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Research paper

PV-Assisted Charging for Electric Three-Wheelers in Sri Lanka: A Comparative TCO and Sensitivity Analysis

Nuwanthi Abeygunawardena [a,*], **Thanushika Jathunga** [a], **Moksha Rodrigo** [a]

[a] *Department of Electrical and Electronic Engineering, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka*

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ABSTRACT

This research explores the potential of solar-powered electric three-wheelers as a sustainable and cost-effective transportation solution in Sri Lanka. Traditional three-wheelers contribute to air pollution and fuel dependency, while electric three-wheelers offer a cleaner alternative. By integrating solar power, these vehicles can further reduce emissions and operational costs. The study examines the economic benefits of three types of three-wheelers, covering fuel-based, electric, and solar-powered electric three-wheeler categories. Survey-based findings are used to calculate the total cost of ownership of tuk-tuks. Fuel and electricity costs, operational and maintenance costs, and more parameters are incorporated for the study. The findings suggest that solar-powered electric three-wheelers offer a promising solution for sustainable transportation solutions for the Sri Lankan context.

1. INTRODUCTION

The traditional three-wheeler or the fuel-powered three-wheeler, commonly known as a rickshaw or tuk-tuk, has been a significant mode of transportation in many developing countries, including Sri Lanka, for decades. These compact vehicles are designed to provide an affordable, efficient, and convenient means of transport, especially in densely populated urban areas where traffic congestion is common. Their ability to navigate narrow lanes has made them popular among locals and tourists alike. The

* *Corresponding author, E-mail address: nuwanthiabey9@gmail.com*

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modern three-wheelers emerged in the mid-20th century, primarily in Asian countries like India, Bangladesh, and Sri Lanka (TukTukPH, n.d.).

Earlier models were powered by two-stroke gasoline engines, but now the advancements have led to the use of more efficient four-stroke engines with fuel injection systems to improve fuel efficiency. As demand for affordable transportation grew, three-wheelers became widely adopted, playing a crucial role in the transportation sector. According to the records by the Department of Motor Traffic (DMT) Sri Lanka, over 1.1 million three-wheelers are currently registered in the country. Figure 1 shows the new registrations of three-wheelers over the years.

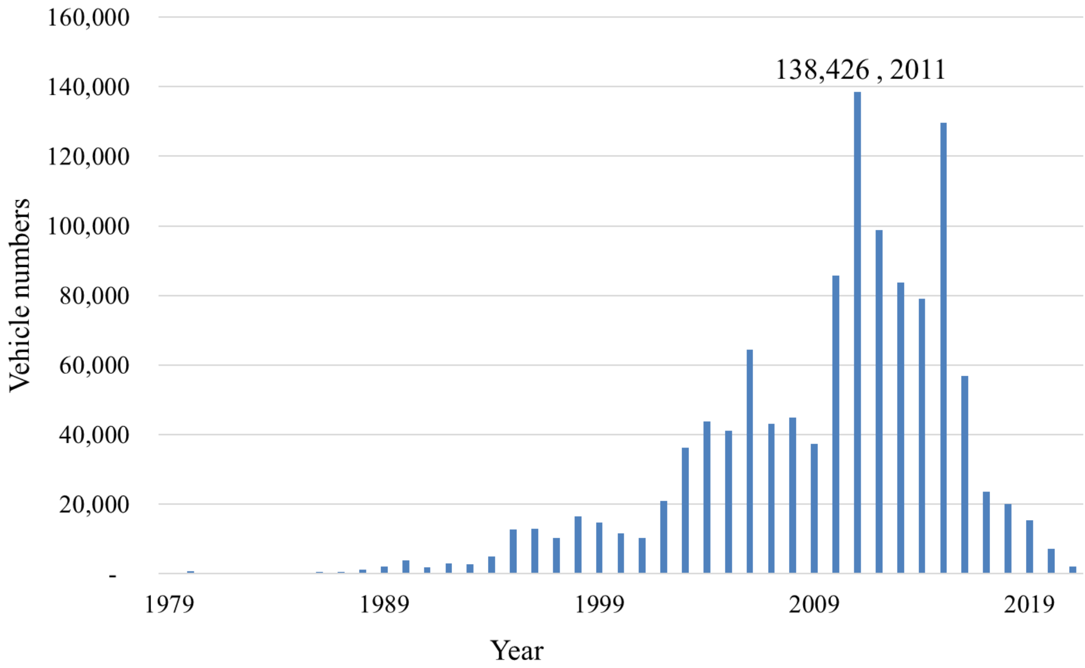

Fig 1. Three-wheel registrations over the years

Recently, there has been a noticeable shift in the transportation industry towards electrification, driven by technological advancements and the growing need for cost-effective alternatives to traditional fuel-powered vehicles.

Electric three-wheelers are becoming increasingly popular as a cleaner and more efficient alternative to traditional fuel-powered tuk-tuks. These electric three-wheelers are designed to operate using battery-powered electric motors, eliminating the need for conventional fuels such as petrol, diesel, or compressed natural gas. This shift offers several benefits, including reduced emissions and lower operating costs.

While electric three-wheelers offer significant environmental benefits, integrating solar power can further enhance their sustainability. By harnessing solar energy, which is freely available, electric three-wheelers can reduce their reliance on the grid and minimize carbon emissions. This integration of renewable energy reduces the demand for grid electricity and minimizes the environmental impacts.

