# Payback Period and Life Cycle Emissions of a Commercial Solar Carport with a Virtual Case Study

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**Abstract.** The solar carport is a significant technology-oriented infrastructural concept for facilitating electric vehicle charging stations (EVCS). The EVCS predominantly utilise the onsite solar photovoltaic energy for the charging of EVs. Moreover, EVCS can act as multipurpose CS to enable Grid to Vehicle (G2V) and Vehicle to Grid(V2G). Photovoltaic Electric vehicle charging station (PEVCS) can feed both EVs, traditional consumer loads, and can also feed power to the grid. Thus, enabling PEVCs across the various organisations and institutions can meet the local as well as dynamic demands incurred during charging of EVs. In this paper, a detailed economic and system analysis for the PEVCS is carried out using PVSyst and Helioscope for the area planning and shadow analysis. The normalised results of PEVCS is analysed along with the payback period and life cycle emissions are calculated for a virtual case study in Taylor's University. At the end of the 25th year, based on the analysis, the overall payback and revenue for 25 years is 2,653.6 kMYR will be generated by selling energy at 0.58 MYR / kWh.

## 1. Introduction

Carbon dioxide ($CO_2$) emissions are increasing day by day from various sectors but majorly contributed by transport sector and electricity sector. So, adapting to electric vehicles (EVs) without having renewable energy-powered charging stations (CS) will again lead to a rise in emission levels [1]. On the other hand, EVs are more suitable for energy conservation, environmental protection and much efficient than fossil fuel-based vehicles [2]. It is noticed that [3] around 18.1% of the people are ready to shift towards EVs, but due to lack of an abundant number of CS, they are in a huge dilemma. This reason alone acts as a significant hurdle to adopt EVs [4]. So, this hurdle can be solved only by deploying a many number of CS even powered by renewable energy sources like solar, wind and fuel cells [5].

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The construction of CS involves a lot of capital investment with viable payback period. Concerned party of private investors or government can induce various schemes like encouraging to charge at night for free, financial incentives for the EV purchasers, and infrastructure investors [6]. The authors from [7] had worked on the idea of utilisation of the existing gas stations and office premises will solve the anxiety problem of the EV users and also initial investment would reduce considerably as well as the penetration of EVs and renewable energy into the grid will be smooth [8,9].

The charging stations have classified into three types such as level 1 (slow) charging stations, level 2 (medium) charging stations, and DC fast-charging stations [10,11]. Lot of works were carried out for the technical aspects of the renewable energy based EV CS [12-19], economic studies [20 - 27] were also conducted and very few studies[16], [22], [24], [28,29] were discussed on the coupling of solar PV-Grid-Battery-EV systems.

The following sections of the manuscript is devised into two types, one is system analysis and the other is economic analysis, by anlysing the two sections the results of the sections can act as basis for calculation of payback period, total revenue generation, and life cycle emissions solar carport.

## 2. System Analysis

The system is represented by PV array, Grid-connected inverter and DC fast chargers to charge EVs is shown in Figure 1. The proposed system can cater two process namely EV charging and ancillary services. The layout of the solar carport is shown in Figure 2 is designed at 280 kWp and installed virtually by utilizing the power of helioscope tool.

