bloomberg*: https://www.bloomberg.com/news/articles/2023-11-27/malaysia-to-cut-blanket-fuel-subsidies-in-second-half-of-2024
[54] As mentioned in: https://www.recurrentauto.com/research/why-doesnt-your-battery-get-all-the-energy-you-pay-for#:~:text=A%20typical%20Level%202%20home,which%20typically%20maximize%20charging%20efficiency.
[55] Gogoro advertises a 799NT$/month (about 25$) "special": https://network.gogoro.com/tw/promotions/network-fet-aycr-promotion/

Re-running the same TCO with these changes, i.e. fuel cost of 1.16$/liter and a charger efficiency of 45%, and a monthly subscription fee of 39.20$/month we get a very different outcome, as shown in Figure



36

Figure 36.

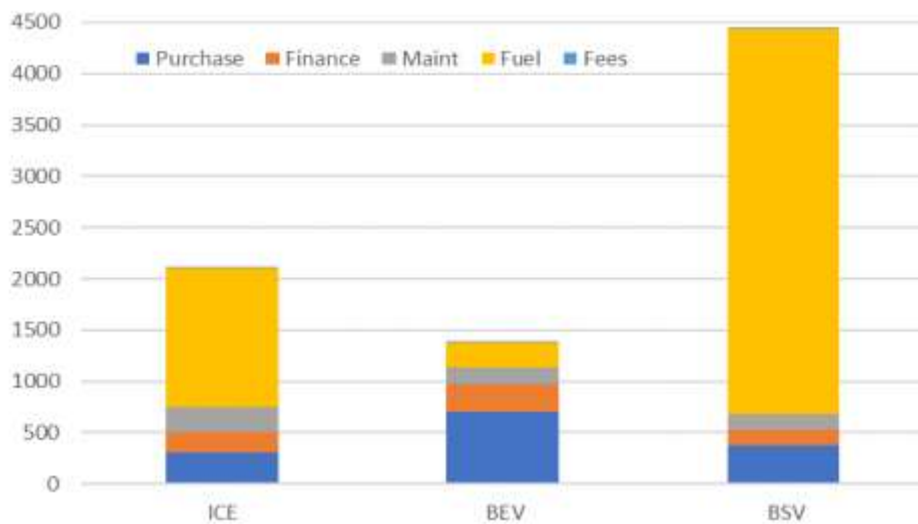


Figure 36 : TCO with 45% efficient BEV Charger and 1.16$/liter fuel and 39.20$/month BSS fee.

With these three changes we now have a much higher cost for the ICE ownership of 2112$. Despite the inefficient charger, the BEV has only risen to 1381$ and compares favorably to the ICE vehicle after eight years of ownership. This is about what one would expect, namely that EVs cost less to operate in the long run (ICCT 2021). This expectation, however, relies on relatively expensive fuel. The BSV vehicle is now significantly more expensive at 4442$ total cost, over twice that of the ICE and more than three times that of the BEV, due to the rather expensive monthly battery swap subscription fee.

A simplified breakdown of major lifetime costs is presented in Figure 37. At this fuel price, around two thirds of the ICE vehicles costs are fuel. About the same proportion of the BEVs costs are the purchase price, owing to the relatively inexpensive charging, and expensive battery. The BSV costing is dominated by the monthly BSS swapping fees, which now account for about 85% of the lifetime cost of the vehicle.

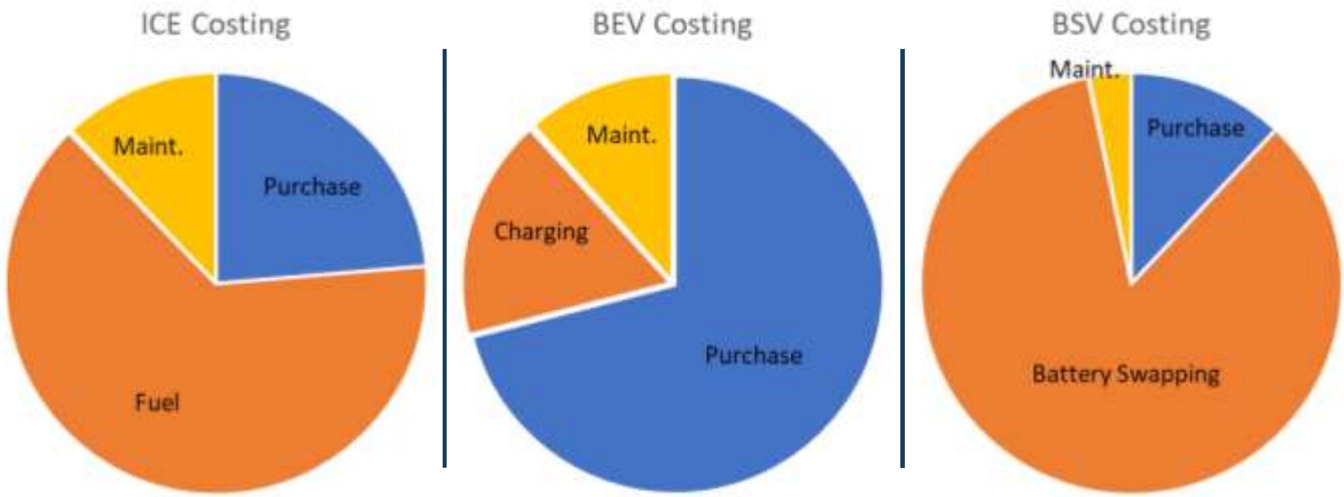


Figure 37 : Costing Breakout assuming 1.16$/liter fuel, 45% BEV charger efficiency, and 39.20$/month BSS fee

The main conclusion to be drawn from this is that while BEV E2Ws can be less expensive to own and operate than ICE 2Ws, the savings depend heavily on the cost of fuel, and in general BSVs, while they cost less to purchase initially, wind up being much more expensive than either ICE or BEV 2Ws.

Battery Swap Service Provider TCO

While the above analysis presents a realistic of costs for the vehicle users, the Battery Swapping System provider has been neglected. The BSS provider plays an important role in reducing the initial cost of the BSV as well as encouraging e-mobility via the longer achievable trips made possible with battery swaps. Determining the cost of the BSS provider is significantly more complex and requires a greater number of assumptions, with even less available data. Our numbers come from interviews with both Blueshark and RyadEV of Malaysia, as well as various papers and online sources (ICCT 2021, ICCT 2022, Honan 2023, Huang 2019, Wibisono 2022).