This paper examines the economic feasibility of three types of three-wheelers: fuel-powered, electric, and solar-powered electric. The study evaluates the daily operational costs of each vehicle type, considering factors such as fuel consumption, electricity usage, and solar efficiency. Additionally, the paper calculates and compares the Total Cost of Ownership (TCO) for each type of three-wheeler, taking into account purchase price, maintenance, and long-term operational expenses. By comparing the three models, the study aims to provide a comprehensive analysis of their economic viability, offering insights into which type of three-wheeler may be the most cost-effective and efficient for transport applications in the Sri Lankan context.

2. LITERATURE REVIEW

In many South Asian countries, three-wheelers, sometimes referred to as tuk-tuks, are the primary mode of urban and semi-urban transportation (Herath Bandara & Thilakarathne, 2025). Their cost, ease of navigation through congested roadways, and suitability for short distance transport are the main motives for their widespread use. Despite these benefits, there are significant environmental and energy related concerns due to the substantial dependence on traditional fuel-powered three-wheelers (Bhutani et al., 2025).

A majority of the existing three-wheelers use small internal combustion engines (IECs), which are inefficient and highly polluting. Previous studies show that three-wheelers contribute to urban air pollution, emitting significant levels of particulate matter (PM), carbon monoxide (CO), and nitrogen oxides (NO_x), specifically in urban areas (Adikaram & Arambepola, 2024). These emissions are further intensified in developing countries, where vehicle emission regulations, inspection mechanisms, and routine maintenance practices are often limited or poorly enforced (Yedla,2015).

Meanwhile, Sri Lanka's transportation sector remains dependent on imported fossil fuels, leaving the national economy highly vulnerable to fuel price fluctuations and supply shortages. The recent economic crisis and recurring fuel shortages have exposed the instability of the existing transportation system, emphasizing the urgent need for alternative solutions (Senarath et al., 2024). Accordingly, minimizing fuel dependency while promoting environmental sustainability has emerged as a key research priority within Sri Lanka's transportation sector (Caldera et al., 2023).

Electric three-wheelers have been identified as a cleaner alternative to conventional fuel-based tuk-tuks (Pushpam et al.,2025). Several research studies have indicated that electric three-wheelers provide significant reductions in air pollution, noise pollution, and operational costs compared to traditional tuk-tuks (Uprety et al., 2019). From an economic perspective, previous studies reveal that electric tuk-tuks have reduced maintenance expenses because of fewer moving parts and the absence of complex engine mechanisms (Yiangkamolsing et al., 2019). However, the higher battery cost and charging infrastructure remain a key concern, which limits the widespread adoption of electric tuk tuks (Thananusak et al., 2020).

The integration of solar photovoltaic (PV) systems with electric vehicles has been explored as a solution to further reduce the operational costs and environmental impacts. Solar-powered electric vehicles can either use onboard PV panels to charge batteries directly or rely on solar-assisted charging stations (Bokopane et al., 2015). While the limited surface area of vehicles restricts the total power that can be harvested, previous studies demonstrate that solar integration can extend driving range and reduce long-term energy expenses, particularly in regions with high solar irradiance (Li et al. 2025). Previous studies have shown that solar-integrated electric vehicles are particularly effective in tropical countries like Sri Lanka, making solar-powered electric three-wheelers a technically feasible solution (Bimenyimana E., 2020).

In the context of tuk tuks, total cost of ownership (TCO) analysis has been employed to identify practical operational patterns, including daily travel distances, fuel or electricity consumption, and maintenance routines. Majority of the existing studies, primarily focus on comparing fuel-based and electric models, with limited consideration given to solar-powered electric tuk tuks as a separate category (Haldar et al., 2025). To address this gap, this study presents a comparative Total Cost of Ownership (TCO) analysis of fuel-based, electric, and solar-assisted electric three-wheelers in the Sri Lankan context.

While this study does not examine battery performance under varying weather conditions, previous studies reveal that factors such as temperature, humidity, and rainfall can significantly affect battery efficiency, degradation, and solar charging performance (Rahman et al., 2024; Zhang et al., 2022). Incorporating weather-dependent battery performance in future studies would improve the robustness of techno-economic analyses and offer a more comprehensive understanding of solar-powered electric tuk tuks in tropical climates.

Overall, this study contributes to the literature by offering techno-economic perceptions into solar-assisted electric tuk tuks, emphasizing their feasibility, and identifying directions for future research.

3. METHODOLOGY

The study focuses on two key aspects. Regarding daily operational cost, a traditional three-wheeler, an electric, and solar-powered electric three wheelers are considered, and the cost per day to complete the daily distance target is calculated. Secondly, the TCO of the three three-wheeler types is calculated and analyzed. Initially, a survey was conducted to identify the driving patterns of the traditional three-wheeler drivers in Colombo, Sri Lanka, who hire out for employment. Around 50 drivers participated in the survey. The type of the three-wheeler, distance covered per day, purchase cost, fuel efficiency, insurance and maintenance cost, and other details were requested in the survey. The selection of the three-wheeler type for the category is as follows.

3.1 Traditional three-wheeler

For this type, a fully fuel-driven three-wheeler is considered. By the survey, a higher availability of Bajaj Twin Spark, 4-stroke DTSi was found, thus it was considered for the analysis. The specifications of the vehicle found on the official website are given in Table 1 (Bajaj Auto. RE 4S Petrol three-wheeler).

