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Feasibility Analysis of Solar Water Heaters for Residential Use in Trinidad and Tobago

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ABSTRACT

In this study, Electric Water Heater (EWH) and Solar Water Heater (SWH) systems were designed and simulated using the Polysun software and their performances were compared. The EWH and SWH both incorporated a 200 L or 53-gallon storage tank utilizing an auxiliary electrical heating element of 4 kW and 2 kW respectively. The SWH configuration included a 3 m^2 solar collector facing South at a 45° tilt angle which achieved an annual total global irradiance of 2,842 kWh on collector aperture area, an average yearly collector efficiency of 52.6%, and an annual average solar fraction of 54%. The yearly total electricity requirement for Domestic Water Heating (DWH) was calculated to be 2,777 kWh and 1,339 kWh using the EWH and SWH respectively, resulting in a 52% SWH savings per year. With a DHW temperature set at 50˚C, the EWH has an estimated value of 1,943.9 kg CO_2 per year emissions compared to 937.3 kg CO_2 per year associated with the SWH. The use of the SWH can result in an annual savings of TT$ 458.91. Using the current subsidized electricity rate at US$ 0.047 per kWh and the 100% tax credit on the cost of a SWH, the Simple Payback Period (SPP) of the SWH was approximately seven years. When the researchers considered the government's proposed electricity rate increase of 40-65.75%, followed by the complete removal of the subsidy, the

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researchers observed that the Simple Payback Period (SPP) for the SWH system was reduced to approximately 4 to 5 years and 1.5 to 2 years, respectively. This study has demonstrated the economic and environmental feasibility of SWH use in Trinidad and Tobago as the Government moves to achieve its Nationally Determined Commitments (NDCs).

1 INTRODUCTION

Unpredictability, global energy market volatility, and the increasing threat of climate change have spurred countries worldwide to review their use, both scale and type of energy. Renewable energy (RE) adoption is now considered a necessity with solar energy as the choice for many[1]. Trinidad and Tobago's (T&T's) energy security requires a concerted broadening of the nation's energy mix[2]. T&T, a Small Island Developing State (SIDS), is the largest oil and gas producer in the Caribbean. T&T is committed towards the implementation of the country's NDC under the Paris Agreement to United Nation's Framework Convention on Climate Change (UNFCCC)[3]. The energy sector in T&T contributes approximately 40% of the nation's GDP, mainly driven by liquified natural gas (LNG) exports and petrochemicals, making up 80% of the total export earnings[4]. To meet its growing energy needs, the country has shifted to the use of natural gas, a cleaner resource. From 2016 to 2020, the country used an average of 91,872 million SCF of natural gas for electricity generation, which accounts for 8% of the total natural gas production[5]. Consequently, the Trinidad and Tobago Electricity Commission (T&TEC), the sole electricity retailer, achieved a 99.3% electricity service coverage in 2020, with only a small portion of the population not connected to the national grid[5].

Electricity consumption (ECS) by sector is 34% residential, 11% commercial, 53% industrial and 2% streetlights[6]. Due to the current grid subsidies at US$ 0.047 per KWh, electricity consumption in T&T is notably high, resulting in financial strain on the government, a substantial carbon footprint, and limited economic motivation for adopting RE technologies. Recently, T&TEC has proposed changes in the residential and commercial pricing structures, transitioning from bi-monthly to monthly billing, expanding from three to four tiers, and increasing tariffs. The proposed rates would lead to residential customers experiencing price hikes ranging from 15% to 64%, while commercial customers would face increases of 51% to 63%[7]. Notably, approximately 45,312 households consume over 1,400 kWh (tier 4), nearly double the average electricity consumption of a typical U.S. residential utility customer (868 kWh)[8]. T&TEC's billing cycles would give all customers ~~h~~ a clearer understanding of their monthly energy costs.

Although natural gas produces fewer emissions than crude oil and coal, and despite its minimal 0.10% share in global CO_2 emissions, T&T ranks the second highest in per capita CO_2 emissions, emitting 24 tonnes per capita in 2021[9]. The Government of T&T acknowledges that RE is a crucial element for the drive of sustainable development as described in the National Development Strategy of T&T: Vision 2030[10].

2 SOLAR WATER HEATERS

This work aims to show that the adoption of RE based technologies such as solar water heaters (SWHs) in T&T will allow for the opportunity to utilize the subsidy funds to expand or improve other aspects of the economy, facilitate economic diversification and preparation for an energy transition while simultaneously engaging in carbon footprint reduction (all essential ingredients for sustainable development). The ample solar radiation supply in the area, averaging 5-6 kWh m^{-2} per day, makes SWHs a highly viable choice[11].

Globally, water heating constitutes a significant 18% of household energy consumption, making it a crucial aspect of the necessary energy transition to limit global temperature increases to well below

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1.5°C[12]**.** In T&T, electricity usage for appliances and water heating is the highest. Electric water heaters (EWHs) stand out as a significant contributor to energy consumption, consistently ranking among the top three appliances consuming the most kilowatt-hours every two months, based on the T&TEC appliance usage data[13]**.** Given the successful adoption of SWHs in nearby Caribbean nations like Barbados, they represent a suitable and promising alternative for T&T.

The Government's participation in the International Solar Alliance (ISA) Framework Agreement facilitates the promotion of the installation of SWHs in the residential and commercial sectors[14]. Participating in the ISA supports the implementation of T&T's NDCs, as well as promoting solar technologies, and boosting the solar sector by making it more cost-effective and accessible to all solar resource-rich countries, such as T&T.

It is projected that the initiative which allows for a 100% tax credit of the cost of a SWH up to a maximum of TT$ 10,000 will benefit approximately 12,000 households[3]. Implementing a 100% tax credit for SWHs in T&T offers significant benefits, including fostering the adoption of RE technology, reducing reliance on fossil fuels, decreasing GHG emissions, enhancing environmental sustainability, and promoting energy efficiency and security. This incentive can lead to lower energy bills, job opportunities, and a reduced carbon footprint. However, challenges include the potential fiscal impact on government revenue and budget, the need to assess financial feasibility and sustainability, the initial investment barrier for some consumers, equity concerns in benefit distribution, the dependence on a well-developed SWH market, and the administrative complexities of managing the tax credit program and ensuring quality and safety in SWH installations.