One of the first distinctions to make is the ownership of the batteries. Theoretically EV owners can "own" their battery and still use a swapping station, in which case the vehicle owner purchased a battery, which is then swapped out at a swapping station that only must charge the batteries. Most battery owners are wary of swapping out their own battery at a public charging station as they are concerned about getting an "inferior" battery in return. The more common scenario is where the EV owner buys the vehicle "without" a battery, and the BSS service provider owns all the batteries in the system. In this case the EV can be purchased at a much lower price, and the owner will have to pay a premium for swapping batteries from a swapping station. We have chosen this model for our analysis as it is the more common case.

For the battery we'll be using the same as previously modeled, namely a 72V, 44Ah Lithium-ion battery pack, the cost of which was taken to be 634$. For charging at the station, we're assuming a commercial electrical tariff, and also that batteries will be returned with about 30% charge remaining, as has been observed in various studies (Feng & Lu 2022), and a 90% charging efficiency. This results in a per-charge electricity cost of 0.27$, as shown in Figure 38. We're assuming the station has a 4-battery capacity. Typically, a station will have eight battery slots, and each vehicle has two batteries of one half of the total capacity per battery, namely 22Ah, for easier handling, but both are swapped out simultaneously, so we count it as a 4-battery station. Based on interviews the stations cost around 3000$ to procure, and 750$ to install. With frequent swapping the station will require some maintenance which we've put at 150$ per year, and we're costing the space rental at 105$ based on vending machine space rental rates and interviews with BSS Service Providers[56]. Finally, we assumed a power overhead of 200W, resulting in a monthly expense of 15.5$ above the battery charging power cost.

BATTERY SWAP STATION COSTING		
Battery Cost	634.25	$
Battery Energy	3.168	kWh
Power Tariff	0.108	$/kWh
SOC upon Swap	30	%
Power Cost	0.27	$/charge
Battery Units	4	batt/stsn
Station Cost	3000	$
Installation Cost	750	$
Station Maintenance Cost	150	$/year
Space Rental Cost	106	$/month
Non-Revenue Power	200	W
Non-Rev Power Cost	15.50	$/month

Figure 38 : Battery Swapping Station Costing

[56] See for example: https://forum.lowyat.net/topic/4999183/+0& which states 500RM/month for a vending machine

One of the most influential factors in the Battery Swap Service Provider TCO will be the number of subscribers per swapping station. From the BSS operators' point of view, they'd like to have as many subscribers as possible. From the user's perspective they would prefer fewer users per station to ensure that there are always plenty of fully charged batteries. Battery charging takes time, in this scenario we have put it at three hours to charge from 30% to 100% State Of Charge (SOC), and the more users there are, the more swaps there will be, resulting in a greater number of batteries which are in the process of charging. One way of looking at this is the charging time per slot: that is the number of hours each slot is in the "charge" mode, and therefore not available to the customers. This can be calculated from the number of subscribers per station times the daily swap rate per person times the charge time divided by the number of slots. Most people will be swapping batteries when they are already on the road for some other purpose, so roughly from morning rush hour (08:00) to after evening rush hour (20:00), meaning that most of the swapping will happen in a 12-hour window[57]. With a 3-hour charge time, this will only allow 4 or 5 swaps per slot per day (the first swapped battery having been charged before the morning rush) without making customers wait for batteries to finish charging.

In our scenario we're assuming there are 16 subscribers (four for each slot), and they swap about every other day, with an average of 0.63 swaps per day, typical of a medium demand user. As shown in Figure 39 this results in a charging time per slot of 7.6 hours, well below the 12-hour window limit. The BSS operator will have to maintain one battery per customer, plus one per slot, for a total of 20 batteries per station. The batteries represent the largest up-front expense for the BSS operator by far. There will be some maintenance or replacement of the batteries required, and we have assumed a 1% chance of a battery requiring replacement per year.

BATTERY SWAP STATION TCO		
Subscribers per Station	16	pax
Subscription Cost	15.86	$/month
Swaps/pax/day	0.63	#
Charg cost per month	80.18	$/month
Total # Batteries	20	#
Charge Time	3	hr
Charging time/slot	7.56	hr
Battery Maintenance Cost	127	$/year
Annual Opex	2693	$/year
Total Capex	16,435	$
Station Lifetime	8	years
Charges per battery	1472	#
Depreciated Battery Value	3171	$
Annual Capex cost	1658	$
Total Annual Expenditure	4351	$
Administrative Overhead	218	$
Subscription Revenue	**3044**	**$/year**
Annual Earnings	**-1525**	**$/year**
Return On Investment	***-9.3%***	

Figure 39 : Total Cost of Ownership of Battery Swapping Station at lower battery swap fee

Total capital expenditures (station, installation plus batteries) work out to about 16,435$. Both the station and batteries will have a limited useful lifetime. For this analysis we've assumed that the station will last eight years, after which time it will most likely become obsolete. The batteries, however, even if somewhat degraded, will still

[57] As per conversation with Blue Shark, 05-06-2024

have some value. This can be thought of as a “resale” value, and we’ve assigned it as 25% of the original price of the battery. The justification for this is that Lithium batteries are purported to have lifetimes on the order of 1000 full discharge cycles, with some manufacturers of these batteries claiming “over 2000 cycles”, while each of the batteries in this scenario will have undergone 1470 cycles of only 70% discharge, and therefore can be reasonably expected to retain a fair capacity even after 8 years of operation, however as seen in the demonstration project, battery degradation may be more severe than expected, reinforcing the lower resale value selected.

Summing up the rental, maintenance (station and batteries), and power expenses, we get the annual operating expense, in this case about 2693$. In addition to the basic operating costs, there will be an administrative overhead required for organizing the procurement of batteries, logistics of installation and maintenance, corporate management, accounting and etc. For this we are assuming an administrative overhead of 5% of the annual expenditure. As a private company, there is the need to generate a profit for those investing in the enterprise. A typical return on investment, that is the revenue minus cost and operational and administrative expenses, might be 5 to 20%[58]. For the purposes of this model, we have set a target of 15%, as there is a higher than typical risk associated with the proliferation of battery swap stations given the nascent nature of the business, and rapidly changing technology.

