energies

MDPI

Article

Quantification of the Impact of Solar Water Heating and Influence of Its Potential Utilization through Strategic Campaign: Case Study in Dimbaza, South Africa

Sinethemba Peter [1,*], Njabulo Kambule [1], Stephen Tangwe [2] and Kowiyou Yessoufou [1]

[1] Department of Geography, Environmental Management and Energy Studies, University of Johannesburg, Auckland Park, Johannesburg 2006, South Africa
[2] Department of Electrical, Electronic and Computer Engineering, Faculty of Engineering and Built Engineering, Central University of Technology, Bloemfontein 9300, South Africa
* Correspondence: sinethembaapeter@gmail.com

Abstract: This paper ascertained the performance of the evacuated tube solar water heater (SWH) coupled with an auxiliary electric heater with reference to the replaced electric water heater with the same storage tank capacity (200 L) in a building. It also examines the influence of the uptake of the SWHs in the community due to different campaign methods. The study evaluated the performance of a 4 kW electric water heater and a 2 kW input SWH with an auxiliary electric heater, and quantified the annual energy and cost savings. A survey using questionnaires was conducted among 150 residences in Dimbaza based on the house representative's perceptions to replace their electric water heaters with solar water heaters (based on the monetary saving inscribed on the solar water heaters, the sensitization of the target population on the environmental benefits of the solar water heaters and both the monetary savings and environmental benefits). The findings revealed that by replacing the electric water heater with the solar water heater with an auxiliary electric heater, the annual electricity savings due to hot water heating was 4408.99 kWh and the net present value payback period was 4.32 years. The desire of the household representatives to replace their existing electric water heaters with solar water heaters due to the campaign strategies increased from 75 to 126. This study is capable of providing a mechanism to increase the penetration of solar water heaters and justifying the techno-economic viability of solar water heaters.

Keywords: solar water heater; techno-economic viability; simple payback period; electricity savings; consumer behavior

check for updates

Citation: Peter, S.; Kambule, N.; Tangwe, S.; Yessoufou, K. Quantification of the Impact of Solar Water Heating and Influence of Its Potential Utilization through Strategic Campaign: Case Study in Dimbaza, South Africa. *Energies* **2022**, *15*, 8283. https://doi.org/10.3390/en15218283

Academic Editors: Mirko Morini, Dionysia (Denia) Kolokotsa, Yukun Hu, Erik Dahlquist and Esko Juuso

Received: 14 October 2022
Accepted: 2 November 2022
Published: 5 November 2022

1. Introduction

Water heating contributes to significant energy consumption in residential buildings. The utilization of solar water heaters can assist in precluding and salvaging the latter situation, both economically and environmentally. It is estimated that approximately 40% of an average South African household's electricity consumption is used for water heating through an electric water heater [1]. Furthermore, water heating in the country derives mainly from electricity, which is the current prevalent energy carrier. The equivalent of a large coal-fired power station (+2000 MW) is used to provide hot water within the domestic sector alone [1].

According to a study by Ismail and Khembo in 2015 [2], the installation of a SWH in low-income households can reduce the electricity consumption, because of water heating, by 60%. This may lead to approximately saving 25–30% on an average monthly electricity bill. Similarly, Mujuru et al. in 2020 [3] also proved that SWHs are efficient at generating hot water for consumption, with a potential to save 49% of energy, and thus, saving 49% of greenhouse gas. Studies by Cassard et al. in 2011 [4] and Shukla et al. in 2013 [5] demonstrated that solar water heating can reduce the hot water energy demand by 50–80%, and it possesses a favorable payback period that ranges from 2 to 4 years. The aforementioned studies, however, show that the performance importantly depends on the type and size of the system.

The payback period of SWH technologies depends on the type of technology, the materials used in construction of the solar collectors and the volume of hot water consumed [6]. A research work by Lin et al. in 2015 [7] established a systematic procedure to estimate the payback period of domestic SWHs with reference to operation costs and the determined energy savings when compared with conventional heating fuels. Zhang et al. in 2018 [8] identified the technology level, supplementary energy type, natural conditions and policy support as the key factors affecting the payback period of SWHs. These authors employed meta-analyses to quantify the impact of these critical factors to the payback period of the SWHs. Meta-analysis is a method to evaluate a messy dataset, which is scattered, from independent studies by integrating it into a single analysis whereby qualitative information is converted to quantitative statistics [9].

Ferrer in 2017 [10] performed an economic analysis on the attractiveness of SWHs within selected municipalities across South Africa with low-density housing, a hot water consumer profile and the average historic economic data. The study focused on the variation of the parameters, such as electricity price, discount rate, mortgage rate, solar water heater efficiency, fuel price inflation and house size in a bid to achieve the best payback period. The findings revealed that the average payback period was 8 years and exceeded the stipulated 3 years warranty period of the SWHs.

Research conducted in Rwanda on the thermal efficiency of SWHs shows that system efficiency ranged from 60–70%, and it also depends on the design and material composition of the absorber plate [11]. The authors further demonstrated that due to higher efficiency, the payback period of the system was attained 2 years lower than the standard payback period of the majority of SWHs. Chang et al. in 2011 [12] assessed the potential of the penetration of SWHs in South Africa. The study depicted that the payback period is reasonably shorter than the lifespan of the system, despite the low tariffs of the electricity produced by Eskom, which is from coal thermal power plants.

