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Innovation through the effects of solar water heating (SWH) in Africa

Abstract

Energy is a useful component that has a positive impact to Africa's socio-economic development. Its effect on households can therefore not be overlooked. Past studies revealed that, the role of the Solar Water Heater is to utilize the energy generated by the sun to heat water. The heating of the water is achieved via the collector. The tubes are filled with water which is heated during the day light hours and this hot water is stored in the main tank. The hot water rises in the tube and is replaced by the cooler water, which is at the lower level of the main tank. This cycle is repeated continuously throughout the day thus heating the water in the main tank. As hot water is drawn from the system, cold water is subsequently supplied. This paper is based on the review of the related literature to show the effects of solar water heating and the usage of innovative technology in residential homes. In particular, the description of SWH product, demand side management potential of solar water heaters, and the innovation diffusion reasons. Then, the conceptual framework as it relates to the innovation diffusion theory will be presented. Lastly, the development of the research problem is outlined. Using a theoretical framework, the paper is able to present the advantages and disadvantages of SWH in Gauteng, South Africa.

Keywords: solar water heater, Africa, diffusion of innovation, socio-economic development.
JEL Classification: L71, L72, Q41, Q42, Q48, Q55.
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Introduction

Wells (2012, p. 4) points out that solar water heating technology is a system designed to capitalize on the heat from the sun by collecting the necessary energy that is meant to transfer the heat to a stored water supply. Hot water flows from the panel up to a tank, which is insulated to prevent the water cooling down too much before it is used. A solar water heater can save money and energy, since the fuel source is both free and renewable. Most people are quite aware of solar water heaters, as they are now quite common.

The heating of the water is achieved via the collector. These tubes are filled with water which is heated during the day light hours and this hot water is stored in the main tank. The hot water rises in the tube and is replaced by the cooler water which is at the lower level of the main tank. This cycle is repeated continuously throughout the day thus heating the water in the main tank. Cold Water is supplied to the system as the hot water is drawn from the system. The cold water mains supply is connected to the cistern (Wells, 2012, p. 4).

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1. Theoretical consideration

According to Solar Ray (2010, pp. 2-3), the header tank is made from polypropylene and has two powder coated galvanized steel brackets that serve to attach the header tank to the main tank. Within the header tank, there is a float ball valve, which controls the inlet of cold water to the header tank. The purpose of the header tank is to supply cold water to the main tank as required by the system. The header tank also serves to collect the excess water from the main tank that has expanded due to heating process.

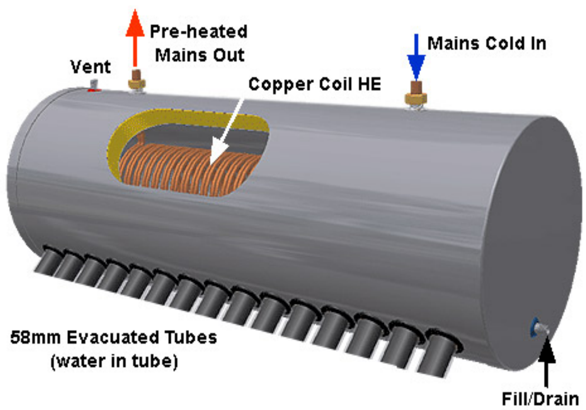

Fig. 1. Solar water heating tank

The system utilizes evacuated glass tubes to heat water. These glass tubes are connected via holes to the main tank. Each hole has a silicone seal to prevent water leaking between the main tank and the body of glass tubes. The description shows that, by inserting the glass tubes into the main tank, these are carried by the tube support cups mounted on the support stand of the system. Plastic rings are placed on each glass tube which lay flat against the main tank. (Solar Ray, 2010, pp. 3-5).

Fig. 2. Collector – evacuated glass tubes

A galvanized and powder coated steel stand is provided to support the assembled system. There are two variations of this stand, namely pitched roof stand and flat Roof Stand (Solar Ray, 2010, p. 10).

