Techno-Economic Study of a Solar Fast Charging Station for a Local Public E-Trike Fleet

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Abstract:
This study investigates the technical and economic parameters of operating a solar fast charging station for a local deployment of public transportation electric tricycle fleet. Relevant operational data from the e-trike fleet were gathered and considered in the deployment of charging equipment and hybrid solar PV systems. Results show that the shift from AC charging to DC fast charging directly resulted in an increase in the end-users' daily earnings, trip distance, and passenger-kilometer. Possible business models for the EVCS were identified and compared by computing for the payback period and return of investment.

Keywords: solar fast charging station, electric tricycle, techno-economic study

1. INTRODUCTION

1.1 Background

Electric vehicles (EV) are gaining traction worldwide due to the evident limitations of fossil fuel resources, resulting to higher fuel prices. Mobility is leaning towards greener and sustainable operations to decrease carbon emissions. (Ali, Mohammad, & Rahman, 2019) (Bhadra, et al., 2020) (Cruzate, Cipriano, Calub, & Tria, 2022) This is also true for the Philippine transportation system, with the government becoming more aggressive in transitioning to modernized transport by adopting policies and establishing the roadmap for the local electric vehicle industry through the enactment and implementation of the Republic Act 11697 also known as Electric Vehicle Industry Development Act (EVIDA). (Lectura, 2022)

The Philippine EV industry is unique because the initial market is mostly low-capacity public transport segments, such as electric tricycles or e-trikes and electric jeepneys or e-jeeps, as well as personal micro-mobility segment in the form of e-scooters and e-bicycles or e-bikes, as shown in Figure 1. (Cruzate, Cipriano, Calub, & Tria, 2022) (Mangun, 2021) (Department of Energy, 2022). According to the Department of Energy presentation during the release of the Comprehensive Roadmap for the Electric Vehicle Industry (CREVI) in 2022, more than 87% of the registered EVs in the country are composed of e-trikes and e-motorcycles. The EV registration has been increasing in the last decade, as shown in Figure 2.

Although there is already traction in the growth of EV units, there is still a considerable study needed for the improvement of infrastructures, such as charging points, to support the increasing operations (Frost and Sullivan, 2020). Locally, there are three types of electric vehicle charging stations (EVCS): battery swapping stations, own-use charging stations, and commercial-use charging stations. Most use cases are still fleet operated or own use charging stations, also known as captive charging.

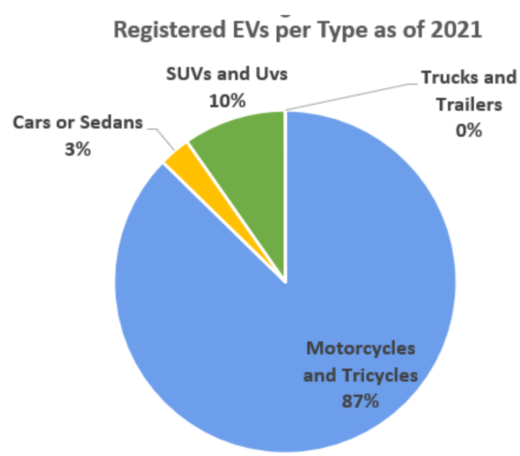


Figure 1: Number of Registered EVs per Type of Vehicle in 2021 (Department of Energy, 2022)

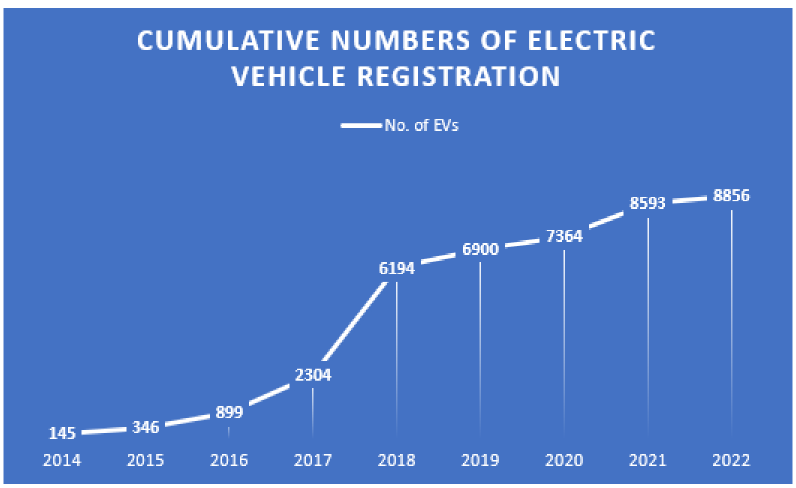


Figure 2: Cumulative Numbers of EV Registration in the Philippines (Department of Energy, 2022)

1.2 Scope and Research Objectives

Although the EVCS are already gaining traction and interest in the Philippines, there is limited information on the feasibility, business models and techno-economic viability of the local deployments. This paper aims to give an insight into the technical performance of a locally deployed EVCS in terms of the direct effect of the deployment to the end users such as trip distance, passenger kilometer, charging time, and daily earnings. The economic feasibility of the deployment is investigated by identifying the relevant costs and operational details, and determining possible business models appropriate for local operations.

A local deployment of solar fast charging station for electric tricycles is evaluated in terms of its performance compared to conventional charging and its commercial viability and profitability. Although the case investigated for this study is specific for e-trikes, the methodology and model are scalable for future deployments targeting a different EV segment.

