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Sustainable Solution to Mitigate Carbon Emission for the Cumulative Electrical and Thermal Energy Demand in Silk Reeling Process in Southern India

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ABSTRACT

Presently, consequence of carbon emission from the unorganized industries has detrimental effect on the environment. In India silk industries are unorganized at the medium and small-scale level, where production of silk fiber through silk reeling process requires large amount of energy. Thermal energy demand for the silk reeling industries accounts for about 50% of the total fuel consumption where temperature range for the process are 25^{o}C to 95^{o}C. Electrical energy demand for different reeling units and equipment and for irrigation contributes most of the energy consumption from the remaining 50% fuel consumption. In the present study, a sustainable solution is provided for the cumulative electrical and thermal energy demand in silk reeling process. The methodology employs photovoltaic thermal with the conventional system to reduce the firewood consumption and to mitigate the carbon emission. In the study multi-domain energy conversion and performance of photovoltaic thermal is simulated using Simscape, Simscape electrical, Simscape fluid and Simulink package on MATLAB software. Total efficiency of photovoltaic thermal conversion system obtained from the simulation is 53.132% where electrical efficiency is 17.578% and thermal efficiency is 35.555%. For the production of 1kg reeled silk from cocoon, carbon emission is reduced from 76.11 kg/day for the conventional system to 29.372 kg/day and 28.203 kg/day for the open field photovoltaic thermal and roof-top photovoltaic thermal system respectively by considering the system life period of 10 years. Further, a relation between water and energy is shown in future work for more potent solution in terms of energy efficiency and carbon mitigation.

Keywords: photovoltaic thermal (PVT) system, carbon emission, efficiency, embodied energy, silk reeling, water-energy-nexus

NONMENCLATURE

Abbreviations	
PVT	Photovoltaic Thermal

1. INTRODUCTION

In the textile industries, fiber from the silk industries is the most expensive and in greater demand in the world. Energy intensive process of getting silk is one of the factors its high cost. Silk worm seed production, chawkie rearing, stifling, cocoon drying and cooking, reeling, re-reeling, twisting, spinning, dyeing, weaving, printing and finishing are the various steps involved in the production of raw silk yarn[1]. Smoke from the burning of large amount of firewood, used to meet the thermal demand of silk reeling process, affecting the health of workers working in the industries[2]. Vijaykumar et.al [3] proposed a modified design of energy efficient re-reeling machine to reduce energy consumption by firewood. He developed a process for multi-end silk reeling unit with solar water heating system[4]. Fritz Vollrath et al [5] conducted the life cycle analysis for mass and energy flow in sericulture industry of Karnataka region in India.

1.1 Motivation

Silk reeling industry at medium and small-scale level are high unorganized and mostly located in villages and town having small land area for reeling process. For energy demand they mainly depend on firewood along with the agriculture residues. The study on energy consumption and firewood consumption in conventional system[6] is tabulated in Table2 for the production of 1kg of reeled raw silk from 6-8 kg of green mulberry cocoon.

Table1: Consumption of Firewood in silk reeling process to meet thermal energy demand

For the silk reeling process, range of temperature for thermal energy demand and equipment used for finishing silk yarn is studied[7] and tabulated in Table1.

Table 1: Requirement for silk reeling process

Process	Operating temp(°C)	Fuel sources used	Equipment involved
Stifling	70-90	Coal, firewood, electricity and other sources	Hot air drier, steamer
Cooking	87-95	Coal, firewood, electricity and other sources	Pan cooker, pressurized cooker
Reeling	40-60	Coal, firewood, electricity and other sources	Multi-end reeling machine
Re-reeling	40-60	Coal, firewood, electricity and other sources	Multi-end reeling machine
Finishing	40-60	Coal, firewood, electricity and other sources	Chamber with humidity less than 60%

Table 2: Energy consumption and Fire wood consumption in silk reeling process

Process in silk reeling	Energy consumption(kJ)	Firewood consumption(kg)
Cooking of cocoon	518,39.42	8.94
Heating of water for reeling basin	139,97.98	2.41
Re-reeling	501,98.51	8.65
losses	116,03.59	2.00
Total	1,276,39.50	22

Due to the land constraint along with the thermal and electrical energy demand, photovoltaic thermal with the conventional system is the potent solution for cumulative energy demand of energy in silk reeling industry.