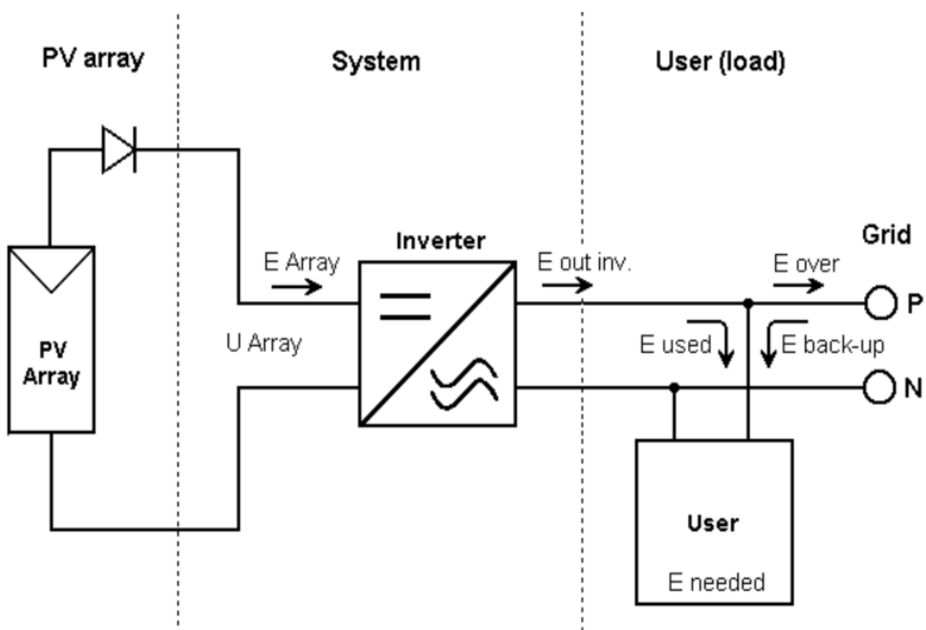


**Fig.1.** Simplified schematic of PEVCS


**Fig.2.** Layout of the proposed SPEVCS

The PEVCS can act as a distributed energy generation unit which can deploy or mount at various locations like workplaces, community grounds, universities etc. the generated output power can utilises to charge an EVs or it can be used to feed the grid as ancillary service. The virtual case study comprises of 280 kWp PECS. The energy supplied from the PEVCS will be able to cater 6675 km drive equivalent of charge [30]. The normalised performance coefficients of the system are given in table 1 and shown in Figure 3. The annual reference incident energy in the collector plane is 4.38 kWh/m$^2$.day and array production of 3.67 kWh/kWp/day with the losses of 0.054 produces 3.62 kWh/kWp/day. The total system losses are shown in the loss diagram in Figure 4. In that, the annual energy generated is 369.5 MWh with a significant loss of 8.3% due to the increase in module temperature, followed by a 3.7% loss due to Incident angle modification (IAM). Figure 5 shows the daily input and output curve for a stipulated day in the entire synthetic simulation period. Figure 6 shows the amount of energy injected into the grid for the whole year. Figure 7 represents the comparisons between the energy injected to the grid and the effective energy at the output of an array.

**Table 1:** Normalized performance coefficients

| | Reference incident energy in collector plane | Normalised array production | Normalised system losses | Normalised system production | Array loss/incident energy ratio | system loss / Incident energy ratio | Performance ratio |
|---|---|---|---|---|---|---|---|
| | kWh/m².day | kWh/kWp/day | | kWh/kWp/day | | | |
| January | 4.25 | 3.56 | 0.052 | 3.51 | 0.161 | 0.012 | 0.827 |
| February | 4.75 | 3.96 | 0.06 | 3.9 | 0.165 | 0.013 | 0.822 |
| March | 4.87 | 4.05 | 0.062 | 3.99 | 0.168 | 0.013 | 0.82 |
| April | 4.65 | 3.89 | 0.058 | 3.84 | 0.162 | 0.012 | 0.825 |
| May | 4.54 | 3.79 | 0.056 | 3.73 | 0.165 | 0.012 | 0.823 |
| June | 4.29 | 3.61 | 0.052 | 3.56 | 0.159 | 0.012 | 0.829 |
| July | 4.24 | 3.55 | 0.053 | 3.5 | 0.162 | 0.013 | 0.825 |
| August | 4.28 | 3.6 | 0.053 | 3.54 | 0.159 | 0.012 | 0.829 |
| September | 4.37 | 3.67 | 0.055 | 3.61 | 0.161 | 0.013 | 0.827 |
| October | 4.4 | 3.69 | 0.055 | 3.64 | 0.161 | 0.013 | 0.826 |
| November | 4.06 | 3.44 | 0.049 | 3.39 | 0.153 | 0.012 | 0.835 |
| December | 3.91 | 3.29 | 0.048 | 3.24 | 0.159 | 0.012 | 0.829 |
| Year | 4.38 | 3.67 | 0.054 | 3.62 | 0.161 | 0.012 | 0.826 |

