Analysis of Energy Economy Rating of E-Trike on Long and Short Routes Along Flat Terrain Condition

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Abstract: The use of e-vehicles is encouraged to reduce the use of fossil fuels and risks of air pollution due to greenhouse gas emissions. Understanding its energy economy rating is essential to determine its environmental benefits and energy efficiency. This study was conducted to assess the performance of three models of passenger and cargo type e-tricycles in short and long flat terrain routes under normal operating conditions subjected to a uniform load of 250 kg and its maximum load capacity. The battery-to-wheel and wall-to-wheel energy economy ratings were measured to determine the energy drawn from the battery and wall outlet, respectively. Results showed that the passenger type and cargo type e-tricycles with the highest energy economy rating were both from NWOW. On the average, it was observed that all e-tricycles have higher energy economy rating when traveling in longer distances.

Keywords: Energy Economy Rating, Battery-to-wheel, Wall-to-wheel

1. INTRODUCTION

Road transport is the most common transportation system in the country and an important aspect in Philippine economy (Asian Development Bank [ADB], 2012). The main mode of transportation in roads are vehicles mostly operated through internal combustion engines and uses fossil fuels that release harmful gases in the atmosphere and cause air pollution. It is claimed that the transportation sector uses one third of the world's total energy consumption (Bayram and Tajer, 2017). The use of motor vehicles already became part of humans' daily needs for a convenient way of transportation. Thus, the increase in population can be associated with the increase also in the number of vehicles. In 2016, former DENR Undersecretary Jonas Leones said that as time progresses, the number of registered vehicles rapidly increases which may also imply the increase in air pollutants due to vehicle emissions. Emissions from vehicles contribute a significant amount of pollutants as it comprises 80% of air pollution (Department of Environment and Natural Resources [DENR], 2016).

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Climate change and global warming are the major effects of air pollution in the environment. These have been big unresolvable issues for several years that worsen through time. Air pollutants not just harm the environment but also the human health. As these pollutants enter the human body, cardiovascular and respiratory diseases may occur. With the aid of modernization, several technologies were developed to eliminate or at least minimize the harmful effects of these pollutants. Clean technologies, specifically e-vehicles, were introduced to minimize the wastes produced by the transportation sector to the environment and to maximize the available resources. E-vehicles were designed to utilize alternative energy sources,
particularly renewable energy, to reduce greenhouse gas emissions and use of fossil fuels for its operation.

Renewable energy sources include solar, wind, hydro, biomass, geothermal, and others. In the Philippines, renewable energy has not been utilized until the enactment of the Republic Act (RA) 9513 or the Renewable Energy Act of 2008. This act was designed for the utilization of locally available renewable energy sources which were claimed to be infinitely and freely available (Aquino and Abeleda, 2014). Its efficiency as an alternative energy source for vehicles can be determined through the establishment of energy economy rating of the vehicle. This measures the distance traveled per energy consumed and is commonly used by vehicle producers to inform its customers about the performance of the vehicles (Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, 2011).

In Philippine provinces, especially in small communities, tricycles or three-wheeled vehicles are the common mode of transportation. Using alternative fueled vehicles starting from small-scale communities could significantly help lessen the pollution caused by the transportation sector. Hence, this study is designed to explore and assess the efficiency of using alternative energy source for operating tricycles through the establishment of its energy economy rating. The selected passenger and cargo type e-tricycles will be used for the transport of people and goods, respectively, in a chosen small community in Rodriguez, Rizal.

Electric vehicles, particularly e-tricycles, have been in the market for several years. However, it has not been widely used due to problems in cost and convenience. The establishment of the energy economy rating of e-tricycles travelling in a flat terrain condition would help consumers assess the environmental advantages of using tricycles operated through an alternative energy source over the conventional ones. The established battery-to-wheel energy economy rating would help evaluate which e-tricycle model would travel the longest distance while wall-to-wheel energy economy rating would help evaluate which would cost the least for electric consumption. This study would also help promote the use of locally-available renewable source of energy to reduce the consumption of fossil fuels, which are projected to deplete due to limited resource and help lessen greenhouse gas emissions in the atmosphere that causes air pollution. The result of this study will determine which of the three selected units of passenger and cargo-type e-tricycles will be the most energy efficient for small community transport.

The general objective of this study is to assess the performance of e-tricycles in flat terrain condition through the establishment and comparison of its energy economy rating in short and long routes. Specifically, it aims to establish the driving cycle of e-tricycles in short and long routes, determine the battery-to-wheel and wall-to-wheel energy economy rating of passenger and cargo-type e-tricycles under normal operating conditions subjected to uniform loads and its maximum loading capacity, compare the energy economy ratings, and determine the most energy efficient unit.

This study covered the utilization of renewable energy as an alternative energy source only for e-tricycles. It focused on the energy economy testing, specifically battery-to-wheel and wall-to-wheel energy economy, of e-tricycles in flat terrain under uniform loading condition and at its maximum loading capacity. Furthermore, the effect of travel distance to the energy economy rating was observed. It is limited only to normal driving conditions such as road characteristics, speed, and passenger's loading and unloading.

2. REVIEW OF LITERATURE

2.1 Electric Vehicles

Vehicles operated through alternative energy particularly renewable energy are one of the proposed solutions to climate change. Electric vehicles were designed to reduce greenhouse gas emissions and reduce the use of fossil fuels. However, this depends on the energy used or the amount of carbon released (Ajanovic, 2014).

2.1.1 Types of Electric Vehicles

There are several classifications of e-vehicles depending on how it is operated. Ajanovic (2014) emphasized five types of electric vehicles. This includes the Hybrid Electric Vehicles (HEV), Plug-In Hybrid Electric Vehicles (PHEV), Range Extenders (REX), Battery Electric Vehicles (BEV) and Fuel Cell Vehicles (FCV). Shown in Figure 2-1 are the differences in the structure of each type of e-vehicle.