Table 1. Bajaj Twin Spark 4-Stroke DTSI specifications

Parameters	**Values**
Max. Power LPG	8.5 kW @ 6000 RPM
Max. Torque LPG	15.2 Nm @ 4250 RPM
Dimensions	2635 × 1300 × 1710 mm
Kerb Weight	337 kg
Average Fuel Consumption	25 km/l

3.2 Electric three-wheeler

It was found from (Rajasuriya et al., 2024) that Bajaj RE E-Tec 9.0, which is manufactured in India, has the optimum Energy Utilization Factor (EUF) when compared to electric three-wheelers introduced by Piaggio and Mahindra models. Thus, the Bajaj RE E-Tec 9.0 was selected for the analysis, and its specifications were collected from the official website, as shown in Table 2 (Bajaj Auto Three-wheeler RE E-TEC 9.0). As this is the same brand as the traditional three-wheeler considered, it was expected to obtain better results from the comparison of the analysis.

3.3 Solar-powered electric three-wheeler

For the third type of vehicle, the same electric three-wheeler (Bajaj RE E-Tec 9.0) was considered, with a roof-mounted solar panel. By considering the vehicle capacity and other factors, the Jinko 350W Tiger N-Type All Black Mono-crystalline panel (JKM350N-6TL3-B) was considered for the analysis. The solar panel specifications are mentioned in Table 3 (Plugin Solar, n.d.).

Table 2. Bajaj Re E-Tec 9.0 specifications

Parameters	**Values**
Battery	8.9 kWh
Range on full charge	178 km
Battery Type	Li-ion
Max. Power	4.5 kW
Max. Torque	36 Nm
Kerb Weight	362 kg

Table 3. Solar panel specifications

Parameters	**Values**
Type	JKM350N-6TL3-B
Peak Power Wp	350 W
Weight	19 kg
Dimensions	1692 × 1029 × 30 mm
Max Open Circuit Voltage (Voc)	41.04 V
Max Short Circuit Current (Isc)	10.84 A

To interface the roof-mounted PV module with the battery system, a Maximum Power Point Tracking (MPPT) based DC–DC solar charge controller was considered. MPPT controllers are widely adopted in solar-powered electric vehicles as they are capable of maximizing the energy extraction under variable irradiance and temperature conditions (Ezeagu et al., 2024).

According to the electrical characteristics of the selected 350 W solar panel, which has a maximum open-circuit voltage of 41.04 V and a short-circuit current of 10.84 A, an MPPT charge controller capable of handling PV input voltages above 60 V and currents exceeding 15 A was considered. Such specifications provide adequate operational margin and are consistent with configurations reported in previous studies on solar powered electric tuk tuks (Scheurer et al., 2012).

To calculate the daily solar harvest using the selected solar panel, the PV potential in Colombo was obtained from the latest report issued by the Sri Lanka Sustainable Energy Authority (SEA), which indicates a value of 1447 kWh/kW/year. This value inherently captures typical weather variability, including cloudy and partially cloudy conditions, as it is based on multi-year irradiance data. To account for additional real-world losses such as cloud cover, shading, dust, and temperature effects, a conservative loss factor of 10% was applied to the theoretical PV generation. During periods of insufficient solar generation, the electric three-wheeler is assumed to supplement the remaining energy demand through grid charging.

Based on the values, the study estimated the distance that can be covered using the solar energy harvested. For any remaining distance beyond what solar power can support, the electric three-wheeler would need to charge from a charging station.

Different charging options, including DC fast charging, Level 2 AC charging, and domestic charging, were evaluated under time-of-use (TOU) tariff periods (day, peak, and off-peak) to illustrate the variation in charging cost. These tariff rates were obtained from the Public Utilities Commission of Sri Lanka (PUCSL, 2024). For the total cost of ownership (TCO) analysis, a single base-case charging scenario was selected to ensure consistency. DC fast charging during the peak tariff period (18:30–22:30 hrs) was selected as the base-case charging scenario, representing a conservative assumption for commercial operation.

Table 4: Charging cost based on different tariff rates

Tariff Category	Time of Use	Unit cost (USD / kWh)
DC Fast Charging	Day (05:30–18:30 hrs)	0.29
	Peak (18:30–22:30 hrs)	0.38
	Off-peak (22:30–05:30 hrs)	0.18
Level 2 AC Charging	Day (05:30–18:30 hrs)	0.24
	Peak (18:30–22:30 hrs)	0.31
	Off-peak (22:30–05:30 hrs)	0.14
Domestic Tariff	Day (05:30–18:30 hrs)	0.19
	Peak (18:30–22:30 hrs)	0.24
	Off-peak (22:30–05:30 hrs)	0.09

3.4 Total cost of ownership

This section utilizes a similar model to those employed in previous studies (Riyanto et al., 2019; Patel et al., 2022) for calculating the total cost of ownership (TCO) and is outlined by Equation (1):

$$TCO = P + \sum_{t=1}^{N} C_t \,(1 + r)^{-t} - R\,(1 + r)^{-N} \qquad (1)$$

where P is the initial purchase cost, C_t is the annual operating and maintenance costs in the year t, R is the resale value at the end of the vehicle's lifetime, r is the discount rate, and N is the service life of the vehicle. All future costs and the resale value are discounted to present value terms.

The initial purchase price (P) includes the purchase price as a one-time cost incurred at the beginning of the vehicle’s lifespan. The purchase price and fuel costs for the study were considered from the year 2020, as the prices drastically started to change from 2020 onwards due to IMF intervention.

