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TECHNO-ECONOMIC ANALYSIS OF PHOTOVOLTAIC-THERMAL (PV-T) IN THE PERSPECTIVE OF MSME SECTOR

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ABSTRACT: The energy demand in the typical MSME (Micro, Small and Medium Enterprises) sector, 60% - 70% energy is required for the heating and the remaining portion of the electricity consumption. Considering the attractive solar policy and targets in India with financial assistance from the Governments, solar PV has been adopted for electricity generation. The rooftop program has gained momentum considering beneficial for clients as well as distribution companies. However, solar PV technology gives the electrical output, and the beneficiary (client) requires to depend on other fuel sources for the heating requirements. The PV-T technology can produce electricity and heat from the system. This paper discusses the performance of 20.5 kWp PV-T technology for the MSME. The various assumption and technical considerations are given in the paper. The electrical output saves the grid dependency on the power requirement and heat generation can reduce the dependency on the LPG fuel source. The paper shows with the economical assessment, for the considered case the PV-T technology is viable technology without any financial assistance from the government.

KEYWORDS

Renewable energy, PV-T, heating, clean energy

Introduction

The world economic growth is now dependent on extensive use of renewable energy. The fossil fuel stock of the world is going to deplete within a very short time. Worldwide efforts are nowadays concentrating on generating energy from renewable sources. Thus, renewable energy-based power generation may be the solution to future energy problems. This trend will continue as ensuring everyone has sufficient access to energy is an ongoing and pressing challenge for global development (Kumar, A., 2020). Despite the global push for renewable energy adoption, the increased consumption of fossil fuel is a greater concern for the sustainable environment. Globally coal demand is rising at around a 4.5% growth rate, with more than 80% growth derived from Asia (IEA, 2021). A similar rise of natural gas consumption increase by around 3.2% in 2021. The end requirement of these fuel sources (fossil or renewable) can be mainly required for electricity generation or heat generation. Globally, efforts are given by the government and corporates for the adoption of renewable energy sources for electricity requirement and heat generation.

Considering India, renewable energy projects have been adopted drastically over the past decade in India. This major adoption was mainly limited to solar photovoltaics (PV) and wind energy. Solar PV gave the distinct advantage to cater the local electricity demand by serving the distributed energy needs. Solar PV adoption alleviated the electricity demand from polluting coal-based thermal power plants. The country has installed 53.9 GW of solar PV installations by the end of March 2022 (MNRE, 2022), out of which 6.64 GW of solar rooftop PV was installed.

The electricity demand in India is likely to increase by around 6% year-on-year (Economic Times, 2021). With this increase in the power demand across the country, and shifting from coal power to renewable power by the government, solar energy can play an essential role in the Indian power segment.

The solar rooftop helps urban distributing companies to reduce the distribution infrastructure deferrals, reduces T&D losses and provides cheaper power than other power generating options. Rooftop solar also helps customers to reduce their electricity bills (by reducing the import from the costlier electricity generated from various sources). The customers can sell their surplus power to the discoms. The rate of power sold is different as per their respective state solar policies.

Regarding heating derived from renewable energy, solar thermal collectors are one of the most adopted technology across the world. The use of solar thermal can be used for mainly three temperature ranges, (i) low temperature (< 150 °C), (ii) medium temperature (150°C to 450°C), and (iii) high temperature (> 450 °C). Mainly for the residential hot water requirement and industrial water heating (or pre-heating) requirements, non-imaging solar thermal collectors are mainly adopted. These non-imaging collectors are mainly flat-plate collectors, evacuated tube collectors, and evacuated tube collectors with reflectors. By the end of 2021, 18.2 million m2 of solar thermal collectors had been installed in India (Epp, 2022).

Though both technologies are being adopted separately as solar PV, and solar thermal, the hybrid version of these technologies has distinct advantages. This hybrid version is known as Photovoltaic-Thermal (PV-T) collector, which can provide electricity as well as heat energy from the collector. As this technology is new comparatively in India, but it has been adopted abroad for space heating and low-temperature heat requirements. PV-T can be deployed in the MSME sector, where both heating and electricity is required. MSME sector is significant in India, producing 40% of the country’s manufacturing output, and estimated employment of 40 million people (Joshi & Kishore, 2017).