Furthermore, a study by Kalogirou in 2009 [13] demonstrated that SWH with and without an auxiliary water heater is a viable techno-economic technology based on the solar fraction contribution and the payback period of the system. Additionally, a similar study by Şerban et al. in 2016 [14] used sensitivity analysis to conclude that an installed solar water heating system with subsidies of up to 50% can reduce the payback period to 3.5 years and increase the net annual savings to approximately EUR 1743.

The majority of countries (e.g., Spain, Israel, Germany, Portugal, Taiwan, and Italy) have adopted rebate programs as the paramount mechanism to accelerate the growth of SWHs in the residential sectors over the conventional heating fuels through direct subsidies and credit tax reductions [15]. Scholars have also argued that the renewable energy policy is a prerequisite to boost market penetration for the renewable and sustainable energy technologies, such as SWHs (Choi et al., 2018) [16].

A lot of research has been conducted on the applications of the economic advantages of renewable energy systems over electric water heaters for sanitary water heating (Esen and Esen, 2005) [17]. The benefits achieved by the implementation of SWHs can be categorized into economic, environmental, and social impacts; the potential of the significant dissemination of technology is eminent due to the ease of harnessing the solar resources [18]. Similar studies by Duffie and Beckman in 2013 [19] and Kalogirou in 1996 [20] also concluded that the primary benefits of installing SWHs for domestic hot water heating are the financial or economic savings, as they are simple to determine. Furthermore, a study by Pan and Wong in 2012 [21] also showed that the great importance of implementing SWHs is the environmental and sustainability benefits over the conventional electric water heaters. Measuring the economic savings of solar water heating technology considers factors such as weather, consumer behavior and energy saving.

The predominant challenges of the SWHs are to provide hot water under extreme cold weather conditions (in winter), as there are usually days that are characterized with clouds and no solar irradiation [22]. Therefore, to guarantee an all-year performance, SWHs are designed to incorporate an auxiliary water heater. Additionally, other challenges include the initial capital and installation costs. The average capital costs and the installation costs of a flat plate 1 kW, 100 L high-pressure SWH, 2 kW, 150 L high-pressure SWHs and a 2 kW, 200 L high-pressure SWH are R 9600, R 16,330 and R 16,000, respectively [23]. The net present value payback period of SWHs can range from 3–8 years and can even be shortened with an increase in the electricity tariff and the rate of return on investment [10]. It is very important to note that the present value of money is also higher than the future value of money.

In South Africa, most electricity (approximately 90%) comes from coal-fired power stations and is owned by Eskom [24]. The Eskom national grid is unstable due to high stress and the huge non-routine maintenance. Load shedding has been in operation since 2007 due to the electricity demand exceeding the generation, which is of concern. A potential solution to remedy the insufficient electricity generation from the base load is the introduction of renewable energies, which the government of South Africa supported through various rollout programs [25]. One of the key renewable energy technologies implemented by Eskom through funding from the Ministry of Energy was SWHs. The rebate program was designed to install 1 million solar water heaters between 2008 and 2014 [26].

The utilization of SWHs as a replacement of the electric water heaters can result in a reduction in both the power and energy consumption as the efficiency of the technology is between 35–55% and depends on the type of SWH, the effectiveness in the installation and the optimization of the operation of the technology [27]. The common types of SWHs can be classified into two categories, namely, the flat plate collector SWH and the evacuated tube SWH [28]. The performance of the evacuated tube is generally better than that of the counterpart's flat plat collector SWH [29].

This study is an extension of the EHH conference paper published in 2021, and it deals with the assessment of the potential update of the SWHs for residential heating as a replacement of the existing electric water heaters through monetary savings on the labelled product, the creation of awareness on the environmental benefits and both money saving and awareness through the conduction of questionnaires to 150 sample households. It also deals with the economic life-cost analysis of a 2 kW, 200 L high-pressure SWH intended to replace an existing 4 kW, 200 L, high-pressure electric water heater installed in a residential building with four adult occupants based on the simple and net present value payback periods.

The study contributes to the body of scientific knowledge by providing sound recommendations of the economic and environmental benefit of replacing the existing electric water heaters by SWHs with auxiliary electric heaters in Dimbaza. This study has proved that the SWH is a viable and sustainable technology with a significant amount of energy reduction. Additionally, this study proved that annual solar efficiency was excellent, and therefore, the mass rollout of the technology would be perfect, but it would require a combined monetary and environmental awareness campaign.

2. Objectives

The objective of this study is:

- To assess the performance of the evacuated tube SWH coupled with an auxiliary electric heater with reference to the replaced electric water heater with the same storage capacity.
- To assess the perceptions and influence of the uptake of the SWH in the community due to different campaign methods.
- To assess the annual energy and cost savings based on electrical consumption and emissions of the greenhouse gases.