Resale value (R) / salvage income refers to the projected price at which a three-wheeler can be sold at the end of its useful life where the study considered a period of 5 years from the purchasing year. Salvage income is a crucial factor in the TCO calculation as it represents a potential recovery of the initial investment. Operational costs encompass fuel or electricity consumption, insurance costs, and other miscellaneous fees. Maintenance costs include engine and vehicle component maintenance, electric component maintenance for electric three-wheelers, and equipment maintenance. Together, these values are given by C_t. C_t includes electricity charging costs calculated using the selected base-case charging tariff.

The discount factor (r) is a crucial tool in economic calculations as it allows us to convert future values into their present value. By considering the Sri Lankan economy, a discount rate of 10% per year was applied. All future operating and maintenance costs, as well as the resale value at the end of the vehicle's lifetime, are discounted to present value terms using the discount rate. In other words, by this, the model incorporates the time value of money into the analysis. A sensitivity analysis was later performed by varying the discount rate to assess the robustness of the results under different economic conditions.

The life span (N) was considered as 5 years for the analysis due to the average lifetime of a three-wheeler from the literature review.

Depreciation is implicitly accounted for through the difference between the initial purchase cost and the discounted resale value of the vehicle at the end of its service life. Capital recovery is therefore represented by the net present value of the investment over the assumed lifetime.

By considering these factors, a comprehensive analysis of the economic viability of the three types of three-wheeler technologies was conducted. Here, the costs for the solar-powered electric three-wheeler are given assuming the additional costs (Jinko 350W Solar Panel, MPPT Charge Controller, mounting structure and wiring, and installation costs) when integrating the solar PV system to the Bajaj RE E-Tec 9.0.

4. RESULTS

This section presents the findings of the study, including charging cost to cover daily targets by three-wheelers, daily solar harvest by the solar-powered electric three-wheeler, and the total cost of ownership for selected three-wheeler models, focusing on electric and solar-powered options. 100 km is considered the daily target distance of the three-wheeler.

4.1 Bajaj Twin Spark, 4 - stroke DTSdi

From the data collected by the survey, the fuel cost per day was calculated. By considering the average fuel efficiency from the survey results as 25 km/l, 4 liters are required to complete the daily target of a rickshaw driver. By considering the unit fuel cost as $1.1, it was calculated that $4.2 is required by a three-wheeler to cover the estimated distance in a day in Colombo.

4.2 Solar panel requirement

It was found from the Sri Lanka Sustainable Energy Authority (SEA) that the PV potential in Colombo is 1447kWh / kW/ year (World Bank, n.d.). Thus, a calculation was carried out to find the PV potential per panel per day. Since the selected panel capacity is 350W, the PV potential per selected panel per year was obtained as 506.45 kWh/ year. However, due to shading, cloud cover, dust accumulation, and temperature effects, it is assumed that 10% of the theoretical PV generation is lost. Therefore, by considering the lost factor, 405.16 kWh / year was calculated as the PV panel generation per year. To consider the daily harvest, the value was divided by the number of days in the year, resulting in 1.1 kWh generation per day.

4.3 Bajaj RE E-Tec 9.0 with and without solar power

Bajaj RE E-Tec 9.0 was considered for the study was with a capacity of an 8.9 kWh battery. However, from the literature review, the efficiency was only found to be 80% of the actual capacity. Therefore, for the calculation, the battery capacity was considered as 7.12 kWh. Further, the specifications mentioned that the maximum distance possible with the full charge is 178 km. However, due to the 80% battery efficiency, the travel distance possible value was reduced to 137 km. As the requirement of the three-wheeler is only to cover 100km, the battery requirement was thus found to be 6.25 kWh.

It was calculated before that the solar harvest per day by the panel is 1.1 kWh, whereas the battery capacity will be 6.25 kWh. This shows that a lack of 5.14 kWh is required to power the travel distance. In other words, 22 km is possible to travel by the solar PV generation in a day, and the remaining 78 km to complete the daily target (100 km) by the driver should be sourced by the electric charging. If the three-wheeler is not running, the solar energy generated will be stored in the battery and will be used later.

With the updated tariff rates issued by PUCSL, the bar chart in Figure 2 displays the charging costs in USD for an electric vehicle, to cover 5.14 kWh under different charging scenarios: DC Fast Charging, Level 2 AC Charging, and Domestic Charging, each broken down into three time slots which are daytime (05:30-18:30 hours), peak hours (18:30-22:30 hours), and off-peak hours (22:30-05:30 hours). The cost in USD is obtained by multiplying each TOU tariff rate (LKR/kWh) by 5.14 kWh and converting the resulting cost from LKR to USD.