The ICE or Internal Combustion Engine is the conventional type of vehicle which only uses fossil fuel as an energy source. These vehicles were said to be less energy efficient than the electric vehicles. The first type of electric vehicle is HEV. HEV uses both an ICE and electric motor or generator in its operation. The ICE in HEV prolongs the driving range while the electric motor regenerates and stores excess energy which makes the vehicle more energy efficient (Ajanovic, 2014). PHEV is another e-vehicle type which can be operated through fossil fuel or electricity or both. However, it uses less oil and is mostly operated through electricity thus, emits less greenhouse gases than HEVs (Chellaswamy and Ramesh, 2017). However, it has a driving range of only 30-60 kilometers. Thus, another type of electric vehicle, REX, was designed to meet the average range of vehicles and improve the electric capacities of vehicles for driving. REX, unlike PHEV, can be operated purely electric. Another classification is BEV, which uses energy from batteries and does not use ICE. Lastly, the FCV type uses hydrogen as an alternative energy source to generate electricity through a fuel cell (Ajanovic, 2014).

Based on an environmental assessment conducted, BEV that used renewable energy as an energy source, and FCV operated through hydrogen also from renewable energy source, had the least carbon dioxide emissions. However, carbon dioxide emissions are found to be greater than the conventional vehicles if the electricity used to operate the electric vehicles are from coal-fired power plants (Ajanovic, 2014).

2.1.2 Electric Vehicles in the Market

Electric vehicles that were previously introduced in the market still have its downsides. Perdiguero and Jimenez, as cited by Ajanovic (2014), stated that the factors that hinder the success of e-vehicles in the market includes *costs*, convenience and availability of *charging* *infrastructures, consumer acceptance* and *evolution of other technologies*. Currently, electric vehicles cost much higher than the conventional ones. However, comfort and environmental benefits could positively influence humans' preference on using it. Liu et al. (2016) emphasized that the advantages that attract most vehicle users in switching to alternative fuel vehicles are the "enhanced energy security and cleaner travel." Moreover, Chellaswamy and Ramesh (2017), emphasized that the information on vehicles' performance, energy consumption, and conservation would also be a factor for consumers' preferences.

Previously introduced alternative fuel vehicles are operated through batteries or internal combustion engines (Chellaswamy and Ramesh, 2017). Studies claimed that these vehicles are inconvenient and not cost-beneficial (Liu et al., 2016). Moreover, Ajanovic (2014) claimed it as a non-zero-emission vehicle and that the emissions from electric vehicles depend on the source of energy (Kuppusamy et al., 2017). Hence, the use of renewable energy as an alternative energy source was proposed to have zero-emission vehicles. Aside from its environmental benefits, renewable energy can be utilized to aid the transportation on distant areas (Chellaswamy and Ramesh, 2017).

2.1.3 Electric Vehicles vs. Conventional Vehicles

The U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (2018) claimed that electric vehicles are more advantageous than conventional vehicles in terms of its energy efficiency, environmental benefits, performance, and energy dependence. Electric vehicles are more energy efficient than gasoline vehicles as this transform 59 to 62% of energy from the grid to the exerted power at the wheels. It has a zero-tailpipe emission, thus more environment friendly than ordinary vehicles. However, emissions depend on the source of electricity. Electricity generated from powerplants may emit pollutants while electricity produced from nuclear, solar, hydro, or wind does not release pollutants. Compared to conventional vehicles, electric vehicles have reduced energy dependence. Electric vehicles also have disadvantages particularly in range and charging time. Most electric vehicles were designed to have a maximum range of only 60 to 120 miles which are relatively less than gasoline-fueled vehicles. Battery charging is another disadvantage of electric vehicles. Compared to conventional vehicles that can be fueled up in minutes, electric vehicles require several hours to be fully charged.

The main concern of consumers in choosing what vehicle to purchase is its affordability. Most are concerned in the initial cost while less are concerned on the cost in the long run (De Clerck et al., 2018). One method used to assess the affordability of the vehicle is the Total Cost of Ownership (TCO) method which considers all the costs in the duration of ownership (De Clerck et al., 2018). Lebeau et al. (2012), cited by De Clerck et al. (2018), defined two types of TCO studies. One is *consumer-oriented*, which considers the factors affecting the cost needed to be paid by the vehicle user. Another is *society-oriented*, which considers the concerns in the society and environment. In a study conducted by Thiel et al. in 2010, cited by De Clerck et al. (2018), TCO results considering *CO_2 well-to-wheel abatement costs* showed that electric vehicles are more costly than conventional vehicles in year 2010. However, as time progresses, the difference in cost reduces until the year 2030 when the TCO are almost similar. Funk and Rabl (1999), cited by De Clerck et al. (2018), also conducted a study in TCO of vehicles but included external costs, particularly social costs for air pollution, in their analysis. Generally, it was concluded that gasoline-fueled vehicles and electric vehicles have greater TCO than external costs while diesel-fueled vehicles have greater external costs than TCO. Considering TCO, it was concluded that electric vehicles are more costly than conventional vehicles by 30 to 40%. On the other hand, considering social costs, results showed that electric vehicles are more costly than petrol vehicles but less than diesel vehicles (De Clerck et al., 2018).

2.2 Energy Economy Rating of Vehicles

According to the Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy (2011), one of the factors considered in the design of vehicles is its fuel consumption. Since 1918, fuel efficiency has been a major concern for vehicles and by the year 1950s, fuel economy became important. It is one of the major factors affecting customers' decision on what vehicle to buy (Liu et al., 2016). Fuel economy is inversely related to fuel consumption. As the fuel consumption decreases, the fuel economy increases (Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, 2011).