2. ELECTRIC VEHICLE CHARGING STATION

With the emerging development of electric vehicles locally and internationally, the industry needs reliable charging stations to service the continuously growing numbers of electric vehicles (EVs) worldwide.

The local modes of charging are adopted from an existing standard, IEC 61851, which is categorized into four modes shown in Table 1 (Department of Trade and Industry Bureau of Philippine Standards, 2020).

Table 1: Summary of PNS IEC 61851-1 Modes of Charging (Department of Energy, 2021)

MODE	DESCRIPTION	MAX CURRENT/VOLTAGE	APPLICATIONS
Mode 1	AC: Non-dedicated circuit and socket-outlet, charging without RCD protection	Single Phase: 16A/250V Three Phase: 16A/480V	Micromobility Or personal mobility home charging
Mode 2	AC: Non-dedicated circuit and socket-outlet, charging with cable-incorporated RCD protection	Single Phase: 32A/250V Three Phase: 32A/480V	Slow AC Charging
Mode 3	AC: EVSE connected to AC grid using fixed cable with communication	Single Phase: 32A/250V Three Phase: 32A/480V	Slow AC Charing and Quick AC Typically used for public EVCS
Mode 4	DC: Dedicated EVSE supplies DC power to EV using a fixed cable with bidirectional communication.	Single Phase/Three Phase: 200A/400V	Fast DC, for quick/rapid DC charging

While each mode has its own pros and cons, it is important to identify the appropriate charging equipment for the fleet operations. The Tokyo Electric Power Company (TEPCO) for example, one of the leading companies in EV infrastructure development and deployment based in Japan, conducted a year-long study on the effect of fast charging stations to their EV fleet. Prior to the mode 4 charger deployment, it became evident that by using mode 3 AC chargers, the fleet is not able to access the whole service area. With the transition to faster charging time, the fleet was able to access the entirety of the service area, comparable to the performance of an ICE vehicle (Anegawa, 2010) as shown in Figure 3. This illustrates how lessening the downtime due to charging maximizes the potential of the fleet.

Aside from identifying the appropriate equipment and mode of charging, the incorporation of renewable sources to address energy resiliency is also an important aspect of the EVCS deployment. Hybrid implementations incorporating the advantages of grid power and renewable energy, through solar or wind energy, can reduce the risk of the infrastructure deployment (Bhadra, et al., 2020) (Biya & Sindhu, 2019).

The business model to be used in operating the EVCS plays a big role in the sustainability of the infrastructure. Some examples of possible business models are the operational cost-based and subscription-based model. With the operational cost model, a fee or profit is billed to the end users on top of their charging consumption. This model ensures that operational costs are being paid by the consumers and payback for hardware and installation costs depends on how much the additional profit will be and how many customers charge per day. Most EV drivers are willing to pay for charging, but also take into consideration if the price is reasonable, especially when compared to home electricity rates (Business Models for Commercial Electric Vehicle Charging, 2022).

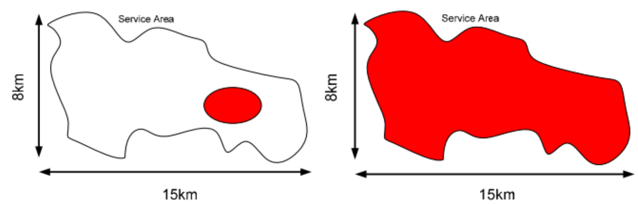


Figure 3: Service Area Accessed by Slow Charger (left) vs. Fast Charger (right) *(Anegawa, 2010)*

For the subscription-based model, end-users pay monthly fees which is already inclusive of their energy usage. This model is viable for operations involving a network of charging stations, so customers could have many charging point options. From a customer standpoint, this is a more convenient option since they don't need to pay per use while having access to the network of charging stations. The operator, however, needs to study the profitability based on the charging behavior of its users (Bellan, 2021).

To verify the economic feasibility of the deployment, several metrics can be used in the analysis. Some of these metrics are the payback period and the return on investment. To be able to determine these values, the relevant data and assumptions should first be identified to contextualize the analysis to the operations of the fleet (Alfonso & Kezunovic, 2019)

3. METHODOLOGY

The methodology used to conduct the study is shown in Figure 4. The baseline data relevant to the operations of the fleet to be serviced by the EVCS were gathered. The operational data was used to determine the specifications needed for the charging station. The initial interviews were also used to identify the parameters needed to be gathered during the actual deployment in the form of survey design. The data gathered during the deployment phase of the study were then used to qualify the performance of the EVCS technically and economically.