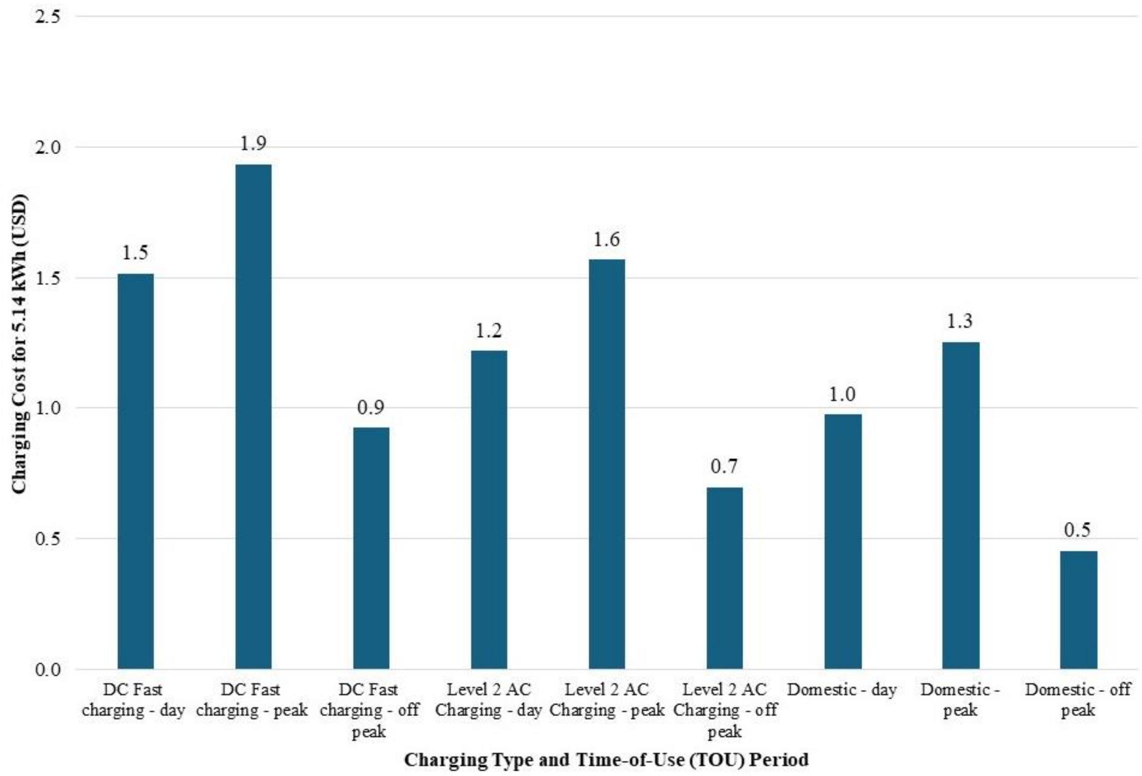

Fig 2. Cost to charge 5.14 kWh from different charging tariff categories with TOU

The data illustrates significant cost variations based on both the charging type and the time of day. Notably, DC fast charging during peak hours (18:30-22:30 hours) incurs the highest cost, being $1.8, making it the least economical option. This is likely due to higher electricity tariffs during peak times, combined with the premium rates associated with fast charging infrastructure. In contrast, the cost drops considerably during off-peak hours for DC fast charging, though it remains higher than other charging methods during the same time slot. For Level 2 AC charging, peak hour costs are only slightly less than $0.3 those of DC fast charging, while off-peak hours offer a more economical solution, making it a viable option for users seeking a balance between charging speed and cost.

Domestic charging stands out as the most cost-effective option across all time slots. Even during peak hours, the cost remains lower than both DC fast and Level 2 AC charging. Off-peak domestic charging is the best economically, with only $0.4, indicating that users who can charge their vehicles overnight can achieve substantial savings. The third-party charging stations are not considered for the study due to their varying charging nature. For cost-conscious users, especially fleet operators, scheduling charging during off-peak hours using domestic or Level 2 AC charging systems could result in significant cost reductions. However, for scenarios requiring quick turnaround times, DC fast charging, despite its higher cost, may still be preferable due to its speed.

Among the charging options presented in Figure 2, the DC fast charging peak tariff was adopted for the base-case TCO calculation.

When considering the electric three-wheeler, the charging cost (DC fast charging at peak time) per day was found to be $2.35. For the solar-powered electric three-wheeler, as 1.11 kWh is covered by the generated solar power, only the remaining 5.14 kWh is required to be charged by the charging station. When calculated assuming the tuk-tuk is charged at a DC fast charging station during peak time, $1.94 was calculated as the required cost to travel in one day.

4.5 Results of the total cost of ownership

From the survey conducted and literature review, the input parameters of the TCO model are shown in Table 4.

Table 4. TCO model inputs (all costs are in USD)

	Traditional tuk-tuk	**Electric tuk-tuk**	**Solar-electric tuk-tuk**
Purchase price P (USD)	3,389.80	3,940.90	4,279.80
Resale/salvage value R (USD)	1,525.40	1,773.40	1,925.90
Annual energy cost (fuel/electricity) (USD)	1,539.20	858.4	705.9
Annual maintenance cost (USD)	67.8	84.7	101.7
Annual insurance cost (USD)	57.6	61.2	67.8
Life time N	5 years	5 years	5 years
Discount rate r	10%	10%	10%

At the time of study, one USD was equivalent to LKR 295; all values are based on that rate. The fuel cost was considered as LKR 311 at the time of the study. When calculating the salvage cost, a fixed depreciation rate was considered from the literature review. According to (Riyanto et al., 2019) and (Saha et al., 2020), a depreciation of 45% of the initial cost was considered.

For the solar-powered electric three-wheeler, these costs were adjusted to account for the additional expenses associated with the solar PV setup in the Bajaj RE E-Tec 9.0. Additionally, when calculating the charging cost, the peak rate for DC fast charging was considered, as the Bajaj RE E-Tec 9.0 is compatible with DC fast charging.

Before calculating the TCO, the annual costs for maintenance, insurance, and fuel/electricity were determined from the survey results and are given in Figure 3. Table 5 demonstrates the Present Value (PV) of annual costs (Ct) and resale value (PV of R).