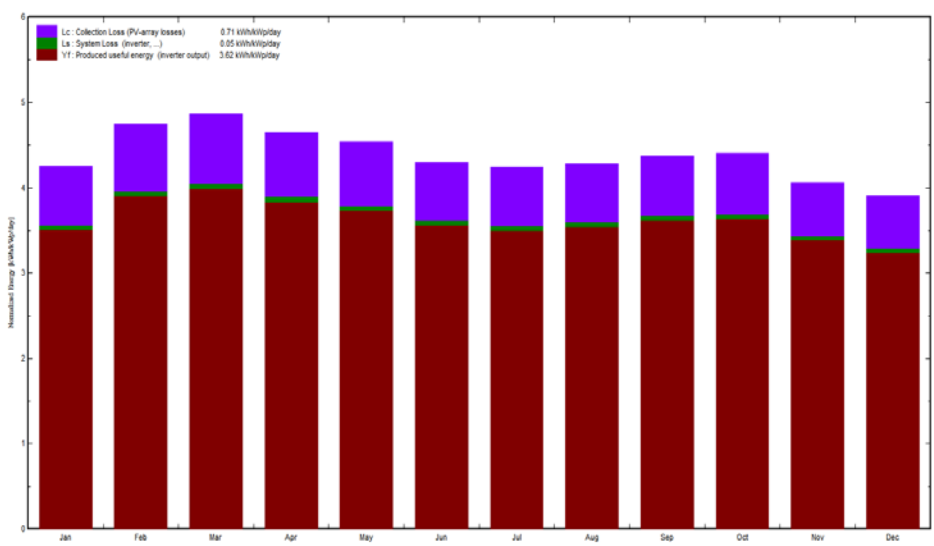


**Fig.3.** Normalized productions (per installed kWp): nominal power 280 kWp

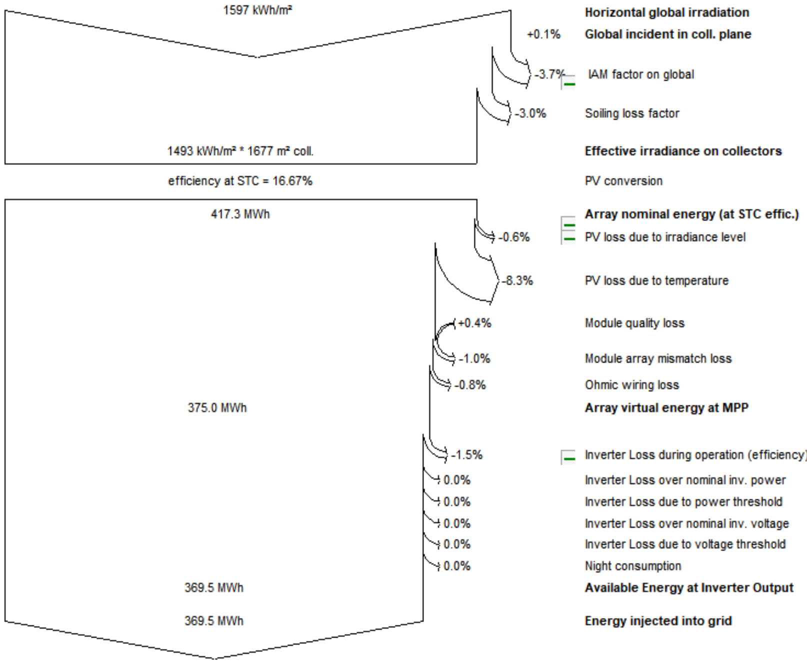


**Fig.4.** Overall System loss flow chart

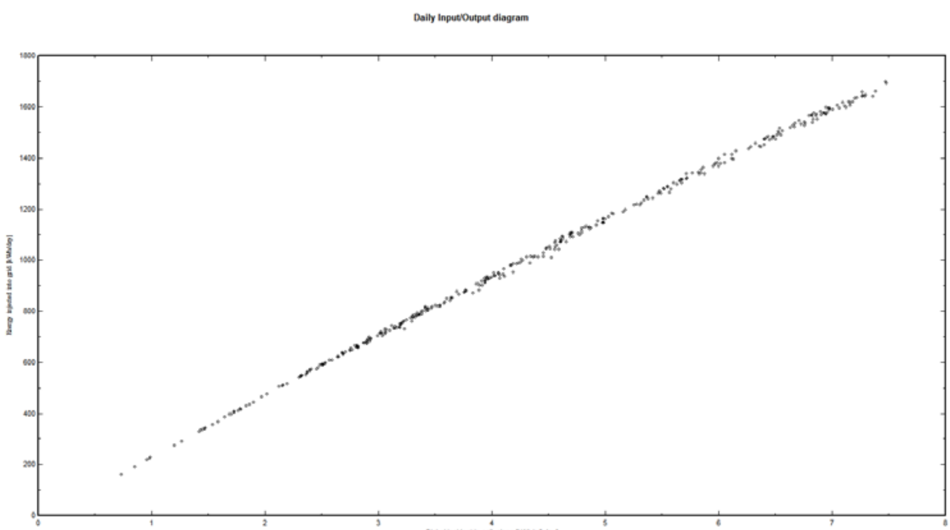


**Fig.5.** Daily Input / Output curve

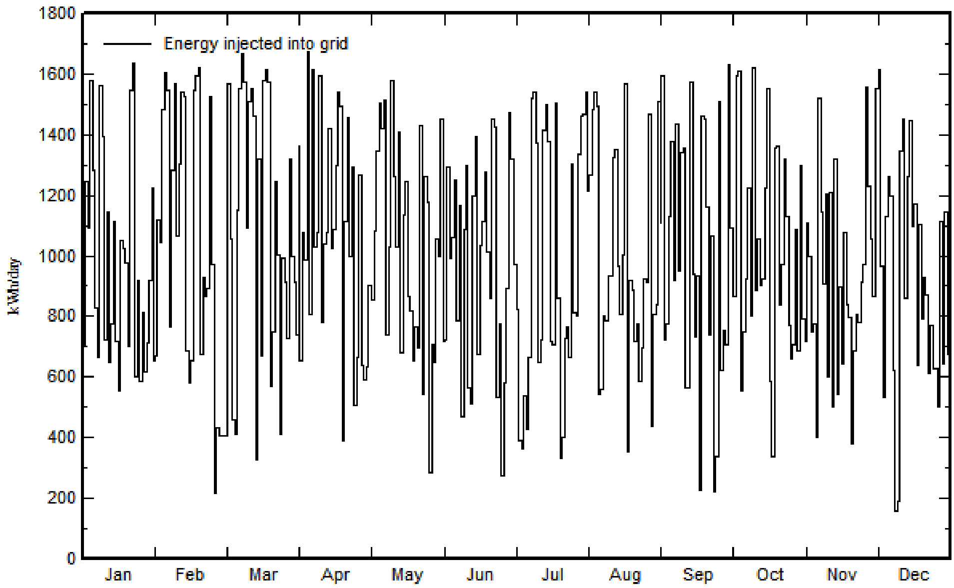


**Fig.6.** Energy injected into the grid

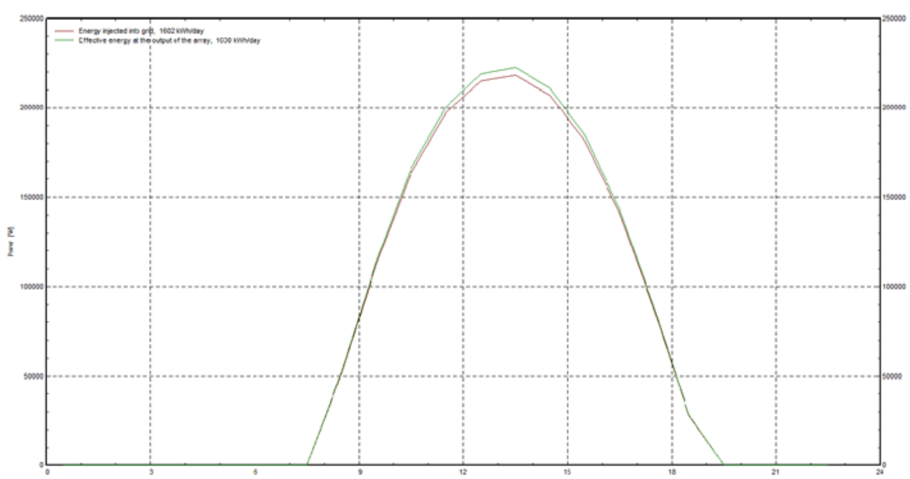

**Fig.7.** Comparisons of energy injected to the grid and effective energy at the output of the array

## 3. Economic Analysis

Economic analysis for the solar carport is carried out in PVsyst for the PV modules, structures, inverters, and all accessories. All the rates are considered in MYR as all the core modules of the system is readily available in Malaysia. The central core modules of the system or high cost are occurring for the PV modules and inverters. Each solar panel is considered for 1153.37 MYR and inverters are considered for 13,472 MYR, complete wiring is considered as 147,350 MYR and support structures 345.98 MYR. Generally, 30% of the system cost is allotted for the structures along with the prices the nominal taxes are 6

% without considering any subsidies. The total investment required to install 280 kWp solar carport is 1616650.41 MYR. Annuities and yearly maintenance cost of 213,573.62 MYR. Availing Project loan for the entire project at a 5% rate of interest for ten years with 12.95% CAP/year can produce energy for 0.58 MYR / kWh.