Fig. 3. Support stand

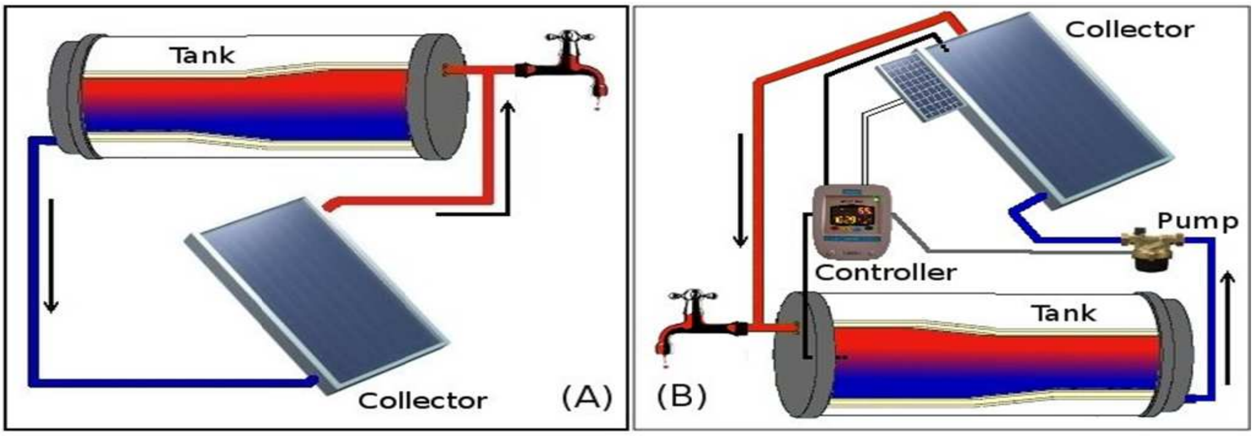

Fig. 4. Solar water heating configuration

A low pressure solar water heater stores up to a maximum of 110 litres stainless steel tank covered in an appliance white outer casing, IPX4. It comes with 12 vacuum tubes: 12 .304 rated. The horizontal solar water operates at zero pressure and relies on gravity to feed water to the taps. A self-filler tank controls the water flow into the solar water heater. The self-filler tank has a high-pressure ball valve, which allows for a direct connection to the municipal mains supply, without any additional valves. The solar water heater relies solely on solar radiation transmitted via an array of vacuum tubes to heat the water and does not have an electrical element and thermostat as a back-up (Solar Ray, 2010, p. 7). According to Allen, Hammond, and McManus (2008, pp. 528-544), solar water heaters offers consumer's enormous benefits as a water heating method, because consumers can save money on utility bills by using solar energy for heating water. Not only will they save money, it will also help preserve our natural gas supplies and decrease air pollution locally. Previous analyses have shown that usage of solar water heaters (SWHs) reduces both the total energy demand, as well as the peak consumption by shifting the demand to non-peak hours (Özdemir et al., 2009, p. 2).

2. Advantages of solar water heaters

When a solar water heater replaces an electric water heater, the electricity displaced over 20 years represents more than 50 tons of avoided carbon dioxide emissions alone. Carbon dioxide traps heat in the upper atmosphere, thus contributing to the "greenhouse effect" (Department of Energy, 2006, p. 6).

By reducing the electricity demand in residential areas through solar water heating, pressure on the electrical grid in certain areas is reduced, resulting in a more stable power supply and reducing the amount of energy loss through the transmission and distribution of electricity. This is just another way that solar energy can help light up South Africa (Eskom, 2012, p. 1).

3. Disadvantages of solar water heaters

For the consumer, the cost of purchasing and installing a SWH system is still relatively high when compared to conventional technologies (Milton & Kaufman, 2005). The average cost of purchasing a high pressure SWH unit ranges from R16,000 to 30,000 and installation costs range anywhere between R2,000 and R6,000 (Hardie, 2010, p. 26). If this cost is compared to the cost of the incumbent technology, the cost of a conventional geyser is between R3,000 and R6,000. It is significantly cheaper, which can have a dampening effect on demand. In general, consumers are more concerned about the cost of electricity and expected increases than the demand on the grid, and saving energy to decrease their electricity bills. According to a study done on economic and environmental analysis of solar water heater utilization in Gauteng province, South Africa by Özdemir et al. (2009), the utilization of SWHs is suitable for mid and high income groups with respect to economic, environmental and demand side management aspects. One burden is the higher investment costs, which have a payback period of up to 4 years. To overcome the burden of high investment costs, a financing scheme or financial incentives would assist in increasing the uptake of SWHs (Özdemir et al., 2009).