Energy economy, commonly known as fuel economy for ordinary vehicles, was defined as the "measure of how far a vehicle will travel with a gallon of fuel." This is commonly used by vehicle producers to inform the customers regarding performance of the vehicles. The U.S. Environmental Protection Agency assessed the fuel economy and fuel consumption of vehicles for two different driving cycles: the urban and highway dynamometer driving schedule. However, it was recommended to modify the different testing procedures for fuel economy to account all driving conditions (Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, 2011). According to Al-Samari, (2017) fuel economy of e-vehicles are better than the ordinary vehicles. Fuel economy rating of e-tricycles is dependent on the type of terrain, travel distance, and driver's behavior.

2.2.1 Effect of the Type of Terrain

Terrains can be classified as rolling and flat. Previous studies claimed that the type of terrain dictates the benefits gained from using E-vehicles (Al-Samari, 2017). For rolling terrains, the fuel economy of the vehicle would vary if the road is descending or ascending. This is because the usage of energy and emissions of vehicles are affected by its speed and acceleration which varies depending on the slope of the road and its length (Liu et al., 2016). Thus, for flat terrains, it would depend on whether the distance travelled is short or long.

2.2.2 Effect of Travel Distance

Travel distance relies on the battery life and the site for charging the batteries (Gill et al., 2014). On a study conducted by Kuppusamy et al. in 2017, it was claimed that compared to the commonly used vehicles, e-vehicles, particularly EV taxicabs, have higher energy saving when travelling in long distances while lower when travelling in short distances. Moreover, the inconvenience and battery supply are also directly proportional to the travel distance thus, it has not been fully established whether the e-vehicles are economically better than vehicles operated through combustion engines. Since the previously introduced e-vehicles costs relatively higher than the ordinary vehicles and are battery-dependent, plug-in e-vehicles as well as automatic charging mechanism was introduced. However, several studies suggested the use of renewable energy, such as wind and fuel cells, for a more economical and environment-friendly way of transportation. These type of energy helps prolong the operating life of e-vehicles and make it travel to distant areas more conveniently (Chellaswamy and Ramesh, 2017).

2.2.3 Effect of Driver's Behavior

Another factor affecting the fuel economy of e-vehicles is the driver's behavior. It was found that driving situations and the way of driving greatly affects the fuel economy of electric vehicles (Greene et al., 2017). As previously stated, Liu, Wang and Khattak claimed that speed and acceleration is associated with the energy used by the vehicle and that each driver has his or her own way and attitude in driving. An estimate of 7-30% increase in fuel economy is expected on vehicles driven at an ideal speed in a clear or normal traffic situation (Greene et al., 2017). However, Liu, Wang and Khattak emphasized that the way of driving of E-vehicle users could be different than that of the ordinary vehicle users due to its difference in engine functions, which would affect the fuel economy. Moreover, estimation of fuel economy is often based on the driving cycles indicated in the Dynamometer Driving Schedule which are said to be related to the amount of energy consumed.

2.2.4 Measures of Energy Economy Rating of E-vehicles

The energy consumption of electric vehicles can be classified according to the scope of energy supply and the method of measurement. Energy economy can be measured through (1) well-to-wheel, (2) wall-to-wheel, and (3) battery-to-wheel.

Well-to-wheel energy economy. The well-to-wheel energy consumption of e-vehicles covers the energy consumption from the primary source of energy to the consumption in the vehicle. This is useful when considering the effect of energy consumption to the environment (De Cauwer, 2015).

Wall-to-wheel energy economy. Wall-to-wheel energy economy refers to the total distance covered per energy consumed from the wall outlet. It also considers the efficiency of the battery charger. This type of energy measurement is essential in economic analysis especially when comparing the electric vehicles to the ordinary ones (Tayo, 2018). In other past studies, this is referred to as the plug-to-wheel energy economy.

Battery-to-wheel energy economy. Battery-to-wheel energy is defined as the extracted energy from the battery which does not include energy losses from the grid and charging. It is dependent on the required mechanical energy at the wheels, which varies depending on the kinematic factors on a route (De Cauwer, 2015).

2.3 Driving Cycles

Driving cycles, represented by the relationship of driving speed and time, are commonly used in emission testing of vehicles on a laboratory or test route. Emission of vehicles depend on several factors including model, size, fuel type, technology level, mileage, speed, acceleration, gear, and road gradient. Thus, driving cycles for different classifications of vehicles were developed to provide a fixed vehicle operating schedule for emission testing to be conducted under similar conditions (Barlow et al., 2009). Aside from vehicle emissions, driving cycle also influences cost and fuel consumption. Hence, this is an essential factor considered in the design and performance assessment of vehicles. However, due to changes in traffic and road conditions, a *representative driving cycle* used at a time is not certain to be always valid (Nyberg, 2015). In addition, driving cycles can also be used in engine and *drive train durability* testing of vehicles (Barlow et al., 2009).

According to Barlow et al. (2009), there are two classifications of driving cycles based on the vehicle speed and loads. One is the steady-state cycle in which the vehicle engine speed and load are constant. The other type is transient driving cycle where the speed and load are varying through time.

3. MATERIALS AND METHODS

3.1 Preparation of Equipment and E-tricycle Drivers

3.1.1 Equipment Procurement

Before the energy efficiency survey of e-tricycles, proper coordination among the concerned units in UPLB Campus such as the Office of the Vice Chancellor for Community Affairs (OVCCA), Office of the Vice Chancellor for Planning and Development (OVCPD) and University Police Force (UPF) was conducted. Six units of e-tricycles were tested on each route. A cargo-type and passenger-type e-tricycle were selected and purchased for testing from three different manufacturers namely Star8, TOJO Motors, and NWOW. For Star8, the passenger and cargo-type e-trikes purchased were the Hybrid and Utility E-trikes, respectively. Lawin II Standard and Customized Pick-Up were purchased from TOJO Motors, and Hero and Warrior e-trike units were purchased from NWOW.