The adoption of the technology in T&T requires the feasibility analyses to be conducted to investigate how SWH can be optimally integrated into the current energy mix. Hence, this study seeks to fill this information gap. Software is used to evaluate the environmental and economic feasibility of SWH system designs for residential purposes by simulating the SWH design with weather data from climatic zones and the design parameters of the thermal collector, storage tank, and auxiliary system which are physically modelled using calculations. Models utilize a realistic load profile to determine thermal loads and system performances, as well as performance indexes such as the monthly solar fractions and collector thermal efficiencies. The Polysun software has been particularly successful for the simulation and evaluation of SWH systems for residential water heating and will be used in this study[15-17]. The Polysun catalogue contains the necessary modules of characteristic data and performance maps required for hydronic and thermal analyses of the system design. It can measure all associated device parameters related to heat and electricity generation[18,19].

SWH technology has become widely used for providing hot water in single or small multi-family homes, and its adoption is expected to grow, particularly in developing countries, as the global population increases. SWHs have been available for over 30 years and are projected to substantially meet the global energy demand[20]. In 2022, global SWH capacity reached a record high of 542 gigawatts thermal, with a 3.6% annual increase[21]. China is the world's largest market for solar water heating. This growth is attributed to the implementation of policies that have boosted sales since 2009[21]. The top 10 countries with the most installed SWH capacity by 2018 include China, Turkey, India, Brazil, the USA, Australia, Germany, Israel, Mexico, and Greece[12].

Barbados and Cyprus have the highest capacity per 1000 inhabitants due to resource scarcity and the high cost of fossil fuel imports. To compare the performance of SWHs and EWHs in three different cities within the Kurdistan region of Iraq, an experimental setup and the POLYSUN program were employed. The setup included a 2.01 m^2 flat plate solar water heating system with a 200 L storage tank, suitable for a single-family household of four individuals. The simulation results indicated that SWHs significantly reduce energy consumption. In Duhok, Erbil, and Sulaymaniyah cities, the annual energy savings amounted to 1,365 kWh, 1,383 kWh, and 1,459 kWh, respectively. This corresponded to solar

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fractions of 39.4%, 40.4%, and 34.2%, resulting in an annual reduction of CO_2 emissions by 771 kg, 781 kg, and 824 kg in the respective cities[22].

In a study by Jahangiri[23], a feasibility analysis was performed to assess the potential for providing hot water to a four-member household using SWH in 10 Canadian provinces. The study aimed to secure government support for solar energy initiatives. T*SOL Pro 5.5 Software and MeteorSyn software were employed for the analysis, including CO_2 assessments. Among the provinces studied, Regina was identified as the most suitable for SWH implementation, contributing 35% of the total heat load for hot water needs, equivalent to 3,113 kWh of energy from a $40m^2$ solar collector. This implementation could avoid up to 2,080 kg of CO_2 emissions and reduce natural gas consumption by 984 m^3 annually[23].

In a study conducted by Dħiugaite-Tumeniene[19], various software tools including TRNSYS, Polysun, and EnergyPRO were employed to simulate and compare a SWH system in a single-family house in a cold climate. This household, accommodating two adults and two children, had an annual hot water demand of 3,825 kWh and a consumption rate of 50 L per person. The study focused on assessing the annual solar thermal output, the auxiliary heater's energy production, and the pipe heat losses. The results indicated that Polysun provided a 5.2% higher annual solar thermal output compared to TRNSYS and a 0.3% higher output than EnergyPRO. When an auxiliary heater was added, Polysun yielded a 24.4% higher annual energy output compared to TRNSYS and 42.3% higher than EnergyPRO[19]. Overall, the simulation results from Polysun and TRNSYS were found to be more reliable than those from EnergyPRO.

Regionally, the average per capita deployment was estimated at 48.9 kWth per 1000 persons by the Caribbean RE Development Programme[11]. Barbados, St. Lucia and Grenada have skewed the regional average, while other countries have lower or unknown per capita penetrations. In Barbados, the penetration of SWHs is the highest in the Caribbean, accounting for 60% of the total installed SWHs and 80% of Flat-Plate SWH manufacturing in the region[24]. As of 2009, Barbados had approximately 50,000 SWHs installed. As a result, consumer energy savings from 1974 to 2009 were calculated to be BDS$ 819,640,720.00 and 21,400 metric tons of CO_2 were saved. Also, 185,000 barrels of oil per year, or 200,000,000 kWh of total energy, is saved per year[25]. To provide financial and regulatory support ~~of~~ to SWHs in Barbados, several measures were employed. These include tax incentives of 30% to the cost of an SWH and tax on traditional EWHs at a rate of 20%. It was mandated that all government housing projects include SWH systems[26]. As SIDS with small SWH markets and small energy ministries, many Caribbean jurisdictions have not collected SWH market data themselves. Persistent barriers to SWH adoption exist across many Caribbean countries, including financial barriers, weak policy support, lack of public awareness and small and fragmented SWH industries.

In T&T, the two main types of collectors available are Flat-Plate Collectors (FPC) and Evacuated Tube Collectors (ETC)[27]. Studies have shown that the efficiency of the ETC supersedes that of the FPC[28,29]. This is becoming more popular in T&T's SWH market compared to FPCs and will be the technology of choice to be compared with the conventional EWH. This is becoming more popular in T&T's SWH market compared to FPCs and will be the technology of choice to be compared with the conventional EWH, as stipulated by Travis Mohammed through a personal communication with the authors. This study surveyed households in Southern Trinidad to acquire data on hot water usage and cost associated with the existing EWH systems. SWH systems were designed and simulated using the Polysun software and their performances compared to those of the conventional EWH system.

3 METHODOLOGY

Fig. 1 shows the method used in this study which involved several evaluations and models.