2. INVESTIGATIONS

2.1 Methodology

In silk reeling process, thermal energy is required for stifling, cooking, Reeling, Re-reeling and finishing. There is range of temperature for a specified process in reeling. Heat exchanger of PVT system along with tank storage system can be used for heating process. Pump can be used for demand, supply and internal flow of water in the heat exchanger. By controlling the rate of flow of water, we can control the temperature of water. However, size and insulation of storage tank also a major role in maintain temperature of water collecting from the PVT system.

Electrical energy is used for irrigation of land, running of reeling units and equipment in the silk reeling industry. Photovoltaic conversion of PVT system will meet the electrical demand. Schematic of methodology is shown in figure1.

2.2 Simulation

Solar irradiance and solar inclination angle are two input parameters used for optical modelling of PVT energy conversion system. The transmitted irradiance on the PV cells, the heat absorbed by the glass, and the radiative power absorbed by the PV cells are the output of optical model[8]. One part of the output gets transformed into electrical energy by solar cell while other part gets absorbed. Parameters used for doing optical modeling are shown in table no.3

Electrical modelling of the PVT is according to single diode model of solar cell. For modelling electrical portion, solar cell block is used along with the load in subsystem block. Various parameter used for simulating electrical portion is tabulated in table no. 4.

The thermal modelling contains the network of resistor for the heat exchanged through conduction, convection, and radiation. Heat exchanger is modelled between the physical components of the PV panel that is glass cover, heat exchanger, back cover[9]. Further pipe, tank, and pumps are all the parts of thermal-liquid network. Parameters for pipe and heat exchanger is shown in table number 5 and 3 respectively.