Taking capital expenditures minus the depreciated (End Of Life) battery value and dividing by the eight year life span, we can get an amortized capital cost of 1658$ per year. Including the annual operations costs and administration overhead there is a total expenditure of 4569$ per year. Subscription rates were previously established on the low side at 15.86$ per month, for an annual revenue of 3044$, resulting in an annual ***loss*** of about 1525$ per year for the BSS provider.

This clearly highlights the difficult situation of the BSS service providers: given the high capital cost of the batteries, station and installation, along with the ongoing operation expenses, a subscription cost of 16$ is not viewed as sustainable, given our assumptions[59]. For a BSS business to succeed at a monthly subscription fee of 16$, the costs will have to be lower. Redoing the calculation for the higher subscription fee of 39.20$/month gives a more realistic result, as shown in Figure 40 below.

BATTERY SWAP STATION TCO		
Subscribers per Station	16	pax
Subscription Cost	39.19	$/month
Swaps/pax/day	0.63	#
Charg cost per month	80.18	$/month
Total # Batteries	20	#
Charge Time	3	hr
Charging time/slot	7.56	hr
Battery Maintenance Cost	127	$/year
Annual Opex	2693	$/year
Total Capex	16,435	$
Station Lifetime	8	years
Charges per battery	1472	#
Depreciated Battery Value	3171	$
Annual Capex cost	1658	$

[58] See for example: https://www.brex.com/journal/what-is-a-good-profit-margin

[59] For example: “*Due to high costs and the complexity of setting up the business to be commercially viable, Mo Batteries will not proceed to launch a battery swopping service for electric motorcycles in 2024 as planned.*”, downloaded from: https://www.straitstimes.com/singapore/transport/s-pore-company-drops-plan-to-launch-electric-motorcycle-battery-swop-service

Total Annual Expenditure	4351	$
Administrative Overhead	218	$
Subscription Revenue	**7525**	**$/year**
Annual Earnings	**2956**	**$/year**
Return On Investment	***18.0%***	

Figure 40 : TCO of BSS Service Provider at the higher subscription rate of 39.20$/month

This gives a much more reasonable balance, resulting in a 18% return on investment, for a brake even period of around 8 years. However, these same swap costs results in the very high total cost of ownership of the BSV of Figure 36.

Doubling the number of subscribers per station would improve the BSS Service Provider's earnings, but now we have exceeded the upper limit of subscribers per station as each charging slot will be charging for 15 hours per day, forcing some consumers to wait for batteries. If, on the other hand, subscribers were to fall to half the expected numbers, e.g. 8 subscribers per station, we again arrive at an unsustainable situation where the BSS could never be profitable, Figure 41.

BATTERY SWAP STATION TCO		
Subscribers per Station	8	pax
Subscription Cost	39.19	$/month
Swaps/pax/day	0.63	#
Charg cost per month	40.09	$/month
Total # Batteries	12	#
Charge Time	3	hr
Charging time/slot	3.78	hr
Battery Maintenance Cost	76	$/year
Annual Opex	2162	$/year
Total Capex	11,361	$
Station Lifetime	8	years
Charges per battery	1226	#
Depreciated Battery Value	1903	$
Annual Capex cost	1182	$
Total Annual Expenditure	3344	$
Administrative Overhead	167	$
Subscription Revenue	**3762**	**$/year**
Annual Earnings	**251**	**$/year**
Return On Investment	***2.2%***	

Figure 41 : Same as above scenario, but with 8 subscribers per station.

The BSS service provider will naturally want to drive up the number of subscribers per station but will also want to increase the subscription costs. One way this is done is to offer a large number, or "unlimited", swaps for some higher monthly fee. One Malaysia company proposed a special rate for 120 swaps per month: that works out to be four swaps per day, or about 300-400km of riding, a very unlikely scenario on a vehicle operating at 50kph. Customers may like the ***idea*** of always being able to swap out their batteries without worrying about the cost, however the BSS provider is literally banking on the customer using far less swaps than they are actually paying for. This is a common ploy with cellphone data packages, where large, or unlimited, monthly data transfer packages are offered for a fixed (and large) price.

If we take the scenario of Figure 40 as the base case, we have the major cost categories are broken out in Figure 42. It can be seen that the cost is dominated by the space rental, the cost of the batteries, and the electrical power for charging and operation of the charging station. To improve the prospects for battery swapping electric motorcycles, we need to work on reducing these costs.

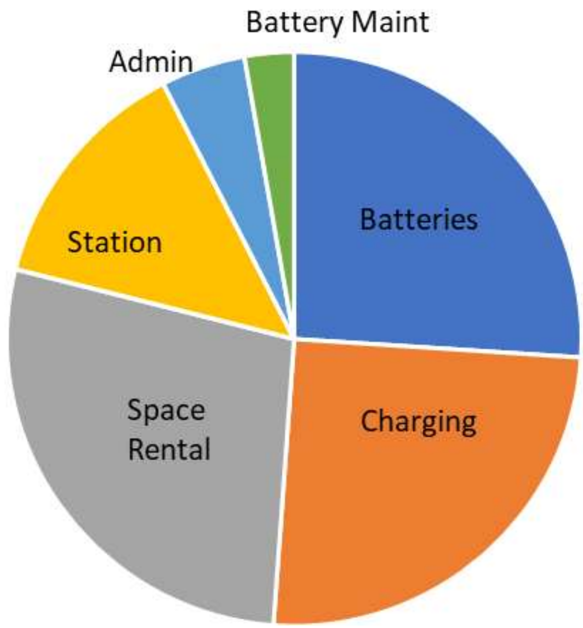


Figure 42 : Major cost breakdown for BSS service provider

Reducing The Cost of Battery Swapping

If we wish to reduce the total cost of ownership of the battery swapping electric motorcycle, then we must reduce the subscription cost, which in turn requires significant reductions in the BSS service provider's costs to allow for a reasonable profit margin. From our analysis there are several ways to go about this, including the following:

- **Reducing the price of the batteries**
- **Reducing the cost of electricity provided to the BSS station**
- **Reducing the cost of the BSS station space rental**
- **Reduction in the cost of the BSS station**

A reduction in the price of batteries will improve the TCO for both BEV and BSV. The most direct way of doing this is by simply subsidizing the battery. While subsidies in general are a bad economic policy, as it commits the government to an ongoing, and potentially increasing liability, a mitigating factor is the fact that EV battery prices are continuing to fall. It may, therefore, be possible to introduce a relatively short-term EV battery subsidy which is diminished as the raw battery price declines over time.