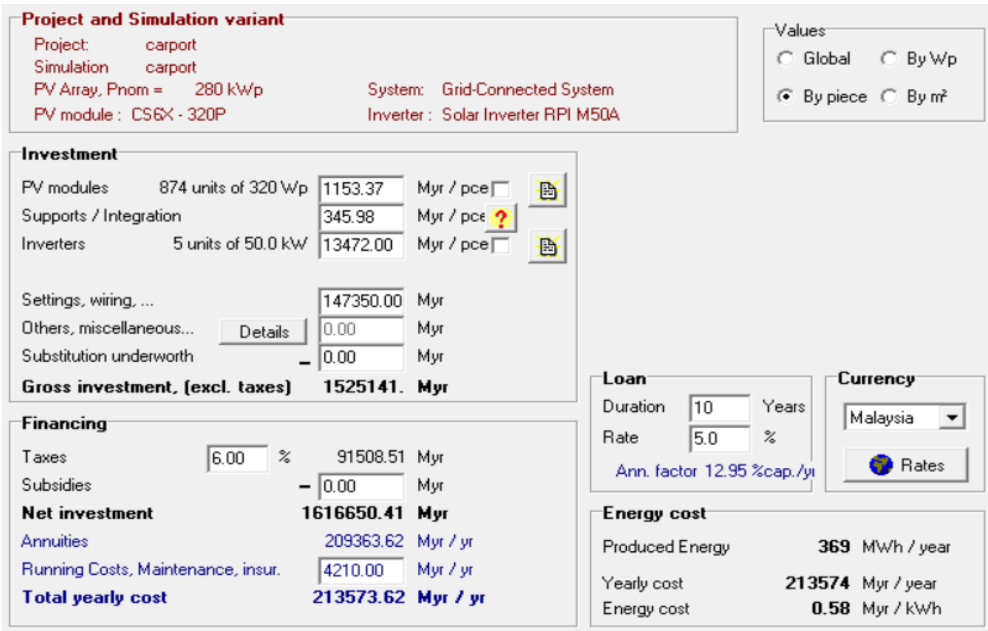


**Fig.8.** Economic evaluation of the proposed system

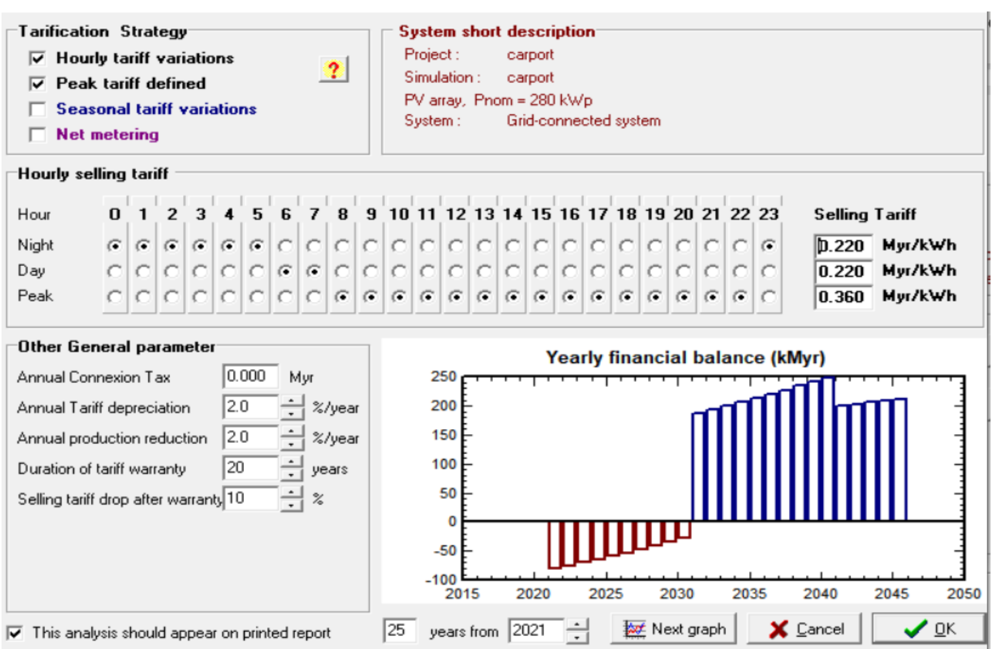


**Fig. 9.** Tariffication strategy

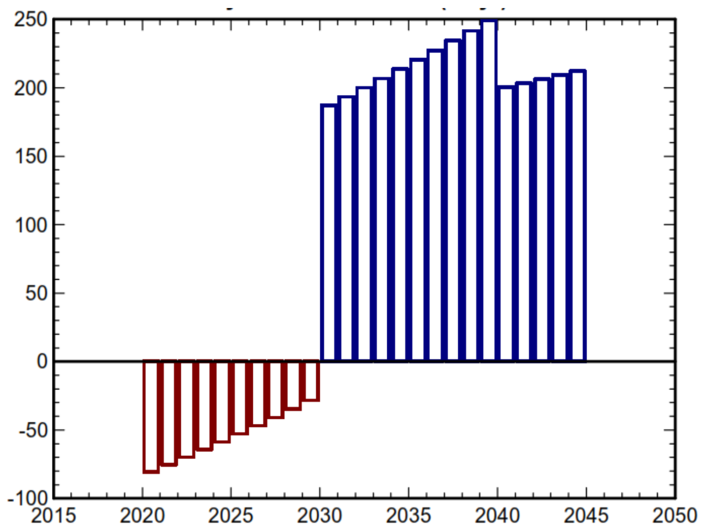


**Fig. 10.** yearly financial balance (kMyr)

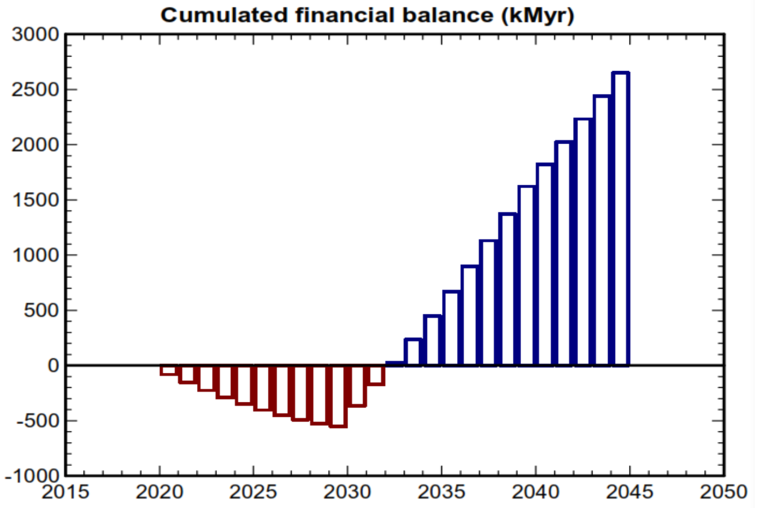


**Fig.11.** Cumulated financial balance (kMYR)

Based on the simulation Figure 8, Figure 9, Figure 10, and Figure 11 calculation performed for the solar carport are designated for 25 years of fully functioning plant by [31] hourly selling tariff of 0.220 MYR / kWh from 2300 hrs to 0700 hrs and 0.360 MYR / kWh from 0800 hrs to 2200 hrs along with 2% tariff depreciation per year and by assuming 10% tariff drop after 20 years, will get the payback from the year 2032 which is given in table 2. At the project period of the 24th year, the cumulative balance of 2,653.6 kMYR will be the profit only the energy generated from the Solar carport. Additionally, the energy generated can be sold to EV drivers at the respective prices decided by the government or the plant proprietor to make additional profits. During this entire process, the amount of $CO_2$ emissions reduced will be 4,890 tons.