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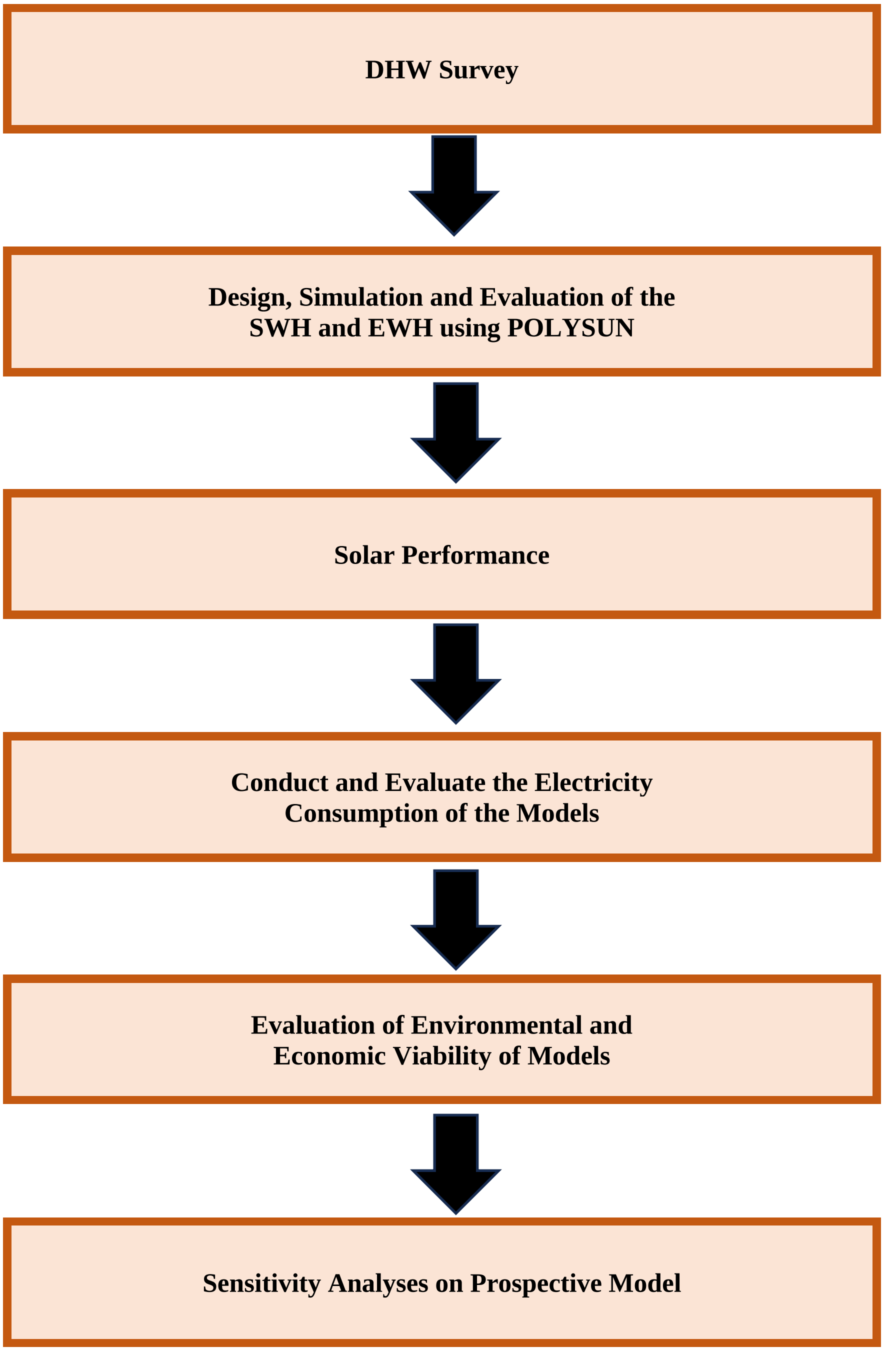

Fig. 1. Methodology flowchart.

3.1 DHW survey

A survey was conducted targeting random households in Southern Trinidad to acquire relevant data on their current EWH systems including type, power, volume of DHW consumed per day and the set hot water temperature.

3.2 Design, simulation and evaluation of the SWH and EWH using POLYSUN

The data from the survey was used as input parameters for the software. Components of the EWH system include a storage tank, an auxiliary heating controller, a 4 kW internal heat exchanger, a mixing valve controller, a three-way valve, and pipes. For the SWH design, the thermosyphon SWH template was chosen with similar components to those of the EWH except that a 2 kW internal heat exchanger was used with the addition of a solar ETC. The design models were simulated within Polysun based on the DHW demand.

Input parameters used in the selected software for the simulation of the water heating models included hot water demand data obtained from the random survey and weather data that is, ambient temperature (Tamb), global irradiation (Gh), diffuse irradiation (Dh) obtained from a built-in weather data generator, Meteonorm, which is an integral part of the Polysun Software. The following parameters were used to perform calculations for the analysis of the water heating models:

(i) Electricity Rates - Average T&T subsidized rate at US$ 0.047 per kWh and unsubsidized rate at US$ 0.12 per kWh[30].

(ii) CO_2 Emission rate - 0.7 kg per kWh of carbon emissions based on electricity generation in T&T from natural gas[30].

3.3 Solar performance

Performance parameters including the total Gh on collector aperture area, solar fraction, collector efficiency (ratio of the given solar thermal energy to the system (Qsol) to the Gh on aperture area (Esol)) were obtained from Polysun to evaluate the SWH system.

3.4 Conducting and evaluating the electricity consumption of models.

Annual and monthly total ECS of the water heating models were calculated within Polysun. For both models, the auxiliary internal heating element was set for four hours per day. The ECS required to obtain a set DHW temperature of 50°C in both models were compared. The total electricity savings was calculated and analysed over the lifetime of the SWH.

3.5 Evaluation of the environmental and economic viability of mode

Based on the ECS obtained for both models and their associated electricity savings, a carbon emission rate of 0.7 kg CO_2 per kWh was applied to generate an estimation of the amount of CO_2 emissions for both systems, along with the amount of CO_2 that can be mitigated over the lifetime of a SWH. Using the subsidized rate of electricity, the cost of ECS by the EWH and SWH, as well as the cost of electricity savings, were determined over the lifetime of the SWH. The economic parameter of the SPP of the SWH was calculated.

3.6 Sensitivity analyses on prospective model

The input variable of the electricity rate was increased above the subsidized rate and its effect on the SPP of the SWH was measured. Another sensitivity analysis involving the tilt angle of the solar collector was conducted at intervals of 15° to determine its effect on the collector efficiency.