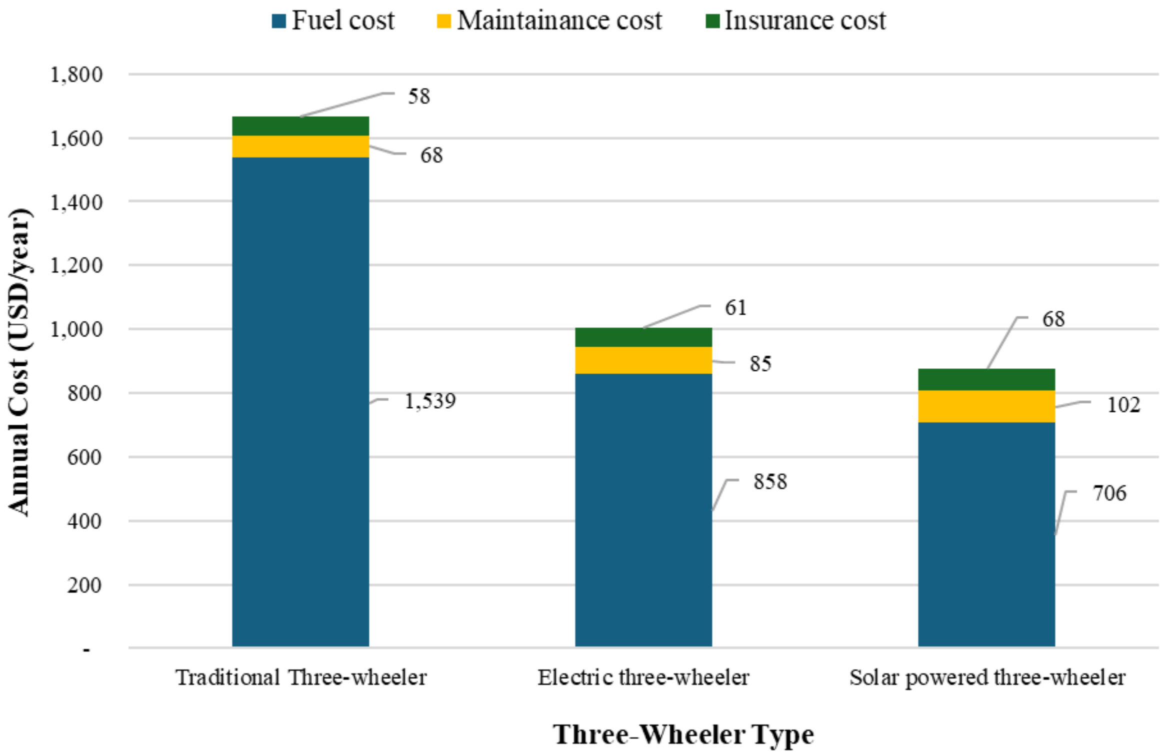

Fig 3. Comparison of annual expenses of three-wheelers

Table 5. Present value of operating costs and resale value for three-wheeler types

	Fuel-based tuk-tuk	Electric tuk-tuk	Solar powered tuk-tuk
PV of Ct	6,310.2	3,806.4	3,318.5
PV of R	(947.2)	(1,101.1)	(1,195.8)

By using the values found above and from Equation 1, the TCO calculation for the traditional three-wheeler, electric three-wheeler with and without solar power was conducted and is as Table 6. From the results, the solar-powered electric three-wheeler emerges as the most cost-effective option, followed by the fully electric version, with the fuel-powered model having the highest overall costs.

Table 6. Total cost of ownership (5 years)

Traditional tuk-tuk	Electric tuk-tuk	Solar-electric tuk-tuk
$8,752	$6,646	$6,402

5. DISCUSSION

5.1 Interpretation of Key Results

In the aim of finding the most economical three-wheeler to be used in the Sri Lankan context, the analysis was conducted between traditional, electric, and solar-powered three-wheelers. Overall, the solar powered tuk-tuk was found to be the most economical vehicle option out of all with only having $6,402 value as the TCO. The electric tuk-tuk comes as the second-best option with $6,646, while the fuel powered tuk-tuk owns the highest TCO of $8,752.

When considering the annual cost of the vehicles (maintenance, insurance, and fuel/electricity costs), it was noted that $1,664 was calculated for the traditional three-wheelers, in which most of the contribution is from the fuel cost. This confirms that the fuel cost factor is a major factor influencing the annual cost of the vehicle. This can lead to significant long-term expenses as fuel price has a trend to increase further with the IMF interventions. These changes may impact the profitability of using fuel-based vehicles as a medium for passenger transportation. Electric vehicles, on the other hand, were calculated to own $1,004 as the annual cost, followed by solar-powered electric three-wheelers at USD 875. Maintenance costs found to be higher in solar-integrated tuk-tuk, due to additional upkeep of solar components.

When considering the TCO results, the long-term financial benefits of investing in electric and solar-powered vehicles, rather than traditional three-wheeler vehicles, are significant. The solar-powered electric three-wheeler achieves a lower TCO primarily due to reduced charging costs, as it can partially utilize solar energy. This is particularly advantageous in Sri Lanka, where ample sunlight throughout the year can significantly offset electricity costs, reducing dependence on the grid.

When considering the environmental perspective, the fuel-powered three-wheelers generate significant emissions, contributing to air pollution and resulting in increasing Sri Lanka’s carbon footprint. The electric and solar-powered models are expected to produce zero tailpipe emissions; however, technically, there is a low percentage of emissions coming from them too, but that is very less when compared to that of traditional three-wheelers. Therefore, from an environmental perspective, the shift towards electric and solar-powered three-wheeler is important for reducing greenhouse gas emissions, improving urban air quality, and as well as for lowering the transportation sector’s overall carbon footprint.