Due to the developing stage of PV-T development in India, the standard testing and performance measurement are not known in the Indian market. Like solar PV, this technology generates electricity but is not considered financial assistance program of MNRE. However, after a successful demonstration of the PV-T technology in the Indian market, financial assistance can bring much faster adoption of the technology. Such adoption shall help to realise the 450 GW of renewable energy target by 2030 declared by the Government of India (MNRE, 2021). Additionally, this shall reduce the usage of fossil fuels for generating heat energy.

This study aims to answer some questions through Techno-Economic Analysis (TEA) of Photovoltaic-Thermal (PV-T). Techno-economic analysis (TEA) is an important tool for evaluating economic viability and plays a significant role in directing further research to evaluate suitability of scale-up. Although TEA is subject to high uncertainties, doing this provides several points of advice for future investigations. The paper is organised into five parts. Part 1 is all about introduction and part 2 illustrates with literature review. Material and method is described in part 3 and part 4 displays data analysis and discussion. Finally, Conclusions are drawn in part 5.

Literature Review

This section of the paper looks into the technical aspects of PV-T technology to facilitate framework of study. Description of various components of PV-T technology, Drivers of Solar Photovoltaic (PV) performance, standard testing condition and the benefits of the PV-T technology are identified. The section also reviews existing literature of study to avoid duplication of already researched matter.

A successful implementation of Solar Photovoltaic (PV-T) contributes towards sustainable energy supply in the future. It is important to explore technical and economic factors before deployment of technology. TEA has importance in risk minimization before commercial deployment. Solar PV electricity production is mainly driven by solar radiation availability at the site. Solar Photovoltaic (PV) collector performance is driven by weather parameters. However, there are other parameters like temperature, clouds, and rain that causes impact the performance.

A total of 65%-70% of the solar electromagnetic spectrum energy can be converted for heat utilization and a small portion of the spectrum is utilized by solar PV technologies (Lämmle, Manuel; Herrando, María; Ryan, Glen, 2020). Fig. 1 represents 100% of the air mass (AM) 1.5 spectrum in which electrical gains are 15%, and heat gains for 61%.

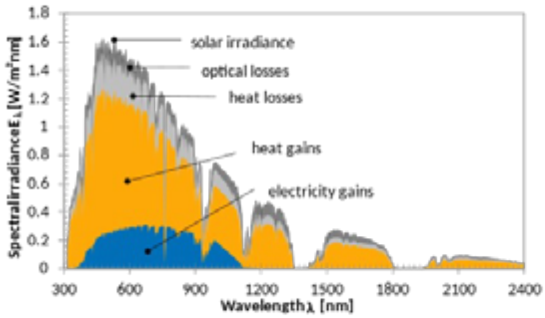

Figure 1: Electromagnetic Solar Spectrum Utilization by PV-T Collector (Lämmle, 2020)

The standard testing condition (STC) for solar PV module testing is at 25 °C and 1000 W/m2. The other efficiencies are measured at the normal operating cell temperature (NOCT) which is 800 W/m2 and 20°C, and wind speed of 1 m/s. At NOCT, the solar PV module-rated capacity performance is lower compared to STC.

Mostly all silicon-based photovoltaic cells electrical output efficiency reduces with the increase in cell temperature. Each degree rise in the cell temperature reduces the cell efficiency by around 0.4 – 0.5%.
The removal of heat from the panel reduces the cell temperature and increases electrical efficiency. The solar PV performance at various operating temperatures is shown in Fig. 2.

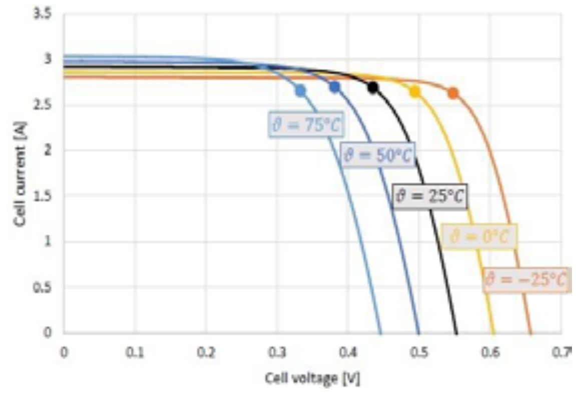

Figure 2: Solar PV performance at various operating temperatures

The benefits of the PV-T technology are as follows:

- Removal of heat from the Panel which increases the PV efficiency
- Extracted heat utilization for needed uses (such as water heating, process heating etc.)
- Efficient use of space (separate solar thermal water heating system can be avoided)