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4 RESULTS AND DISCUSSION

4.1 DHW consumption profile

According to Marzolf[31], an average household in T&T consists of four persons and consumes about 16.5 kWh per day for all energy services. Many of these households have basic appliances, not including EWHs. EWHs account for 45% of ECS in a typical household with AC units[14]. The survey conducted in households in Southern Trinidad found that the most common types of EWHs used presently are shower heads, tank, and tankless models. DHW data collected within the survey found that a 150 L or 40-gallon tank EWH, at 4 kW power consumption, is mostly used in a three-to-five-person household with an average DHW temperature of 50°C and average water inlet temperature of 25 to 27°C. DHW consumption varies from one household to another, depending on the time of the day, day of the week, or season of the year. However, in most cases, peak energy consumption is in the morning, late afternoon, and evening when occupants get home from work. The DHW data obtained were used as parameters for the water heater designs utilizing the Polysun software.

4.2 Weather data

The weather data generator Meteonorm of the Polysun Software was used to obtain the most up-to-date monthly weather data from the selected location. The software requires calculated hourly data of the following parameters from external monthly values; Gh (Wh m^{-2}), Dh (Wh m^{-2}), Long Wave Irradiation (Lh) (Wh m^{-2}), Tamb (°C), Wind Speed (Vwnd) (m s^{-1}) and Air Humidity (Hrel) (%).

SWH, a system's performance depends primarily on the outdoor temperature to which water is heated and the amount of sunlight that reaches the collector. Fig. 2 shows the monthly variation of Tamb in Southern Trinidad provided by Meteonorm Webservice in Polysun Software. T&T's Meteorological Service Center indicates that the wet season temperatures are commonly warmer than the dry season temperatures with September being the warmest wet season month and May the warmest in the dry season[32]. It was found that the average Tamb is 26.8°C, the highest temperature (27.6°C) was obtained in September 2022 and the lowest temperature (25.8°C) was obtained in January 2022.

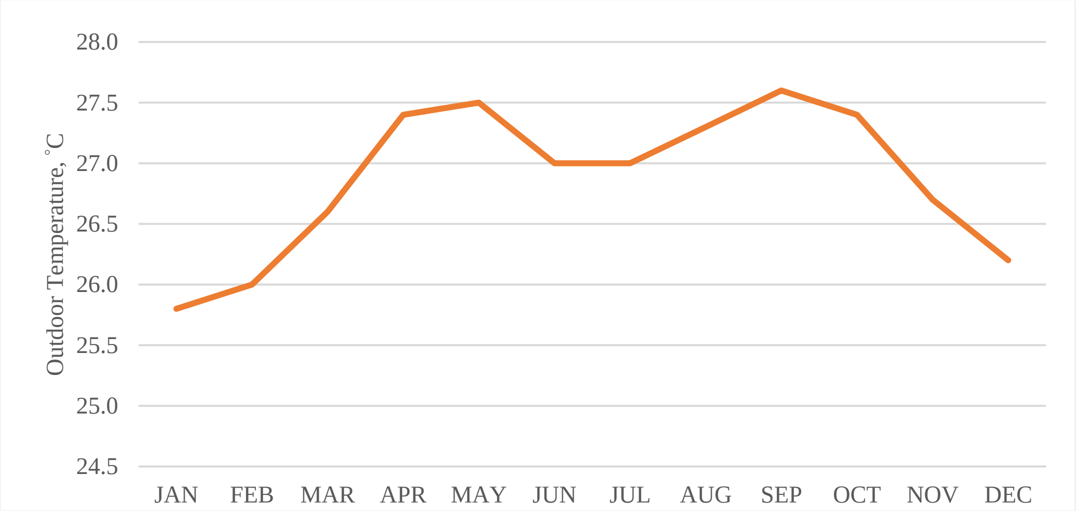

Fig. 2. Ambient monthly temperature in Southern Trinidad.

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4.3 Water heating model designs

The EWH base model

Based on the DHW consumption data obtained from the survey, a model of the EWH system was designed in Polysun and is shown in Fig. 3.

The structure of the EWH system consists of a 200 L storage tank with a built-in internal heater, an auxiliary heating controller, a mixing valve controller, pipelines, a three-way valve, a cold water inlet, a hot water outlet, and a residential building, with an assumption that the roof is flat.

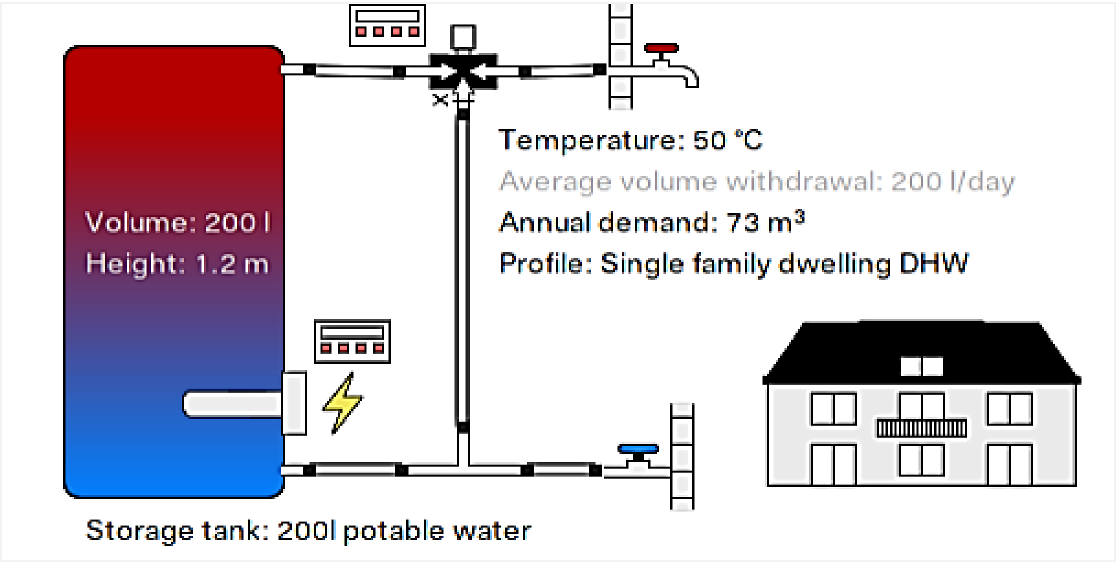

Fig. 3. Polysun schematic design of an EWH.