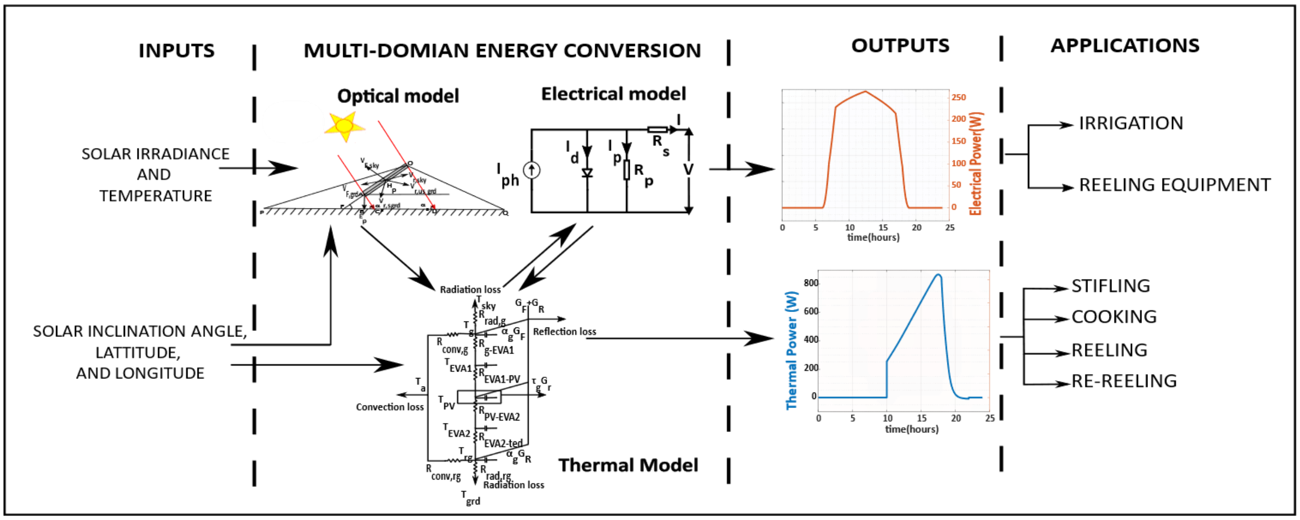

Figure 1:Schematic of methodology

Table 3:Solar panel parameters

Geometry	
Area of the cell	$0.0275m^2$
Number of cells	72
Optical properties	
Refractive index ratio (glass/air)	1.52
Absorption coefficient of glass per unit length	0.2 per m
Thickness of glass cover	0.01m
Reflection factor of PV cell	0.15
Heat transfer Properties	
Mass of glass cover	4kg
Mass of one PV cell	0.2kg
Mass of heat exchanger	15kg
Mass of back cover	5kg
Specific heat of glass	800J/kg/K
Specific heat of PV cell	200 J/kg/K
Specific heat of heat exchanger	460J/kg/K
Specific heat of back cover	400 J/kg/K
Emissivity of glass	0.75
Emissivity of PV cell	0.7
Free convection coefficient between glass and ambient air	$10 W/m^2/K$
Free convection coefficient between PV cells and glass	$20 W/m^2/K$
Free convection coefficient between back covers and ambient air	$10 W/m^2/K$
Thermal conductivity of heat exchanger	130 W/m/K
Thickness of heat exchanger	0.04 m
Thermal conductivity of insulation layer	0.1 W/m/K
Thickness of insulation layer	0.03m

Table 4: Electrical properties of PV cell

Short circuit current	8.88 A
Open circuit voltage	0.62 V
Diode saturation current	1*10^-6 A
Quality factor	2
Series resistance	1*10-6 ohm
Parallel resistance	1*10^9 ohm

Table 5:Pipe parameter for PVT systems

Pipe length	5m
Cross section area of pipe	0.0007 m2
Hydraulic diameter	0.03
Internal surface absolute roughness	15*10^-6
Shape factor for laminar flow viscous friction	64
Nusselt number for laminar flow heat transfer	3.66

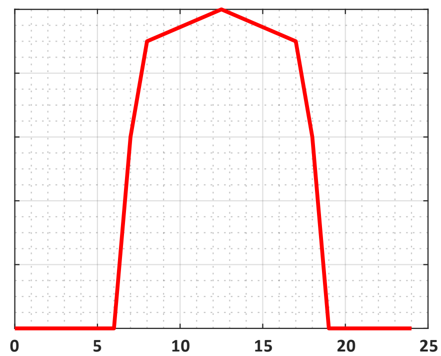

Figure 2: Solar irradiance variation

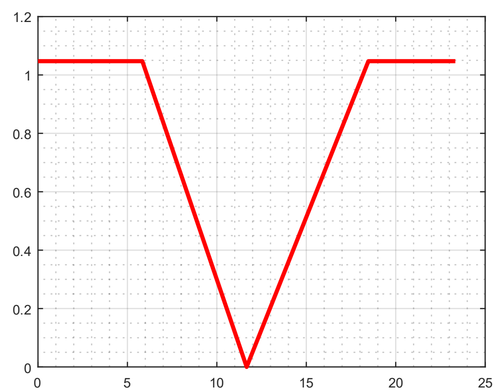

Figure 3: Solar inclination angle variation

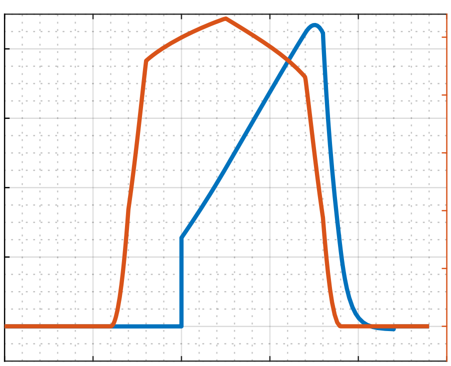

Figure 4: Thermal power and electrical power supplied by PVT system

From figure 2, figure 3 and figure 4, following bullet points we can enumerate:

- Average input energy from the sun per day: 14.8028 kWh/day.
- Average electrical energy supplied per day: 2.602 kWh/day.
- Average used thermal energy per day :5.2631 kWh/day.
- Electrical efficiency: 0.17578
- Thermal efficiency: 0.35555
- Total efficiency: 0.53132

2.3 Calculation of CO_2 emission by PVT system

Energy is consumed for the production, installation, operation, and disposal of the PVT system. Energy required during lifetime for the system comes under embodied energy. The embodied energy of mono crystalline PVT system is shown in Table 6[10]. Reason for high embodied energy of open field PVT system compared to rooftop PVT system is the heavy mounting structure required in open area. Therefore, a constant difference of 300kWh/m^2 is visible throughout the system life period of both the PVT system.