Keh-Chin Chang et al. (2011) found that payback period of a SWH is shorter than the life-span of the system itself, indicating that SWHs are economically viable even with low production cost of electricity and thus represent a profitable investment proposition for end users, manufacturers and distributors. However, the subsidy programs offered by the government of South Africa may not be sufficient to facilitate diffusion. This is attributed to the high initial capital cost of the system and low affordability of the majority of the South Africa population with low income. Alternative financing mechanisms are required.

Solar energy systems require periodic inspections and routine maintenance to keep them operating efficiently. Also, from time to time, components may need repair or replacement. Home owners are concerned, because at the time of installation, it is still uncertain as to what will the cost of maintaining the solar water heaters amount to. These are unknown until when the system is due for maintenance, some systems require yearly maintenance and this comes with costs, as the maintenance must be conducted by a qualified solar installer (Department of Energy, 2006, p. 6). Although a solar water heater comes with a 5 year warranty, some components might fail and some might require replacement during the warranty period and after (Solar Lord, 2013).

Solar water heaters only heat water while exposed to sunlight. This means they cannot generate heat at all during the night, and even during the day, the amount of heat they can generate is limited by the weather: i.e., cloud cover. Furthermore, demand for electricity does not always coincide with times when the sun is shining. In winter, for example, more lighting and heating is needed, but the days are shorter, colder and prone to be cloudy (Solar pay, 2010). The key challenge is to deal with pertinent market restraints, which include consumer confusion regarding the product and its correct usage, installation problems, and the price of the rebate (Frost & Sullivan, 2011). Once these challenges have been overcome, the focus should be on driving the demand side of the market in order to stimulate substantial growth (Cronje, 2011).

Table 1. Comparison of solar water heaters to a conventional water heater

Solar water heater	Standard water heater
FREE energy from the sun	COSTLY gas or electric
Low operating cost	High operating cost
Life expectancy 15-30 years	Life expectancy 8-12 years
Storage capacity	Storage capacity
Does not pollute environment	Depletes fossil fuels
increase equity in your home	No added value to homes
10-20% return on investment	No return on utility payments
Protection from future increases	At mercy of utility
Hot water during blackouts	No hot water during blackouts

Source: according to think-solar-power.

The table below, for every GWh saved, 0.99 kt of CO2 is avoided, resulting in a saving of ~ 60 kt of CO2 per annum.

Table 2. SWH environmental implications

Parameter	Savings per 1 kWh
Coal use	0.53 kilograms
Water use	1.40 litres
Ash produced	155 grams
Particulate emissions	0.33 grams
CO2 emissions	0.99 kilograms
SO2 emissions	7.75 grams

Source: Eskom Annual Report.

4. Demand side management potential of SWH's

According to Nelson and Winter (1982), after space conditioning, water heating represents the largest use of energy in the residential sector. Solar water heating has far greater potential and this is due to the greater cost effectiveness of these systems. SWHs are particularly promising as a renewable energy application (Kothari, Singal, & Rakesh, 2011). It is one of the simplest and least expensive ways to harness renewable energy and can be comparatively cost-effective for reducing GHG emissions. Enver, Doruk, and Özdemir (2009, pp. 2-18) indicate that the utilization of SWHs is suitable for mid and high income groups with respect to economic, environmental and demand side management aspects. The hot water demand of a household depends on income group and access to water (Meyer & Tshimankinda, 1997). The higher the income level of the household the greater access to water with high income households averaging 88% access and poor income households have only 56% access.