The SWH ideal model

Fig. 4 shows the ETC thermosyphon SWH design, similar to the previously designed EWH system but with slight variations of the storage tank and the addition of the Solar ETC.

Parameters and specifications of both EWH and SWH systems are summarized in Table 1. Although a 150 L or 40-gallon storage tank was found to be commonly used in a four-person household in T&T, a 200 L or 53-gallon storage tank was chosen in both designs since it was the smallest tank size available within Polysun and it was also used in other studies from the literature. Distribution of heat within the tank was taken into consideration as water is stratified at different temperatures with the hottest water being found at the top. Stratification is desirable as it allows for the generation of the least possible turbulence during the transfer of heat to the tank and the withdrawal of water[33].

DHW demand can be obtained even in periods of bad weather using the SWH since water in the tank can be heated up to 95°C which can last several days, and the desired temperature can be achieved by mixing with cold water[33]. Efficient transfer of heat from the ETC to the tank was accomplished using an internal heat exchanger, whereby the solar liquid is pumped through a copper coil inside the tank. The design utilized an auxiliary electrical heating element (4 kW and 2 kW elements for the EWH and SWH respectively). The operating times of the auxiliary heating were set to four hours per day but at different times for each system consistent with the findings of the survey where operating hours of an EWH are usually from 5-7 a.m. and 6-8 p.m. The SWH utilized the auxiliary heating only when irradiation no longer

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reached the collector or when the level of required heat was not obtained in the tank. Control of the auxiliary elements was accomplished using temperature sensors with the switch-on temperature set at 25°C and the switch-off temperature set at 60°C. For conditions in T&T, the total aperture and absorber areas were set at 1.85 m^2 and the optimum ETC orientation was facing South at a 45° tilt angle, on a flat roof.

Table 1. Design parameters of the EWH & SWH systems

Parameter	EWH	SWH
Number of persons in household	4	4
Occupancy rate	100%	100%
Hot water demand		
Profile	Single Family Dwelling DHW	Single Family Dwelling DHW
Hot water temperature	50°C	50°C
Average volume withdrawal	200 L per day	200 L per day
Annual demand	73 m^3	73 m^3
Storage Tank		
Volume	200 L	200 L
Material	Stainless Steel	Stainless Steel
Height	1.2 m	1.2 m
Wall thickness	2.5 mm	2 mm
Insulation	Rigid Polyurethane Foam	Polyurethane Foam
Thickness of insulation at top of tank	80 mm	50 mm
Thickness at tank base	50 mm	50 mm
Internal heater	Electric resistance	Electric resistance
Internal heater capacity	4 kW	2 kW
Auxiliary heating controller		
Operating days per week	7 days	7 days
Operating hours per day	4 hrs.	4 hrs.
Cut-in differential	25°C	25°C
Cut-off differential	60°C	60°C
Maximum tank temperature	95°C	95°C
Pipe		
Pipe material	Copper 22x1	Copper 22x1
Insulation	Loose glass fibres & mineral wool	Loose glass fibres & mineral wool
Solar evacuated-tube collector		
Number of collectors	-	1
Number of arrays	-	1
Total gross area	-	3 m^2
Parallel piping	-	20
Total aperture area	-	1.85 m^2
Total absorber area	-	1.85 m^2
Tilt angle	-	45°
Orientation (E = +90°, S = 0°, W = –90°)	-	South
Pump: Natural convection		
Circuit pressure drop	-	0.002 bar
Flow rate	-	17.9 L per hr
Solar loop		
Fluid mixture	-	Propylene mixture
Fluid concentration	-	33.3%
Fluid domains volume	-	11L
Pressure on top of circuit	-	4-bars

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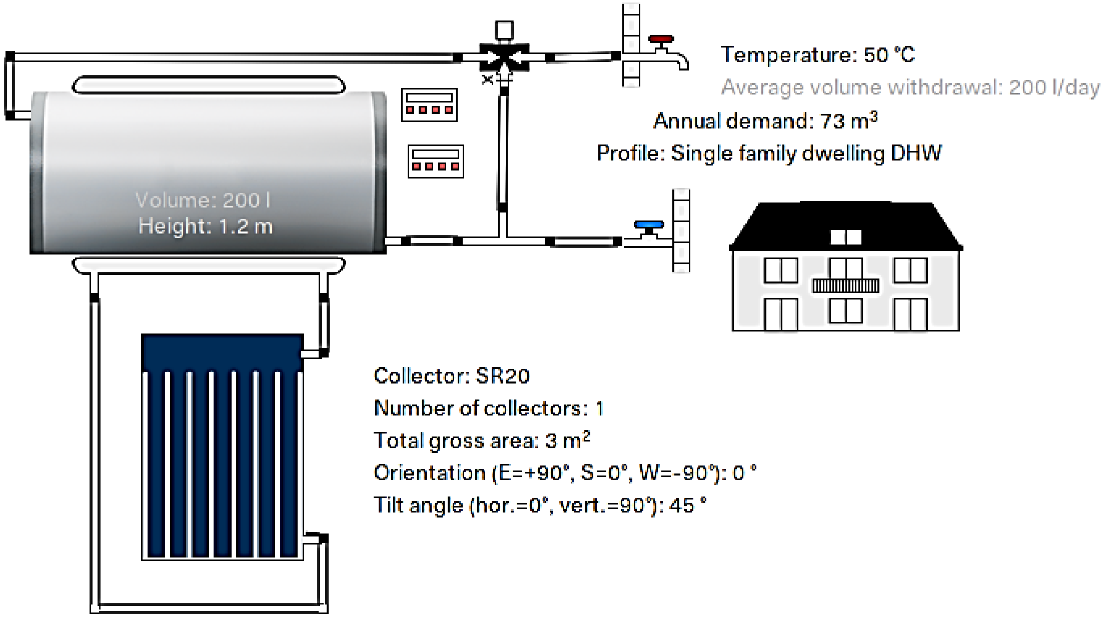

Fig. 4. Polysun schematic design of a SWH.