3. Research Questions

The research questions of this study are:

- What is the amount of electrical energy savings per month/annually because of replacing an electric water heater with an SWH with an auxiliary electric heater?
- What greenhouse savings are achieved by replacing an electric water heater with an SWH?
- How will the savings look like between the two seasons (winter and summer) in conjunction with the volume of hot water consumptions?
- How did the adopted campaigned strategies impact the perception and potential uptake of the utilization of the SWH technology in the community of Dimbaza?

4. Types of SWH

The primary categories of SWHs are the flat plate collector and the evacuated tube SWHs [30,31]. The flat plate collector SWHs comprised of a flat plate collector and the water storage tank, as shown in Figure 1. The evacuated tube SWH consists of a series of evacuated tubes and a storage tank, and is illustrated in Figure 2. Both systems can function as a passive or active system. In both systems, in either the evacuated tubes or the flat plate collector, solar energy is converted into heat to increase the temperature of the heating water. The tank acts as the thermal energy storage of the gained heat that is contained in the storage water tank.

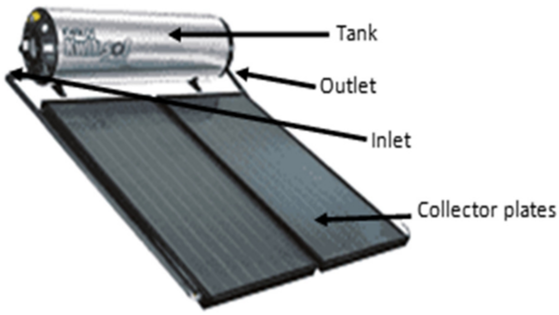

Figure 1. A flat plate collector SWH.

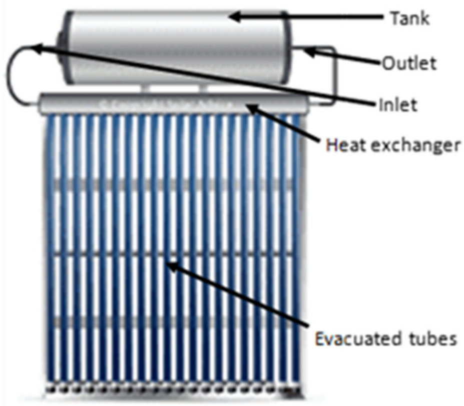

Figure 2. Evacuated tube SWH.

5. Materials and Methods

5.1. Materials and Specification of Solar Collector

Table 1 illustrates the hot water devices, sensors, transducers and data loggers used in the study.

Table 1. List of materials for the experimental setup.

Item	Material	Quantity
1	4 kW, 200 L electric geyser	1
2	2 kW, 200 L flat plate collector SWH	1
3	TVER-E50B2 power meter	1
4	T-Minol 130 flow meters	1
5	12 bits S-TMB temperature sensors	4
6	12 bits S-THB ambient temperature and relative humidity sensor	1
7	Solar radiation shield	1
8	RXW-LIB-868-Silicon pyranometer	1
9	S-UCC electronic input pulse adapter	10
10	U30-NRC 15 channels hobo data loggers	1
11	4.5 V DC battery	1
12	Waterproof enclosure	1
13	Hoboware pro software	1

Table 2 illustrates the manufacturer's specification of the evacuated tube SWH used in the study.

Table 2. Specifications of the SWH used in the study.

Parameter	Domestic Hot Water System
Gross collector area (m^2)	1.8
Aperture area (m^2)	1.3
Collector slope (^{o})	33.0
Storage tank (L)	200.0
Auxiliary power (kW)	2.0
Internal tube diameter (mm)	43.0
External tube diameter (mm)	58.0
Length of evacuated tube (mm)	1800.0

5.2. Experimental Setup

The experiment (Figure 3) was designed and implemented in a residence in Dimbaza (a household with 4 adults). The metering sensors and transducers were installed on the hot water heating devices (electric water heater and SWH) as well as in the vicinity to record the relevant measurements that are needed to assess the performance of both systems. Temperature sensors were installed at the inlet and outlet of the hot water tank and the collector of the SWH. These temperature sensors measured the temperature at both the inlets and outlets of the water tank and the collector. A power meter was installed on the electric cable that was supplying electricity to the electric water heater and the auxiliary element. The power meter measured the electrical energy consumed by the electric water heater and the auxiliary electric heater of the SWH. A flow meter was installed at the outlet of the water tank of both the electric water heater and the SWH and measured the volume of water consumed by the occupants in the building. The pyranometer, ambient temperature and relative humidity were installed in the vicinity of the electric water heater and SWH. They measured the global solar radiation, ambient temperature and relative humidity during the monitoring periods. All the sensors and transducers were connected to a 15-channel data logger and were configured to log in five-minute intervals. The ambient temperature and relative humidity sensors were protected by a radiation shield, while the data logger was accommodated in a waterproof enclosure.

Figure 3. The installation of the SWH in the experimental residence in Dimbaza.

5.3. Methods

The methods used are divided into a qualitative and quantitative approach. The electric water heater was monitored from January to December 2020, while the SWH with an auxiliary electric heater was monitored from January to December 2021. The replacement of the electric water heater with the hybrid SWH resulted in a reduction in the electrical energy consumed due to hot water heating.