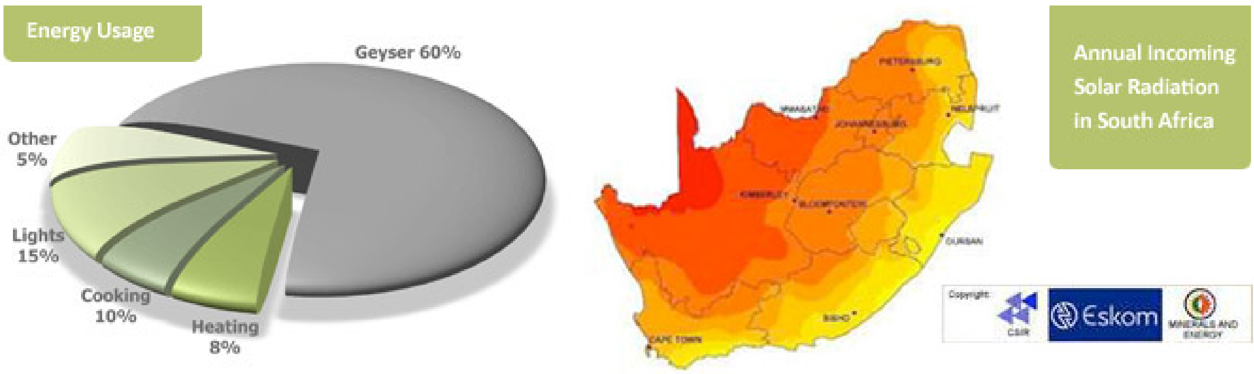

Fig. 5. Energy usage in a household

South Africa is one of the sunniest countries in the world, with approximately 309 sunny days per annum in the province of Gauteng. These two facts combined provide a very powerful case for the use of solar water heating systems (Dezulovic, 2015).

5. Diffusion of innovation perspective

Technology refers to the theoretical and practical knowledge, skills, and artefacts that can be used to develop products and services as well as their production and delivery systems, (Burgelman et al., 2009, p. 2). According to Burgelman, Technology can be embodied in people, materials, cognitive and physical processes, plant, equipment, and tools. From consumers perceptive, the innovation decision process thus begins when "an individual (or other decision-making unit) is exposed to an innovation existence and gains an understanding of how it functions" (Rogers, 2003). According to Rogers's model of the innovation process, this first stage is referred to as the knowledge stage and is followed by four stages: persuasion, decision, implementation and confirmation. The diffusion of Innovation process is described in terms of five stages in the adoption process.

Fig. 6. Five stages in the decision innovation process

6. The development of research problem and conceptual framework

Despite the rebate incentives, uptake of SWHs in Gauteng remains depressed at the same time. The research problem, therefore, is as follows:

There is a strong evidence that SWH has the potential to play an important part in reducing overall energy demand and CO2 emission in the residential sector and help South Africa meet its renewable energy targets. The comparatively slow uptake of SWH technologies in Gauteng suggests that home owners' willingness to adopt SWH is significantly lower posing a serious challenge for policy makers and marketers. More importantly, the figures imply that current grant are not able to bridge the gap between consumer willingness to adopt and actual market prices, providing scope for research on home owners and their general perception of SWH technologies.

Existing studies focussed on financial, regulatory and information barriers to account for slow adoption of Solar Water Heaters. As such, the effect of how perceptions of SWH product characteristic influence householders to adopt solar water heating technologies is not clearly described in the literature. Therefore, the limited studies reporting on homeowners' perceptions of SWH characteristics and their influence in the adoption of SWHs can be regarded as a research gap in need of further investigation. To understand how solar water heaters are perceived and adopted, the conceptual framework, developed mainly from the existing literature, becomes useful.

