A Mathematical Approach to Analyze Factors Influencing Adoption of Solar Based Power Production in Residential Buildings in Tamilnadu State of India

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Abstract- The objective of this research paper is to find out the important factors influencing the adoption of solar photo voltaic system for individual households and to find out if there is any difference in the adoption of solar photo voltaic system (SPVS) among the households with differing income levels, and their place of residence namely rural and urban place. Further, TOPSIS is applied for ranking the groups of households based on the influencing factors. Data was collected from respondents in rural and urban areas, living in own and rented houses. Respondents also represented various income strata. It is found that people with higher income levels are generally more open to the idea of adopting SPVS and people living in rented houses are less likely to adopt SPVS compared to those living in own houses whether in urban or rural areas. The outcome of TOPSIS shows that the respondents with high income, residing in their own houses in urban areas are ranked first in the willingness to adopt SPVS.

Keywords Solar photo voltaic system adoption, Roof top solar, TOPSIS, Domicile, Household income, Own and Rented house.

1. Introduction

India is the third biggest producer and the third biggest user of electricity in the world [1]. It is a comprehensible fact that per capita energy consumption is an indicator of the standard of living of people in that country and this is evident from studies done very early to till date [2, 3, 4]. Electricity (energy in general) is an important catalyst for socioeconomic development [5, 6]. According to [7], the consumption of electricity is a direct reflection of the economic development of a country and electricity has become an essential commodity.

Choice of fuels used for generation of electricity by any country or organisation has consequences on the global environment and economy as well [8]. Renewable energy technologies were ranked in [9]. Dependence on fossil fuels for electricity production draws criticism to those technologies. These fossil fuels are both environmentally harmful and unsustainable. India's electricity production is dominated by fossil fuels especially coal. During the 2018-19 fiscal year, about three-quarters of the country's electricity produced was through coal. There is a clear correlation between the residential environmental quality and energy generation through fossil fuels implying that use of fossil fuels generates environmental effects that negatively impact social wellbeing beyond tolerable limits [10]. To alleviate the drawbacks of fossil fuels, Intergovernmental Panel on Climate Change (IPCC) endorses renewable fuels for generation of electricity [11]. Renewable fuels can achieve a major role in fulfilling rising energy demand [12] and the use of renewable energy is on the rise [13]. Since renewable energy is environmental friendly [14] it is gaining much importance these days [15].

The government is making efforts to increase investment in renewable energy in India [16]. Electricity generation by thermal power stations in India declined by 2.15 percentage during April-October of financial year 2019-20 compared with the corresponding period in financial year 2018-19 [17]. Public acceptance or public support of solar energy is an important contributing factor in the success or failure of government decisions about the sources (renewable/non-renewable) used for electricity generation that will meet the growing demand for energy needs and public support is recognized as an important factor in shaping the implementation of renewable energy technologies [18].

Among the various renewable energy sources, solar photovoltaic system is considered the most environment friendly, economical [19] and sustainable [20] for electricity production. Adoption of solar power becomes a necessity due to rising fuel costs, global climate change, and growing demand for electricity [21]. During the last decade, solar photo voltaic systems (SPVS) ranging from kilowatts (kW) to hundreds of megawatts (MW) were widely deployed, demonstrating the feasibility of photo voltaic (PV) technology as a major sustainable power source [22].

In India, the potential of wind power [23] is lower than the solar power potential [24], and hence solar energy resources have gained a significant attention. Consequently, the world's largest solar photovoltaic (PV) project is in India [25]. The Jawaharlal Nehru national solar mission introduced in 2010 with a target of producing 22 GW solar power by 2022 has already lead to a substantial growth in the installed solar capacity with more than 7.5 GW added in last 6 years [26].

From the literature it is evident that a large portion of residential electricity demand can be met only by solar power when it is combined with battery storage system. Further, to make solar installations attractive to general households, suitable tariffs and subsidies are to be provided by the government. Also, suitable changes to grid operations are necessary to facilitate the penetration of electrical power generated from solar energy into the grid in order to enable large-scale adoption of solar PV systems [27].

In recent times, in many countries, solar PV systems have gained acceptance as a source of clean energy at household level [28]. The solar PV module is made up of silicon which converts solar irradiance to DC voltage which is then converted to AC voltage by an inverter. Adoption of solar PV system at household level can provide an environment friendly solution to electricity shortage and can reduce the burden on grid thus freeing up precious electricity for other applications.