The ideal useful thermal energy gained from the solar energy by the collector is given in Equation (1).

$$Q_u = G\eta A_C \tag{1}$$

where Q_u = the useful thermal energy gained per day, G = the global solar irradiation for a day, η = collector's efficiency and A_C = the total collector area.

The modifier equation for the useful thermal energy gained, with the collector—aligned at an angle—and the heat balance of the system taken into consideration, is given in Equation (2).

$$Q_u = A_c F_R \lfloor G(\tau\alpha)K - U_L(T_i - T_a) \rfloor \tag{2}$$

where F_R = the heat removal factor, T_i = the inlet temperature of collector, T_a = the ambient temperature, $\tau\alpha$ = the transmittance–absorptance constant, U_L = the heat-loss coefficient and K = the alignment parameter constant given by Equation (3).

$$K = 1 - b_0\left(\frac{1}{cos\theta} - 1\right) \tag{3}$$

where, b_0 = the experimental determined constant.

The collector efficiency of the SWH is defined in Equation (4).

$$\eta = \frac{mc(T_{out} - T_{in})}{GA_c} \tag{4}$$

where m = the mass of water heated in the tank, c = specific heat capacity, T_{out} = the outlet water temperature from the tank, T_{in} = the inlet water temperature into the tank.

The thermal energy supplied to the load or consumed by the occupants is a combination of the useful thermal energy gained, auxiliary energy consumed and the heat loss in the SWH, and is given in Equation (5).

$$Q_{load} = Q_{aux} + (Q_u - Q_{loss}) \tag{5}$$

where Q_{load} = the thermal energy supplied to the load, Q_{aux} = the electrical energy consumed by the auxiliary electric heater, Q_u = the useful thermal energy gained in the tank, Q_{loss} = the heat loss in the tank and pipes.

The energy savings per day is the difference in electrical energy consumed by the electric water heater and the SWH for identical months and assuming no significant difference in the volume of hot water consumed. The energy savings can be expressed as shown in Equation (6).

$$ES = E_{gey} - E_{SWH} \tag{6}$$

where, ES = the electrical energy saved per day, E_{gey} = the electrical energy consumed by the electric water heater per day, E_{SWH} = the electrical energy consumed by SWH per day.

The cost of investment of the SWH is the sum of the capital cost and the maintenance cost over the life cycle (15 years).

$$C_{in} = C_c + C_m \tag{7}$$

where C_{in} = the cost of investment of the SWH, C_c = the capital cost of the SWH and C_m = the maintenance cost over the life cycle.

The simple payback period of the SWH is the ratio of the cost of the investment and the product of the annual energy savings and the electricity tariff (R 1.20 per kWh), and is given by Equation (8).

$$SPB = \frac{C_{in}}{(Annual\ ES)\ tariff} \tag{8}$$

where SPB = simple payback period.

The net present value of money in relation to the future value of money, the annual rate and the number of years is given by Equation (9).

$$NPV = \frac{FV}{(1+r)^n} \tag{9}$$

where NPV = net present value of money, FV = the future value of money, r = annual rate and n = the number of years.

Secondly, a survey (see Appendix A) was conducted on the representatives of 150 sampled houses in Dimbaza from the 3–21 January 2022 on their readiness to use SWHs. All the sampled houses were using electric water heaters for hot water heating. In the first week of the survey (3–7 January 2022), the participants were given the opportunity to express their interests to switch from electric water heaters to SWHs for their sanitary hot water heating. This was based on our demonstration to participants on the monetary savings that accompanied the replacement of electric water heaters with SWHs. In the second week of the survey (10–14 January 2022), the participants were provided the opportunity to express their interest to switch to SWHs for their sanitary hot water heating just for the sensitization of the environmental and health benefits of the technology. In the last week (17–21 January 2022), the participants were allowed to express their interest based on both monetary savings and the awareness campaign regarding the benefits of avoiding environmental pollutions.

6. Results and Discussion

6.1. Performance Profile of an Average Month Day Electrical Energy Consumed by Electrical Energy Consumed by Electric Water Heater and Hybrid SWH

Figure 4 illustrates the average month–day profiles of the electric water heater (January 2020) and hybrid SWH (January 2021). It could be depicted that the two major peaks of the electrical energy consumed occurred between 07:00–11:00 and 18:00–20:00, of which are associated with the Eskom morning peak (07:00–10:00) and evening peak (18:00–20:00). The average month–day electrical energy consumed by the electric water heater was 19.55 kWh and the volume of hot water consumed was 240 L. The average month–day electrical energy consumed by the hybrid SWH (solar water heater with an auxiliary electric heater) was 11.73 kWh. The volume of hot water consumed was 243 L and the collector's efficiency was 55%. It can be determined that the average month–day energy saving was 7.82 kWh. Therefore, the implementation of the SWH resulted in an average month–day energy reduction of 40%.

