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Solar water heater uses in hotels in Pacific Island Countries: Techno-economic-environmental analysis for a typical hotel in Fiji

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ABSTRACT

The hospitality sector in Pacific Island Countries (PICs) remains highly dependent on. imported fossil fuels for hot-water production, contributing to high operating costs and greenhouse-gas (GHG) emissions. This study evaluates the techno-economic and environmental feasibility of a glazed flat-plate solar water-heating (SWH) system for a representative 46-room, 3-star hotel in Rakiraki, Fiji. A design hot-water demand of 1,500 L day^{-1} was estimated for 70% occupancy, and RETScreen Expert was used to assess alternative storage-to-collector-area ratios. The selected 80 L m^{-2} configuration was independently compared using the System Advisor Model (SAM). The system achieved a solar fraction of 45.5% and first-year energy savings of approximately 9,996 kWh, reducing operational carbon dioxide (CO_2) emissions by about 3.5 t/year. The baseline RETScreen case yielded a simple payback period (SPP) of 7.7 years and a net present value (NPV) of FJD 15,151. Under a conservative lifecycle scenario incorporating annual operating expenditure (OPEX), pump electricity, 0.5% annual degradation, and 3% cost escalation, payback increased to approximately 8.3 years and NPV decreased to FJD 13,078. Findings indicate that SWH is technically feasible and financially attractive for reducing diesel dependence in Fiji's hotel sector while providing decision-support evidence for sustainable energy planning in island tourism.

Keywords

Solar water heating;
Techno-economic analysis;
RETScreen;
Sustainable energy planning;
Hotel energy systems;

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Abbreviations

CAPEX	Capital expenditure	OPEX	Operating expenditure
CO_2	Carbon dioxide	PICs	Pacific Island Countries
EPP	Equity payback period	SAM	System Advisor Model
FJD	Fijian dollar	SDGs	Sustainable Development Goals
GHG	Greenhouse gas	SIDSs	Small Island Developing States
IRR	Internal rate of return	SPP	Simple payback period
LEDS	Low Emission Development Strategy	SWH	Solar water heating
NPV	Net present value		

1. Introduction

Pacific Island Countries (PICs) are globally recognised for their rich natural environments and tourism-driven economies. However, these nations face persistent challenges in achieving sustainable development due to their heavy reliance on imported fossil fuels for energy production and consumption. Recent assessments indicate that energy imports in PICs have declined only marginally over the past decade, leaving these economies highly exposed to global fuel price volatility and external supply shocks [1]. Such vulnerabilities are particularly pronounced for Small Island Developing States (SIDSs), where limited domestic energy resources and dispersed island geographies constrain large-scale energy infrastructure development [2, 3].

In parallel with energy security concerns, climate change is intensifying energy demand across many island states. Rising ambient temperatures increase cooling loads and can alter building-service energy requirements. Fiji has experienced rising average temperatures and more frequent hot days and nights, trends that are projected to continue [4]. Recent building-energy research also demonstrates the value of localized climatic data and real-time monitoring when evaluating thermal performance, because generalized coefficients may not fully represent site conditions [5]. These considerations reinforce the need for low-carbon energy solutions and transparent treatment of climatic inputs in island contexts.

Tourism remains a cornerstone of economic growth in many PICs and is among the most energy-intensive sectors in these economies. In hotel facilities, energy consumption is dominated by electricity and thermal energy demand, with hot water production representing a substantial share of total energy use [6-8]. Studies have shown that hotel laundries, kitchens, and guest services require continuous hot water supply, often generated using electricity or diesel-fired boilers [9]. As a result, the hotel sector contributes disproportionately to greenhouse gas (GHG) emissions, highlighting the importance of targeted mitigation strategies to reduce its environmental footprint [10, 11].

Solar thermal technologies, particularly solar water heating (SWH) systems, have emerged as a technically mature and cost-effective option for reducing fossil fuel consumption in hot water applications. Previous studies conducted in hotel settings across Europe and other regions have demonstrated substantial energy savings and emission reductions following the adoption of SWH systems [12, 13]. More recent research confirms the suitability of solar thermal technologies for tourism facilities in tropical and island environments, where high solar irradiance and year-round hot water demand create favourable operating conditions [14].

Transitioning to renewable energy technologies offer significant potential to reduce both operational costs and emissions in the hospitality sector. Energy expenses can account for up to 60% of total hotel operating costs in Pacific Island contexts [15]. Despite this, publicly available data on hotel energy consumption and hot water usage in Fiji remain limited. An assessment of twenty-four hotels in Fiji identified substantial energy-saving potential through efficiency measures but did not explicitly evaluate the role of SWH systems in reducing fuel consumption and emissions [16]. While early studies have confirmed the technical feasibility of SWH systems in the South Pacific [17], detailed techno-economic analyses focused on Fiji's hotel sector remain scarce, particularly when compared to countries such as Taiwan, where comprehensive datasets and supportive policy frameworks have enabled widespread adoption [18].

According to Fiji's Low Emission Development Strategy (LEDS 2018–2050), commercial buildings

including hotels rely primarily on electricity, liquefied petroleum gas (LPG), and diesel for thermal energy services [7]. A review of energy practices in six Fijian hotels found that only two had installed SWH systems, despite broader interest in renewable energy and energy efficiency measures [19]. Policy reviews indicate that high initial cost, limited access to concessional finance, and weak technology-specific incentives continue to constrain commercial deployment [20]. Adoption is also influenced by awareness, trust, perceived compatibility, and user experience; these social-acceptance factors should therefore complement purely technical and financial interventions [21].

From a sustainable energy planning and management perspective, hotel SWH should be considered not only as an equipment-level efficiency measure but as a distributed renewable-heat investment that links end-use demand, locally available resources, technology sizing, operating conditions, finance, and policy. Island-energy planning research emphasises the importance of context-specific modelling that reflects local resource constraints, demand characteristics, and implementation conditions [22, 23]. For solar thermal planning, spatial and temporal matching of solar resources with thermal demand is important when determining the appropriate role and scale of SWH within the energy mix [24]. In tourism, sustainable energy management also depends on organisational readiness and operational characteristics, while hotel-focused renewable-thermal studies show that occupancy, integration with existing systems, scheduling, and techno-economic performance can materially affect investment outcomes [25, 26]. These studies position building-scale renewable heat as a component of broader energy-planning decisions rather than an isolated technology choice.

A range of modelling tools has been employed internationally to assess the performance and economic feasibility of SWH systems. RETScreen and EnergyPlus have been widely used for system sizing and performance evaluation [27], while custom software and MATLAB-based tools have been developed for small-scale applications [28]. The System Advisor Model (SAM), developed by the National Renewable Energy Laboratory (NREL), has also been applied to assess the techno-economic performance of SWH systems under diverse climatic and tariff conditions [29-31]. However, the application of dual-model validation approach using both RETScreen and SAM remains limited in the context of small island tourism facilities.

The literature therefore reveals a clear gap in detailed, hotel-scale assessments of hot-water demand and SWH performance in Fiji and the wider South Pacific. Although similar techno-economic studies exist for other tropical and island settings, few combine site-informed demand estimation, storage-ratio screening, probabilistic risk analysis, and independent RETScreen-SAM comparison for a Pacific hotel. Within sustainable energy planning and management, the missing evidence is not only whether SWH can operate technically, but how a distributed renewable-heat option performs under site-specific demand, storage, financing, occupancy, and lifecycle uncertainty and how such evidence can inform sectoral investment and policy decisions. The contribution of this study is therefore methodological as well as location specific: it provides a reproducible dual-model framework, quantifies model disagreement, tests occupancy and lifecycle assumptions, and translates the results into planning-relevant evidence for technology portfolios, hotel energy standards, financing programmes, and decarbonisation strategies in data-limited SIDSs. This focus is consistent with broader evidence that renewable-energy expansion can reduce carbon dioxide (CO_2) emissions and support evidence-based environmental policy [32].