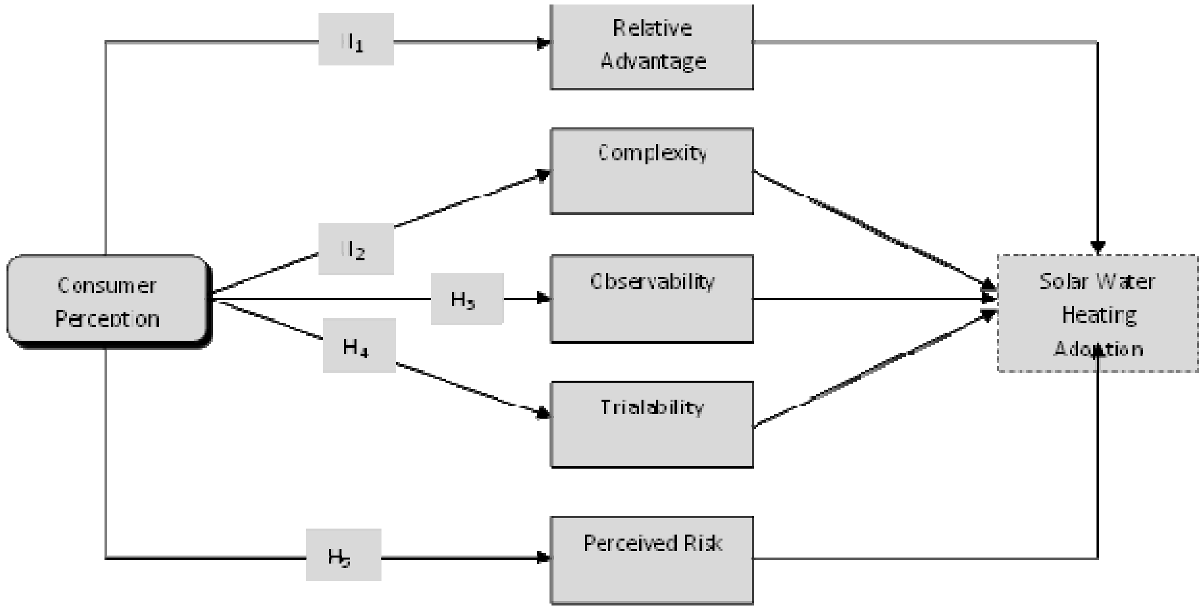

Fig. 7. SWH adoption model

The above model shows how consumer perception of product characteristics can influence the adoption of solar water heaters. This study focuses on the five constructs of the model above, which are relative advantage, complexity, observability, trialibility and perceived risk. Another well-established concept in the innovation literature of perceived risk has been considered in the model because of its importance in this study. It was used to determine the effectst of perception of SWH characteristics on the adoption of SWH by homeowners in Gauteng Province, South Africa. The study aims to determine if these perceived characteristics will impact, either negatively or positively, on the adoption of solar water heaters.

7. Findings from hypotheses

To test the formulated hypotheses, linear regression analysis was utilized. This meant testing the relationships between dependent and independent variables, as well as their significance. A total of 5 dependent variables (i.e., relative advantage, complexity, trialibility, observability, perceived risk) were identified as being affected by adoption of solar water heaters. The five hypotheses proposed by the conceptual model are as follows:

H1: Perceived relative advantage has a positive effect on homeowner's willingness to adopt solar water heater.

H2: Perceived complexity has a positive effect on homeowner's willingness to adopt solar water heater.

H3: Perceived trialability has a negative effect on home owner's willingness to adopt solar water heater.

H4: Perceived observability has a positive effect on homeowner's willingness to adopt solar water heater.

H5: Perceived performance risk has a negative effect on homeowner's willingness to adopt solar water heater.

Thus, the linear regression model: $y = a + bx + e$ was individually applied to test each dependent variable with the independent variable (adoption of solar water heaters). The regression model consists of:

(a) Y = dependent variable;

(b) X = independent variable;

(c) a = Y-axis intercept;

(d) b = beta or the coefficient of X (independent variable);

(e) e = Error term.

So, the value of beta indicates whether the dependent and independent variables are positively or negatively related. In other words, when the independent variable increases, at what rate would the dependent variable increase? As a corollary, a positive beta indicates a positive relationship and the converse is also true. The p-value was used to assess the significance of the beta score. A significant relationship is a p-value less than 0.05. If the p-value was observed to be greater than 0.05, then the relationship was found to be non-significant. After determining a favorable p-value, the R-square was used to depict the strength of the relationship. The higher the R-square, the stronger the relationship; and then a lower R-square depicted a weak relationship.

Hypothesis 1. The rationale of this hypothesis was to test the relationship between relative advantage of solar water heater and adoption, as well as discover the impact of relative advantage on the adoption rate.

Table 3. The results of test of the relationship between relative advantage of solar water heater and adoption

Independent variable	Chi-square	df	Significance level
Relative advantage	.639	15	0.05

The p-value is < 0.0001. The result is significant at p< 0.05 and this means that the relationship between two variables is positive.

Conclusion on H_1: hypothesis is accepted.

Hypothesis 2. The rationale of this hypothesis was to test the relationship between complexity of solar water heater and adoption, as well as discover the impact of relative advantage on the adoption rate.

Table 4. The results of test of the relationship between complexity of solar water heater and adoption

Independent variable	Chi-square	df	Significance level
Complexity	290	15	0.05

The p-value is < 0.0001. The result is significant at p< 0.05 and this means that the relationship between two variables is positive.

Conclusion on H_2: hypothesis is accepted.