**Table 2.** Long term economic balance (kMYR)

| Sl.No | Year | Loan @ 5.0% | Running costs | Energy sold | Yearly balance | Cumulative balance |
|---|---|---|---|---|---|---|
| 1 | 2020 | 209.4 | 4.2 | 132.9 | -80.7 | -80.7 |
| 2 | 2021 | 209.4 | 4.2 | 138.3 | -75.3 | -155.9 |
| 3 | 2022 | 209.4 | 4.2 | 143.8 | -69.8 | -225.8 |
| 4 | 2023 | 209.4 | 4.2 | 149.3 | -64.2 | -290.0 |
| 5 | 2024 | 209.4 | 4.2 | 155.0 | -58.5 | -348.5 |
| 6 | 2025 | 209.4 | 4.2 | 160.8 | -52.7 | -401.3 |
| 7 | 2026 | 209.4 | 4.2 | 166.7 | -46.8 | -448.1 |
| 8 | 2027 | 209.4 | 4.2 | 172.7 | -40.8 | -489.0 |
| 9 | 2028 | 209.4 | 4.2 | 178.8 | -34.7 | -523.7 |
| 10 | 2029 | 209.4 | 4.2 | 185.1 | -28.5 | -552.2 |
| 11 | 2030 | 0.0 | 4.2 | 191.4 | 187.2 | -365.0 |
| 12 | 2031 | 0.0 | 4.2 | 197.8 | 193.6 | -171.4 |
| 13 | 2032 | 0.0 | 4.2 | 204.4 | 200.2 | 28.8 |
| 14 | 2033 | 0.0 | 4.2 | 211.0 | 206.8 | 235.6 |
| 15 | 2034 | 0.0 | 4.2 | 217.8 | 213.6 | 449.1 |
| 16 | 2035 | 0.0 | 4.2 | 224.6 | 220.4 | 669.6 |
| 17 | 2036 | 0.0 | 4.2 | 231.6 | 227.4 | 896.9 |
| 18 | 2037 | 0.0 | 4.2 | 238.7 | 234.5 | 1131.4 |
| 19 | 2038 | 0.0 | 4.2 | 245.8 | 241.6 | 1373.0 |
| 20 | 2039 | 0.0 | 4.2 | 253.1 | 248.9 | 1621.9 |
| 21 | 2040 | 0.0 | 4.2 | 204.7 | 200.5 | 1822.4 |
| 22 | 2041 | 0.0 | 4.2 | 207.6 | 203.4 | 2025.8 |
| 23 | 2042 | 0.0 | 4.2 | 210.5 | 206.3 | 2232.1 |
| 24 | 2043 | 0.0 | 4.2 | 213.5 | 209.3 | 2441.4 |
| 25 | 2044 | 0.0 | 4.2 | 216.4 | 212.2 | 2653.6 |

## 4. Discussion on Analysis

The virtual study carried at simulation level for the mentioned location at Taylor's University shows that System and economic analysis shows that the PEVCS is suitable sustainable EV charging Station with less carbon emissions and great revenue generator. Most of the PEVCS are designed based on the distance to drive per day which is the primary criteria to install Solar PV in home and condominiums. But, as a distributed energy resource and as a virtual power plant the proposed virtual study will be a stand-alone application for work place CS. Earlier most of the solar carport are not intend for EV charging rather they are used for insight solar power generation to cater the local load demand. Whereas now the solar car port can be integrated with EV chargers to charge EVs. So, this virtual study in Taylor's University can be considered as feasibility study for future implementation. As per the analysis without any government subsidy Taylor's university can sell power at 0.58 MYR for both power generation and as well as charging session. The main limitation of this study is based on the availability of solar panels, Inverters and EV chargers as the main design is considered with predefined solar modules and inverters in the software. Despite of these limitation the analysis can considered for the implementation of the PEVCS.

## 5. Conclusion

PEVCS is designed which is quite common structure for most of the PEVCS. So, the system and economic analysis carried out is applicable for most of the general feasibility studies. In this paper, system and economic analysis is carried out for 25 years where the payback period will be of 12 years. The generated energy from solar PV will be either used to charge EVs or it can give back to TNB at 0.58 MYR / kWh and reduce 4,890 tons $CO_2$ emissions. Since Malaysia is lacking in charging station infrastructure, there is a need for different feasibility studies and virtual case studies for PEVCS. By choosing appropriate methodology and tools various organisations and institutions can accommodate PEVCS with full utilisation of generated power. PEVCS can also make to consume less energy from the grid (TNB). As solar PV and EV are both in budding stages of development in Malaysia, this work can act as a suitable reference. Further as per the program, Feed-in Tariff (FiT) [31] TNB will provide a fixed price for energy produced and exported to the grid once if the virtual study becomes real time case study. From the above analysis it is feasible for Taylor's University to apply this new methodology to become sustainable university.

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