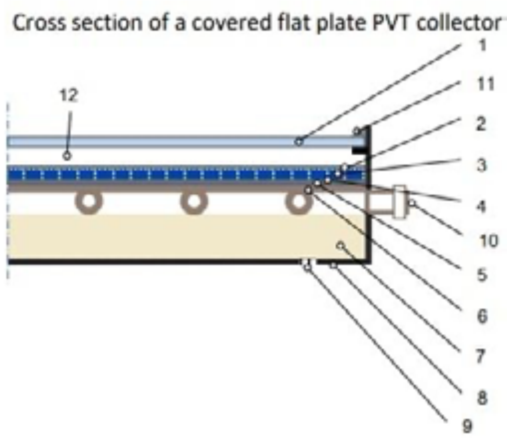

Figure 3 : Cross Section of a covered flat plat PV-T collector (Hadorn, et al., 2020)

As per the Fig. 3, the description of the components is given in the following Table 1. These are the tentative components of the PV-T, which means in the actual case some optional components can be absent in the actual PV-T Collector.

Sr. No.	Description	Remarks
1.	Transparent cover	Optional
2.	Front cover glass of PV module & Encapsulant	PV
3.	Solar PV cells	PV
4.	Encapsulant	PV - Optional
5.	Back sheet / Cover	PV - Optional
6.	Absorber & Heat Transfer Medium	Thermal
7.	Insulation	Thermal - Optional
8.	Casing	Optional
9.	Air vent	Optional
10.	Fluid Outlets	Thermal
11.	Sealing	For Cover – Optional
12.	Gap	Optional

Table 1: Components of the PV-T collector (Hadorn, et al., 2020)

Globally, the cumulative installation of PV-T collector area of 1.27 million m2 was installed, and the installation is increasing at 9% growth rate from 2018 to 2020 (IEA-SHC, 2021).The new larger market for PV-T technologies is the Netherlands, China, France, Ghana and Germany (REN21, 2021).

The PV-T technology is ideal for electricity and heat energy requirement conditions such as residential houses, hotels, guest houses, hospitals and process heat industries. The four-year discounted payback for PV-T for a 200-bedroom hotel in Barcelona, Spain was reported (Epp, Bärbel, 2020). The selection criteria for PV-T with the separate solar PV or solar thermal collector depend on the heat energy and thermal energy requirement at the site with the same occupied area.

In the literature were found some relevant studies. Barun K. Das et al. analysed economic and environmental benefits of stand-alone and grid integration with different system configurations of a PV/Wind/Diesel/Battery based hybrid energy system (HES) for five different climatic regions using hybrid optimization model for electric renewables (HOMER) (Das, et al., 2021). Faizan A. Khan et al. analysed social aspects of the renewable energy system in a distinguished manner, based on the techno-economic and socio-environmental parameters (Khan, Pal, Saeed, & Yadav, 2022). Soowon Chang et al evaluated the energy, economic, and environmental performance of rooftop PV and EVs for the five built forms in Korea and different building types in Seoul (Chang, Cho, Heo, Kang, & Kobashi, 2022).

Material and Method

This section presents the methodologies used in this study to achieve the goals of this study. TEA is a methodological approach to analyse the technical and economic performance of a process, product, or product system (AW, et al., 2020). The study has been designed to be based on the inductive approach. A solar PV module operates in the field at high temperature and its efficiency performance varies based on the range of radiance. The study required an appropriate geographical location. Taking this into account, we have considered the temperature conditions of a major city (Ahmedabad) located in India. In India, the major part of the country has a daytime temperature above 25 °C. As per the standard testing conditions, solar PV modules are tested at 1000 W/m2 radiation and 25 °C. The rise in temperature can reduce the power generated by the solar PV module. The per degree Celsius rise in the module (or cell) temperature, reduces the power from the panel in the range of -0.3% to -0.5%. Considering the hot and dry climatic conditions, Ahmedabad, Gujarat, the module peak temperature rise approx. 75 °C in the summer months. The average module temperature rises above 55 °C in most of the months in a year. The module temperature rise in the summer month is shown in Fig. 3. It is visible from Fig. 3 that, the module temperature is much higher than STC condition, i.e. 29.92 °C difference for the considered day.