(a) (b)

Figure 1. TOJO Motors – Lawin II Standard passenger type (a) and TOJO Motors – Lawin II Customized Pick-Up cargo type (b)

(a) (b)

Figure 2. NWOW-Hero passenger type (a) and NWOW-Warrior cargo type (b)


(a) (b)

Figure 3. Star8-Hybid passenger type (a) and Star8-Utility cargo type (b)

3.1.2 Installation of Equipment

Cycle analysts were installed in each e-trike with the aid of an electrician. The cycle analyst measures and displays the energy consumption (in watt-hrs) of the e-tricycle as well as the voltage, current and ampere hours used while running. A data logger, that has a built-in GPS, was connected to each cycle analyst to log the data measured by the analyst. These instruments were connected in series with the batteries and controller using power connector and Cat 5 wires. Current shunt with 50mV and 500A was also installed in series, which acted as a resistor to calibrate the current consumed by the e-trike.

A charging station was set-up in Agricultural and Machinery Display Area (AMD) as shown in Figure 4. Each e-tricycle has an assigned outlet with sub meters installed to monitor the energy consumed throughout its charging time.

Figure 4. Charging station

3.1.3 Preparation of E-tricycle Drivers

Three (3) personnel as e-trike drivers were selected and hired from the association of e-trike drivers and tricycle drivers in Barangay Putho-Tuntungin Los Baños, Laguna and Mayondon, Los Baños, Laguna. A survey was conducted, and it was found that the average daily wage for drivers was Php 600. The hired drivers were oriented regarding the project, safety, instruments and e-trike operation days prior the testing period.

The hired drivers tested the e-tricycles along the test routes before the proper testing period. They were also instructed on how to fill up the data sheet for each testing day and how to use the GPS and cycle analyst

3.2 Data Gathering

3.2.1 Test Route

E-tricycles were tested along two different routes for the flat terrain condition. The shorter route was a loop system from the administration building via Silangan Road- Dawis Avenue – Aglibut Avenue – Pili Drive – Mondonedo Avenue – Espino Avenue – Juliano Avenue – Narra – Kanluran Road and back to administration building, which measures about 3 kilometers (Figure 5). The test route for the long route condition was from the administration building to Biotech and vise-versa which measures about 9.5 kilometers (Figure 6).

Figure 5. Test route for short route

Figure 6. Test route for long route

3.2.2 E-tricycle Operation

The on-road testing and monitoring was conducted by the drivers and researchers on the selected area for 10 days per route. The operation started at 8:00 AM and ended when the battery reached its minimum allowable voltage. To normalize the driving speed, the three e-tricycles tested at a time moved in convoy.

At the end of each testing day, the drivers drove the e-tricycles back to the charging station (AMD) and were charged through standard battery chargers. Table 1 shows the manufacturer's recommendation of the maximum and minimum charge of each e-tricycle unit.

Table 1. Minimum and maximum charge (in voltage) of each e-tricycle unit

Type of E-tricycle	E-trike model	Minimum Charge (V)	Maximum Charge (V)
Passenger	TOJO Motors – Lawin II	60	70
	NWOW – Hero	48	54
	Star8 – Hybrid	60	68
Cargo	TOJO Motors – Lawin II	60	70
	NWOW – Warrior	48	54
	Star8 – Utility	60	68

Cargo-type e-tricycles simulated actual loading and unloading of goods through stopping for at most 10 minutes at the start and end points respectively. Passenger-type e-tricycles stopped at designated loading and unloading areas for at least five seconds to simulate actual loading and unloading of passengers. The stopping points for the short route were the loading and unloading stations of jeepneys in the UPLB Campus. For the long route, the stopping points were the selected areas on the route from the administration building to Biotech. At the end of each test route, the drivers recorded the data displayed on the cycle analyst and GPS.

Dummy weights, which were composed of gravel bags and concrete blocks, were loaded to the e-trikes at the start of each testing day. The e-tricycles were tested under two loading conditions: under a uniform load of 250 kg and under its maximum loading capacity. Table 2 shows the maximum loading of each passenger and cargo e-trike model, respectively. A pre-testing was conducted to assure that the e-trike can proceed at its maximum loading capacity.

Table 2. Maximum load capacity of each e-tricycle unit

Type of E-tricycle	E-trike model	Maximum loading capacity (kg)
Passenger	TOJO Motors – Lawin II	420
	NWOW – Hero	350
	Star8 – Hybrid	500
Cargo	TOJO Motors – Lawin II	420
	NWOW – Warrior	300
	Star8 – Utility	350

3.3 Driving Cycles

The data logger with a built-in GPS was used to generate the driving cycle of the e-tricycles. The average of the recorded instantaneous speed of the three e-tricycles tested at a time was computed to graph the representative driving cycle at each test route. These driving cycles represent the vehicle operation used to determine the energy economy rating of the e-tricycles.

3.4 Determination of Battery-to-Wheel Energy Economy

The battery-to-wheel energy economy was determined using cycle analyst. This is used to determine the energy consumption of the e-tricycles at each lap and differentiate the energy consumption in short and long routes. To determine the energy consumed at each lap, the drivers reset the cycle analyst at the end points of the route and the data were automatically saved to the data logger. At the end of each testing day, the data loggers connected to the cycle analysts were collected. The trip analyzer from *www.ebikes.ca*, where the cycle analysts were purchased, was used to graph the logged data. The battery-to-wheel energy economy was computed through the equation:

$$\text{Battery-to-wheel energy economy} = \frac{\text{Total distance traveled in one lap (km)}}{\text{Total energy spent from the battery (kWh)}} \tag{1}$$