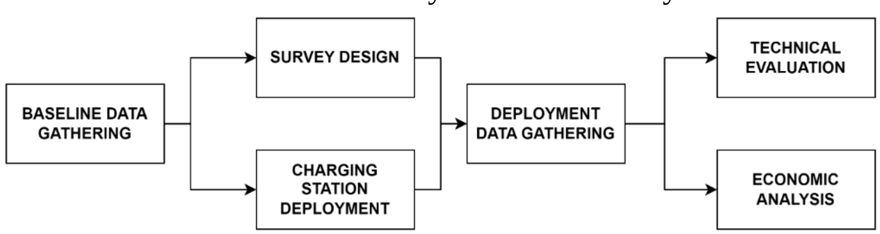


Figure 4: Framework of Study

3.1 Baseline Operations Data Gathering

One of the beneficiaries of the Department of Energy (DOE) donated e-trikes is Quezon City (Rivera, 2021). The city has received a donation of 300 units which are distributed to different barangay beneficiaries as detailed in Table 2. The proximity of the sites as well as the nature of operations were considered in choosing the possible location of the charging station. Brgy. Commonwealth and Brgy. Payatas were two of the first recipients of the e-trikes and were operating for at least 6 months already prior to the conduct of the study. These barangays cover several Tricycle Operators and Drivers Associations (TODA) which share the Payatas road as their main route. Through coordination with the Green Transport Office (GTO) under the Department of Public Order and Safety, the target deployment sites were narrowed down to two TODAs: Payatas E-Trike TODA and Parkwoods TODA, citing cooperation and performance of the TODAs as the main factor in the choice.

Table 2: DOE E-Trike Distribution in Quezon City

NO	SITE/TODA	NO. OF E-TRIKES
1	Brgy. Batasan - Batasan Hills TODA	37
2	Brgy. Culiat - Salam TODA	26
3	Brgy. Obrero	9
4	Quezon Memorial Circle	5
5	Brgy. Sacred Heart	15
6	Brgy. Paligsahan	15
7	Brgy. Kalusugan	5
8	Brgy. Kristong Hari	5
9	FilTODA	34
10	Brgy. Old Balara	20
11	Brgy. Payatas – PeTODA	50
12	Brgy. Payatas – Parkwoods TODA	12
13	Brgy. Bagong Silangan	15
14	Brgy. Commonwealth – Litex-Commonwealth TODA	22
15	Brgy. Payatas – Litex-Payatas TODA	20

The TODAs identified were interviewed to get the data of their route, operations, and nature of charging. This information was used to formulate and design the survey that will be used in the deployment data gathering. A summary of the initial data is shown in Table 3.

Figure 5: Interview with TODAs: Payatas TODA; Parkwoods TODA

Table 3: Summary of Baseline Data Gathered from Payatas TODA and Parkwoods TODA operations.

PARAMETER	PAYATAS TODA	PARKWOODS TODA
Trip Time	4 – 6 hours per day	4-7 hours per day
Daily Charging Time	3- 4 hours per day	4-6 hours per day
Daily Trip Distance	40-50 km	60-80 km
Daily Earnings	PHP 300- PHP600	PHP 300-PHP600

3.2 Design of Survey

The interview results and ocular visits were taken into consideration in the design of the e-trike trip survey. The data gathering is a combination of manual logging for the ridership and automated GPS logging. For the manual logging, the survey sheet used is shown in Figure 6.

Name of Surveyor			
Date		E-Trike Body Number and TODA	
Odo Reading at Start of Day (km)		Odo Reading at End of Day (km)	

Time	GPS Coordinates	Landmark	Odo (km)	No. of Pax	Passenger Sex		Wait pax / Loading / Unloading / Go to CS / Wait Charge / Charge / End Charge
					Male	Female	

Figure 6: E-trike trip survey sheet

The mechanics of the manual logging are as follows:

(a) The surveyor rides the e-trike from a TODA for at least 1 week with a 12-hour period of operation: 6am - 6pm.

(b) The surveyor gets the odometer reading at the start and end of day.

(c) The surveyor logs 1 row for each time the e-trike does one of the following: picks up passenger; drops off passenger; e-trike charging; lining up at terminals.

(d) GPS data is taken from a smartphone via the Ultra GPS Logger application.

(e) Location (Landmark): Notable landmarks are logged onto the survey sheet.

(f) Odometer: The odometer reading will be taken for each of the events detailed in c.

(g) No. of Pax: This pertains to the passenger count on the vehicle after every event detailed in c.

(h) Passenger Sex: This indicates the demographics in terms of passenger gender.

(i) Remarks: This can be used to indicate whether the e-trike driver dropped off or picked up passengers, or even charged the e-trike for that certain period.

3.3 Charging Station Deployment

One of the charging locations identified is at the Brgy. Payatas Environment Police Building, situated along the Payatas Main Road and accessible to both TODAs. Taking into consideration the initial data gathered regarding the operations of the two TODAs, the following equipment was deployed to this location: one (1) Mode 4 DC fast charger, and one (1) Mode 3 dual output AC charging terminal and features one (1) solar PV system that supports hybrid operations.

Figure 7 shows the block diagram of the charging station with all the components integrated while Figure 8 shows the fully commissioned solar fast charging station at deployed at Brgy. Payatas and used for the purpose of this study.

The DC fast charger deployed in the charging station is a mode 4 charger with a rated power output of 6.5kW. The actual picture of the charger as well as the nameplate ratings are shown in Figure 9 and

Table 4. The fast charger can fully charge one BEMAC e-trike at an average time of 30-45 minutes. This is significantly shorter than the conventional charging time of 3-4 hours being experienced by the end-users before the charger deployment.