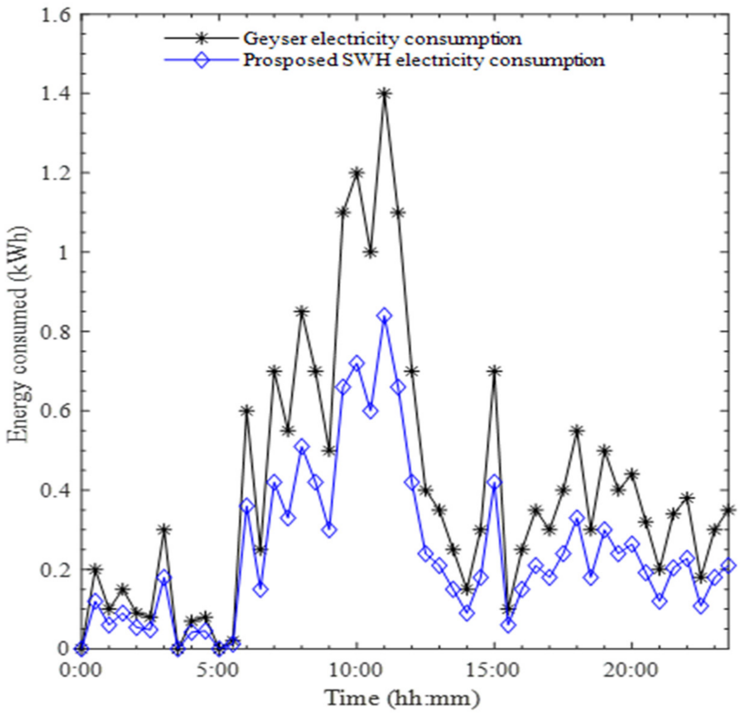

Figure 4. Average month–day electrical energy profiles of the electric water heater (geyser) and hybrid solar water heater (SWH).

6.2. Average Month–Day Performance of the Electric Geyser and the Solar Water Heater

Table 3 shows the average month–day performance of the electric water heater and the hybrid SWH for the year 2020 and 2021, respectively. The average month–day volume of water consumed for identical months for both the electric water heater and the hybrid SWH were practically equal, with an annual difference of 1.33 L. The annual difference in the volume of hot water consumed for the average month–day was negligible, while the annual difference in electrical energy saved due to the replacement of an electric water heater with the hybrid SWH was 11.85 kWh. The total average month electrical energy saving achieved was 367.42 kWh with a reasonable average annual solar energy of 9820.80 kWh incidence on the solar collectors. In addition, the average annual thermal energy gained by the stored water in the solar water heating system was 8733.60 kWh, giving rise to an excellent efficiency of 88.90%.

Table 3. Average month–day performance of electric geyser and solar water heater performance.

Month–Day	Vg (L)	Eg (kWh)	Vs (L)	Ets (kWh)	Ebs (kWh)	Esol (kWh)	Esa (kWh)
January	206.16	18.43	216.49	20.14	2.70	30.83	487.48
February	209.18	18.56	219.75	20.46	3.87	31.22	455.40
March	221.77	22.87	226.91	24.29	7.97	29.67	461.80
April	231.59	24.69	231.14	27.27	12.41	27.73	380.63
May	241.70	24.91	245.13	27.47	15.00	24.45	307.06
June	261.88	25.89	268.6	28.36	15.53	24.58	321.26
July	266.44	26.56	261.62	29.11	17.83	23.99	270.63
August	256.49	24.61	255.50	27.24	18.55	21.92	188.02
September	251.81	22.59	249.39	23.70	17.27	18.86	164.96
October	249.62	20.60	231.82	22.68	6.18	30.28	447.12
November	211.17	18.54	213.00	20.54	3.71	30.38	459.72
December	201.65	18.07	206.16	19.91	3.08	33.49	464.91
Average	234.12	22.19	235.45	24.26	10.34	27.28	367.42

Vg = Volume of hot water consumed from electric water heater; Eg = Electrical energy consumed by electric water heater; Vs = Volume of hot water consumed from SWH; Ebs = Electrical energy consumed by an auxiliary water heater in SWH; Ets = Thermal energy gained by stored water in the tank of the SWH; Esol = Solar energy incidence on the collectors of the SWH; Esa = Monthly electrical energy savings.

6.3. Life-Cost Economic Analysis of the Hybrid SWH

Table 4 shows the detailed life-cost analysis of the hybrid SWH in terms of the annual energy savings, the tariff hikes (15%), annual interest rate (6.5%) and the life cycle of the technology (15 years). The capital and installation cost of the hybrid SWH was R 22,200. The maintenance cost was considered as 7.5% of the capital cost and was R 1800. The cost of investment of the SWH was R 24,000. The simple payback period was 4.54 years with the annual electrical energy consumed by the electric water heater and hybrid SWH as 8099.35 and 3774.10 kWh, respectively. These results are in agreement with the findings of Nwood et al. (2021). The annual cost saving was R 5290.788, using an electricity tariff rate of R 1.20. Furthermore, by considering the electricity tariff hike, the interest rate and the net present value of the annual cost savings, the net present value payback period was determined to be 4.32 years. A review study by Zang et al. (2018) also confirms that the net present value payback period is likely to be lower when compared to the simple payback period. The net present value cost savings by the SWH over the 15 years was R 93,338.789. The life-cost savings likely to be achieved by replacing the electric water heater with the solar water heater with reference to the net present value would be R 69,338.789. Therefore, the significant life-cost savings and the favorable payback period of the solar water heater makes the technology economically viable.