Given these factors, the solar-powered electric three-wheeler is particularly well-suited for Sri Lanka. It provides a balance of lower operating costs and reduced emissions, making it both a financially and environmentally sustainable option. Even though the initial investment is high, with proper government support, people will tend to purchase solar-powered e-three-wheelers. As the country continues to face inflationary pressures, especially in fuel prices, investing in solar-powered and fully electric three-wheelers offers long-term economic resilience while contributing to cleaner air and reduced carbon emissions.

5.2 Impact of Charging Strategy and Energy Assumptions

All three vehicles were assumed to remain at an average performance level over the analysis period. Battery degradation and gradual performance may increase energy consumption and maintenance costs over time in real case. However, the study uses conservative assumptions on usable battery capacity and maintenance costs. The impact of usage intensity is partially examined through sensitivity analysis on daily travel distance.

Although multiple charging types and TOU periods are presented for comparison, a conservative base-case charging scenario (DC fast charging during peak hours) was used for the TCO calculation to ensure consistency across vehicle types.

5.3 Sensitivity Analysis

For the study, a 10% discount rate was applied when calculating the TCO by considering the Sri Lankan economy. However, a sensitivity analysis was conducted to identify the effect of the discount rate on the TCO. Figure 4 shows the changes in TCO of the base case interest rate of 10%, with 5% and 15%. It showed that with a higher interest rate, the TCO drastically decreases, implying that the interest rate of a country is a significant factor when deciding the economic viability of the three-wheeler.

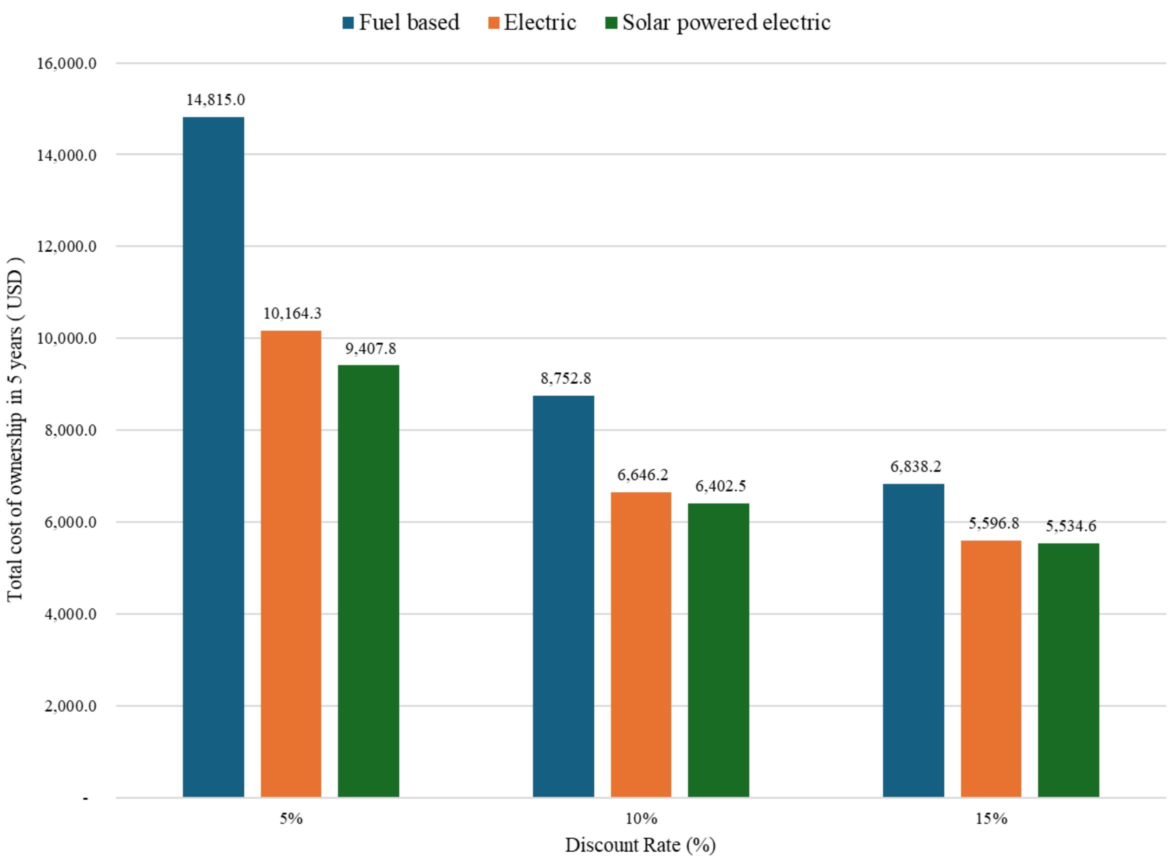

Fig 4. Impact of interest rate on the total cost of ownership for three-wheeler types

The model was further tested to determine the impact on TCO when the distance travelled is varied. Along with the base case distance at 100km, the model was tested for 80 km and 120 km as daily travel distances. The results shown by Figure 5 confirm that higher distance targets lead to a proportional increase in TCO over the 5 years. In fact, the fuel-based tuk-tuk still appears to be the vehicle with the highest TCO value.

5.4 Assumptions and Limitations of the Study

There were several important assumptions made when conducting this analysis. When considering the solar-powered three-wheeler, it is assumed that the photovoltaic (PV) panel is roof-mounted on the vehicle. Further, the solar PV system is designed to partially offset the daily energy requirement, while any remaining energy shortfall (5.14 kWh/day in the base case) is assumed to be supplied through grid charging. Although different charging tariffs are evaluated, a single base-case charging scenario is used in the total cost of ownership (TCO) analysis (DC fast charging during peak hours). Therefore, charging costs may vary under alternative tariff structures.