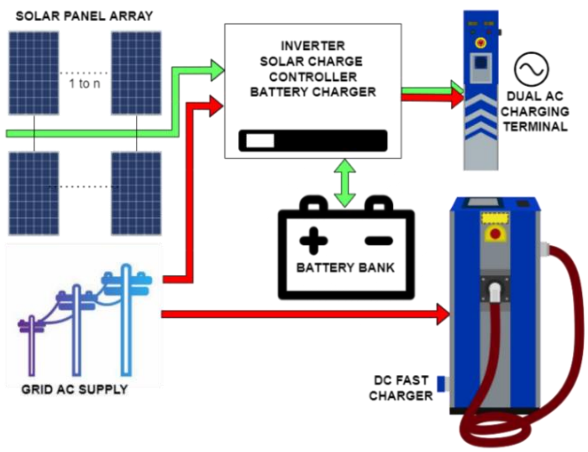


Figure 7: Solar Fast Charging Station Block Diagram

Figure 8: Actual pictures of solar e-trike fast charging station at the Environmental Office Building

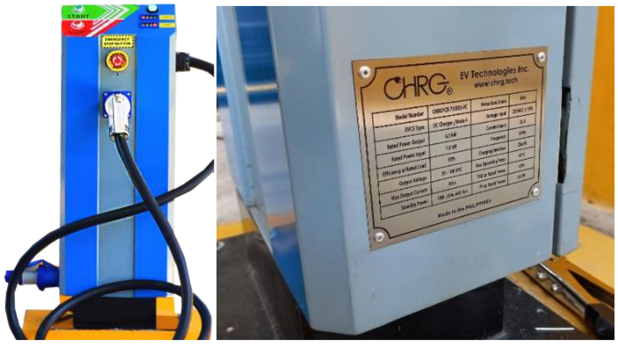


Figure 9: DC Fast Charger with nameplate

Aside from the fast charger, a level 1, mode 3 dual AC charging terminal was also installed to support the operations of the station. Two vehicles can simultaneously use this AC charging terminal should queuing occur with the fast charger.

The specifications of the solar PV system were based on the operational load, space requirements, and availability of location. The hybrid system is expected to specifically support the operations of the dual output mode 3 charger. All relevant technical computations can be found in (Cruzate, Cipriano, Calub, & Tria, 2022). The detailed specification of the system is shown in

Table 6 while the block diagram is shown in Figure 11.

Table 4: DC Fast Charger Technical Specifications

TECHNICAL SPECIFICATIONS	
Electric Vehicle Supply Equipment	DC Charger Mode 4
Rated Power Output	6.5kW
Rated Power Input	7.0 kW
Efficiency @ Rated Load	93%
Output Voltage	50VDC – 100 VDC
Max Output Current	80A
Standby Power	10W | 45W with fan
Protection Grade	IP44
Voltage Input	230VAC +/- 10%
Current Input	32A
Frequency	60 Hz

Figure 10: Dual Output AC Charging Terminal

Table 5: Dual Output AC Charging Terminal Technical Specifications

TECHNICAL SPECIFICATIONS	
Electric Vehicle Supply Equipment	AC Charger Mode 3
Rated Power Output	4kW – 2kW per port
Rated Power Input	4kW – 2kW per port
Efficiency @ Rated Load	99%
Output Voltage	230VAC +/- 10%
Max Output Current	20A – 10A per port
Standby Power	5W
Protection Grade	IP44
Voltage Input	230VAC +/- 10%
Current Input	20A
Frequency	60 Hz

Table 6: Specifications of Solar PV System

TECHNICAL SPECIFICATIONS		
ITEM	**QUANTITY**	**SPECIFICATIONS**
Photovoltaic Module	10	450W per module ≈ 4.5kW
Inverter	1	5.5kW V_{OC_nom} = 450V – 550V
Solar/ AC Charger	1	48VDC nominal With MPPT
Battery Storage	4	12VDC, 200Ah each cell, Bank voltage = 48VDC Lead Acid, VRLA Type, SOC 50%-100%

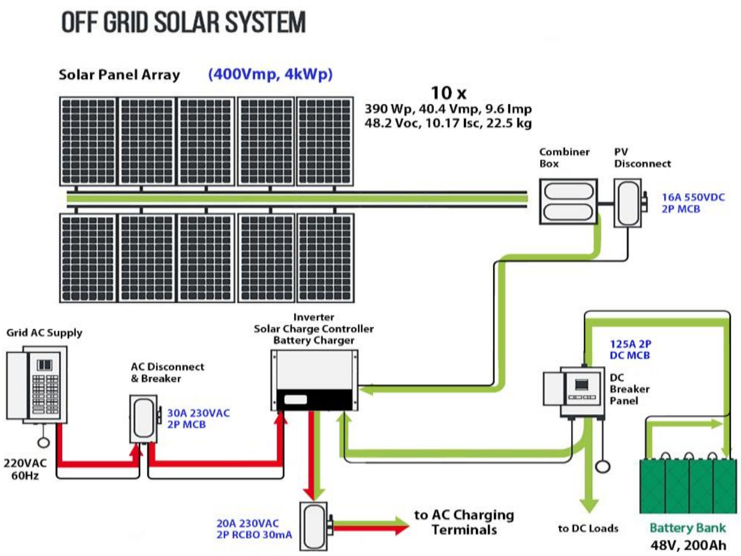
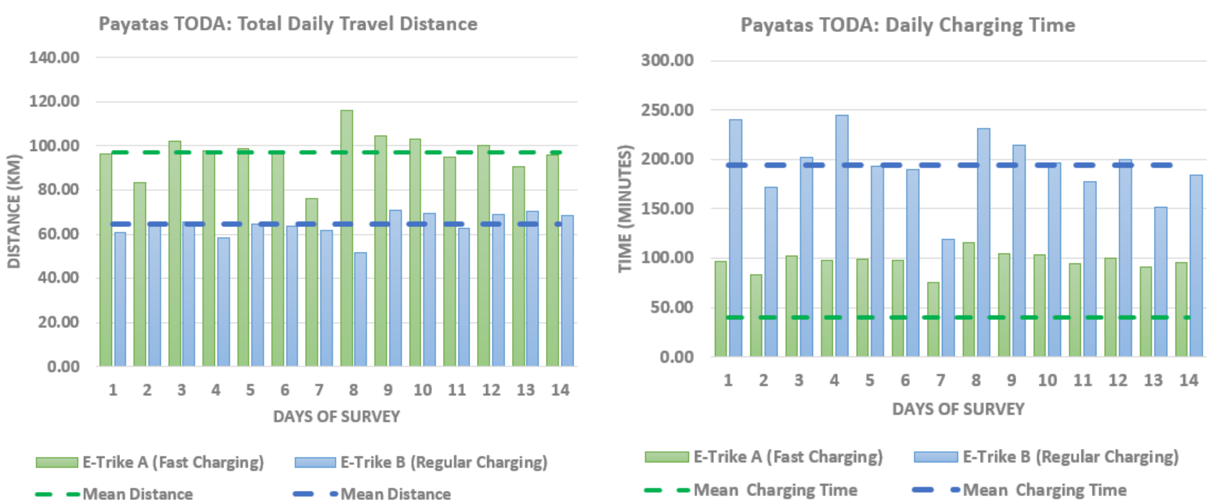