Another way to reduce the battery cost, at least theoretically, is by launching large scale local battery production. This option appears very attractive on the surface as it can also enhance the country's foreign exchange position by keeping more money in the domestic economy and increasing employment locally. The main problem with this approach is that battery production must be done on a very large scale to be competitive with the major suppliers in China. If the country could develop a "national standard battery" and had several models of electric vehicles being sold in large volumes that could use the standard battery, this indeed might be a viable option. However, it would require a very large investment and long-term dedication to the goal, while controlling costs and ensuring quality product delivery on an aggressive timeline. This is not something government projects are well known for, so it would probably have to be driven by private industry.

For charging, we have assumed that the station will be using electricity at the commercial rate of 0.108$/kWh. While some countries have introduced special discounted tariffs for EV battery charging, we can make a case for using the residential tariff of 0.06$/kWh, which is very common in Malaysia. PLN of Indonesia has introduced a special tariff of 0.05$/kWh for EV charging stations[60].

As with batteries, or even electric vehicles, a subsidy could be applied to the battery swap station as well. Alternatively, less expensive battery swap stations already exist on the market, however many of them have reduced features, while still providing basic battery charging and swapping.

Battery swapping stations should ideally be located in high traffic areas. Some of the best locations include transportation hubs, as this can also encourage the use of public transportation. In some cases, space owned by a government authority could be used to host a BSS station at reduced costs, or potentially even free. While this won't address all potential BSS station locations, it might reduce the average cost of BSS station space substantially. The government could also encourage lower rental fees via offsetting tax incentives to privately held locations, potentially affecting almost all BSS station locations.

For an "optimum" BSV costing, we will make the following modifications to the base case of Figure 40

BATTERY SWAP STATION TCO		
Subscribers per Station	16	pax
Subscription Cost	39.19	$/month
Swaps/pax/day	0.63	#
Charg cost per month	80.18	$/month
Total # Batteries	20	#
Charge Time	3	hr
Charging time/slot	7.56	hr
Battery Maintenance Cost	127	$/year
Annual Opex	2693	$/year
Total Capex	16,435	$
Station Lifetime	8	years
Charges per battery	1472	#
Depreciated Battery Value	3171	$
Annual Capex cost	1658	$
Total Annual Expenditure	4351	$
Administrative Overhead	218	$
Subscription Revenue	**7525**	**$/year**
Annual Earnings	**2956**	**$/year**
Return On Investment	***18.0%***	

Figure 40: Subscribers per station will be raised to 24, keeping the average charging time per slot just below 12 hours, reducing the electricity tariff to the lower domestic rate of 0.06$/kWh, reducing the BSS space rental from the "high" local estimate of 106$/month, to the lower estimate of 42$/month, and reducing the station cost from 3000$, the higher cost of the domestic stations, to 2000$ the lowest cost station. This optimum solution gives the

[60] https://bolt.earth/blog/ev-landscape-in-indonesia

data shown in Figure 43. Under this scenario a monthly swapping fee of 24.40$ is sufficient to yield a return on investment of 15% for the BSS service provider.

BATTERY SWAP STATION TCO		
Subscribers per Station	24	pax
Subscription Cost	24.40	$/month
Swaps/pax/day	0.63	#
Charg cost per month	70.89	$/month
Total # Batteries	28	#
Charge Time	3	hr
Charging time/slot	11.34	hr
Battery Maintenance Cost	178	$/year
Annual Opex	1745	$/year
Total Capex	20,509	$
Station Lifetime	8	years
Charges per battery	1577	#
Depreciated Battery Value	4440	$
Annual Capex cost	2009	$
Total Annual Expenditure	3754	$
Administrative Overhead	188	$
Subscription Revenue	**7027**	**$/year**
Annual Earnings	**3086**	**$/year**
Return On Investment	***15.0%***	

Figure 43 : Optimum Battery Swap Station costing, and 15% ROI

The breakout of costing under this scenario is shown in Figure 44. The battery cost is now the most expensive component, followed by space rental and charging.

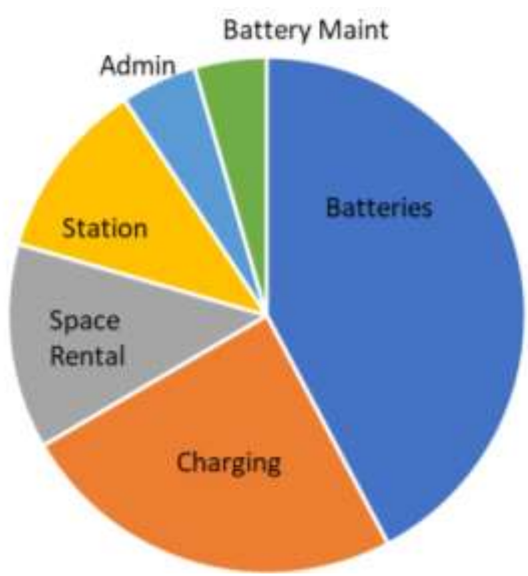
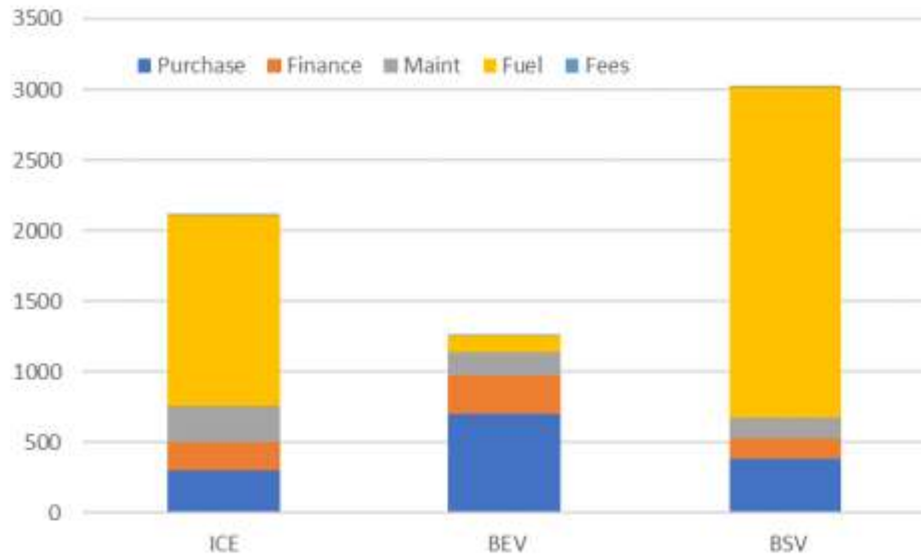


Figure 44 : Battery Swap Station Service Provider cost breakout under the optimum costing scenario.