Table 6:Embodied energy of mono crystalline PVT system

System life period(year)	Embodied energy (kWh/m^2): Rooftop	Embodied energy(kWh/m^2): Open field
5	2994	3294
10	3040	3340
15	3086	3386
20	3132	3432
25	3178	3478

Approximately 0.98kg of CO_2 per kWh is produced by the electricity generated by thermal power plant based on coal input. If losses of domestic devices are 20% and losses due to transportation and distribution are 40%, then 1.58 kg of CO_2 per kWh is produced due coal-based electricity. Based on the embodied energy and the life time of system we can calculate the annual CO_2 emission by the PVT system.

$$Annual\ CO_2\ emission\ by\ PVT\ system = \frac{Embodied\ energy * 1.58}{System\ life\ period}$$

Using above equation and Table 6 we can calculate the annual CO_2 emission by the PVT system which are shown in figure 5 and figure 6 for open field and rooftop system with the system life period.

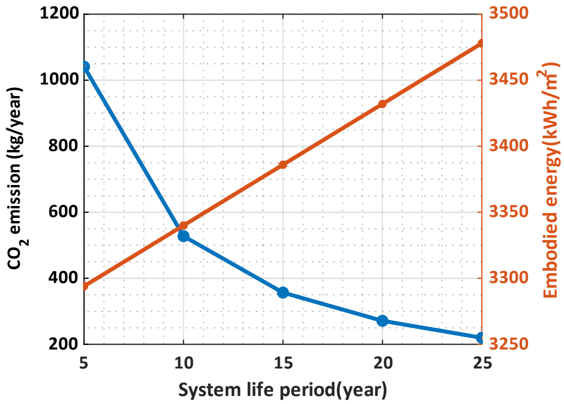

Figure 6: CO_2 emission and Embodied energy of open field PVT system

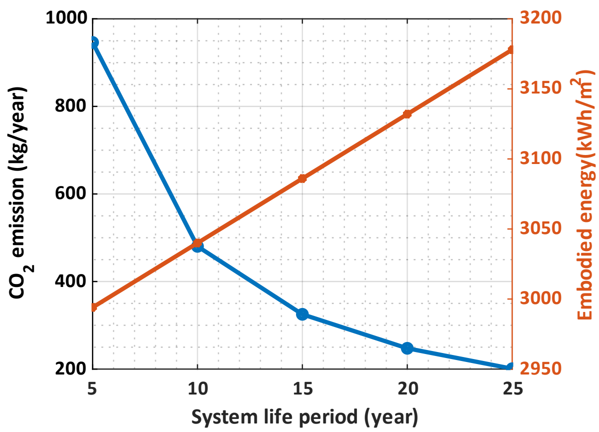

Figure 5: CO_2 emission and Embodied energy of rooftop PVT system

2.4 Results and discussion

From table 2, 127.639 MJ of thermal energy required for silk reeling process, whereas from the simulation result of figure 4 it is observed that a module can give 18.947 MJ. Therefore, seven such module is required to fulfil the thermal demand.

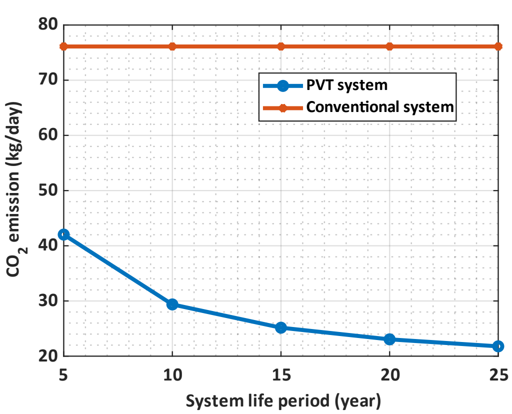

Figure 7: Comparison of conventional system and open field PVT system

The electrical demand for irrigation, multiend reeling equipment, automatic reeling equipment and others accounts 32% of energy consumption in silk reeling industry. Therefore, 81.689 MJ of electrical energy required for the process. From figure 4, a PVT can provide 9.367MJ of electrical energy. Hence, the number of PVT panel required is nine.