Figure 11: Off grid solar PV system diagram

4. TECHNICAL PERFORMANCE OF THE EVCS

In this section the following convention will be used: E-trike A is the vehicle that uses the fast-charging station while e-trike B is using regular charging for both TODAs. To compare the effect of the usage of the fast-charging station to the performance of the e-trikes using regular charging, a survey was conducted during the months of November and December 2021. Two surveyors rode two e-trikes belonging to the same TODA at the same period. One e-trike exclusively uses the deployed mode 4 charger while the other uses the regular mode 3 charger at their designated charging area or at home. The activities were logged during a 12-hour period, 6AM to 6PM for both e-trikes. The results of this data gathering are presented in the next section.

4.1 Payatas TODA



(a) (b)

Figure 12: Payatas TODA (a) Daily Travel Distance and (b) Daily Charging Time

For the Payatas TODA, the data collection was done for 14 days (November 4-10 and December 1-7, 2021). Out of the 50 e-trikes belonging to the PTODA, two (2) units were used to collect the data. The results shown in Figure 12 and Table 7 indicate that the charging time for e-trike A is four times faster than e-trike B. Since the charging time is shorter and charging is more frequent this resulted in e-trike A spending more time traveling on the road and servicing passengers within the 12-hour duration of the survey. This can be observed by looking at the average daily trip distance recorded from the results. E-trike A recorded almost 33 km more than the e-trike B. This trip distance difference is the reason behind the higher passenger kilometer (pkm) and daily earnings for A, as these metrics are directly proportional with one another.

Table 7: Payatas TODA charger performance comparison

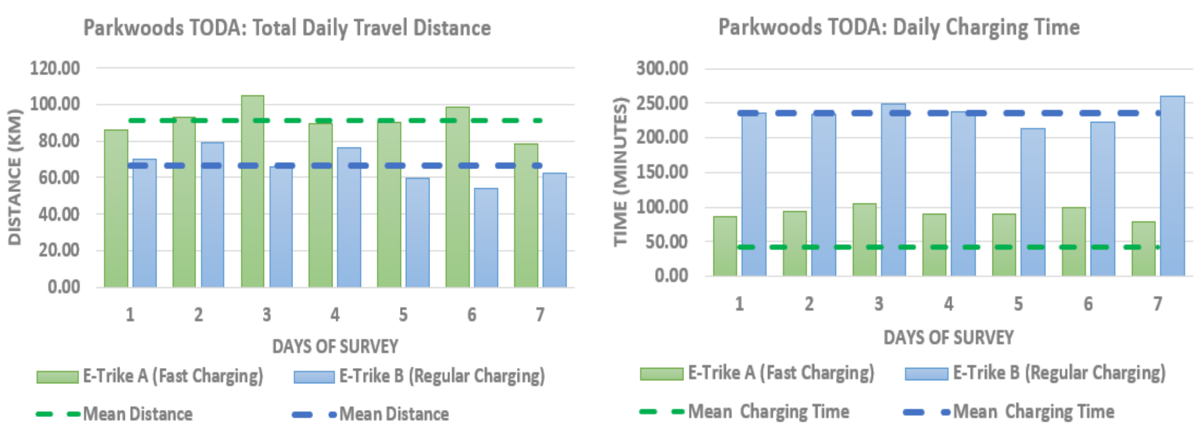
METRIC	E-TRIKE A FAST CHARGING			E-TRIKE B REG CHARGING		
(units)	**MEAN**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**
Charging Time (mins)	39.62	33.58	49.78	194.06	119	245
Daily Total Travel Distance (km)	97.01	76	116	64.45	51.8	71.1
Daily Passenger-kilometer (pkm)	145	55.8	220.5	118.71	64.1	172
Daily Earnings (PhP)	1,184.00	550.00	1,700.00	875.00	580.00	1,485.00

4.2 Parkwoods TODA

The data collection for Parkwoods TODA was done for 7 days (November 20 – 26, 2021), utilizing two (2) out of twelve (12) e-trikes of the fleet. The results follow the trend of the Payatas TODA as shown in Table 8 and Figure 13. E-trike A of Parkwoods TODA is five times faster in charging time. This shorter charging time also translates into more frequent charging which leads to higher trip distance, at more than 20km compared to e-trike B. The average daily earnings made by the e-trike A is also significantly higher. This can be explained by higher pkm of the e-trike A compared to B, implying that it has serviced more passengers than the latter.