Using these "optimum" numbers, will allow us to run the vehicle TCO comparison, a significant reduction in the BSV from the above-mentioned changes. For this final cost assessment, we are considering the fuel price to be the

higher value (1.16$/liter) and charging efficiency to be 90%. The resulting costs are shown in Figure



45

Figure 45. The BEV still has the lowest overall cost, while the BSV is still the highest, but has dropped substantially from 4442$ to 3022$.

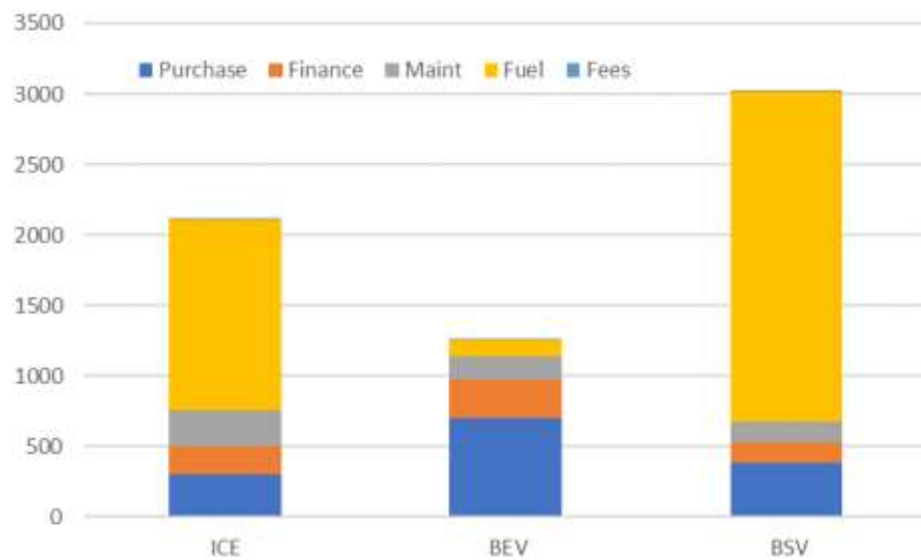


Figure 45 : Vehicle ownership TCO under the "optimized" BSS costing scenario

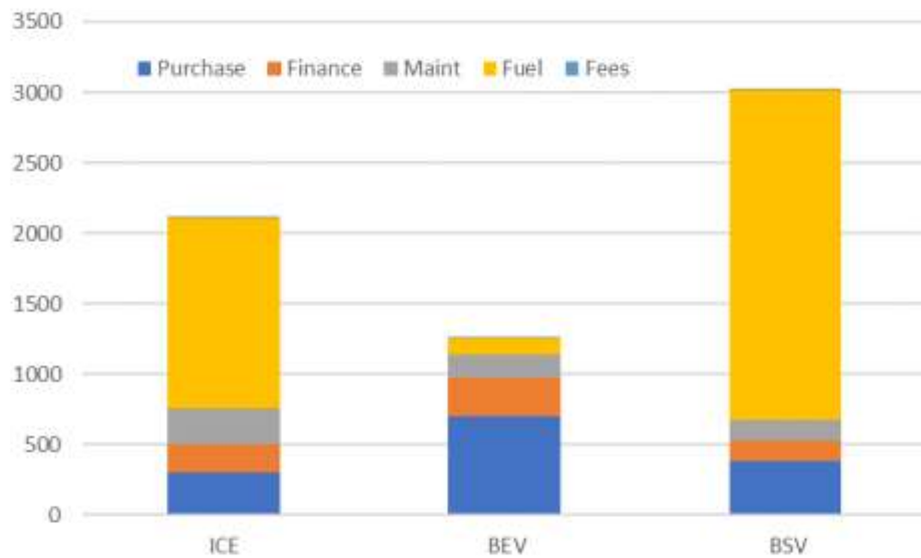
Even under this "optimum" scenario the BSV wound up being the most expensive of the vehicles analyzed for "medium" demand riders, and any reduction in the subscription fees will make the BSS unattractive to the service provider. Any increase in the number of subscribers per station may help the BSS service provider but will start to interfere with customer satisfaction as they have to wait in a queue for batteries to be charged. The batteries are quite expensive, and there is a fairly narrow range of subscribers per station that is both profitable to the BSS provider and acceptable to the customers. While further reductions of station rental costs might be realizable, and subsidies could be applied more liberally to the station, batteries and electrical tariff, the BSV will always be more expensive than the BEV in the long run, as it requires more batteries to be procured, and at least some overhead and profit margin for the BSS service provider.

The main conclusion is that, while a Battery Swapping EV costs less to buy initially, the BSS service is relatively expensive, requiring a lot of up-front capital, and relatively low return in a fairly risky environment. The Battery

Swapping System TCO, according to our analysis here, can be economically viable but it is likely to push the total cost of ownership of the BSV up to a point where it no longer makes sense for low and medium demand consumers. Higher demand customers, however, will have to spend substantially more for fuel for the ICE vehicles, thus there is a potential niche to serve them with the BSV.