Against this backdrop, the present study aims to address this gap by conducting a techno-economic and environmental assessment of a glazed flat-plate hybrid SWH system for a representative 3-star hotel in Fiji. The specific objectives of the study are to:

(i) estimate the energy required to meet the hot water demand of a hotel located in Rakiraki, Fiji.
(ii) design and evaluate a cost-effective and environmentally sustainable hybrid SWH system using RETScreen; and
(iii) validate the RETScreen results through independent simulation using the SAM.

The remainder of the paper is organised as follows: Section 2 presents an overview of solar resources and the status of SWH deployment in the Pacific region. Section 3 describes the methodology and modelling approach. Section 4 discusses the results, compares the findings with similar studies, and outlines the study's limitations. Section 5 concludes the paper and identifies directions for future research.

2. Solar Resource Availability, Solar Water Heating Deployment, and Energy Planning Context in the Pacific

PICs are endowed with abundant solar energy resources due to their tropical latitudes, with average

global horizontal irradiance typically exceeding 4.5–5.5 kWh m^{-2} day^{-1} across much of the region [33, 34]. In Fiji, satellite-derived datasets and long-term climate observations indicate relatively stable solar availability throughout the year, with only modest seasonal variation [33, 35]. These conditions are particularly favourable for solar thermal applications, such as SWH, which require consistent irradiance rather than peak power output.

Despite this high solar potential, the penetration of solar thermal technologies in the Pacific remains limited. The energy sectors of many PICs continue to rely heavily on imported diesel and LPG for electricity and thermal energy services, particularly in commercial and tourism facilities [7, 36]. Although national and regional strategies increasingly recognise renewable energy as a pathway to improving energy security and reducing emissions, deployment has focused predominantly on solar photovoltaic systems, while solar thermal technologies have received comparatively less attention [37, 38].

In Fiji, the tourism sector represents a significant opportunity for SWH deployment due to its high and continuous hot water demand. Government assessments indicate that hotels primarily use electricity, LPG, and diesel for water heating, contributing substantially to operational costs and GHG emissions [7]. While a small number of hotels have adopted SWH systems, uptake remains sporadic and largely limited to pilot projects or early adopters [19]. Barriers to wider adoption include high capital expenditure (CAPEX), limited awareness of long-term economic benefits, and the absence of targeted financial incentives for solar thermal technologies [20, 36].

From a technological perspective, flat-plate and evacuated tube collectors are the most commonly available SWH technologies in the Pacific region. Flat-plate collectors are generally favoured in tropical island contexts due to their robustness, lower maintenance requirements, and cost effectiveness under high ambient temperature conditions [39, 40]. Regional guidelines and technical manuals further recommend flat-plate SWH systems for hotel applications where roof space is available and hot water demand is distributed throughout the day [41, 42].

Recent regional studies and policy reviews emphasise the need to expand renewable thermal energy deployment as part of broader decarbonisation strategies for the tourism sector in PICs [37, 43]. Integrating SWH systems into existing hotel infrastructure offers a practical and scalable solution to reduce fossil fuel dependence, enhance energy resilience, and support national climate commitments. However, achieving this potential requires site-specific techno-economic assessments that account for local climatic conditions, energy prices, and demand profiles, an evidence gap that this study seeks to address.

In sustainable energy planning context, the relevance of SWH extends beyond annual solar yield. Decision-makers require evidence on the alignment between thermal demand and local solar resource, the scale of fuel displacement, investment and operating costs, service reliability, and sensitivity to changing occupancy or financing conditions [22-26]. For Fiji, these factors connect building-level heat decarbonisation with broader objectives for reducing imported-fuel exposure, improving tourism-sector energy management, and implementing national low-emission strategies [7, 37, 43]. The present case study therefore treats the hotel as a bottom-up planning unit whose results can inform wider commercial-sector renewable-heat programmes, while recognising that other properties require site-specific recalibration.

3. Methodology

This study adopts a techno-economic-environmental assessment framework to evaluate the feasibility of integrating a hybrid SWH system into an existing diesel-fired hot water system for a 3-star hotel in Rakiraki, Fiji. The methodology combines demand assessment, system design, performance simulation, and financial evaluation using two established modelling tools, RETScreen Expert and the SAM, to enhance the robustness and credibility of the results.

3.1 Overview of the Assessment Framework

The overall methodological framework is presented in Figure 1, which illustrates the sequential steps followed in the study. The process comprises: (i) preliminary research and a critical review of the relevant literature; (ii) collection and analysis of data on the hotel's hot-water demand; (iii) modelling and simulation of the proposed SWH system using RETScreen; (iv) evaluation of the system's technical, economic, and environmental feasibility; (v) validation of the RETScreen results using the SAM; and (vi) interpretation and reporting of the findings.

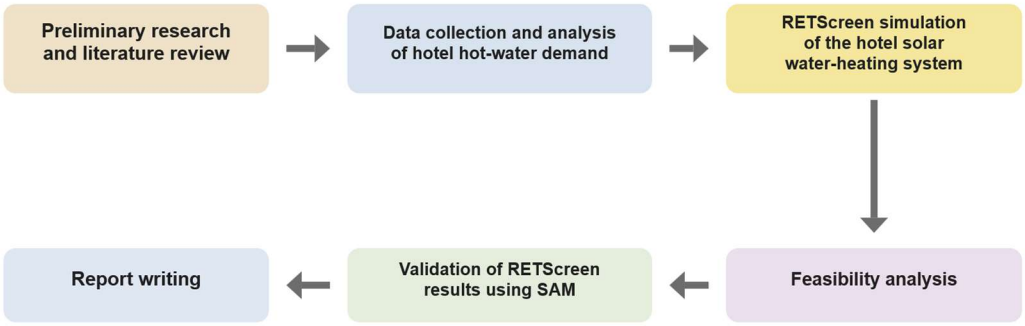


Figure 1: Standardized methodological workflow used in the study

To improve model transparency and reproducibility, the internal workflow of the two simulation tools is presented in Figure 2(a) and Figure 2(b). These flowcharts highlight key input parameters, calculation stages, and output indicators used in the analysis.