Table 8: Parkwoods TODA charger performance comparison

METRIC	E-TRIKE A FAST CHARGING			E-TRIKE B REG CHARGING		
(units)	MEAN	MIN	MAX	MEAN	MIN	MAX
Charging Time (mins)	42.52	34.93	49.78	236.07	213.50	260.00
Daily Total Travel Distance (km)	91.50	78.40	104.80	66.74	54.40	79
Daily Passenger-kilometer (pkm)	201.3	163.1	299.90	72.49	32.30	143.00
Daily Earnings (PhP)	1,452.86	1,200.00	1,900.00	541.43	300.00	750.00



(a) (b)

Figure 13: Payatas TODA (a) Daily Travel Distance and (b) Daily Charging Time

5. ECONOMIC ANALYSIS OF EVCS

To complete the techno-economic study of the deployed EV charging infrastructure, this section investigates different case scenarios and business models using the data collected from the deployment as well as the investment cost required for the EVCS. The focus is on identifying the capital investment and operating cost, and subsequently doing a sensitivity analysis using different scenarios on the length of payback period and percentage of return on investment (ROI).

5.1 Capital Cost of Fast Charging Station

The breakdown of the cost of the system described in Section 3.3 is detailed in Table 9. The capital cost of the infrastructure is mostly attributed to equipment cost. There is a minimal cost for infrastructure and installation. For this model, the space used by the charging station is not attributed to the capital outlay, instead it is considered in the operational expenses as a rental fee.

Table 9: Capital cost breakdown of fast charging station

ITEM	QTY	ESTIMATED COSTS
Solar System DC Components Inclusions: 10 pieces 450W Solar PV Panels 6 pieces 12V 200AH Lead Acid Gel Type Battery Mounting Kits (Railings, Connectors, Clamps, PV Cable)	1 set	PhP 175,000.00
Solar System AC Components Inclusions: 1 unit 5kWp Hybrid Off-Grid Inverter	1 set	Php 200,000.00
Solar System Protection Kit and Services Inclusions: AC/DC CB, SPD, Grounding System Enclosure limiter Wifi Monitoring	1 set	PhP 35,000.00
Fast Charging Equipment	1	PhP 375,000.00
AC Charging Terminal, Dual Output	1	PhP 65,000.00
Canopy	1	PhP 50,000.00
Electrical and Wiring	1	PhP 35,000.00
Total	**PhP 935,000.00**	

The amount indicated in this section is the actual acquisition cost during the project implementation and may be subject to price changes due to the volatility of the market prices of the electronics industry worldwide. However, for the purpose of this study, the breakdown below will be the basis of the calculations for the different scenarios and business models for this section.

5.2 Return on Investment Computations

A key metric to determining the profitability of the solar charging station is to perform a sensitivity analysis on the rate of return on investment and how soon the payback period is for each of the business models. Before the actual computations, detailed in Table 10 are the different operating expenses and assumptions used to build the model.

Table 10: Summary of operating expenses and assumptions used for the model

PARAMETER	VALUE	ASSUMPTIONS AND REMARKS
Operational days per year	365	The charging station is operational all days of the year.
Operational hours	24	The station is open 24 hours a day.
Expected daily number of e-trike fast charging transactions	24	At least one e-trike can use the fast-charging equipment per hour.

Expected daily number of e-trike AC charging transactions	12	One e-trike can use the AC charger every 4 hours, two AC charging terminals installed.
Risk Factor due to possible charging station closure	0.75	Risk factor addresses the operability of the station annually, addressing the following possible concerns: a. Alert Levels and Quarantine Measures b. Number of Retrofitted E-trikes for service c. Holidays and Temporary Breaks d. Storm surges and other calamities e. Graveyard Shifts f. Charging Equipment Errors and Malfunctions It is estimated that 75% of the time, the charging station will stay operational for the whole year.
Estimated average electricity rate (general service b type) (Php/kWh)	PhP 8.57	Based on Meralco Schedule of Rates (Meralco, 2021)
Average energy consumption per full charging transaction	2.85 kWh	Average energy consumption per transaction observed based on real life usage of the charging consumption.
Expected annual operational costs on auxiliary installations (lighting, Wi-Fi, CCTV, and others)	₱5,000.00	Around 5kWh per month based on actual usage on the solar charging station.
Annual solar energy system energy production subsidy	30%	Percentage utilization assumed to be contributed by the solar PV system, based on actual energy harvested from the system for at least 6 months.
Annual charger maintenance	20%	Estimated cost of charger maintenance (percentage of capital cost) annually based on data from existing deployments. This is accounted annually after the 2-year warranty period that comes with the purchase of the chargers.
Rental cost per sqm (QC)	₱300.00	This is the assumed rental cost in Quezon City based on commercial space rates.
Minimum space needed for current setup (sqm)	25.00	Minimum of 25 sqm space for the specific number of charging equipment and operational requirements. This can be scaled up as needed.
Annual minimum wage	₱134,640	Based on rates of minimum wage in NCR (Take-Profit.Org, 2022)

These parameters are used on a case-to-case basis, depending on the scenario that is aimed to be replicated and tested. The general business model tested that was also replicated in the actual deployment of the charging station in Brgy. Payatas is what we call "captive charging" or fleet-based charging. This is a business model for charger operators wherein a fleet of EVs being operated by a certain entity, in this case the TODA, have access to a dedicated station. There were two scenarios that were investigated using the captive charging assumption, and their difference lies on how the end-user pays for the energy consumed at the charging station.