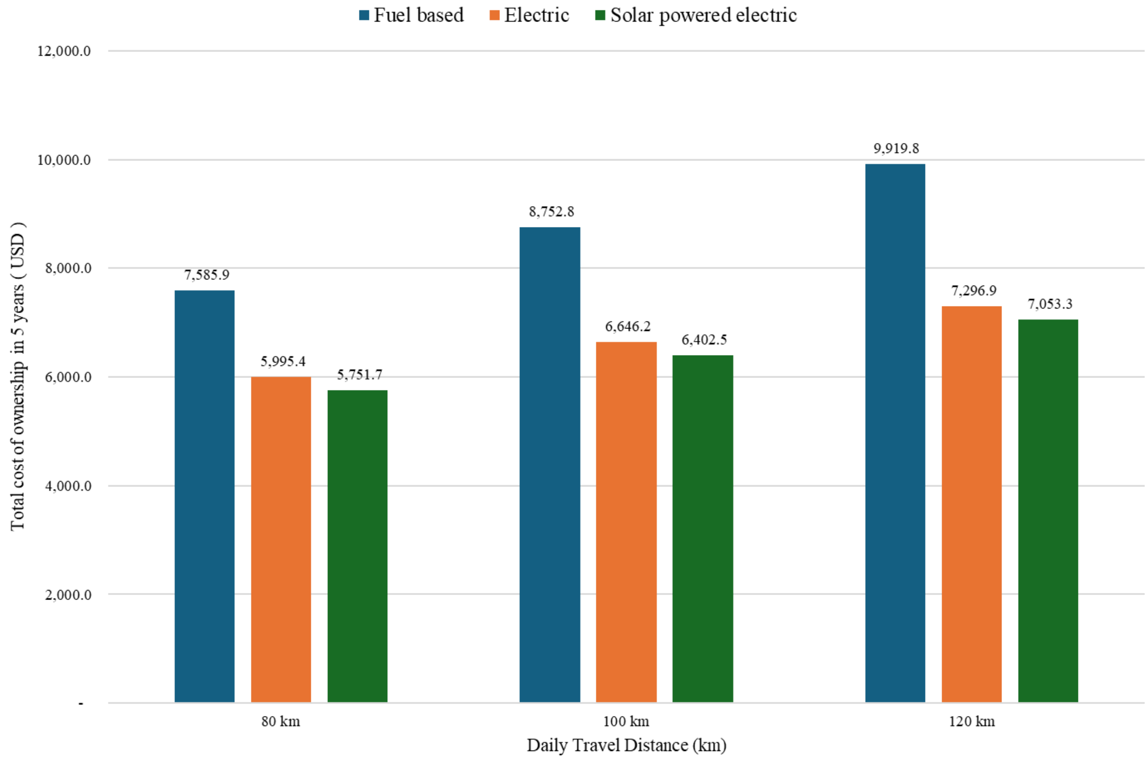

Fig 5. TCO comparison of three-wheeler types for different daily travel targets

Solar energy generation is estimated using long-term average PV potential data, rather than short-term or hourly weather data. To account for shading, cloud cover, dust accumulation, temperature effects, and other real-world inefficiencies, a 10% loss factor was considered when doing calculations. The analysis is geographically limited to Colombo, the capital city of Sri Lanka. As solar irradiance varies across different regions of the country, the daily solar harvest and corresponding charging requirements may differ outside this study area.

In terms of technical performance, the usable battery capacity is assumed to be 80% of the nominal capacity, based on values reported in the literature and survey. However, battery degradation and gradual performance deterioration over time are not explicitly modeled, which may influence long-term energy consumption and maintenance costs, particularly for electric and solar-powered three-wheelers.

Regarding economic parameters, fuel prices, electricity tariffs, component costs, and maintenance costs are assumed to remain constant over the five-year analysis period. A discount rate of 10% is applied in the TCO calculations to account for the time value of money. While these assumptions provide a consistent basis for comparison, variations in market conditions, policy changes, or tax structures (e.g., CIF-based pricing) could lead to deviations in actual costs.

Finally, the scope of this study is limited to techno-economic analysis. A detailed life-cycle environmental assessment (LCA), including battery manufacturing, recycling, and upstream electricity emissions, is not included and is identified as an area for future research.

6. CONCLUSION

The research highlights the economic advantages of transitioning to solar-powered and fully electric three-wheelers in Sri Lanka. By evaluating the fuel costs, solar potential, and total cost of ownership for various three-wheeler models, the study demonstrates that solar-powered electric vehicles are the most cost-effective solution. This is particularly relevant given the rising fuel prices and inflation in any country. The integration of solar panels reduces grid dependency, significantly lowering operational expenses while also contributing to cleaner air and reduced carbon emissions. The analysis of charging costs under different scenarios indicates that domestic and off-peak charging are the most economical options, offering considerable savings for cost-sensitive users and fleet operators. While DC fast charging provides quicker turnaround times, it comes at a higher cost, especially during peak hours, making it less ideal for regular use. Adopting electric and solar-powered three-wheelers provides a sustainable solution that aligns with Sri Lanka's environmental goals. This shift not only helps reduce the transportation sector's carbon footprint but also ensures long-term economic benefits. As the country continues to face challenges related to energy costs and climate change, investing in solar-powered transportation can be a key strategy for achieving both economic resilience and sustainability.

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AUTHORS CONTRIBUTION

All authors contributed equally to this review.

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