Hypothesis 3. The rationale of this hypothesis was to test the relationship between Observability of solar water heater and adoption, as well as discover the impact of relative advantage on the adoption rate.

Table 5. The results of test of the relationship between observability of solar water heater and adoption

Independent variable	Chi-square	df	Significance level
Observability	.56	1	0.05

The p-value is < 0.0001. The result is significant at p< 0.05 and this means that the relationship between two variables is positive.

Conclusion on H_3: hypothesis is accepted.

Hypothesis 4. The rationale of this hypothesis was to test the relationship between trialability of solar water heater and adoption, as well as discover the impact of relative advantage on the adoption rate.

Table 6. The results of test of the relationship between trialability of solar water heater and adoption

Independent variable	Chi-square	df	Significance level
Trialability	266	21	0.05

The p-value is < 0.0001. The result is significant at p< 0.05 and this means that the relationship between two variables is positive.

Conclusion on H_4: hypothesis is accepted.

Hypothesis 5. The rationale of this hypothesis was to test the relationship between perceived risk of solar water heater and adoption, as well as discover the impact of relative advantage on the adoption rate.

Table 7. The results of test of the relationship between perceived risk of solar water heater and adoption

Independent variable	Chi-square	df	Significance level
Perceived risk	.518	36	0.05

The p-value is < 0.0001. The result is significant at p< 0.05 and this means that the relationship between two variables is positive.

Conclusion on H_5: hypothesis is accepted.

Conclusion

This paper provided a comprehensive theoretical framework of the body of knowledge pertaining to SWH system components and configurations, perceptions of SWH product characteristics and the influence on the adoption of solar water heater in in African in general and in Gauteng, South Africa in particular. It is clear from the research reviewed that the adoption of solar water heating is much immersed and remain a global focus. The empirical evidence on SWH technology is comparatively scarce. Few studies have been conducted to examine SWH systems, but most of them focused on the design aspects of SWH systems and its application. It is therefore imperative to understand that very few studies have been focused at factors affecting the adoption of SWH system, a wide gap is however left in this field of research.

The research problem was resolved and the contribution of the study was indicated by means of hypotheses tested. Findings were summarised and provided from the data collected and analyzed, which indicate that solar water heating technologies has great potential to help Gauteng Province in meeting its energy and emission targets and to trigger positive shifts in energy consumption patterns. Yet, despite policy efforts, the rate of adoption among home owners remains low. The findings presented in this study clearly show that a major reason for the slow uptake is home owner's perception of this technology. More importantly, the results suggest that home owners' purchase or investment decisions are not entirely "rational" but are influenced by factors other than cost-benefit evaluations. Using Rogers' (1995) "innovation diffusion theory" as a theoretical framework, our findings show that home owners' perceptions of product characteristics, relative advantage, compatibility, complexity, observability, trialability and facilitating conditions characteristics influence and (partly) account for differences in diffusion for the respective technologies.

In relation to annual energy cost savings, home owners are willing to pay most for solar water heaters. They strongly believe that solar water heaters have a relative advantage, as it will make them to be more independent from the national grid. They perceive this technology as environmentally friendly, which translates directly into higher diffusion. Further, observability stimulates awareness and homeowners who know someone who operates a solar water system have a higher adoption rate. Majority of homeowner's perceived solar water heaters as non-complex technologies which translate to higher adoption rate. On the contrary, homeowners perceived using as risky; they were worried about the dependability of solar water heaters and uncertain performance.

This finding indicates that word of mouth is an important vehicle to communicate the benefits of solar water heating and that positive social pressure can translate into higher adoption. Yet social influence can also have adverse effects. Any effort to promote micro wind power thus needs to address, for example, issues on safety and noise. Also, policy makers and marketers need to further investigate consumer preferences for visually less intrusive and thus more acceptable turbine designs (e.g., vertical versus horizontal design). Wood pellet boilers are perceived as being difficult to operate, adversely affecting home owners' daily routines and habits. In order to increase WTP for wood pellet boilers, operational requirements could be communicated to home owners more clearly. However, wood pellet boilers are perceived by home owners as a viable alternative to conventional fuels such as oil or gas, which can be communicated as a selling point. The same is true for solar panels. However, as with wood pellet boilers and wind turbines, initial costs are a major barrier. This study will therefore strongly contribute to the body of knowledge on the perceptions and adoption of solar water heaters.

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