Equation 1: Return on Investment

$$ROI = \frac{Net\ Profit}{Cost\ of\ Investment}\ x\ 100$$

For the succeeding sensitivity calculations, Equation 1 was used to calculate for the rate of ROI per year of operations. This is also the method used to be able to determine the payback period or the number of years it will take to recover the initial investment cost.

5.2.1 Cost of Energy with Profit

The first scenario is operating the charging station using the captive charging business model with the end-user paying for the charging transactions based on cost of energy with enough profit margin. The assumed suggested retail price (SRP) per kWh of energy is at PhP18.00 per kWh and PhP 20.00 per kWh. Using these values, the computation for the cost of fully charging an e-trike belonging to the TODA in this study will amount to PhP 59.40 and PhP 66.00, respectively. Multiple iterations can be tested using the template depending on other details such as inclusion of the solar PV system and/or hiring of dedicated personnel to handle the operations.

Equation 2: Full charge cost calculation

$$Full\ charge = SRP\ x\ battery\ capacity$$

$$Full\ charge\ (PhP18.00) = PhP\ 18.00\ x\ 3.3kWh3 = PhP\ 59.40$$

$$Full\ charge\ (PhP20.00) = PhP\ 18.00\ x\ 3.3kWh3 = PhP\ 66.00$$

5.2.2 With Solar Installation

The base case for the cost of energy with profit margin scenario is detailed in the table below. Both types of chargers, AC terminal and DC fast charger, are present in the station with a solar PV system installed but with no personnel hired for the operations. This is possible if the TODA or entity operating the station are using a centralized monitoring system for the charging transactions which is implemented in the Environmental Building solar charging station. The entity assumes the cost of personnel needed to oversee the payment and monitoring of transactions.

Table 11: Cost of energy with profit, with solar but no personnel

FLEET TYPE:	E-TRIKE TODA
Charger Type/s:	AC Charger and Fast Charger
Payment:	Cost of Energy + Profit
w/ Solar:	Yes
w/ Personnel:	No

Using the values enumerated in the previous sections, the results of the analysis are shown in Table 12 and Table 13 for the two rates. The payback period for PhP 18.00 per kWh is at 7 years and for PhP 20.00 per kWh is at a shorter period of 5 years. For the latter, at year 10 the expected ROI is at 84%. That is at year 5, the operator has already recovered the investment cost.

Table 12: Payback period for base case of cost of energy with profit, with solar but no personnel

SRP PER KWH OF FAST CHARGER	PAYBACK PERIOD
PhP18.00 per kWh	**7 years**
PhP20.00 per kWh	**5 years**

Table 13: ROI sensitivity analysis for PhP 20.00 per kWh rate

NO. OF YEARS (PHP 20/KWH)	EXPECTED ROI
Year 5	**2%**
Year 7	**35%**
Year 10	**84%**

5.2.3 Without Solar Installation

If the TODA or operator of the charging station would opt not to install the solar PV system and instead be fully reliant on grid power, the techno-economic viability of the scenario detailed in Table 14 can also be analyzed.

Table 14: Cost of energy plus profit, no solar power

FLEET TYPE:	E-TRIKE TODA
Charger Type/s:	AC Charger and Fast Charger
Payment:	Cost of Energy + Profit
w/ Solar:	No
w/ Personnel:	No

For this case, the same payback period can be achieved at a slightly higher rate of ROI for years 5, 7 and 10 using the PhP 20.00 per kWh SRP. Instead of 84% ROI by year 10, the station can reach up to 113% if the solar provision is not installed.

Table 15: Payback period for base case of cost of energy with profit, with no solar installation

SRP PER KWH OF FAST CHARGER	PAYBACK PERIOD
PhP18.00 per kWh	**7 years**
PhP20.00 per kWh	**5 years**

Table 16: ROI sensitivity analysis for PhP 20.00 per kWh rate with no solar installation

NO. OF YEARS (PHP 20/KWH)	EXPECTED ROI
Year 5	**23%**
Year 7	**59%**
Year 10	**113%**

5.2.4 Subscription-Based

Another scenario explored in this study is the possibility of subscription-based payment for the members of the TODA. For this scenario a fast charger to e-trike ratio is added to the list of parameters and was based on the actual capacity of the charging station deployed in Brgy. Payatas. Only the fast charger is considered in the ratio, because once available, end users are more likely to use this than AC charging, and it is assumed that to be able to attract subscribers, the equipment must not be too overbooked in terms of charging transactions. Other details are described in Table 17.