4.4 Solar performance parameters

Fig. 5 above shows the monthly irradiance power (kWh) generated from the simulation onto the collector-sloped aperture area. The result shows that the available power gradually decreased up to June and then increased for the rest of the year. The total Gh in the collector area for the year was 2,842 kWh, while the highest power at 310 kWh was obtained in January, and the lowest power at 164 kWh was obtained in June. Evidence that the SWH collector was able to utilize the energy from the sun efficiently is also demonstrated in Fig. 5, as the efficiency of the solar collector had a positive association with the solar Gh. The efficiency varies throughout the year from 46.8% to 55.6%, with an annual average of 52.6%. Collector efficiency can also be affected by many factors such as Tamb, slope of collector, collector area, dust built-up on collector surface and heat losses from the collector[34]. Solar fraction refers to the percentage of the required energy supplied by the sun to the system. The higher the solar fraction, the greater the solar contribution to water heating and the lower the energy needed for the auxiliary heating element[34]. The average monthly solar fraction shown in Fig. 5 is 54%, ranging between a minimum of 39% (June) and a maximum of 64.1% (January).

4.5 Electricity consumption analysis

For both water heating systems, the simulations showed that the total energy demand value was 1,507 kWh (energy required to heat the inlet (cold) water to the desired hot water temperature) and the associated total annual ECS was 2,777 kWh and 1,339 kWh for the EWH and SWH respectively. The use of the SWH resulted to a savings of 1,438 kWh (52%) in annual ECS. According to Millennial Management[35], the minimum lifetime of a SWH is 15 years and if applied, it is translated to approximately 21,570 kWh reduction over the lifetime of the SWH. A comparison of the total monthly ECS for both systems are presented in Fig. 6 along with the monthly ECS savings.

The results show that the total monthly ECS did not vary significantly throughout the year as the hot water demand was said to be fairly constant throughout the year peaking in the cooler months (December to March).

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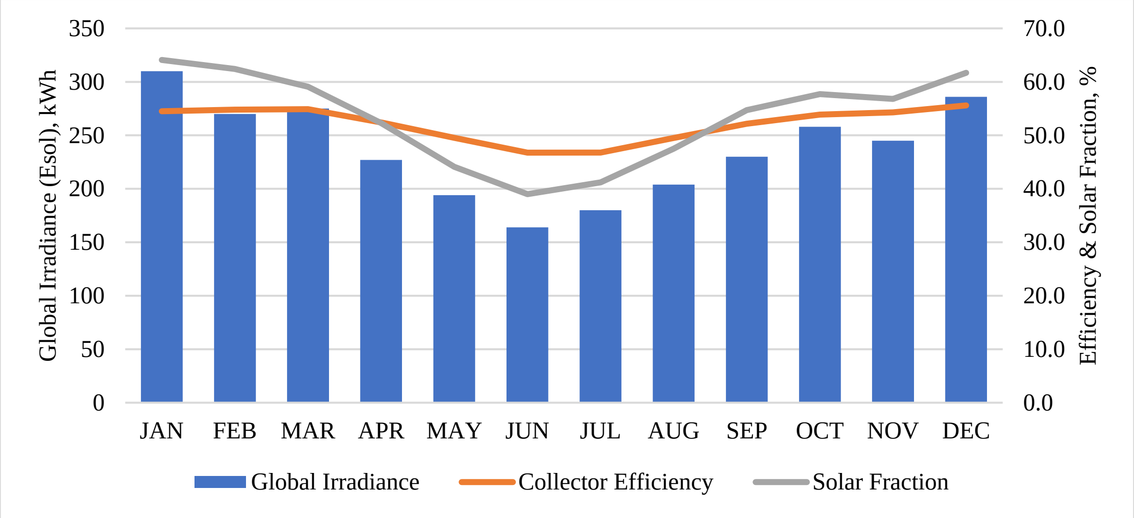

Fig. 5. Global Irradiance onto collector aperture area, collector efficiency and solar fraction.

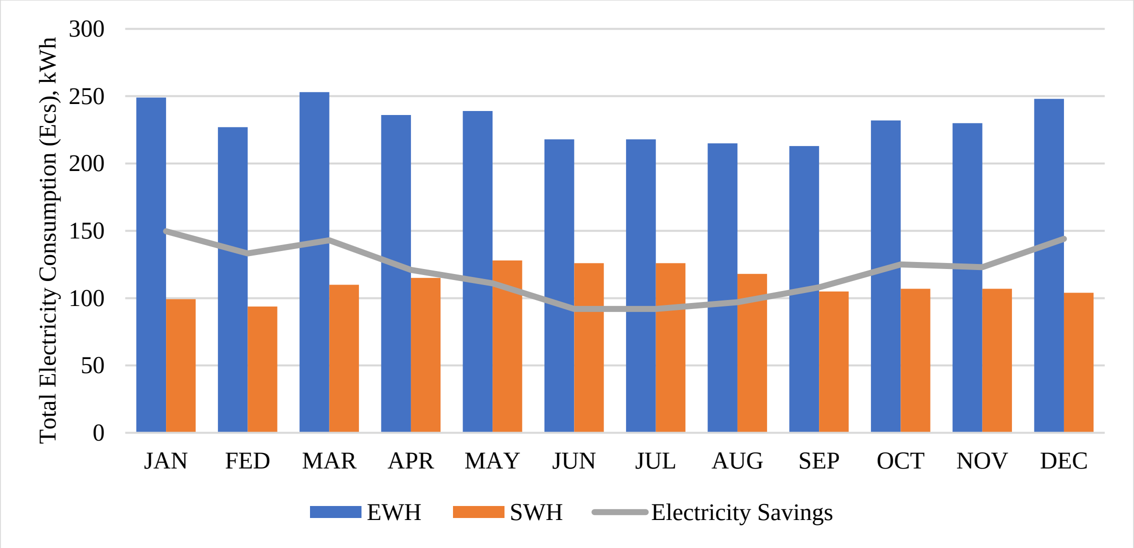

Fig. 6. Total monthly ECS of the EWH and SWH systems and electricity savings.

4.6 Environmental analysis

The CO_2 emissions associated with the designed SWH and EWH systems were determined using a CO_2 emission factor of 0.7 kg per kWh based on electricity generation from natural gas[30]. This factor is the level of CO_2 emitted per unit input energy and was derived using Equation 1.

$$CO_2 \text{ emissions} = \text{ECS} \times CO_2 \text{ emissions factor} \quad (1)$$

Fig. 7 shows the monthly variation of the CO_2 emissions from the EWH and SWH systems and the resulting savings.