3.5 Determination of Wall-to-Wheel Energy Economy

The wall-to-wheel energy efficiency was determined through the energy consumed during charging and the total trip odometer reading from the GPS. To estimate the kWh used corresponding to the distance traveled, the e-tricycles were fully charged before operation and were advised to be charged when it reached its minimum allowable voltage (Table 3.1). The initial kWh reading from the sub meter was subtracted to the final kWh reading to calculate the kWh consumed during charging. Wall-to-wheel energy efficiency was calculated using the equation:

$$\text{Wall-to-wheel energy economy} = \frac{\text{Total distance traveled in a testing period (km)}}{\text{Total energy consumed during charging (kWh)}} \tag{2}$$

4. RESULTS AND DISCUSSION

4.1 Battery-to-Wheel Energy Economy

4.1.1 Passenger Type E-tricycles

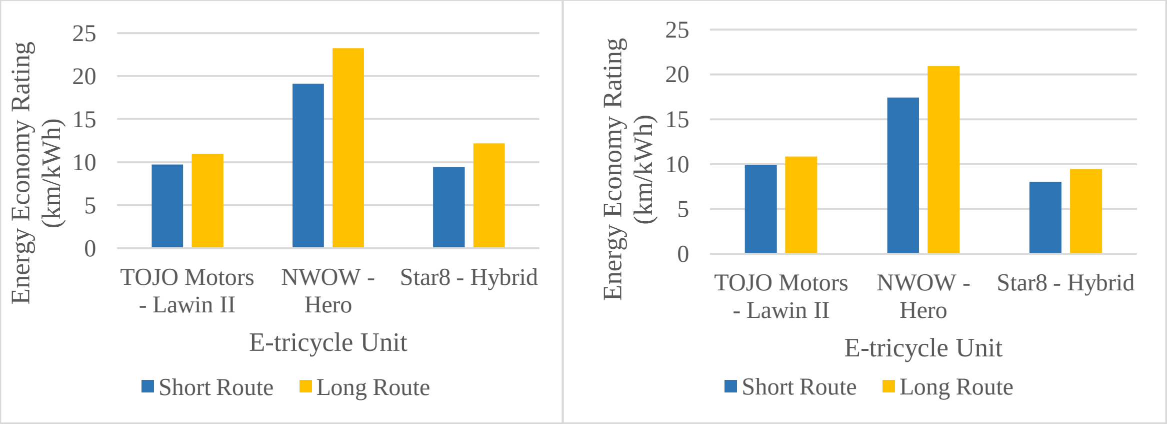
Table 3 shows the data for the battery-to-wheel energy economy rating of passenger type e-tricycles in short and long routes.

Table 3. Data for the battery-to-wheel energy economy of passenger-type e-tricycles.

Route	E-trike model	Loading condition	Distance traveled (km)	Energy consumed (kWh)	Average speed (km/h)	Battery-to-wheel energy economy rating (km/kWh)
Short	TOJO Motors – Lawin II	250 kg	3.080	0.320	13.656	9.744
		Maximum	3.059	0.310	12.380	9.880
	NWOW – Hero	250 kg	3.058	0.162	13.104	19.128
		Maximum	3.091	0.179	12.824	17.427
	Star8 – Hybrid	250 kg	3.137	0.346	14.013	9.438
		Maximum	3.062	0.383	13.28	8.018
Long	TOJO Motors – Lawin II	250 kg	9.632	0.885	17.954	10.975
		Maximum	9.615	0.903	17.300	10.860

NWOW – Hero	250 kg	9.766	0.421	17.178	23.242
	Maximum	9.658	0.465	16.329	20.928
Star8 – Hybrid	250 kg	9.788	0.808	17.171	12.204
	Maximum	9.637	1.024	18.100	9.441

Figure 7 displays the summary of the battery-to-wheel energy economy rating of passenger type e-tricycles in the two test routes and loading conditions.



(a) (b)

Figure 7. Summary of the battery-to-wheel energy economy rating of passenger type e-tricycles under 250 kg load (a) and its respective maximum loading capacity (b)

It can be observed that in both routes and loading conditions, NWOW-Hero passenger type e-tricycle has the highest battery-to-wheel energy economy rating while Star8 – Hybrid has the least. Figure 8 shows the representative driving cycle of passenger type e-tricycles in short route.

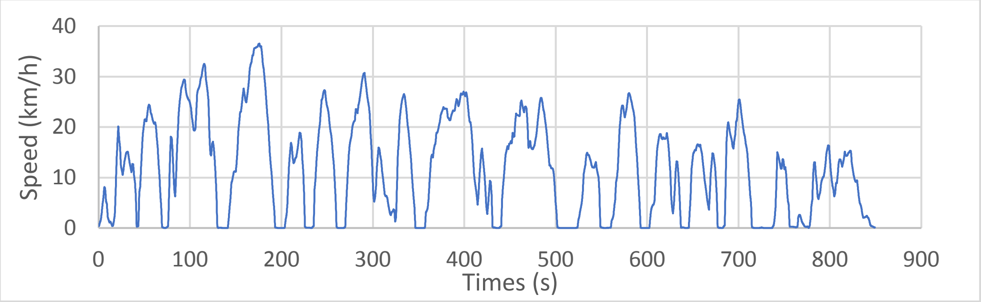


Figure 8. Representative driving cycle of passenger type e-tricycles in short route

The speed drops indicate the response of the e-tricycles in stopping points, junctions and queues along the test route. Figure 9 shows the representative driving cycle of passenger e-tricycles in long route. Similarly, the speed drops are the response of the e-tricycles in stopping points, junctions, and queues along the test route.