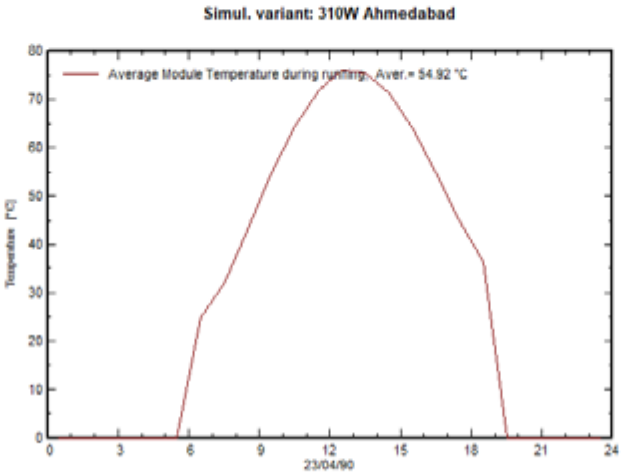

Figure 4: Solar PV module temperature rise in a summer day at Ahmedabad using PVSyst 6.88 (PVsyst, 2020)

The solar power output reduction can be calculated using Eq. (1):

Solar Power Loss due to temperature = Temperature Difference from STC * Temperature Co-efficient for power

For the temperature co-efficient for power -0.4%/°C, the solar power loss due to temperature will result into a loss of 12%. For the plant capacity of 1 kWp, the loss due to temperature ranges from 200 kWh to 380 kWh based on the local temperature condition.

The month-wise ambient temperature, solar PV module temperature during the operating time, and their difference are shown in Table 2. The average difference between the ambient temperature and the module temperature during operation is 24.2 °C.

	Ambient Temperature °C	Solar PV Module Temperature at Normal Operation °C	Day Time Temperature Difference (Panel Temp - Ambient Temperature) °C
January	25.7	53.5	27.8
February	31.0	60.8	29.8
March	35.3	64.4	29.1
April	41.0	68.0	27.0
May	39.0	62.3	23.3
June	35.6	54.7	19.1
July	30.5	47.6	17.1
August	29.4	46.3	16.9
September	29.4	53.1	23.7
October	29.5	56.7	27.2
November	27.8	53.8	26.0
December	26.2	53.3	27.2
Year	**32.0**	**56.2**	24.2

Table 2: Solar PV panel temperature and ambient temperature difference for Ahmedabad (Blair, et al., 2021)

In the PV-T technology, the panel consist of a heat transfer pipe below the solar PV module, which carries the heat away from the panel using fluid (mostly water). This reduces the panel temperature, increasing the solar PV output and getting extra heat energy for further utilization.

Using testing standard EN 12975 (QAiST, 2012), the heat energy from the PV-T technology can be derived from the following Eq. (2):

$$Q/A = G*\eta_0 - a_1*(t_m - t_a) - a_2*(t_m - t_a)^2$$

where, Q = Thermal output (W), A = Area (m2), G = Solar irradiation (W/m2), φ0 = Optical efficiency (%), a1 & a2 = heat loss co-efficient, tm = mean module temperature (K), ta = ambient temperature (K)

The performance of the PV-T module is derived from the Eq. (1), Eq. (2) and the weather data available in PVsyst v6.88 (PVsyst, 2020). The output water heating temperature from PV-T module is considered 45 °C. The reduction in temperature difference will increase the solar PV performance according to Eq. (1). This increased generation is added to the generation estimated using PVsyst v6.88 (PVsyst, 2020). The thermal output was estimated using Eq. (2).

Analysis & Results

This section discusses technical and economic factors in the TEA framework to allow for an objectivity in the feasibility.

Technical Analysis:

The PV-T technology converts solar radiation into useful electrical energy and heat energy, which can be further utilised by the beneficiary. Considering the MSME unit, where there is a constant need for heating energy, and the electricity requirement for the running plant, the PV-T techno-economic viability is shown in this section.

For evaluating the techno-economic assessment of the PV-T technology one MSME located in Ahmedabad, Gujarat is considered. The considered MSME can utilise electricity produced by PV-T and also pre-heat the water produced by PV-T. The photovoltaic capacity considered is 20.5 kWp for the analysis. The LPG gas is considered the fuel source utilised in MSME for the heating requirement. The heat energy derived from the PV-T shall reduce the heating requirement from the LPG fuel source. The heating temperature required from the PV-T is considered 45 °C. The electrical energy produced by the PV-T shall be consumed by the MSME, which means saving imports from the grid. The other assumptions for the techno-economic viability are shown in Table 3.