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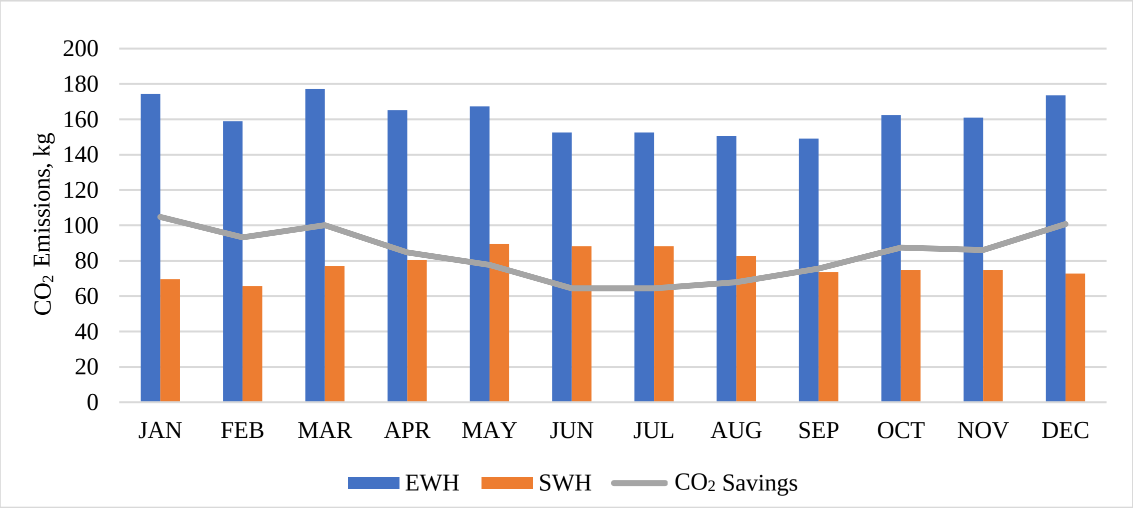

Fig. 7. Monthly CO_2 emissions from the EWH and SWH and CO_2 savings.

Fig. 6 demonstrates the significant monthly reductions in CO_2 emissions (between 42-60%) associated with the SWH system. The conventional EWH can emit a total of 1,943.9 kg CO_2 per year compared to the SWH due to the use of an auxiliary heating value of 937.3 kg CO_2 per year. Replacing the EWH with a SWH can save approximately 1,006.6 kg CO_2 per year and 15,099 kg CO_2 over the lifespan of a SWH for an average household. It would significantly contribute to achieving T&T's NDC target[36].

4.7 Economic analysis

The economic feasibility associated with the transition from an EWH to SWH depends on the initial cost of the system (inclusive of installation cost), the lifespan of the system, the cost of ECS and the payback period. Currently in T&T, electricity is charged at a subsidized rate of US$ 0.047 per kWh with the unsubsidized rate being US$ 0.12 per kWh with the present currency exchange rate at US$ 1.00 equal to TT$ 6.79[30,37].

Using the current subsidized electricity rate, the total cost of ECS by both systems and its associated savings were calculated and presented in Table 2. It was found that an average household in T&T pays a total of TT$ 886.22 per year using a conventional tank EWH while usage of the SWH will cost approximately TT$ 427.32 per year (savings of TT$ 458.91 or 52%).

The SPP which refers to the number of years necessary to recover the initial investment cost of a SWH was calculated from the ratio of the initial investment and the annual savings[34]. Using the initial investment as the supply and installation cost of a 200 L SWH as TT$ 13,000 (obtained from a local supplier) and the annual savings at TT$ 458.91, the SPP was calculated to be approximately 29 years. The SPP is relatively high as compared to typical acceptable values of between 2 to 8 years indicated in the literature and is associated with the subsidized cost of electricity in T&T. When the 100% tax credit incentive (up to TT$ 10,000) on the cost of a SWH introduced in 2020 is applied, the SPP would be reduced to approximately 7 years.

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Table 2. Calculated monthly subsidized costs of electricity consumed by the EWH and SWH

	Consumed Electricity Costs (TT$)		
	EWH	SWH	Cost Savings
Jan	79.46	31.69	47.77
Feb	72.44	29.93	42.51
Mar	80.74	35.10	45.64
Apr	75.31	36.70	38.61
May	76.27	40.85	35.42
Jun	69.57	40.21	29.36
Jul	69.57	40.21	29.36
Aug	68.61	37.66	30.96
Sep	67.97	33.51	34.47
Oct	74.04	34.15	39.89
Nov	73.40	34.15	39.25
Dec	79.14	33.19	45.95
Year	886.22	427.32	458.91

4.8 Analysis of the influence of the cost of electricity

There is a planned rate increase of the current subsidized electricity rate of between 40% and 65.75% (equivalent to a rate increase of between TT$ 0.45 and TT$ 0.54) for residential customers in T&T[38]. The increase in the cost of electricity will affect the SPP of the SWH option and the expected results are depicted in Fig. 8.

As discussed earlier, at the current subsidy level with a 100% tax credit, the SPP of a SWH will be at approximately 7 years. However, it will steadily decrease as electricity rates are increased over approximately 4 years to a rate increase of 65.75%. Suppose the unsubsidized rate of electricity of TT$ 0.82 per kWh (US$ 0.12 per kWh) is considered and the electricity rate is increased to between 40% and 65.75% (unsubsidized rate of between TT$ 1.14 per kWh and TT$ 1.35 per kWh). In that case, the SPP of the SWH will decrease even further as shown in Fig. 8.