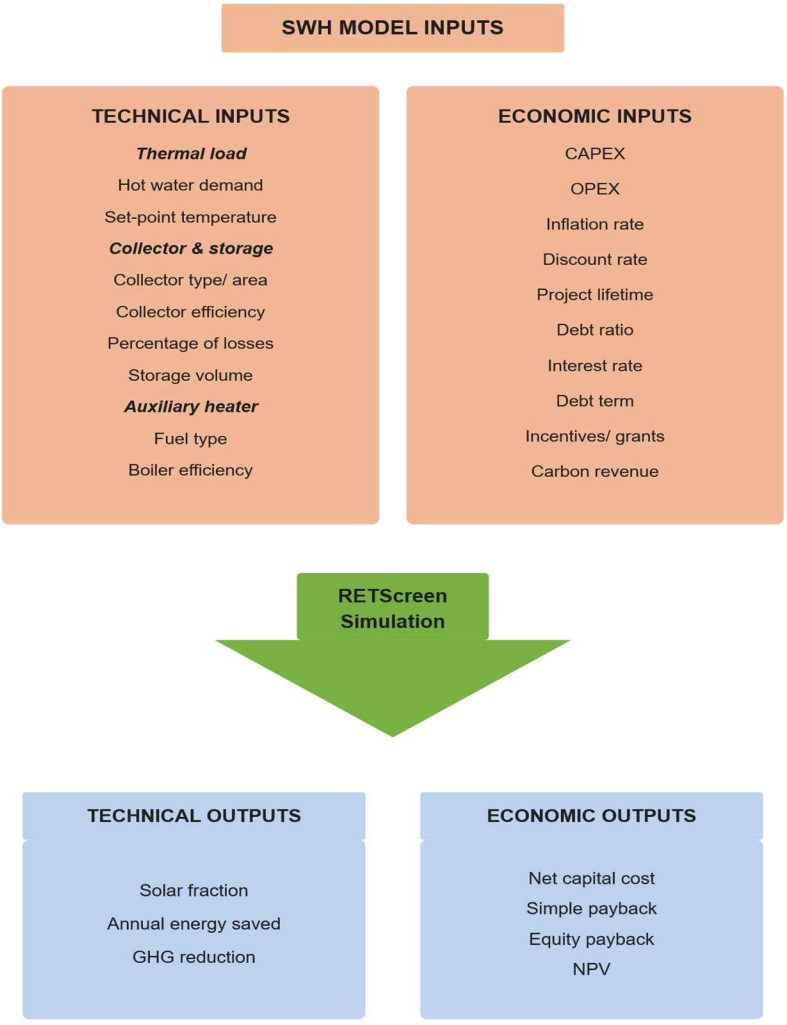


Figure 2(a): RETScreen-based SWH assessment workflow

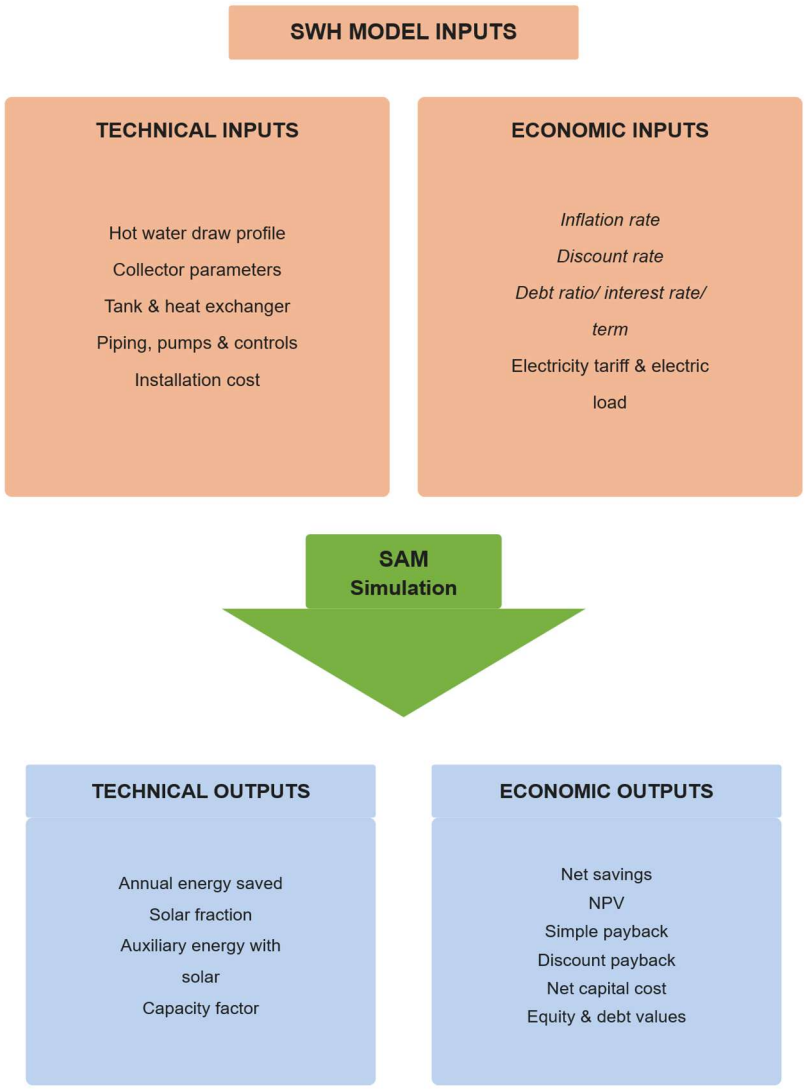


Figure 2(b): SAM-based SWH assessment workflow

3.2 Description of the Case Study Hotel and Existing System

The case study considers a 46-room, 3-star hotel in Rakiraki on the northern coast of Viti Levu, Fiji. Rakiraki was selected because it combines a tourism-based local economy, year-round solar availability, dependence on imported diesel, and access to operational information from an existing hotel hot-water system. The 3-star category represents a medium-scale property with continuous guest-room, kitchen, and laundry demand but without the very high service intensity and capital resources typically associated with luxury resorts. The case is therefore relevant to many small and medium hotels in Fiji and other PICs, although transfer to other properties should account for differences in occupancy, service level, climate, and fuel price. Based on site observations and information obtained through interviews with hotel management, Figure 3 illustrates the existing diesel-boiler system configured as a closed-loop hot-water circulation system [44].

The design hot-water demand was estimated rather than directly metered. At the base occupancy of 70%, the calculation is 46 rooms × 0.70 × 2 guest room^{-1} × 20 L guest^{-1} day^{-1} = 1,288 L day^{-1} for guest use. A further 212 L day^{-1} was assigned to kitchen and laundry activities from the hotel audit and management interview, giving

a total of 1,500 L day^{-1} [44, 45]. RETScreen then applied monthly mains-water temperature and a 60 °C set-point to obtain an annual useful-thermal demand of 21,952 kWh. This decomposition is reported to improve reproducibility and permits the occupancy sensitivity analysis presented in Section 4.6.1.