Special Case of High Demand Users

As previously established, a typical motorcycle operator accumulates about 8000km per year in Malaysia. Delivery riders can achieve well over this, racking up to 200km per day. With greater mileage, however, we need to increase the number of battery swaps per day. Surveys of BSS operators have shown that batteries tend to be swapped out with about 30% charge remaining, and we can use this, together with the batteries real-world range to determine how often batteries will have to be changed out. However, as the number of swaps per day increases, the charging time per slot also increases, requiring a reduction in the number of users per charging station to ensure that charged batteries will always be available. This is especially important for delivery riders, as time spent waiting for batteries to charge represents a significant opportunity cost (ICCT 2021). Re-using the "optimum" BSS costing, we can easily check the costs for riders accumulating 20,000km per year. This results in 1.8 swaps per rider per day. To ensure 12 hours of charging per slot, this reduces the users per station down to 9, seriously impacting the BSS service provider revenue. Reverting back to the higher subscription charge of 39.2$/month, we get a return on investment for the BSS service provider of about 11.5%, a low but viable margin. The results, Figure



46

Figure 45, show that at this point the BSV is now almost competitive with ICE vehicle at the higher fuel price of 1.16$/liter.

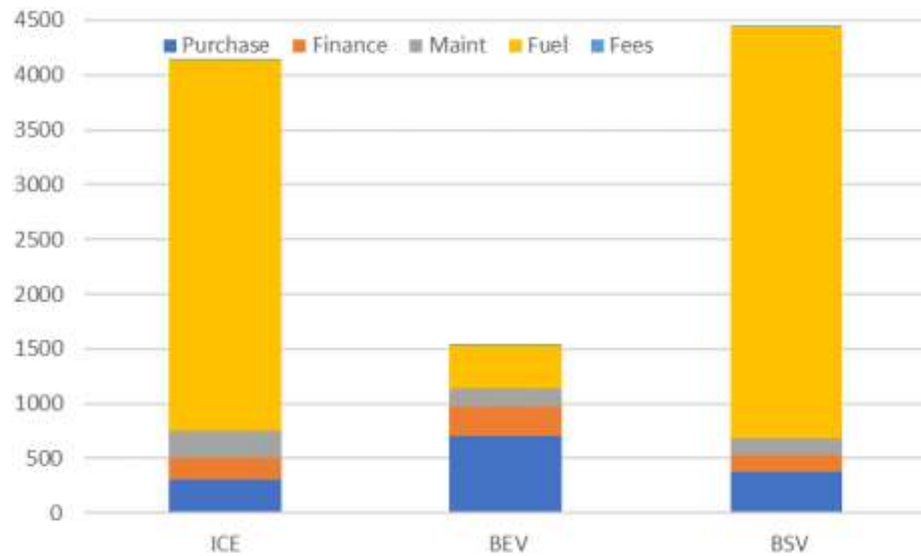


Figure 46 : Total Cost of Ownership for High Demand Users with Optimum BSS costing

If we further set the Battery Swapping station space rental cost drop to zero by, for example, having municipalities provide public spaces for the stations free of charge, and reduce the electricity tariff to 0.05$/kWh (as done in Indonesia), we can reduce the monthly swapping fee down to 35.7$ and we finally have a solution where the BSV cost (4107$) is slightly cheaper than the ICE motorcycle (4142) after 8 years of operation, however this is for the case of the higher fuel price and high demand users.

While our analysis shows that the long-term costing of the battery swapping electric motorcycle is likely to be higher than even the combustion motorcycle, several observations indicate that this is in fact the case. Firstly, we are using known costing of the BSS service, and numbers provided by BSS service providers with confirmation via component pricing (e.g. searches of battery swap station prices). Secondly, BSS systems have become popular in some markets and are likely to succeed despite the higher long-term cost, because the battery swapping electric motorcycle costs less to buy than the conventional motorcycle, and individual consumers tend to be relatively short-sighted financially. Two-stroke engine motorcycles were long popular for their low purchase cost, compared to four-stroke motorcycles, although their high consumption of fuel pushes the long-term cost above that of an equivalent 4-stroke machine. Another factor likely to enhance the success of the BSV is the convenience factor of quickly swapping batteries rather than having to charge them yourself. While it may not seem like much of a burden to plug in a charger to your motorcycle, forgetting to do so occasionally, can leave you without the range required, causing serious inconvenience. Additionally, many users may not have access to charging where their vehicle is parked, requiring them to carry the 10kg battery to their apartment for charging. Finally, as battery swapping systems increase in number, the cost of components can be brought down, and the business will encounter a positive return on scale, making the business more viable (RMI 2023).

Figure 47 : BSS Service Provider advertisement targeting extreme high-mileage users

To help justify the cost of the BSS system, some manufacturers resort to rather extreme scenarios. Figure 47 shows a comparison of a 150cc motorcycle, which produces 10 to 15kW and can travel up to 150kph, with a 5kW, 80kph (claimed) top speed electric motorcycle. Even our most generous assessments put a delivery rider's range at 200km per day, and assuming they do this for 200 days a year, they accumulate 40,000km annually. The above assessment, however, assesses the cost at up to 73,800km per year. Most motorcycle riders in Malaysia travel about 8,000km annually, well below the minimum range analyzed in Figure 47, which would result in a loss for the BSS customer. It should be noted, however, that this assessment is done at the current fuel price of at 0.43$/liter.

Total Cost of Ownership Conclusions

The main conclusion is that electric motorcycles will only make economic sense in an environment where the fuel price is much higher than it is today in Malaysia. With petrol priced at 0.43$/liter there is very little incentive to go electric, and none to use a battery swapping vehicle when the long-term costs are included. The fixed battery electric motorcycles cost is dominated by the purchase price due to the high cost of the battery, however, given the low cost of electricity this BEV ends up costing about the same as the combustion motorcycle at current fuel prices. As the cost of batteries reduces over time, and the cost of fuel increases, it is very likely that BEVs will be significantly less expensive to own and operate than ICEs. While moderate and low demand users will not find the BSV financially attractive in the long run, it may still be popular for two main reasons. Firstly, the purchase price is lower than the BEV and on par with the ICE vehicle. Secondly, as has been noted with the Gogoro experience in Taiwan, users value the convenience of swapping batteries any time they like, especially if stations are located close to their normal commuting route and are willing to pay a premium for the convenience. High-demand users, such as delivery riders, will find the BSV competitive if not superior to the ICE vehicle economically, especially in a case where other BSS users swap batteries less frequently, thus freeing up charged batteries for the high demand users. This will essentially be a case of lower demand users paying higher prices per swap for convenience and offsetting the cost for the higher-demand users, more frequent swaps.