From table1, temperature required for cooking and stifling is higher than the temperature a PVT system can give. Therefore, in addition to thermal energy supply by a PVT system 8.94kg of firewood is also required for stifling and cooking process.

In conventional system, CO_2 emission is due to both firewood used for thermal energy and coal-based electricity for electrical energy demand. Burning of 1 kg of firewood produces 1.83 kg of CO_2 per kWh. For silk reeling process 22kg of firewood is used for thermal energy demand, whereas 81.689MJ of energy required for electrical energy demand.

Based on above calculation and data in Table2 and Table 6, comparison of emission of CO2 produced (kg/day) by conventional method and sustainable method is shown in figure7 and figure 8.

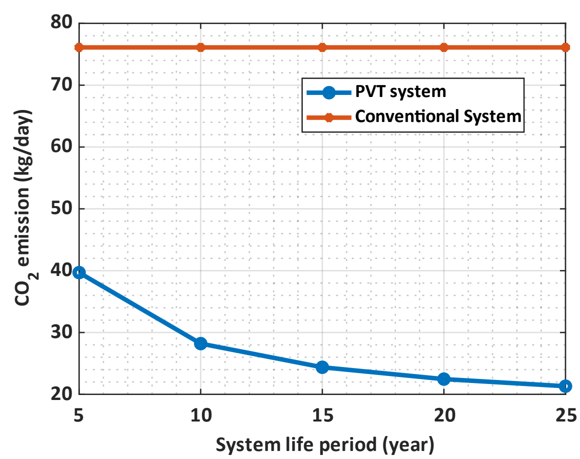

Figure 8: Comparison of conventional system and rooftop PVT system

2.5 Conclusions

Simulation of PVT system is conducted using the optical, electrical and thermal modelling. Electrical efficiency and thermal efficiency of PVT system are 17.578% and 35.555% respectively. Therefore, the cumulative efficiency of the system becomes 53.132%. Carbon emission by PVT system based on embodied energy is calculated for open field condition and rooftop condition. For the production of 1kg reeled silk from cocoon, carbon emission is reduced from 76.11 kg/day for the conventional system to 29.372 kg/day and 28.203 kg/day for the open field photovoltaic thermal and roof-top photovoltaic thermal system respectively by considering the system life period of 10

2.6 Future outlook

In the process of making silk water consumption and maintenance along with energy supply are key factor in the quality of production of silk fiber. Recycling and desalination of waste water from silk reeling process will further improve the energy demand.

Peltier based heating of water along with the PVT system will be the potent solution for complete eradication of firewood consumption. Thermal energy supply along with the water treatment by desalination using Peltier module[11], can be the best solution for energy and water demand. Prototype of Peltier based desalination unit is depicted in figure 9.

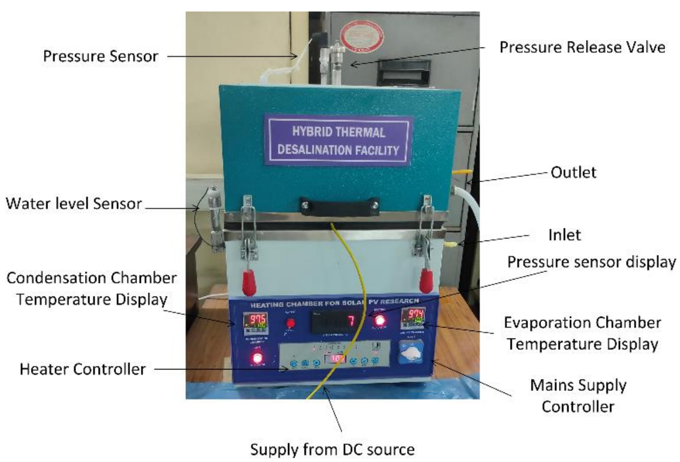

Figure 9:Experimental setup for Peltier based desalination

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