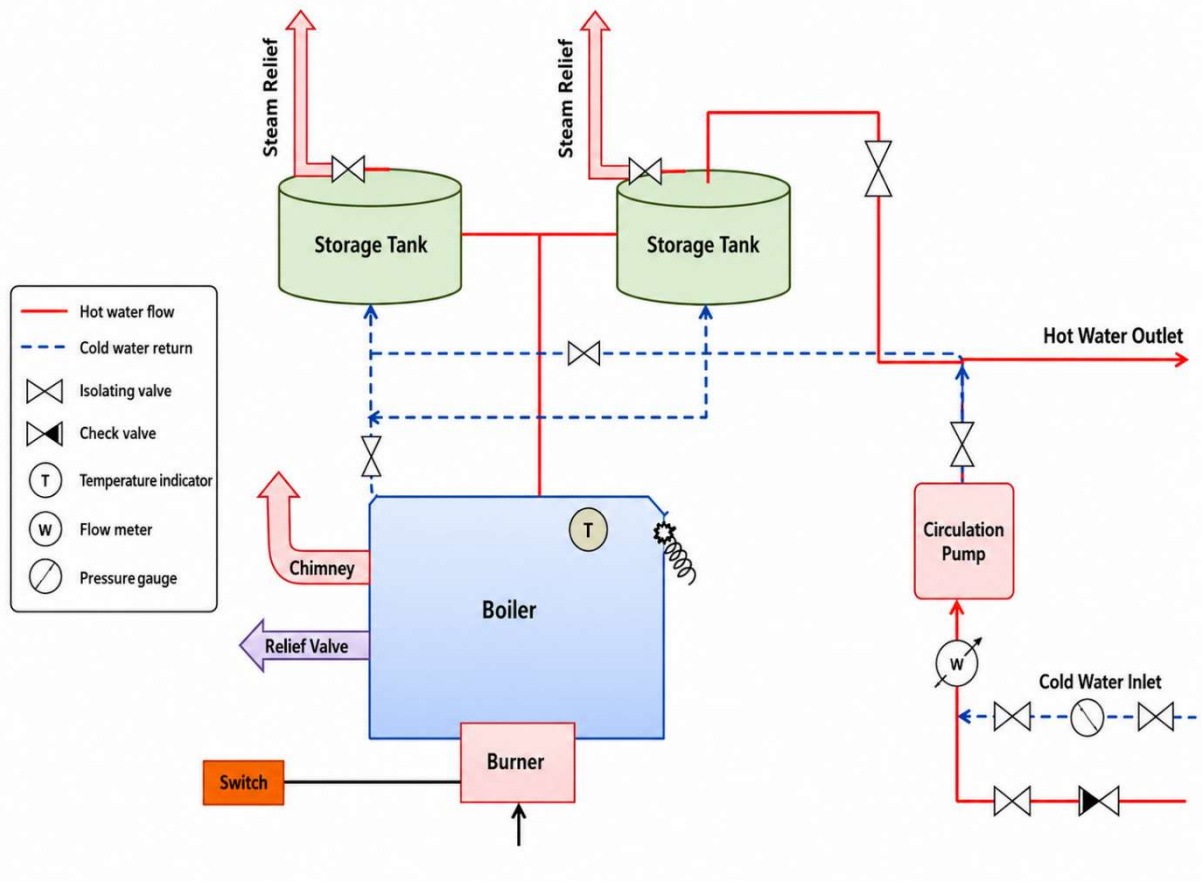


Figure 3: Existing hot-water circulation system at the case study hotel

The diesel-boiler efficiency was not determined through flue-gas testing; a 70% seasonal efficiency was adopted from the equipment condition, site information, and literature for an older non-condensing boiler [44, 46]. The value is internally consistent with 21,952 kWh year^{-1} of useful heat and approximately 2,948 L year^{-1} of diesel consumption. The diesel price of FJD 3.06 L^{-1} represents the prevailing retail value used for the 2024 assessment [47]. Since both parameters materially influence savings, fuel price is included in the RETScreen risk analysis and the limitations section explicitly notes the uncertainty associated with the assumed boiler efficiency.

Baseline system characteristics, fuel consumption, boiler efficiency, and operating assumptions used to represent the existing diesel-based hot water system are summarised in Table 1. These parameters form the reference scenario against which the performance of the proposed SWH system is evaluated.

Table 1: Input parameters for the base-case hot water system

Parameters	Value	Source
Hot water demand (L day^{-1})	1,500	[44, 45]
Supply temperature (°C)	55-65	[45]
Diesel boiler efficiency (%)	70	[44, 46]
Diesel price (FJD L^{-1})	3.06	[47]

3.3 Climatic Data and Solar Resource Assessment

Climatic and solar-resource inputs were obtained from the RETScreen integrated climate database for the nearest available grid point. The database combines long-term satellite and ground-based information and supplied monthly global horizontal irradiance, ambient temperature, and related variables. As a plausibility check, the RETScreen seasonal pattern and annual mean

irradiation, approximately 5 kWh m^{-2} day^{-1}, were compared with NASA POWER climatology for the Rakiraki area [33]. The two sources show the same seasonal pattern and comparable annual resource magnitude. This comparison is not a substitute for on-site validation because no co-located long-term pyranometer record was available; consequently, climate-data uncertainty is retained as a study limitation. The same monthly series was used in both RETScreen and SAM to improve comparability.

The selected site exhibits favourable solar conditions typical of tropical island environments, supporting the suitability of solar thermal technologies for year-round hot water production.

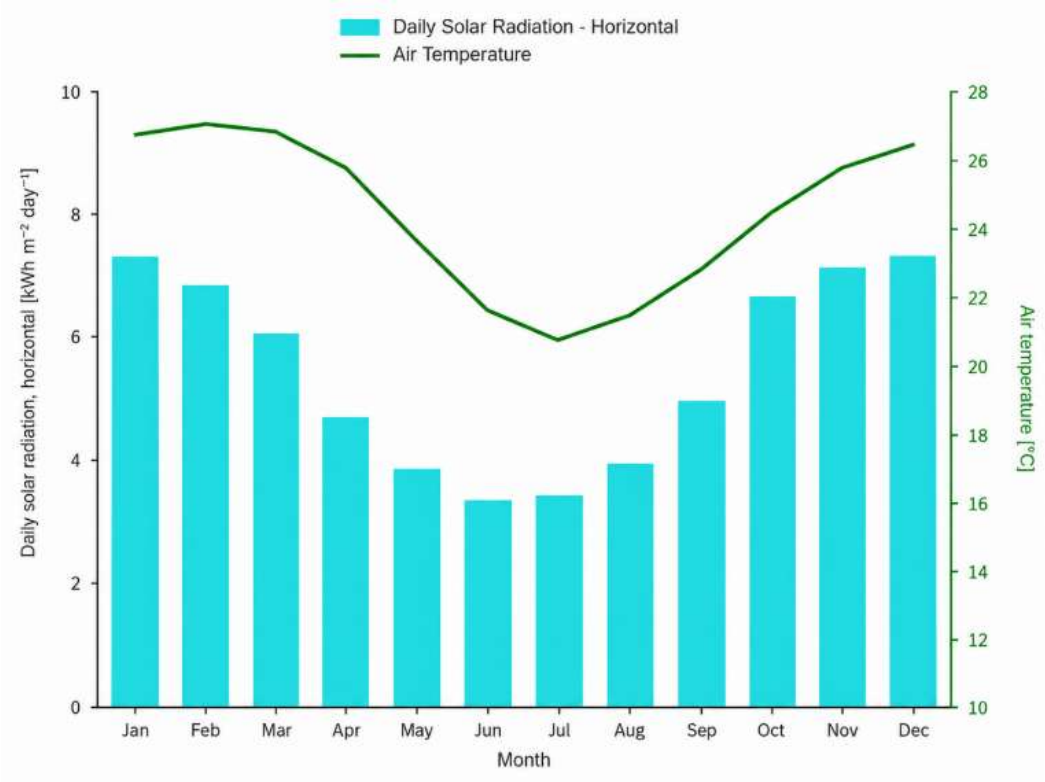


Figure 4: Climatic parameters of selected site

3.4 Solar Water Heating System Configuration

Based on local availability, climatic suitability, and regional guidelines, a glazed flat-plate collector technology was selected for the proposed SWH system. Flat-plate collectors are widely recommended for hotel applications in tropical regions due to their durability, lower maintenance requirements, and stable performance under high ambient temperatures.

The system design was screened by varying the storage-to-collector area ratio. Selection was based on four criteria: annual solar fraction, useful-energy output, payback period, and operational reliability during lower-irradiance months. The final 14 kW configuration uses ten collectors with 20 m^2 total area and 1.6 m^3 storage, equivalent to 80 L m^{-2}. Auxiliary diesel heating is retained so that service reliability is not compromised during cloudy periods or peak hot-water demand. The technical specifications and design assumptions used for modelling the SWH system in both RETScreen and SAM are consolidated in Table 2.

3.5 Evaluation Metrics and Economic Assessment

The performance of the proposed SWH system was evaluated using standard technical, economic, and environmental indicators commonly adopted in renewable energy feasibility studies. Technical performance is assessed through the solar fraction and annual useful thermal energy delivered by the system.

Economic feasibility was evaluated using CAPEX, OPEX, net present value (NPV), simple payback period (SPP), and equity payback period (EPP). For consistency and direct comparison, the baseline RETScreen and

SAM cases assumed zero annual OPEX and pump electricity consumption. In addition, a conservative lifecycle scenario was evaluated using annual OPEX equivalent to 1% of CAPEX, electricity consumption from a 45 W circulation pump operating for an assumed average of 6 h day-1, and an annual collector-output degradation rate of 0.5%. The supplementary scenario is reported separately to preserve the reproducibility of the RETScreen–SAM validation while providing a more realistic assessment of long-term system performance and investment viability.