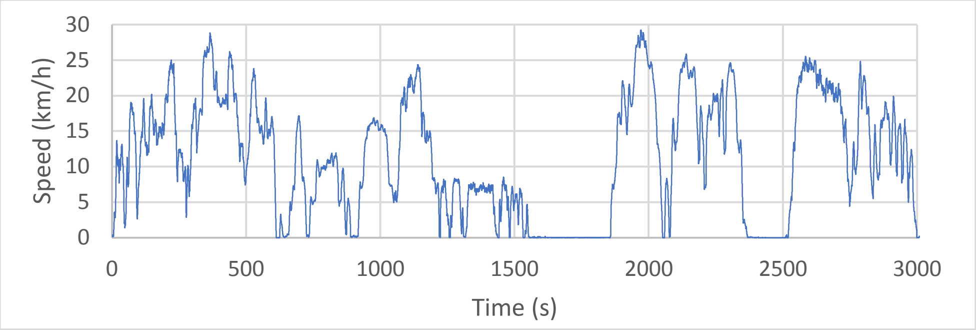


Figure 9. Representative driving cycle of passenger type e-tricycles in long route

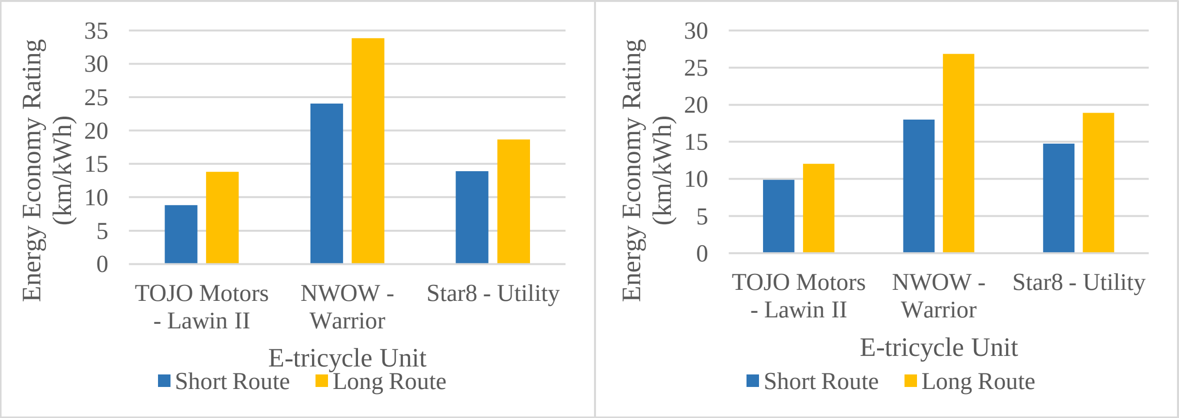
4.1.2 Cargo Type E-tricycles

Table 4 displays the summary of the data for the battery-to-wheel energy economy rating of cargo type e-tricycles in short and long routes.

Table 4. Data for the battery-to-wheel energy economy of cargo-type e-tricycles

Route	E-trike model	Loading condition	Distance traveled (km)	Energy consumed (kWh)	Average speed (km/h)	Battery-to-wheel energy economy rating (km/kWh)
Short	TOJO Motors – Lawin II	250 kg	3.048	0.347	20.277	8.804
		Maximum	3.038	0.314	16.735	9.876
	NWOW – Warrior	250 kg	3.022	0.127	13.847	24.046
		Maximum	3.033	0.168	12.200	18.006
	Star8 – Utility	250 kg	3.048	0.220	14.200	13.913
		Maximum	3.038	0.207	13.520	14.768
Long	TOJO Motors – Lawin II	250 kg	9.609	0.705	20.208	13.820
		Maximum	9.601	0.798	18.645	12.208
	NWOW – Warrior	250 kg	9.682	0.300	14.900	33.827
		Maximum	9.683	0.369	16.817	26.855
	Star8 – Utility	250 kg	9.562	0.513	19.250	18.651
		Maximum	9.629	0.513	14.700	18.922

Figure 10 shows the summary of the battery-to-wheel energy economy rating of cargo type e-tricycles in the two test routes and loading conditions.



(a) (b)

Figure 10. Summary of the battery-to-wheel energy economy rating of cargo type e-tricycles under 250 kg load (a) and its respective maximum loading capacity (b)

In both loading conditions and test route, NWOW-Warrior has the highest battery-to-wheel energy economy rating while TOJO Motors – Lawin II has the least. Figures 11 and 12 show the representative driving cycle of cargo type e-tricycles in short and long route, respectively. It can be observed that compared to the driving cycle of passenger e-tricycles, there are less points with 0 km/h speed since cargo type e-tricycles have no designated stopping points. The speed drops indicate the response of the e-tricycles in junctions and queues.

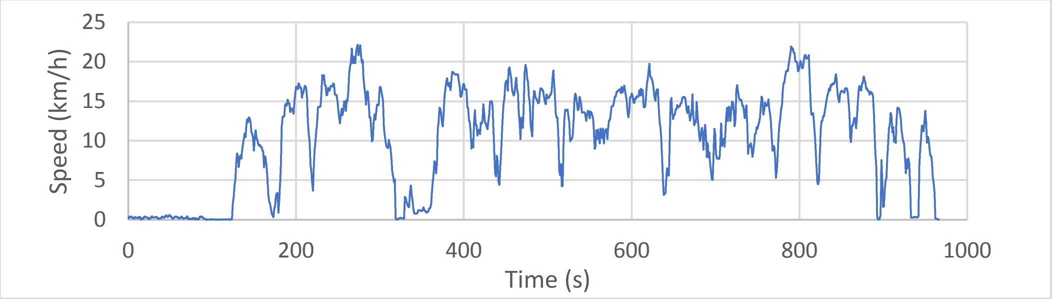


Figure 11. Representative driving cycle of cargo type e-tricycles on short route.