Table 4. Life-cycle cost analysis of the SWH.

Year	Energy Saving (kWh)	Tariff with 15% Hike (R)	FV Cost Saving (R)	NPV Cost Saving (R)
1	4408.99	1.2	5290.788	4967.876
2	4408.99	1.38	6084.406	5364.373
3	4408.99	1.56	6878.024	5693.966
4	4408.99	1.74	7671.643	5963.345

Table 4. *Cont.*

Year	Energy Saving (kWh)	Tariff with 15% Hike (R)	FV Cost Saving (R)	NPV Cost Saving (R)
5	4408.99	1.92	8465.261	6178.632
6	4408.99	2.1	9258.879	6345.426
7	4408.99	2.28	10,052.5	6468.844
8	4408.99	2.46	10,846.12	6553.561
9	4408.99	2.64	11,639.73	6603.84
10	4408.99	2.82	12,433.35	6623.57
11	4408.99	3	13,226.97	6616.292
12	4408.99	3.18	14,020.59	6585.23
13	4408.99	3.36	14,814.21	6533.313
14	4408.99	3.54	15,607.82	6463.204
15	4408.99	3.72	16,401.44	6377.316

FV = Future value, NPV = Net present value, R = Rand.

6.4. Analysis from the Questionnaire (See Appendix A) Administered to the Sample Population

Table 5 shows the sample population based on gender, age ranges, occupations, the electric water heater sizes and the number of household representatives willing to switch from an electric water heater to a hybrid SWH after each phase of the survey. The sample demography revealed that there were more females (84), relative to the male counterparts (66). There were males and females in the age group (45–59) and their numbers were 30 and 36, respectively. The occupational distribution of the sample population shows 33 of the participants with full employment and depend on their monthly source of income, while 90, 9, 9 and 3 had their source of monthly income through children grants, pension grants, disability grants and small business, respectively. Therefore, the bulk of the participants' source of income (60%) of the sample population is from children grants. Hence, there is a high level of unemployment and lack of skills to enable the active population to become entrepreneurs. The electric water heaters in the sample households were composed of three categories of 2 kW, 100 L, 3 kW, 150 L and 4 kW, 200 L electric water heaters. The largest number of installed electric water heaters were the 2 kW, 100 L electric water heaters, which was 60; followed by 3 kW, 150 L electric water heaters, which was 51; and 4 kW, 200 L electric water heaters which was 39. The primary reason for the high increase in the number of the 2 kW, 100 L electric water heaters may be the capital cost, which was lower compared to the other two categories. The installed electric water heater sizes in the sample households did not take into consideration the number of occupants or the habits of hot water patterns by the occupants. The strategic campaign conducted on the sampled representatives' houses focused on the readiness of the participants to switch from an electric water heater to an SWH for sanitary hot water heating. Additionally, the campaign was on the sensitization of the environmental and health benefits of using SWH technology, as well as promoting the awareness on monitory savings derived from using an SWH. The first phase of the survey campaign resulted in 81 participants in the sample population to switch to SWHs due to the monetary saving likely to be achieved from the utilization of the technology. The implementation of both the monetary savings and sensitization of the environmental benefits due to the utilization of the hybrid SWHs in the third phase leads to 126 of the sample population expressing an interest in installing SWHs. Therefore, a combined strategy of monetary savings and the awareness campaign is required for the potential increase in the uptake of SWHs.

Table 5. Sample population and their responses to the utilization of an SWH after each phase of the survey.

Age Group	**25–34**	**35–44**	**45–59**	**>60**
		Sex distribution		
Male	12	15	30	9
Female	18	24	36	6
		Occupation distribution		
Employed	9	12	12	0
Child grant	18	21	39	12
Pension grant	0	0	6	3
Disable grant	0	6	3	0
Small business	3	0	3	0
Others	0	0	3	0
		Electric Water heater sizes		
2 kW 100 L	12	12	33	3
3 kW 150 L	9	15	24	6
4 kW 200 L	9	12	12	3
Number of interested household personals				
Monetary saving	15	21	39	6
Environmental benefits	18	27	42	6
Combined campaign	27	33	60	6

7. Conclusions

The study revealed that the net present value payback period of the hybrid SWH was 4.32 years, and the technology was efficient and sustainable. The implementation of the hybrid SWH as a replacement of the electric water heater resulted in an annual energy reduction of 40% due to sanitary hot water heating. It was depicted that 60% of the sample population depend on children grants for their source of income and insinuated that the population's lack of skills can encourage people to become more entrepreneurial. The campaign to encourage the uptake of SWHs for sanitary hot water heating using the monetary savings of the technology resulted in 81 out of the 150 participants expressing interest in switching from electric water heaters to hybrid SWHs. Additionally, the adoption of both monetary and environmental awareness campaigns on the benefits of SWHs resulted in an overwhelming increase of 126 of the participants expressing their interest to switch to SWHs. We can conclude that the annual solar efficiency of the hybrid SWH was excellent (88.9%). The payback period could further be shortened if the volume of hot water consumed increases and the electricity tariff continues to rise over the years. Hybrid SWH is a viable and sustainable type of technology to roll out in Dimbaza as a permanent replacement of the inefficient electric water heaters, but requires a combined monetary and environmental awareness campaign to guarantee a significant increase in the uptake of the technology.