Table 2: Input parameters used for modelling the SWH system

Category / Parameter	Value (RETScreen / SAM)	Reference
Hotel operation		
Number of rooms	46 / 46	[44]
Average occupancy rate (%)	70 / 70	[44]
Daily hot water demand (L day^{-1})	1500 / 1500	[44]
Hot water set-point temperature (°C)	60 / 60	[40, 48-50]
System configuration		
Solar tracking mode	Fixed	[44, 48, 51]
Collector tilt angle (°)	17 / 17	[48, 52, 53]
Solar collector		
Collector type	Glazed flat-plate	[40, 48, 54, 55]
Manufacturer	Rheem Australia Pty Ltd	[54, 55]
Supplier (Fiji)	Poly Products (Fiji) Pte Ltd	[55]
Model	ED L305	[55]
Gross/aperture area per collector (m^2)	2.0 / 2.0	[54, 55]
Optical efficiency, η_0 (–)	0.68 / 0.68	[40, 48, 54]
Heat loss coefficient (W m^{-2} $°C^{-1}$)	4.9 / 4.9	[31, 41, 56]
Incidence angle modifier (–)	– / 0.20	[31, 56]
Collector field		
Number of collectors	10 / 10	This study
Total collector area (m^2)	20 / 20	This study
SWH thermal capacity (kW)	14 / 14	[31, 56]
Thermal storage		
Storage tank volume (m^3)	1.6 / 1.6	[41, 31, 56]
Tank height-to-diameter ratio (–)	– / 2.0	[31, 56]
Hydraulics & auxiliary system		
Working fluid	– / Water	[31, 56]
Total piping length (m)	– / 10	[31, 56]
Pipe internal diameter (m)	– / 0.019	[31, 56]
Pump power (W)	– / 45	[31, 56]
Pump efficiency (–)	– / 0.85	[31, 56]
Economic & financial assumptions		
Collector cost (FJD m^{-2})	1550 / 1550	[55]
Storage tank cost (FJD m^{-3})	0 / 0	[48]
Annual operating expenditure, OPEX (FJD $year^{-1}$)	0 / 0 (model-validation case); 310 in lifecycle scenario	[39, 41, 48]
Project lifetime (years)	20 / 20	[40, 57-59]
Discount rate (%)	8 / 8	[60]
Inflation rate (%)	0.2 / 0.2 (validation case); 3.0 in lifecycle scenario	[20, 48, 52]
Debt fraction (%)	70 / 70	[40, 57-59]
Loan interest rate (% yr^{-1})	5 / 5	[40, 57-59]
Loan term (years)	15 / 15	[40, 57-59]
Electricity tariff (FJD kWh^{-1})	0.401 / 0.401	[62]
Peak electrical load (kW)	0.17 / 0.17	[44]

Note: The validation case reproduces the original RETScreen-SAM inputs. The conservative lifecycle scenario is a separate post-processing assessment that includes operating expenditure (OPEX), pump electricity, degradation, and 3% escalation.

The NPV is calculated using Eq. (1):

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_o \qquad (1)$$

where C_t represents the net cash flow in year t, r is the discount rate, n is the project lifetime, and C_0 is the CAPEX. A positive NPV indicates that the project generates returns exceeding the discount rate and is therefore considered financially viable [60, 63].

The SPP represents the time required for the cumulative annual savings to recover the CAPEX. The SPP is calculated using Eq. (2):

$$SPP = \frac{C_o}{A_s} \qquad (2)$$

where A_s is the annual net savings resulting from reduced fuel or electricity consumption after accounting for OPEX. Although SPP does not consider the time value of money, it remains a commonly used preliminary indicator for assessing renewable energy investments in the hotel sector [48, 64]. These financial indicators provide complementary insights into investment profitability and capital recovery time. All economic calculations follow established methodologies described in the literature [60, 65].

The environmental benefit of the proposed SWH system was quantified in terms of annual GHG emission reductions by displacing diesel- or electricity-based hot water generation. Emission reductions were calculated using RETScreen default emission factors consistent with internationally accepted accounting methodologies, as expressed in Eq. (3):

$$GHG_{emission\ reduction} = E_{baseline} - EF \qquad (3)$$

where E_{baseline} is the annual energy displaced (kWh) and EF is the corresponding emission factor. This approach aligns with established RETScreen procedures and carbon accounting practices [65, 66].

supplementary lifecycle scenario applies a 3% annual cost-escalation assumption consistent with medium-term Fiji inflation projections reported by the International Monetary Fund [20]. The ±25% sensitivity ranges around CAPEX and interest rate, together with the occupancy scenarios, show how results change when actual hotel financing and operating conditions differ. Software versions were RETScreen Expert (2022) and SAM 2020.2.29 [56, 65].

3.6 Simulation Tools and Input Parameters

RETScreen Expert was selected as the primary modelling tool due to its widespread use in renewable energy feasibility assessments and its integrated climate, technology, and financial databases. SAM was employed as an independent validation tool to verify energy output and financial trends using a different modelling architecture. The use of dual modelling platforms strengthens confidence in the results and addresses concerns related to tool-specific bias.

To improve clarity and avoid redundancy, input parameters for both RETScreen and SAM are presented in a single consolidated table (Table 2), with tool-specific columns. Parameters not applicable to a particular model are indicated as zero or not required, reflecting differences in internal calculation structures rather than data omissions. This approach ensures transparency while maintaining a compact presentation.

All inputs were derived from site information, national tariffs, supplier data, literature, and official databases, as referenced in Table 2. The 70% debt fraction, 5% loan interest rate, and 15-year term are financing scenarios informed by Fiji's sustainable-energy financing context [59], not guaranteed commercial offers. The validation-case inflation input follows the country-level inflation source used in the original assessment [61], while the

4. Results and Discussion

This section presents and discusses the simulation results obtained for the proposed SWH system for a representative 3-star hotel in Rakiraki, Fiji. The existing diesel-fired hot water system is first analysed as the baseline case. The proposed hybrid SWH–diesel system is then evaluated in terms of energy savings, CO_2 emission reductions, and financial feasibility. Sensitivity and risk analyses are subsequently presented, followed by validation of the RETScreen results using SAM. Finally, the findings are compared with those of similar studies conducted in island and tropical regions.

4.1 Baseline Case Performance: Diesel-Fired Hot Water System

The baseline case represents the hotel's existing hot water system, which relies entirely on a diesel-fired

boiler. The key technical, energy, and environmental performance indicators are summarised in Table 3.

Table 3: Performance indicators of the baseline case diesel hot water system

Parameter	Value
Annual useful thermal energy (kWh)	21,952
Annual diesel consumption (L)	2,948
Annual fuel cost (FJD)	9,020
Boiler efficiency (%)	70
Annual emissions (t CO_2 $year^{-1}$)	7.9

The existing boiler meets the hotel's annual useful-thermal demand but at a high operating and environmental cost. A 70% seasonal efficiency requires approximately 2,948 L $year^{-1}$ of diesel, costing about FJD 9,020 at FJD 3.06 L^{-1}. The associated operational emissions are approximately 7.9 t CO_2 $year^{-1}$. These values form the reference case for evaluating solar integration; uncertainty in boiler efficiency and fuel price is addressed in the sensitivity and risk analyses.

4.2 Performance of the Proposed Hybrid Water Heating System

Multiple storage-to-collector area ratios were evaluated using RETScreen to determine the most suitable system configuration. The comparative performance of the evaluated configurations is presented in Table 4.

Table 4: Performance comparison of SWH configurations

Storage-to-collector ratio (L m^{-2})	Solar fraction (%)	Annual energy savings (kWh)	Emission reduction (t CO_2 $year^{-1}$)	SPP (years)
37.5	31.2	6,845	2.4	6.9
50	38.6	8,412	3.0	7.2
80	45.5	9,996	3.5	7.7
90	44.1	9,530	3.3	8.1
100	42.0	9,102	3.1	8.6

Among the evaluated configurations, 80 L m^{-2} gives the highest solar fraction (45.5%) and useful-energy saving (9,996 kWh $year^{-1}$). Lower ratios restrict available storage and reduce the amount of midday solar heat retained for evening and morning use. Ratios above 80 L m^{-2} do not improve annual performance because additional tank volume increases thermal losses and capital requirement while collector area remains unchanged. Monthly checks also confirmed that the retained diesel auxiliary system can meet demand during the lower-irradiance season. The 80 L m^{-2} configuration was therefore selected on the combined basis of annual performance, diminishing marginal benefit, seasonal service reliability, and lifecycle cost rather than payback alone.