The most effective steps that can be taken to enhance the viability of battery swapping include the following:

- **Reduce the subsidies on the price of fuel, thereby increasing the price of fuel**
- **Provide the BSS service providers with the lowest viable electrical tariff**
- **Provide publicly owned locations for charging stations, especially at transportation hubs, either free, or at low cost**
- **Special tax incentives could be provided to BSS system operators to help encourage investment in this area**
- **Short term subsidies of EV batteries could be considered, with the intention of reducing the subsidy as battery prices decrease over time**
- **Subsidizing battery swap stations could also be considered; however, this will have a smaller effect as the cost of the station is a relatively small component of the BSS system's costing.**
- **Establish a plan for 2nd life batteries from partially depleted EV battery packs. This could help increase the resale value of the end-of-life batteries and reduce environmental impact.**

Fixed battery electric motorcycles are rapidly growing in popularity[61], and are likely to be cost competitive or superior to combustion motorcycles under any reasonable scenario. Due to the lower purchase cost of battery swapping vehicles, with a few well-chosen actions, these may become popular as well, especially with higher demand users, even if the long-term cost is higher than combustion vehicles. Both of these vehicles can play a major role in reducing road transportation emissions with proper integration into a holistic approach including substitution of car travel by electric motorcycle and public transit.

[61] Electric motorcycles sales up 187% from last year: https://www.motorcyclesdata.com/2024/05/07/malaysia-motorcycles/

ABBREVIATIONS

BEMF	Back Electro-Motive Force
BEV	(Fixed) Battery Electric Vehicle
BLDC	Brush-Less Direct Current Motor
BMS	Battery Management System
BSS	Battery Swapping System
BSV	Battery Swapping Vehicle
CBU	Complete Built Up
cc	Cubic Centimeter (engine displacement)
CKD	Complete Knocked Down
CO_2	Carbon Dioxide
E2/3W	Electrical 2 / 3 Wheeler
EOL	End of life
EV	Electric Vehicle
FAT	Focus Applied Technologies
h	Hours
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IEA	International Energy Agency
km	Kilometer
kph	Kilometers Per Hour
kWh	Kilo-Watt Hour
LDEV	Light Duty Electric Vehicle (2-, 3- and smaller 4-wheelers)
MAI	Malaysian Automotive Institute (also called MARII)
MASAAM	Motorcycle and Scooter Assemblers and Distributors Association of Malaysia
MGTC	Malaysia Greentech Corp
MOU	Memorandum Of Understanding
OEM	Original Equipment Manufacturer
RM	Ringgit Malaysia
SBMC	Swappable Batteries Motorcycle Consortium
SE	South East
SOC	State Of Charge
SOH	State Of Health
SUV	Sport Utility Vehicles
TCO	Total Cost of Operation
UN	United Nations
UNEP	United Nations Environment Program
USD	United State Dollar
USM	University Science Malaysia
VDC	Direct Current Voltage
WMTC	World Motorcycle Test Cycle

APPENDIX

Appendix 1 follow on project

MGTC BATTERY SWAPPING EV STUDY

This project is similar to the above BEV study but performed on Standard ICE motorcycles and Battery Swapping E2Ws (Blue Shark and RydeEV). ICE vehicles being used in the same role will have their data tracked for comparison. Additionally, BSS stations will be logged to determine typical battery SOC when returned, time of day batteries are swapped, etc. Emphasis will be on higher-demand users, with a few medium and low demand users included to examine their feedback. The ultimate goal of this study is to fine tune the TCO calculation for the BSS service providers and offer more refined suggestions for reducing the cost to the BSS service provider and BSV customers.

Appendix 2 Total Cost of Ownership Calculations

TOTAL COST OF OWNERSHIP CALCULATIONS

As the Total Cost of Ownership calculations are rather detailed, we have chosen to enumerate them in this appendix.

Annual mileages for combustion motorcycles in Malaysia was recently measured at 8,500 km per year[62]. For the relatively small 100cc conventional motorcycle we have chosen a mileage of 8,000km per year. It has been established that lower power vehicles accumulate lower mileages, and the demonstration vehicles gave an average of around 6000 km per year which we chose for the costing comparison.

The fuel/energy consumption numbers, 55km per liter, or 32km per kWh, are typical measured values for these vehicles. Annual maintenance costs, shown below, have been estimated from interviews with actual users.

MAINTENANCE			
	ICE	**BEV**	**BSV**
Tires	14.80	14.80	14.80
Oil	8.46		
Filter	1.06		
Breaks	1.06	1.06	1.06
Misc	2.11	2.11	2.11
Clutch	1.90		
Plug	0.37		
Battery	2.11	0.00	0.00
Charger		1.90	
TOTAL	**31.87**	**19.87**	**17.97**

Figure 48 : Annual Maintenance Costs (USD) by vehicle type

The only contentious issue is the battery maintenance cost of the fixed battery EV. It is generally assumed that lithium batteries are "maintenance free", however the lower cost vehicles investigated in this study had some battery related fall out, generally due to the failure of the BMS. These failures tended to show up early, when the vehicle was still under warranty, thus we have chosen to put the battery maintenance value at zero. Keep in mind, however, that this is not true of the lead acid batteries used in the very inexpensive "E-scooters", as they tend to last only 6 to 24 months in normal usage, and thus have to be replaces fairly often. The resulting battery replacement cost dominated the vehicle maintenance for this class of vehicles. For the vehicles investigated in this analysis, the ICEs have the highest maintenance cost, due to the larger number of replaceable items, followed by the fixed battery BEV. The Battery Swapping Vehicle should have a slightly lower maintenance cost than the BEV due to the lower usage of owner supplied charging.

PURCHASE COSTING	*ICE*	*BEV*	*BSV*	
Purchase Price	1000	1902.75	1268.50	$
EV Subsidy	0	507.40	507.40	$

[62] "Consultancy for Moving Towards Green/Smart City: A gap analysis on selected Malaysian cities" commissioned by the WWF, and completed by the author in 2019

Financing Cost	200	279.07	152.22	$
Registration	1.06	0	0	$

Figure 49 : Vehicle Purchase Costing

Figure 49 shows the purchase cost. Prices are the current (2024) advertised prices, and the EVs qualify for a 500$ subsidy. Finance costing of 20% of the net price (price less subsidy) has been included as that is typical of motorcycle purchases in Malaysia. EVs are exempted from registration fees, which are modest in any evet for small vehicles.