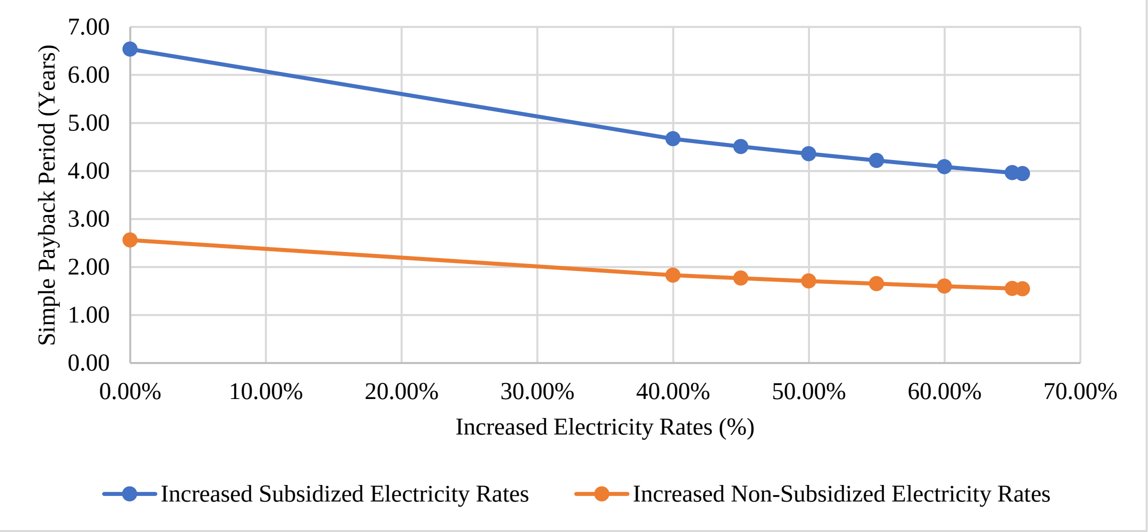

Fig. 8. The impact of increased electricity rates (via reduction in subsidy levels) and increased non-subsidized electricity rates on the SPP of a SWH.

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The results of this scenario show that if a 100% tax credit is applied in the calculation of SPP, the SPP of a SWH at the current unsubsidized electricity rate will decrease to approximately 2 years and 1.5 years after a 40% and 65.75% increase in rates, respectively.

When T&T is compared to other islands in the Caribbean, the highest price scenario considered in this study which was total subsidy removal with an increase in electricity rate of 65.75%, the new rate of TT$ 1.35 per kWh (US$ 0.20 per kWh) is still significantly lower than the rates in other Caribbean territories which average around US$ 0.35[36]. It is likely that as electricity prices increase, the penetration of RE technologies including the use of SWHs will increase.

The study offers valuable insights and recommendations for policymakers aiming to foster the adoption of SWHs. To drive sustainable change in the energy sector, the government can utilize these findings in several ways. Firstly, creating public awareness is of utmost importance, with public awareness campaigns educating residents about the advantages of SWH systems, such as cost savings, reduced emissions, and improved energy security. This awareness forms the basis for widespread SWH adoption. Furthermore, policymakers can enhance SWH accessibility by offering financial support, such as low-interest loans and means-tested subsidies, which can help alleviate financial barriers, particularly for lower-income households. Updating regulations, building codes, and collaborating with industry stakeholders to establish standards and certification programs can improve SWH system quality and build consumer trust. At the same time, partnerships with local businesses and non-governmental organizations can further enhance SWH accessibility. Investing in research and development, supporting vocational training initiatives, and continuously assessing policy impact are essential steps. Additionally, fostering knowledge-sharing and partnerships with other nations and international organizations can boost the effectiveness of SWH adoption initiatives. Encouraging green building certification systems that reward the use of SWH technology and providing information to consumers about the long-term cost savings and environmental benefits of SWH systems through workshops and webinars can complement these efforts. By implementing these recommendations, the government can drive sustainable change in the energy sector, promoting SWH adoption, reducing carbon emissions, and enhancing energy security.

Social, cultural, and technological factors are crucial to research for adopting SWHs because they directly influence people's willingness to embrace and invest in this RE technology. The government can collect information on social, cultural, and technological factors affecting the adoption of SWHs through methods like surveys, focus groups, interviews, online platforms, community meetings, collaboration with local organizations, pilot programs, academic studies, government hotlines, social media, and public workshops. By engaging the public through these diverse approaches, the government can gain valuable insights to effectively shape policies and strategies for promoting SWH adoption.

The government should seek to obtain a comprehensive understanding of the factors influencing the adoption of SWHs in T&T through a multifaceted approach. Demographic segmentation is crucial to identify trends within specific groups, including age, gender, location, education, occupation, household income, and composition. Behavioural segmentation should categorize respondents into core groups based on attitudes and preferences related to SWH adoption. Understanding respondents' perceptions of electricity supply, ownership of electrical appliances, and their income levels will provide insights into economic factors. It's essential to gauge respondents' knowledge of energy efficiency concepts, familiarity with SWHs, and their willingness to change energy consumption habits. Assessing their attitudes towards energy, perception of SWHs, awareness of electricity subsidies, preferred communication channels, bill payment habits, and reactions to potential rate increases will help shape informed policies and strategies for promoting SWH adoption tailored to the diverse needs and preferences of the population.

5 CONCLUSION

In this study, the appropriate EWH and SWH systems were designed and simulated using the Polysun software and their performances were compared. The EWH and SWH both incorporated a 200 L or 53-gallon storage tank utilizing an auxiliary electrical heating element (4 kW and 2 kW elements for the

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EWH and SWH, respectively). The total annual electricity requirement for DWH was calculated to be 2,777 kWh and 1339 kWh using the EWH and SWH, respectively, resulting in 52% SWH savings per year. With a DHW temperature set at 50˚C, the EWH has an estimated 1,943.9 kg CO_2 per year emissions compared to 937.3 kg CO_2 per year associated with the SWH. The use of the SWH can result in an annual savings of TT$ 458.91. Using the current subsidized electricity rate at US$ 0.047 per kWh and the 100% tax credit on the cost of a SWH, the SPP of the SWH was approximately 7 years. The application of the government's proposed electricity rate increased between 40 to 65.75% and reduced the SPP to between 4 and 5 years. The SPP of the SWH was further reduced to 1.5 and 2 years when the proposed rate increases were applied to the unsubsidized rate of US$ 0.12 per kWh. The highest rate of US$ 0.20 per kWh considered in this study resulted in a SPP of 1.5 years, and this rate is significantly lower than the rates in other Caribbean territories, which average around US$ 0.35.

As the Government of T&T moves to achieve its NDCs and policies such as subsidy removal and electricity rate increases take effect, this study demonstrated the economic and environmental feasibility of the SWH compared to the conventional EWH. It also provides the scientific justification for implementation of SWHs.

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CONFLICT OF INTEREST

The author declares that there was no conflict of interest.

AUTHORS’ CONTRIBUTIONS

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Formal analysis: V. Hosein
Visualisation: Not applicable
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