Description	Value	Unit
PV-T – Electrical Capacity	20.5	kWp
PV-T Area	110	m^2
Inverter Capacity	10	kVA
No. of Inverters	2	Nos.
GHI	1946	$kWh/m^2/year$
Required Hot Water Temperature	45	°C
LPG Calorific Value	10500	Kcal/Kg of LPG
LPG Burner Efficiency	90%	%
PV-T Warranty – Electrical	25	Years
PV-T Warranty – Thermal	15	Years
Inverter Replacement Year	13	Year (beginning)

Table 3: Technical values and assumptions for the PV-T case study

The performance of the PV-T is calculated using the PVSyst Software (version 6.88) (PVsyst, 2020), manufacturer data sheet, Eq. (1) and Eq. (2). The performance for the PV-T for the above case study is shown in Table 4.

	GlobEff kWh/m^2	E_Grid kWh_e	Performance Ratio - PV	E_thermal kWh_th
January	176	3,129	0.84	2,960
February	177	3,084	0.82	2,788
March	201	3,416	0.80	3,074
April	190	3,200	0.79	2,902
May	183	3,071	0.78	2,902
June	145	2,478	0.79	2,540
July	109	1,877	0.80	2,158
August	112	1,940	0.80	2,100
September	146	2,513	0.80	2,578
October	176	3,007	0.80	2,998
November	167	2,891	0.82	2,902
December	166	2,926	0.83	3,017
Year	**1,946**	**33,533**	**0.81**	**32,920**

Table 4: Estimated PV-T performance (PVsyst, 2020) (Dualsun Wave, 2017) (QAiST, 2012)

It can be seen from Table 4, that the electrical energy from the PV-T system is around 4.5% higher than the only solar PV installation of the same capacity. This is due to limiting the temperature rise up to 45 °C, and hence limiting the power loss due to temperature rise. The performance ratio also increases by around 5% compared to the solar PV installation of the same capacity. The predicted electricity generation from the 20.5 kWp PV-T system is 33,533 kWh and the thermal energy generation is 32,920 kWh.

Economic Analysis:

The assumptions and values considered for economic assessment are shown in Table 5.

Description	Value	Unit
Electricity Rates	7.5	INR/kWh
LPG Gas (Non – Subsidized)	89.1	INR/Kg
LPG Cost Escalation	4%	%/Year
Annual PV-T module degradation – Electrical	-1%	%/year
Annual PV-T module degradation – Thermal	-1%	%/year
O&M Inflation Rate	5%	%
Annual Maintenance Contract with Purchase	5	Year
Electricity Price Escalation	4%	%/Year
Loan Interest Rate	10%	%/Year
Loan Duration	10	Years
PV-T Panel Cost	65	INR/Wp
Thermal Storage Cost	36,750	INR
Solar BoS Cost	21	INR/Wp
Piping & Control Cost	10,000	INR
Discount Factor	8%	%
Debt	70%	%
Equity	30%	%
Effective Income Tax	25.17%	%
Reinvestment Interest Rate	8%	%

Table 5: Economic values and assumptions for the PV-T case study

Considering the financial benefits in the first year, PV-T system can save the electricity imported from the Grid around INR. 2.5 lacs and saves the LPG gas worth INR. 2.6 lacs. The life of thermal output is considered 15 years and the electricity production is considered 25 years as per the manufacturer's warranty terms. The economic analysis summary is shown in Table 6.

Description	Value
Project IRR	21%
Project MIRR	12%
Project Payback Period	5 Years 9 Months
Discounted Project Payback Period	5 Years 3 Months
Discounted Net Present Value (INR)	22,71,420

Table 6: Economic analysis results for PV-T

Considering the heat energy and electricity replacement from 20.5 kWp PV-T technology, the investment can give the project internal rate of return (IRR) is 21% and modified internal rate of return turns-out to 12%. The discounted payback period for the investment is 5 years and 3 months.

Conclusion

In the present paper, a comprehensive study of PV-T technology for industrial heating and electricity replacement has been carried out. The PV-T technology can save electricity imports from the grid and reduces the imports of fuel sources for the heating requirement. This paper shows the case study of the installation of 20.5 kWp capacity PV-T technology at MSME located in Ahmedabad, Gujarat, India. The technology can give around 5% more electrical output compared to a normal solar PV plant of the same capacity and saves around 2900 Kg of LPG for the heating requirement. The investment can give discounted payback period of 5 years and 3 months with the project IRR of 21%. The payback period can vary based on the heat energy replacement, and existing fuel source (coal, biomass, biogas, LPG, PNG, FO, SKO etc.). The positive NPV shows the attractiveness of the investment. Further, any financial assistance from the government, shall reduce the payback period and also increase the IRR.

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