OPERATIONS COSTING	*ICE*	*BEV*	*BSV*	
Fuel Cost	1.16	0.071	39.20	
	$/liter	$/kWh	$/month	
Charge or Transfer Efficiency	1	0.9	1	
Annual Mileage	8000	6000	6000	km
Maintenance Cost (annual)	31.87	19.87	17.97	$/year
Road Tax + Insurance (annual)	0.42	0.42	0.42	$/year

Figure 50 : Operations Costing Factors

Operations cost is shown in Figure 50. The green highlighted cells indicate factors which are subject to manipulation for different scenarios. For example, the fuel cost in Malaysia is currently 2.05RM/liter (0.43$/liter), however result will be presented for this, and the ASEAN average costing of 5.5RM/liter (1.16$/liter) in a comparative scenario. Similarly, the electricity costing for the BEV is based on the electrical tariff, which varies from about 0.07$/kWh at typical residential rates, to 0.11$/kWh in most commercial situations. Generally, we'll be assuming that BEV users will be charging at home (ie. 0.07$/kWh) and that BSS stations are subject to a rate of 0.11$/kWh. Another number which is subject to manipulation is the Charge Efficiency for the BEV. Generally, EV chargers are expected to be 80-90% efficient, and our measurements confirm this, however the chargers used in this demonstration study are exceptionally inefficient, delivering only about 45% of the energy they consume to the battery (the rest lost as heat). This aberrant value is modeled in a scenario investigating its effect on the overall evaluation of the vehicles. The BSV battery swapping value is also subject to manipulation for the different scenarios.

LIFE TIME COST	*ICE*	*BEV*	*BSV*	
Years of Operation	8	8	8	years
Vehicle Purchase Cost	1201	1674	913	$
Vehicle Resale Value	500	698	381	$
Depreciated Vehicle Cost	500	977	533	$
Fuel, Electric, or Swap Cost	1350	107	3763	$
Total Fees	4.44	3.38	3.38	$
Maintenance	255	159	144	$
TOTAL COST	**2109**	**1246**	**4443**	**$**
Cost per year	264	156	555	$/year
Cost per kilometer	0.0330	0.0260	0.0926	$/km

Figure 51 : Lifetime costing calculations

The resulting Total Cost of Ownership calculations are given in Figure 51. In each case we're assuming 5 years of operation, a typical "first owner" duration for motorcycles in Malaysia. The "On The Road" price is the purchase price less subsidy plus the financing charges and registration fees. Resale value for eight-year-old motorcycles is about 50% of their purchase price, and we have used the same factors for the EVs, however we have applied this to the subsidized price. This allows calculation of the Purchase price minus the resell value at the year of ownership, on the flowing line. Fuel costs are the total mileage (annual mileage times the number of years of operation) times the fuel cost and divided by the fuel economy, i.e. Total kilometers times the cost per liter (or kWh for BEV) and divided by the kilometers per liter (or kWh). For the BSV it is simply the total number of months times the monthly subscription fee. There is an inherent danger in this in that we're assuming that the subscription fee will remain constant for the whole eight-year span of ownership, however this is our "best guess" in the absence of further data. Total fees and maintenance costs are simply the annual costs times the number of years of operation.

The resulting Total Cost is the purchase cost less the resale value plus the fuel, maintenance and fees over the period of operation, in this case resulting in 2100$ for the ICE, 1250 for the BEV and 4445$ for the BSV, indicating a significantly higher TCO for the BSV and lower TCO for the BEV compared to the ICE vehicle.

REFERENCES

Feng 2022: Feng, Yu and Lu, Xiaochun, “Deployment and Operation of Battery Swapping Stations for Electric Two-Wheelers Based on Machine Learning”, Hindawi Journal of Advanced Transportation, Volume 2022

Fost & Sullivan 2022: “Strategic Analysis of the Global Electric Two- and Three- Wheeler Battery Swapping Market”, Frost & Sullivan, August 2022

ICCT 2021: Dash, Nibedita and Bandivadekar , Anup, “COST OF BATTERY SWAPPING, POINT CHARGING, AND ICE TWO-WHEELERS IN INDIA”, INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, November 2021

ICCT 2022: Gode, Pramoda, Kohli, Sumati, and Callahan, Jennifer, “BATTERY SWAPPING FOR ELECTRIC TWO-WHEELERS IN INDIA, STRATEGY HINTERLANDS”, INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, May 2022

Gtiano 2023: Gitano, Horizon, Khairudin, Nurul, “LIGHT DUTY ELECTRIC VEHICLE PROLIFERATION IN MALAYSIA”, December 2023

Honan 2023: Honan, Mat, “Gogoro Electric Vehicles Scooter Battery Pack Network”, https://www.technologyreview.com/2023/10/04/1080115/2023-climate-tech-companies-gogoro-electric-vehicles-scooter-battery-pack-network/

Huang 2019: Huang, Fei-Hui, “Understanding user acceptance of battery swapping service of sustainable transport: An empirical study of a battery swap station for electric scooters”, Taiwan, International Journal of Sustainable Transportation, 2019

Setiawan 2023: Setiawan , Andri, Zahari , Teuku, Anderson ,Kenny, Moeis , Armand and Hidayatno, Akhmad, “Examining the effectiveness of policies for developing battery swapping service industry”, Elsevier Energy Reports 9, 2023

Rietveld 1999: Rietveld, Piet, Zwart, Bert, Van Wee, Bert, and Van Den Hoorn, Toon “On the relationship of Travel Time and Travel Distance of Commuters”, The Annals of Regional Science, August 1999

RMI 2023: Newcomb, James “Emergence Strategy in Action: Gogoro Seizes Opportunity in the Transition to Sustainable Mobility. Case study: How did Gogoro go from stealth startup to global battery-swapping leader in just over a decade?”, September 2023, Downloaded from: https://rmi.org/

Wibisono 2022: Wibisono, Imam, Nugrahadi, Bekti, and Yuniaristanto, Wahyudi “Development of Location-Allocation Model of Network Design for Battery Swapping Station and Battery Charging Station Facilities for E-Trike and E-Motorcycle”, Proceedings of the International Conference on Industrial Engineering and Operations Management, March, 2022