4.3 Energy Savings and Solar Fraction

The proposed SWH system achieves a solar fraction of 45.5%, indicating that solar thermal energy meets nearly half of the hotel's annual hot-water demand. The annual energy savings of 9,996 kWh are presented in Figure 5.

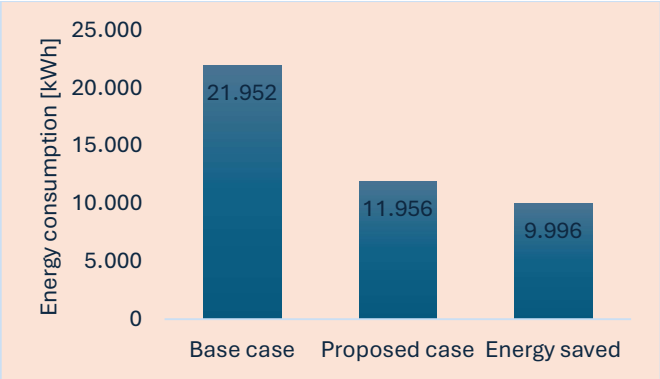


Figure 5: Annual energy consumption of the baseline and proposed system

This level of solar contribution lies within the recommended range of 30–50% for commercial SWH systems, which balances system reliability, collector area requirements, and capital investment. Fully solar-based systems were found to be impractical for the study site due to seasonal variability in solar availability and the need for oversized storage and collector fields to maintain service reliability.

4.4 Carbon Dioxide Emission Reduction and Fuel Savings

Integrating the SWH system substantially reduces diesel consumption and associated CO_2 emissions. As shown in Figure 6, annual diesel use decreases from 2,948 L in the baseline case to 1,606 L in the proposed hybrid system, corresponding to annual fuel savings of 1,342 L (45.4%). The corresponding operational emissions decrease from approximately 7.9 to 4.4 t CO_2 $year^{-1}$, an annual reduction of about 3.5 tonnes (44.3%). A constant-output multiplication would give about 70 t CO_2 reduction over 20 years. Applying 0.5% annual degradation assumption reduces the projected 20-year operational-emission benefit to approximately 66.8 t CO_2. The assessment excludes embodied lifecycle emissions and should therefore be interpreted as avoided operational emissions only.

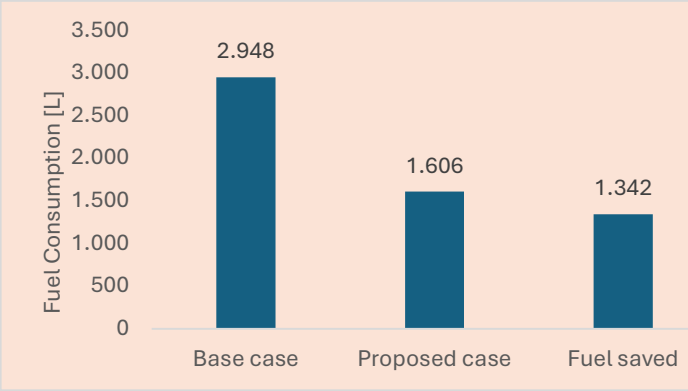


Figure 6: Annual diesel consumption of the baseline and proposed system

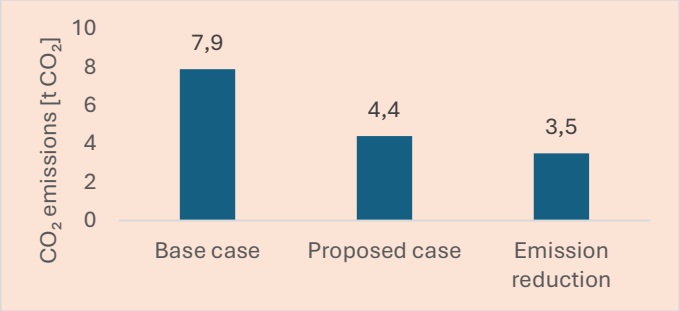


Figure 7: Annual CO_2 emissions of the baseline and proposed system

4.5 Financial Feasibility Analysis

The financial performance of the proposed SWH system was evaluated using standard investment appraisal indicators. The results are summarised in Table 5.

Table 5: Financial performance indicators of the proposed SWH system

Indicator	Value
CAPEX (FJD)	31,000
SPP (years)	7.7
EPP (years)	4.7
NPV (FJD)	15,151
Pre-tax internal rate of return (IRR) on equity (%)	21.4
OPEX - validation case (FJD year^{-1})	0

The RETScreen model yields an NPV of FJD 15,151, an SPP of 7.7 years, an EPP of 4.7 years, and a pre-tax equity IRR of 21.4%. These results reproduce the original model outputs and provide the basis for comparison with SAM. A separate conservative lifecycle post-processing scenario incorporates annual OPEX of FJD 310, pump electricity consumption of approximately 98.6 kWh year^{-1} (FJD 39.5 year^{-1} at the adopted tariff), annual collector-output degradation of 0.5%, and annual cost escalation of 3%. Under these assumptions, the adjusted SPP increases to approximately 8.3 years, the EPP to approximately 5.0 years, and the project NPV decreases to approximately FJD 13,078. Figure 8 presents the cumulative equity cash-flow trajectory of the hybrid SWH system relative to the diesel-only business-as-usual reference case, while Table 6 summarises the lifecycle adjustments.

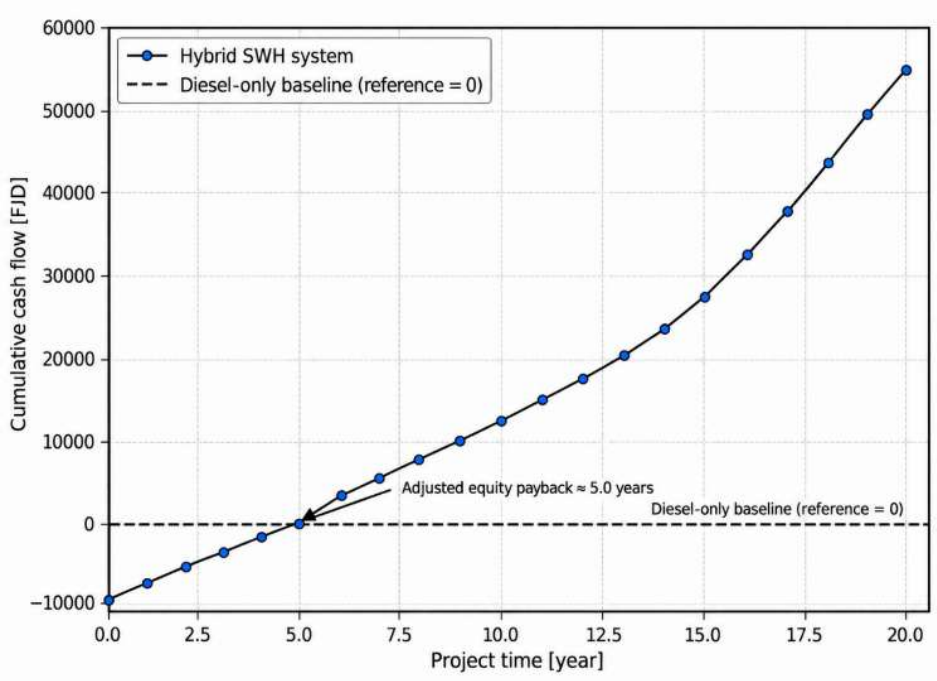


Figure 8: Cumulative equity cash flow relative to the diesel-only baseline.