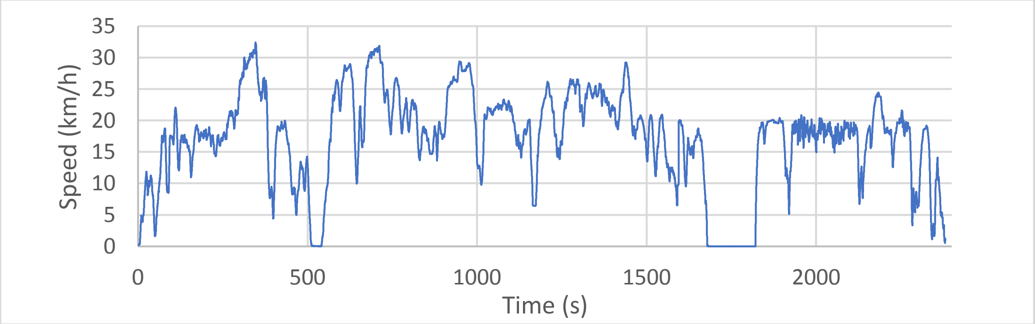


Figure 12. Representative driving cycle of cargo type e-tricycles in long route.

4.2 Wall-to-wheel Energy Economy Rating

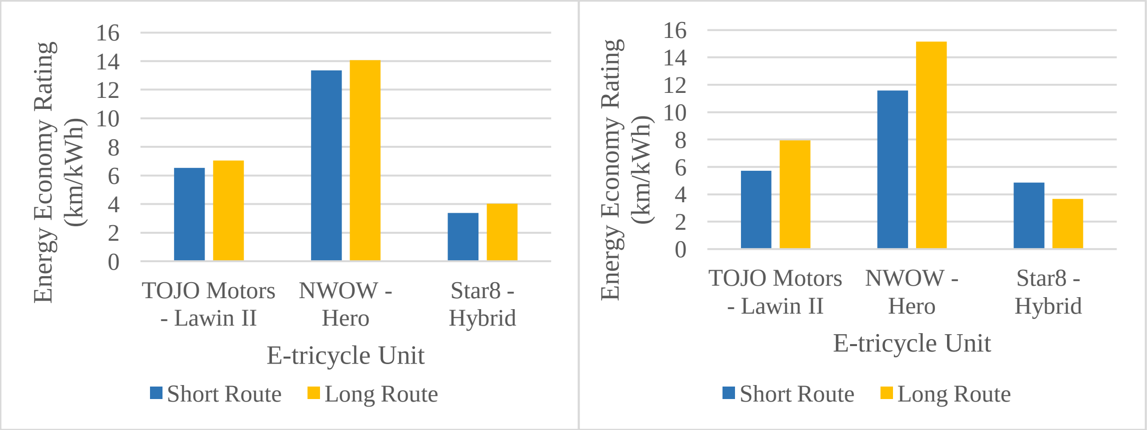
4.2.1 Passenger Type E-tricycles

Table 5 shows the summary of the data for the wall-to-wheel energy economy rating of passenger type e-tricycles.

Table 5. Average wall-to-wheel energy economy of passenger type e-tricycles

Route	E-trike model	Loading condition	Distance traveled (km)	Energy consumed (kWh)	Time of charging (km/h)	Wall-to-wheel energy economy rating (km/kWh)
Short	TOJO Motors – Lawin II	250 kg	20.848	3.2	7.5	6.526
		Maximum	22.238	4.150	6.500	5.719
	NWOW – Hero	250 kg	20.685	1.55	4.000	13.358
		Maximum	26.966	2.280	4.737	11.576
	Star8 – Hybrid	250 kg	19.843	6.967	7.33	3.370
		Maximum	17.800	5.275	5.217	4.864
Long	TOJO Motors – Lawin II	250 kg	29.012	4.140	7.400	7.040
		Maximum	25.878	3.730	5.700	7.941
	NWOW – Hero	250 kg	32.350	2.420	4.200	14.059
		Maximum	34.057	2.250	4.925	15.144
	Star8 – Hybrid	250 kg	27.623	7.063	7.750	4.034
		Maximum	22.550	6.900	6.439	3.663

Figure 13 shows the summary of the wall-to-wheel energy economy rating of passenger type e-tricycles.



(a) (b)

Figure 13. Summary of the battery-to-wheel energy economy rating of passenger type e-tricycles under 250 kg load (a) and its respective maximum loading capacity (b)

NWOW-Hero is observed to have the highest wall-to-wheel energy economy rating while Star 8-Hybrid has the least.

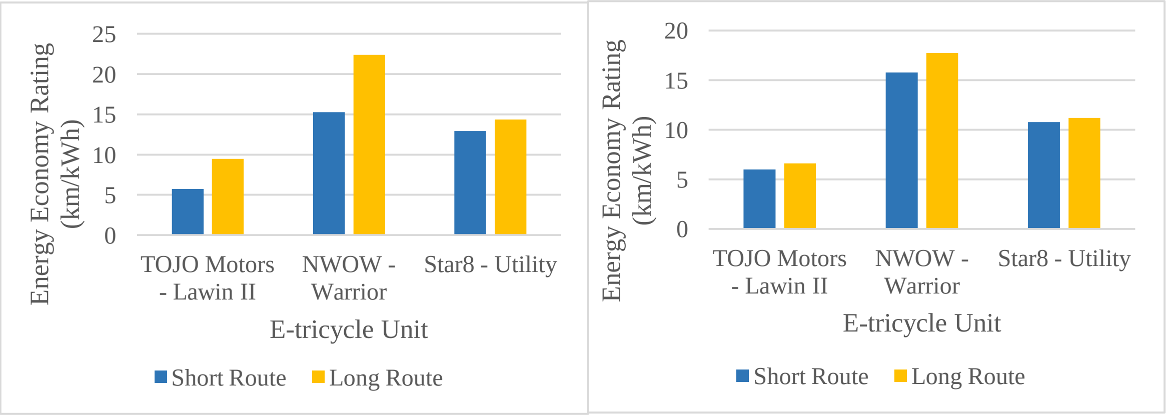
4.2.2 Cargo Type E-tricycles

The summary of the data for the wall-to-wheel energy economy of cargo type e-tricycles in the two test routes is shown in Table 6.