The findings of this study must be seen in the light of some limitations. The survey was conducted in one ward in Dimbaza due to a lack of funds. Thus, the researchers could not obtain a fair representation of the entire population. Therefore, the study recommends a further study that will cover the range of the entire population of Dimbaza and exploit the payback period for different sizes of SWHs. Additionally, a future study on the potential impact of the introduction of the rebate program as a strategy regarding the uptake of the Solar Water Heater for low-income households in Dimbaza is recommended.

Author Contributions: Conceptualization, S.P.; Formal analysis, S.P.; Investigation, S.P.; Methodology, S.P.; Project administration, S.P. and N.K.; Supervision, N.K. and S.T.; Validation, N.K.; Visualization, K.Y.; Writing—original draft, S.P.; Writing—review and editing, N.K., S.T. and K.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. A Template of a Questionnaire Used to Collect Data in Low Income Residences in Dimbaza

The following interview questions will be aimed at low-income households in Dimbaza that already have electric water heaters with the potential to use a SHW (it is assumed that all participants are connected to the national electricity grid). The questions in the questionnaire focused on background, electricity consumption, knowledge on SWHs, etc.

Date	
Interviewee	

Questions for the Questionnaire

The questionnaire was structured to produce information on the resident's readiness to use SWH, and about their interest to switch from an electric water heater to SWH for water heating and for environmental and health benefits. It was designed to be administered to low-income households with electric water heaters in the area. The questionnaire and interview questions were subdivided into structured questions, and were open-ended with unstructured responses; the results would then be interpreted and described from the participant's point of view, with contextual descriptions and direct quotations from the research participants.

1. Background

1.1. Education level **(mark box with** "X"**)**

- ☐ No school
- ☐ Primary school
- ☐ High School
- ☐ University or college completed
- ☐ Other post grade-12 qualification (specify)______________

1.2. Household size (persons living in it) **(mark box with** "X"**)**

- ☐ ≤3
- ☐ 4–7
- ☐ 8–11
- ☐ ≥12

1.3. Marital status **(mark box with** "X"**)**

- ☐ Married
- ☐ Single
- ☐ Divorced

1.4. Gender **(mark box with** "X"**)**

- ☐ Female
- ☐ Male
- ☐ Not specified

1.5. Occupation/Source of Income **(mark box with** "X"**)**

- ☐ Employed
- ☐ Unemployed
- ☐ Child Grant
- ☐ Pension Grant
- ☐ Disabled Grant
- ☐ Small Business

1.6. Monthly income **(mark box with** "X")

- ☐ R 0–R 1860
- ☐ R 1861–R 5000
- ☐ R 5001–R 10,000
- ☐ R10,001 and more

1.7. Electric Water heater Size **(mark box with** "X"**)**

- ☐ 2 k 100 L
- ☐ 3 k 150 L
- ☐ 4 k 200 L

1.8. Interested Household's personals **(mark box with** "X"**)**

- ☐ Monitory Savings
- ☐ Environmental benefits
- ☐ Combined Campaign

2. Interest and knowledge about SWHs and perceptions

- Do you have any knowledge about SWH?
- Do you think it installation of SWH would reduce your monthly electric cost?
- Do you think the use of SWH would have a positive impact on you economically, environmentally?
- Do you think hot water generated by fossils fuel for electric geyser contributes to climate change
- Can solar water heater be recommended for installation in the building?
- Do you think installation of SWH would contribute positively to your livelihood?

References

1. Nogxina, A.S. *Department: Minerals and Energy*; Department of Minerals and Energy: Pretoria, South Africa, 2006.
2. Ismail, Z.; Khembo, P. Determinants of energy poverty in South Africa. *J. Energy S. Afr.* **2015**, *26*, 66–78. [CrossRef]
3. Mujuru, M.; Dube, T.; Mabizela, H.; Ntuli, N. Evaluating greenhouse gas emission reductions by using solar water heaters: A case of low income households in Ekurhuleni, South Africa. *Phys. Chem. Earth* **2020**, *116*, 102843. [CrossRef]
4. Cassard, H.; Denholm, P.; Ong, S. Technical and economic performance of residential solar water heating in the United States. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3789–3800. [CrossRef]
5. Shukla, R.; Sumathy, K.; Erickson, P.; Gong, J. Recent advances in the solar water heating systems: A review. *Renew. Sustain. Energy Rev.* **2013**, *19*, 173–190. [CrossRef]
6. Ayompe, L.M.; Duffy, A.; Mc Keever, M.; Conlon, M.; McCormack, S.J. Comparative field performance study of flat plate and heat pipe evacuated tube collectors (ETCs) for domestic water heating systems in a temperate climate. *Energy* **2011**, *36*, 3370–3378. [CrossRef]
7. Lin, W.M.; Chang, K.C.; Chung, K.M. Payback period for residential solar water heaters in Taiwan. *Renew. Sustain. Energy Rev.* **2015**, *41*, 901–906. [CrossRef]
8. Zhang, R.; Shen, G.Q.; Ni, M.; Wong, J.K. Techno-economic feasibility of solar water heating system: Overview and meta-analysis. *Sustain. Energy Technol. Assess.* **2018**, *30*, 164–173. [CrossRef]
9. Nelson, J.P.; Kennedy, P.E. The use (and abuse) of meta-analysis in environmental and natural resource economics: An assessment. *Environ. Resour. Econ.* **2009**, *42*, 345–377. [CrossRef]