Figure 8 illustrates the cumulative equity cash flow of the hybrid SWH system relative to the diesel-only business-as-usual baseline. The diesel-only case is represented as the zero-reference line, while the hybrid system initially shows a negative cumulative cash flow because of the upfront equity investment. As annual fuel-cost savings accumulate, the cash-flow trajectory improves and intersects the diesel-only reference at approximately 5.0 years, corresponding to the adjusted equity payback period. Beyond this point, the cumulative financial benefit of the hybrid SWH system continues to increase over the remaining project lifetime.

Table 6. Adjusted lifecycle indicators

Indicator	Adjusted value
SPP (years)	8.3
EPP (years)	5.0
NPV (FJD)	13,078
20-year energy savings (kWh)	190,703
20-year emission reduction (t CO_2)	66.8

Sensitivity analysis

Perform analysis on: Net Present Value (NPV)

Sensitivity range: 25%

Threshold: 0 FJD

- Remove analysis

Initial costs ▼ FJD

Debt interest rate ▼		23,250	27,125	31,000	34,875	38,750
%		-25.0%	-12.5%	0.0%	12.5%	25.0%
3.75%	-25.0%	23,417	20,071	16,725	13,379	10,033
4.38%	-12.5%	22,833	19,390	15,947	12,503	9,060
5.00%	0.0%	22,236	18,693	**15,151**	11,608	8,065
5.63%	12.5%	21,626	17,982	14,338	10,694	7,049
6.25%	25.0%	21,004	17,256	13,508	9,760	6,013

Figure 9: NPV sensitivity to CAPEX and debt interest rate.

4.6 Sensitivity and Risk Analysis

The RETScreen sensitivity matrix evaluates the effect of ±25% variations in CAPEX and debt interest rate on project NPV, as shown in Figure 9. The NPV remains positive across all tested combinations, ranging from FJD 6,013 to FJD 23,417, indicating that the proposed system remains financially viable within the specified parameter ranges.

A Monte Carlo risk analysis comprising 500 simulations was conducted to examine the combined effects of uncertainty in the principal financial parameters. Figure 10 presents the standardised effects of the selected variables on NPV and identifies diesel price and CAPEX as the dominant drivers of project performance. Figure 11 shows the resulting NPV probability distribution. At the 10% risk level, the simulated NPV remains positive, ranging from approximately FJD 1,245 to FJD 29,357. These results indicate a low probability of financial loss within the assumptions and uncertainty ranges considered. Nevertheless, the distribution confirms that project viability remains sensitive to changes in diesel prices and CAPEX.

4.6.1 Occupancy and Operational Sensitivity

A screening-level sensitivity assessment was conducted to examine the effect of hotel occupancy on SWH performance. Guest-related hot-water demand was assumed to vary linearly with occupancy, while the kitchen and laundry demand was held constant at 212 L

day^{-1}. The results are summarised in Table 7.

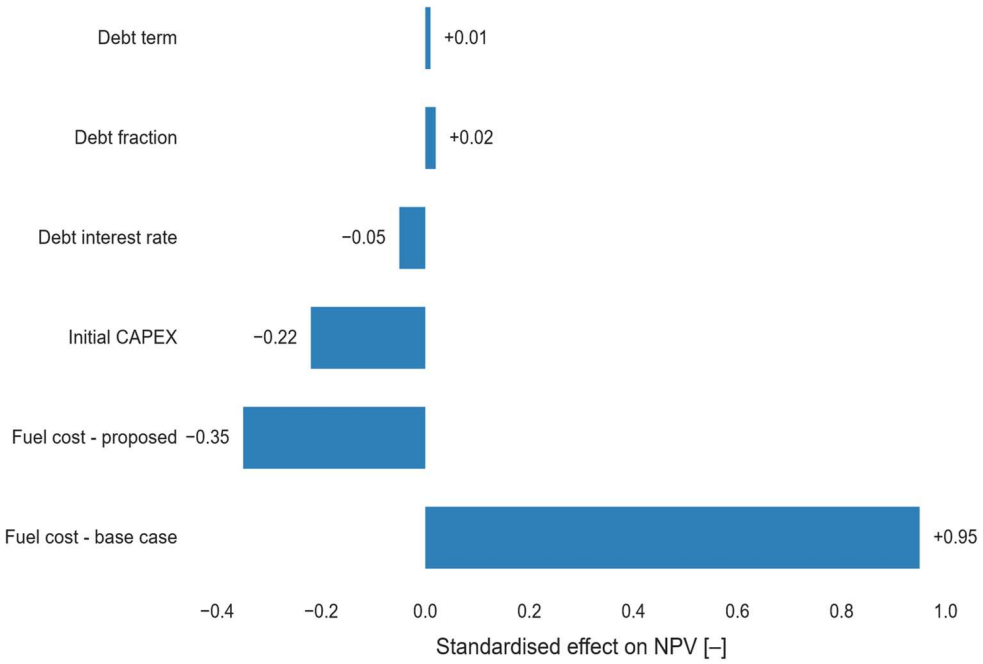


Figure 10: Standardised effects of risk variables on NPV.

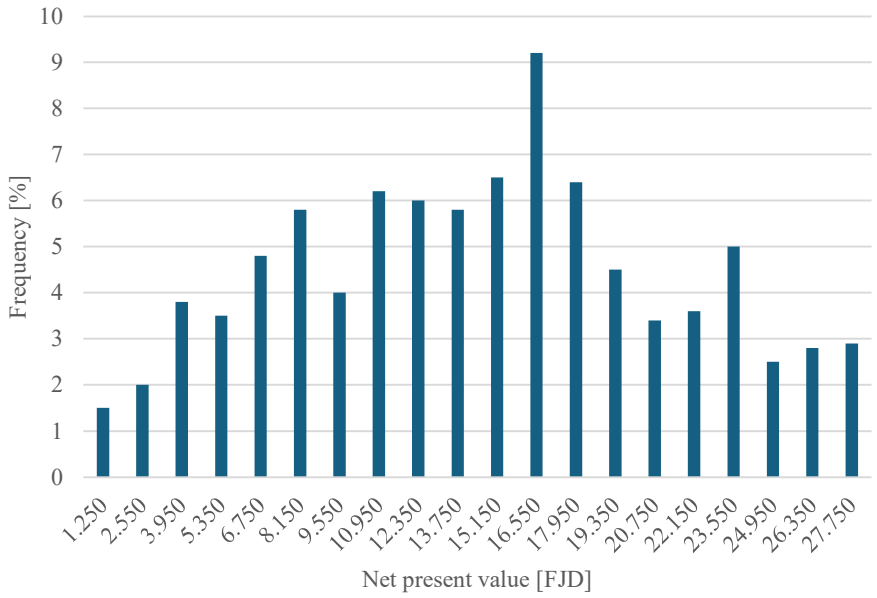


Figure 11: Simulated NPV probability distribution.

As occupancy decreases from 70% to 50%, the solar fraction increases from 45.5% to 55.5% because the available solar output supplies a greater proportion of the reduced thermal load. However, the adjusted SPP increases from 8.3 to 9.0 years because lower demand reduces the utilisation of the collector output and the

resulting fuel-cost savings. Conversely, increasing occupancy to 90% reduces the solar fraction to 38.2% but shortens the adjusted SPP to approximately 7.9 years. These findings demonstrate that higher occupancy improves collector utilisation and financial performance, although a greater proportion of the total hot-water demand must be supplied by the auxiliary diesel system.