Table 6. Average wall-to-wheel energy economy of cargo-type e-tricycles

Route	E-trike model	Loading condition	Distance traveled (km)	Energy consumed (kWh)	Time of charging (km/h)	Wall-to-wheel energy economy rating (km/kWh)
Short	TOJO Motors – Lawin II	250 kg	26.065	4.538	8	5.738
		Maximum	23.570	4.100	7.200	5.992
	NWOW – Warrior	250 kg	20.772	1.380	6.200	15.286
		Maximum	22.447	1.433	6.667	15.754
	Star8 – Utility	250 kg	23.105	1.800	8	12.930
		Maximum	20.473	1.900	7.5	10.775
Long	TOJO Motors – Lawin II	250 kg	34.943	3.700	7.333	9.471
		Maximum	28.333	4.488	6.626	6.605
	NWOW – Warrior	250 kg	31.368	1.460	6.300	22.374
		Maximum	27.413	1.575	5.875	17.719
	Star8 – Utility	250 kg	28.905	2.050	8.000	14.365
		Maximum	24.520	2.220	6.900	11.184

Figure 14 displays the summary of the wall-to-wheel energy economy rating of cargo type e-tricycles.



(a) (b)

Figure 14. Summary of the battery-to-wheel energy economy rating of cargo type e-tricycles under 250 kg load (a) and its respective maximum loading capacity (b)

It can be observed that NWOW-Warrior has the highest wall-to-wheel energy economy rating while TOJO Motors-Lawin II has the least.

4.3 Statistical Analysis

4.3.1 Battery-to-wheel Energy Economy Rating

Table 7 shows the summary of the result of the MANOVA test for the battery-to-wheel energy economy rating of passenger and cargo type e-tricycles under both loading conditions in the two test routes.

Table 7. Summary of the MANOVA test result for the battery-to-wheel energy economy rating

Type of e-tricycle	Route	Loading condition	Wilks' λ	DF1	DF2	F (critical value)	P-value
Passenger	Short	250 kg	0.172	6	112	2.181	<0.0001
		Maximum	0.021	6	70	2.231	<0.0001
	Long	250 kg	0.047	6	66	2.239	<0.0001
		Maximum	0.105	6	46	2.304	<0.0001
Cargo	Short	250 kg	0.018	6	56	2.266	<0.0001
		Maximum	0.268	6	80	2.214	<0.0001
	Long	250 kg	0.123	6	40	2.336	<0.0001
		Maximum	0.071	6	38	2.349	<0.0001

It can be observed that the values of Wilks' lambda in all routes and loading conditions are close to zero. Also, the p-values, which are all <0.0001, are much lower than the significance level of 0.05. Therefore, the null hypothesis stating that all passenger type e-tricycles have equal average battery-to-wheel energy economy rating can be rejected at a risk of only 0.01%. This means that each passenger type e-tricycle have different speed, distance, and energy consumption relationship, thus significantly different battery-to-wheel energy economy rating.

Table 8 shows the summary of the result from the MANOVA test for the wall-to-wheel energy economy rating of passenger and cargo type e-tricycles.

Table 8. Summary of the MANOVA test result for the wall-to-wheel energy economy rating

Type of e-tricycle	Route	Wilks' λ	DF1	DF2	F (critical value)	P-value
Passenger	Short	0.172	6	112	2.181	<0.0001
	Long	0.047	6	66	2.239	<0.0001
Cargo	Short	0.018	6	56	2.266	<0.0001
	Long	0.123	6	40	2.336	<0.0001

MANOVA results showed that the values of the Wilks' lambda are all approximately zero and the p-values are <0.0001. Thus, at a risk of only 0.01%, the null hypothesis indicating that all e-tricycles have equal mean wall-to-wheel energy economy ratings can be rejected.

5. CONCLUSION

For the passenger type e-tricycles, results showed that NWOW – Hero has the highest energy economy rating among the passenger-type e-tricycles tested in short and long routes under two loading conditions, while Star8 – Hybrid has the least. At 250 kg loading condition in short route, NWOW – Hero has an average battery-to-wheel energy economy rating of 19.128 km/kWh and average wall-to-wheel energy economy rating of 13.358 km/kWh. Under its maximum loading capacity in short route, it has an average battery-to-wheel and wall-to-wheel energy economy rating of 17.427 km/kWh and 11.576 km/kWh, respectively. In long route, it has an average battery-to-wheel and wall-to-wheel energy economy rating of 23.242 km/kWh and 14.059 km/kWh, respectively, under 250 kg load. At its maximum loading capacity, it has an average battery-to-wheel energy economy rating of 20.928 km/kWh and wall-to-wheel energy economy rating of 15.144 km/kWh.

Among the three units of cargo type e-tricycles, NWOW – Warrior has the highest energy economy rating in short and long routes under both loading conditions, while TOJO Motors – Lawin II (Customized Pick-Up) has the least. NWOW – Warrior has an average battery-to-wheel and wall-to-wheel energy economy rating of 24.046 km/kWh and 15.286 km/kWh, respectively, under 250 kg load in short route. At its maximum loading capacity, it has an average battery-to-wheel energy economy rating of 18.006 km/kWh and wall-to-wheel energy economy rating of 15.754 km/kWh. Under 250 kg load in long route, it has an average battery-to-wheel energy economy rating of 33.827 km/kWh and wall-to-wheel energy economy rating of 22.374 km/kWh. While at its maximum loading capacity, it has an average battery-to-wheel energy economy rating and wall-to-wheel energy economy rating of 26.855 km/kWh and 17.719 km/kWh, respectively.

From the established energy economy rating, it was observed that, on the average, the e-tricycles have higher energy economy rating when traveling in long route than in short route. Thus, it can be concluded that e-tricycles are more energy efficient when traveling in longer routes. In addition, due to varying traffic condition along the test route, the energy economy rating per lap and testing day is variable.

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