10. Ferrer, P.A.F. Average economic performance of solar water heaters for low density dwellings across South Africa. *Renew. Sustain. Energy Rev.* **2017**, *76*, 507–515. [CrossRef]
11. Nshimyumuremyi, E.; Junqi, W. Thermal efficiency and cost analysis of solar water heater made in Rwanda. *Energy Explor. Exploit.* **2019**, *37*, 1147–1161. [CrossRef]
12. Chang, K.C.; Lin, W.M.; Ross, G.; Chung, K.M. Dissemination of solar water heaters in South Africa. *J. Energy S. Afr.* **2011**, *22*, 2–7. [CrossRef]
13. Kalogirou, S. Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters. *Sol. Energy* **2009**, *83*, 39–48. [CrossRef]
14. Şerban, A.; Bărbuţă-Mişu, N.; Ciucescu, N.; Paraschiv, S.; Paraschiv, S. Economic and environmental analysis of investing in solar water heating systems. *Sustainability* **2016**, *8*, 1286. [CrossRef]
15. Roulleau, T.; Lloyd, C.R. International policy issues regarding solar water heating, with a focus on New Zealand. *Energy Policy* **2008**, *36*, 1843–1857. [CrossRef]
16. Choi, G.; Heo, E.; Lee, C.Y. Dynamic economic analysis of subsidies for new and renewable energy in South Korea. *Sustainability* **2018**, *10*, 1832. [CrossRef]
17. Esen, M.; Esen, H. Experimental investigation of a two-phase closed thermosyphon solar water heater. *Sol. Energy* **2005**, *79*, 459–468. [CrossRef]
18. Zafar, U.; Rashid, T.U.; Khosa, A.A.; Khalil, M.S.; Rashid, M. An overview of implemented renewable energy policy of Pakistan. *Renew. Sustain. Energy Rev.* **2018**, *82*, 654–665. [CrossRef]
19. Duffie, J.A.; Beckman, W.A. *Solar Engineering of Thermal Processes*; John Wiley & Sons: Hoboken, NJ, USA, 2013.
20. Kalogirou, S. Economic analysis of solar energy systems using spreadsheets. *Renew. Energy* **1996**, *9*, 1303–1307. [CrossRef]
21. Pan, T.C.; Kao, J.J.; Wong, C.P. Effective solar radiation based benefit and cost analyses for solar water heater development in Taiwan. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1874–1882. [CrossRef]
22. Li, W.; Song, G.; Beresford, M.; Ma, B. China's transition to green energy systems: The economics of home solar water heaters and their popularization in Dezhou city. *Energy Policy* **2011**, *39*, 5909–5919. [CrossRef]
23. Solar Geyser Prices and Quality Assured Domenstic Solar Geysers. Available online: https://solaradvice.co.za/solar-geyser-price-comparisons/ (accessed on 1 March 2021).
24. Petroleum, B. BP Statistical Review of World Energy June 2015. 2015. Available online: http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf (accessed on 1 July 2022).
25. ESKOM: What is Loadshedding? Available online: http://loadshedding.escom.co.za/loadshedding/description (accessed on 1 April 2016).
26. Sebitosi, A.B.; Pillay, P. Renewable energy and the environment in South Africa: A way forward. *Energy Policy* **2008**, *36*, 3312–3316. [CrossRef]
27. Islam, M.R.; Sumathy, K.; Khan, S.U. Solar water heating systems and their market trends. *Renew. Sustain. Energy Rev.* **2013**, *17*, 1–25. [CrossRef]
28. Papadimitratos, A.; Sobhansarbandi, S.; Pozdin, V.; Zakhidov, A.; Hassanipour, F. Evacuated tube solar collectors integrated with phase change materials. *Sol. Energy* **2016**, *129*, 10–19. [CrossRef]
29. Ayompe, L.M.; Duffy, A. Thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector using data from a field trial. *Sol. Energy* **2013**, *90*, 17–28. [CrossRef]
30. Vasanthaseelan, S.; Kumar, P.M.; Anandkumar, R.; Ram, K.H.; Subbiah, R.; Suresh, V.; Abishek, A.S.; Anith, R.; Aravinth, P.; Balaji, S.V. Investigation on solar water heater with different types of turbulators. *Mater. Today Proc.* **2021**, *47*, 5203–5208. [CrossRef]
31. Nwodo, J.C.; Overen, O.K.; Meyer, E.L. Decoupling the Monitoring of Solar Water Heaters and their Usage Profiles. *Water* **2021**, *13*, 3186. [CrossRef]