Table 17: Subscription-based scenario of captive charging

FLEET TYPE:	**E-TRIKE TODA**
Charger Type/s:	Fast Charger and AC charger
Payment:	Monthly payment – subscription
w/ Solar:	Yes
w/ Personnel:	No
No. of E-Trike (per Fast Charger)	10
Number of Operational Days per Month	22

To facilitate the calculations, two monthly subscription rates were considered: at PhP150.00 daily and PhP 180.00 daily, which results in PhP 3,500.00 and PhP 4,000.00 monthly subscription fee. These rates were validated with the end users in terms of their monthly charging fees using conventional charging which can go as high as PhP3,000.00 monthly. The premium fee for fast charging is considered in the rates for computation.

The resulting computations show that using the subscription-based payment coupled with solar installation, the payback period for PhP 3,500.00 and PhP 4,000.00 monthly fee is at 7 years and 5 years, respectively. The expected ROI for the latter at year 10 is 86%. These are shown in Table 18 and Table 19. The slight increase in rate of ROI is due to the possibility that end users may not fully charge their units every single charging transaction. Thus, what the subscription-based payment system ensures is that the fleet is being billed more than the energy being consumed every month, as opposed to billing them per charging transaction.

Table 18: Payback period for subscription based with solar installation

MONTHLY SUBSCRIPTION	**PAYBACK PERIOD**
PhP 3,500.00	7 years
PhP 4,000.00	5 years

Table 19: ROI sensitivity analysis for PhP 4,000.00 monthly subscription with solar installation

NO. OF YEARS (PHP 4,000.00)	EXPECTED ROI
Year 5	**3%**
Year 7	**36%**
Year 10	**86%**

Table 20: Subscription based captive charging without solar installation

FLEET TYPE:	E-TRIKE TODA
Charger Type/s:	Fast Charger and AC charger
Payment:	Monthly payment - subscription
w/ Solar:	No
w/ Personnel:	No
No. of E-Trike (per Fast Charger)	10
Number of Operational Days per Month	22

Another possible scenario is excluding the solar installation in a subscription-based captive charging business model as shown in

Table 20. By eliminating the investment cost of the solar PV system, the payback period of the station went down to 3 years should the monthly subscription fee be billed at PhP 4,000.00 for end users. Sensitivity analysis in Table 22 also shows more income generation at year 10 for this kind of model.

Table 21: Payback period for subscription based with no solar installation

MONTHLY SUBSCRIPTION	PAYBACK PERIOD
PhP 3,500.00	**5 years**
PhP 4,000.00	**3 years**

Table 22: ROI sensitivity analysis for PhP 4,000.00 monthly subscription with no solar installation

NO. OF YEARS (PHP 4,000.00)	EXPECTED ROI
Year 3	**25%**
Year 7	**62%**
Year 10	**117%**

5.3 Summary of Scenarios

A summary of the different scenarios calculated using the methodology of this paper is summarized in Table 23. All the scenarios used a captive charging model but differed in infrastructure inclusion as well as in payment strategy. Out of the four sub-scenarios computed, the subscription-based without solar installation is the most profitable option, while the per-transaction billing with solar installation is the least profitable one. The template used in this paper is not limited to computing only the ones presented but can also be applied to different business models and different nuances of operations that may be applicable to the local Philippine setting.

Table 23: Summary of payback period and ROI of captive charging business model

SCENARIO	KEY ASSUMPTIONS	PAYBACK PERIOD	ROI AT YEAR 10
Cost of Energy + Profit With Solar	Cost of Energy + Profit PhP 20.00 per kWh for Fast PhP 12.00 per kWh for AC	5 Years (2%)	84%
Cost of Energy + Profit Without Solar	Cost of Energy + Profit PhP 20.00 per kWh PhP 12.00 per kWh for AC	5 Years (23%)	113%
Subscription-based with Solar	PhP 4,000.00 per month	5 Years (3%)	86%
Subscription-based Without Solar	PhP 4,000.00 per month	3 Years (25%)	117%

6. CONCLUSIONS

The results presented in Section 5 and 6 were able to highlight both technical and economical aspects of operating a solar fast charging station locally for the use of public utility e-trikes.

For the technical performance of the deployed EVCS, actual benefits of using an appropriate mode of charging relative to the operational requirements were observed, in this case using mode 4 DC fast charging over AC charging. The survey data from simultaneous operations of two e-trikes using the station and the other using the conventional charging, showed the increase in opportunity for operations if the four hours of charging is shortened to less than one hour, which consequently increased the income generation of the end-users.

In the economic analysis, the operational variables and necessary assumptions were identified to be able to model different business cases for the EVCS. Possible disruptions to the operations of the EVCS such as maintenance activities, calamities due to storms and flooding, quarantine measures, and holidays were considered and included in the computations. It was highlighted that different nuances of implementation are relevant to the overall feasibility of the station, such as the presence of renewable energy sources and mode of payment, and these affect the metrics of evaluation, namely the payback period and rate of return of investment. Although the scenarios presented in the results are specific to the scope presented, the template developed during the study can be used as an initial evaluation tool for future charging station projects.

The process used in the data gathering was also detailed and presented in this paper. This methodology can be used and replicated on different localities around the country, to be able to determine the operational behavior and charging requirements of different EV deployments. In future, green routes and other government-sanctioned regulations for the EV industry can be incorporated in the study. This will make the recommendations more wholistic and more tied to the sustainability efforts and projects being implemented by the government.

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