Table 7: Screening-level effect of hotel occupancy on SWH performance

Occupancy (%)	Demand (L day^{-1})	Thermal load (kWh yr^{-1})	Solar delivery (kWh yr^{-1})	Solar fraction (%)	SPP (yrs)
50	1,132	16,566	9,194	55.5	9.0
60	1,316	19,259	9,653	50.1	8.6
70	1,500	21,952	9,996	45.5	8.3
80	1,684	24,645	10,251	41.6	8.0
90	1,868	27,338	10,442	38.2	7.9

Note: The SPP values include the conservative lifecycle OPEX and pump-electricity allowances. The calculations represent screening-level post-processing rather than new hourly RETScreen simulations.

4.7 Cross-model Verification of RETScreen Results Using SAM

To assess the consistency of the simulation results, the principal RETScreen outputs were independently compared with those obtained using SAM. Equivalent technical and financial input assumptions were applied in both models wherever possible. Table 8 compares the selected performance indicators and reports the absolute percentage difference relative to the RETScreen results.

Table 8: Comparison of RETScreen and SAM results

Parameter	RETScreen	SAM	Absolute difference (%)
Solar fraction (%)	45.5	45	1.1
Annual energy savings (kWh)	9,996	8,509	14.9
NPV (FJD)	15,151	15,092	0.4
SPP (years)	7.7	6.8	11.7

Note: Absolute percentage difference = $[SAM - RETScreen]/RETScreen \times 100\%$

The two models show close agreement for solar fraction and NPV, with absolute percentage differences of 1.1% and 0.4%, respectively. Moderate differences are observed for annual energy savings and SPP, at 14.9% and 11.7%, respectively. These variations may reflect differences in weather-data processing, tank representation, pump-control logic, thermal-loss calculations, and financial modelling procedures. The mean absolute percentage difference across the four indicators is approximately 7.0%.

Overall, the cross-model comparison supports the technical and financial trends obtained using RETScreen. However, the results should be interpreted as feasibility-level estimates rather than exact predictions of field performance, which would require validation using measured operational data.

4.8 Comparison with Similar Studies in Island and Tropical Regions

The performance of the proposed hybrid SWH system is broadly consistent with findings from studies conducted in tourism facilities and other commercial buildings in Mediterranean, tropical, and developing-country contexts. The solar fraction of 45.5% falls within the range reported for comparable SWH applications, although system performance varies with collector area, storage capacity, climatic conditions, occupancy, and hot-water-use patterns [58, 59].

Comparable levels of solar contribution and fossil-fuel displacement have been reported in studies conducted in Albania, Pakistan, and selected tropical regions [45, 60, 63, 67]. The SPP of 7.7 years is also consistent with values reported for hotel and institutional SWH applications in developing economies, where investment recovery is strongly influenced by fuel prices, CAPEX, financing conditions, and system utilisation [66, 68].

The principal contribution of this study lies in its integrated assessment framework for a data-limited Pacific Island setting. The analysis combines a site-informed estimate of hotel hot-water demand, screening of storage-to-collector-area ratios, consideration of seasonal reliability, sensitivity and risk analysis, occupancy-related operational assessment, conservative lifecycle adjustments, and quantified cross-model comparison between RETScreen and SAM. This approach provides Fiji-specific decision-support evidence that was not available in earlier hotel-energy assessments and offers a framework that may be adapted to other SIDSs following appropriate local calibration.

4.9 Policy Implications, Limitations, and Sustainable Development Goal Relevance

From a sustainable energy-planning perspective, the quantified solar fraction, diesel displacement, lifecycle economics, and occupancy and risk sensitivities provide

screening evidence for deciding where SWH may fit within hotel-sector decarbonisation portfolios. Such bottom-up evidence complements island-level planning studies by translating resource, demand, cost, and operational constraints into implementable technology and policy choices [22-26]. The findings suggest four policy measures that could support SWH adoption in Fiji and other SIDSs. First, SWH technologies could be explicitly incorporated into hotel energy-performance standards, building approval requirements, and sustainable-tourism certification schemes. Second, financing mechanisms such as concessional loans, partial credit guarantees, accelerated depreciation, and time-limited capital support could help address the CAPEX barrier, while performance-based incentives should be linked to verified energy savings. Third, hotels should undertake hot-water energy audits and install basic heat and fuel metering to ensure that system sizing and projected savings are based on measured demand. Fourth, technical standards, installer training, maintenance arrangements, and targeted awareness programmes are needed to improve confidence in the technology and support long-term system reliability. Previous research indicates that trust, usability, compatibility, and targeted communication can influence the acceptance of solar technologies [21]; therefore, financing measures alone may be insufficient to achieve widespread adoption.

Several limitations should be acknowledged. The analysis is based on a single medium-scale hotel and uses an estimated rather than continuously measured hot-water draw profile. Boiler efficiency was assumed rather than verified through field testing, while the climatic data were compared with an additional satellite dataset but not with observations from a co-located meteorological station. The occupancy sensitivity assessment represents a calibrated screening analysis rather than a complete hourly simulation. In addition, the lifecycle financial results depend on assumptions regarding OPEX, pump operating hours, collector degradation, and cost escalation. The environmental assessment considers avoided operational emissions only and excludes embodied emissions, equipment replacement, and end-of-life impacts. These limitations identify priorities for future research, including long-term field monitoring, analysis of multiple hotels, and comprehensive life-cycle assessment.

The proposed hybrid SWH system directly contributes to two Sustainable Development Goals (SDGs): SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), by reducing fossil-fuel consumption and operational CO_2 emissions. It may also support SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 11 (Sustainable Cities and Communities) through improved energy efficiency, enhanced local technical capacity, and more sustainable tourism infrastructure. Given Fiji's favourable solar resource and the potential benefits of appropriate policy and financing support, SWH represents a promising pathway for reducing fossil-fuel dependence in the hotel sector. These findings are consistent with broader recommendations for advancing sustainable development in PICs [69].

5. Conclusion

This study evaluated the techno-economic and environmental feasibility of a glazed flat-plate SWH system for a representative 3-star hotel in Fiji using RETScreen, with the principal outputs independently compared with those obtained from SAM. The findings demonstrate the potential of SWH systems to reduce fossil-fuel dependence in hot-water production within energy-intensive tourism facilities in SIDSs.

The proposed 14 kW SWH system achieves a solar fraction of 45.5% and annual energy savings of approximately 9,996 kWh. It also reduces diesel consumption by approximately 1,342 L $year^{-1}$ and operational CO_2 emissions by about 3.5 tonnes $year^{-1}$. Under the constant-performance assumption, this corresponds to approximately 199,920 kWh of cumulative energy savings and 70 t CO_2 of avoided operational emissions over the 20-year project lifetime. When an annual collector-output degradation rate of 0.5% is considered, the cumulative operational emission reduction is approximately 66.8 t CO_2.

The RETScreen model yields an SPP of 7.7 years, an EPP of 4.7 years, an NPV of FJD 15,151, and a pre-tax equity IRR of 21.4%, without subsidy support. Under the additional conservative lifecycle scenario incorporating OPEX, pump electricity consumption, collector degradation, and cost escalation, the adjusted SPP is approximately 8.3 years, the EPP is approximately 5.0 years, and the NPV remains positive at FJD 13,078. The cross-model comparison with SAM supports the principal technical and financial trends, while highlighting the importance of field monitoring for confirming long-term performance.

Overall, the findings indicate that SWH technology represents a technically feasible, economically viable, and environmentally beneficial option for Fiji's hotel

sector. The study provides site-informed and cross-model evidence that can support hotel-sector renewable-heat planning, investment screening, and policy design in Fiji and other tropical island and SIDS contexts.

5.1 Future Work

Future work should prioritise long-term field monitoring of collector output, pump electricity, storage losses, auxiliary diesel use, occupancy, and delivered hot-water volume. A multi-hotel dataset should compare hotel categories and locations and should validate satellite climate inputs against local instruments. Further studies should incorporate embodied carbon, component replacement, end-of-life treatment, and measured degradation, and should test financing, incentive, and social-acceptance interventions under Fiji and wider Pacific conditions.

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