1.1 Importance of Power to Economy/GDP

The relationship between a country's electricity consumption and economic growth is well established by several studies [5, 29, 33, 31, 32, 33, 34]. Since 1970s, economists and policy analysts have focussed on the causal relationship between a country's energy consumption and economic growth and have found that there is a positive relation between the two [35, 36, 37, 38, 39, 40, 41]. It's long been obvious that economic growth and energy demand are linked. As economies grow, energy demand increases; if energy supply is inhibited, GDP growth of a country reduces in turn. This has been observed since the Industrial Revolution [42]. This is because energy is the basic building block of economic development. Electricity is one of the significant infrastructural inputs in socio-economic development of a country [43]. Growth in industrial consumption of electricity is an immediate indicator of a country's economic development [44].

1.2 Power Scenario in India

With the development of Indian economy, the households in the country has seen fuel progression starting from firewood to coal, to oil, to electricity. Because of their higher disposable income, households have become more and more dependent on the electric gadgets for basic necessities, recreation and comfort. Economic growth of a country causes expansion in both domestic and industrial or commercial sectors where electricity is used as basic energy input. Electricity consumption in agricultural sector has also accelerated keeping pace with country's growth [45].

As per the data given in the booklet 'Growth of Electricity Sector in India from 1947-2019' published annually by Central Electricity Authority (CEA) of India, it can be observed that there is a steady increase in growth rate of household demand for electricity in India, and a large portion of this demand is met by thermal power plants [45]. The Installed Capacity of India as on March 2017 was 3,26,833 MW which includes 2,18,330 MW of thermal power, 6,780 MW of Nuclear power, 44,478 MW of hydel power and 57,244 MW from renewables. The per capita energy consumption in India was 883.64 kWh at the beginning of the 12th five-year plan (April 2012) and as on March 2019, the per capita energy consumption was 1181 kWh [46]. According to Brookings India study [47], aggregate electricity demand in India could grow from 949 TWh in 2015 to between 2074 TWh and 2785 TWh by 2030.

The country's total installed capacity of solar power plants reached 34.406 GW as of February 2020 [48]. Rooftop solar power accounts for 2.4 GW, of which 70% is industrial or commercial production [49].

1.3 Power Scenario in Tamilnadu

Tamil Nadu has added 13,287 MW to the State grid through conventional and non-conventional means from the year 2011 to 2018, thus making the state not only self sufficient but also a power surplus state [50]. The present average power demand of Tamil Nadu is about 14,800 MW to 15,300 MW which is fulfilled by the electricity board. An all-time high maximum demand of 15,440 MW was required and successfully met on 27.04.2018. The daily average State consumption has increased from 200 MU during 2011 to 330 MU in 2018 [50].

1.4 Importance of solar power in power independence among households

Power independence among households has many advantages first to those households and subsequently to the country as such. Adoption of SPVS will free up precious electricity required by the industry. The immediate benefit of installing SPVS is that it drastically reduces the electricity bill of households, and this benefit can be enjoyed until the life time of solar panels which could be about 25years [51]. Usually electricity is generated far away from the consumption point and almost 23% of electricity generated is lost in transmission and distribution. Unlike the conventional energy produced, electricity from solar energy is usually produced using the rooftop solar panels and is consumed within the building, thereby literally eliminating the transmission and distribution loss [51]. Solar power provides reliable energy and energy security along with energy independence to households and industry. The "fuel" for solar panels is free for all to use [52]. Solar energy is an important source for clean energy which helps to overcome the increasing anxieties about greenhouse effects caused by conventional energy sources [53, 54]. Solar panels as such release no pollutants, requires very less maintenance and is highly reliable, with life span of 20–30 years [55, 56]. However the same cannot be said for lead acid batteries which are conventionally used to store energy.

Tropical climate with abundant sunshine favours SPVS deployment in India. The Annual Average Direct Normal solar Irradiance in Tamilnadu is 5.52 kWh/m^2/day. This is ideal for the installation of household rooftop SPVS. There is an assumption that beyond 2020, solar energy could surpass all other forms of renewable energy sources [57].

1.5 Factors affecting adoption of solar panels

An energy transition from one system to another is characterized by socio-technical complexity [58], where the success of transition is dependent on changes happening in energy production and distribution infrastructure; and consumption patterns at the consumers' end. Uptake of renewable energy technologies by the larger sections of the society is influenced by or constrained by economic, policy and societal acceptance challenges. The economic barriers include higher capital costs generally associated with renewables [11], and additional cost or expenditure that may be required to integrate renewable energy produced with the existing electricity-grid infrastructure [59]. Overcoming these constraints which the general public may face in adopting renewable energy sources especially solar PV requires supportive government policies [60]. However, policies designed regarding electricity supply and procuring electricity from the public are often conceived and executed by different governmental bodies [61]. This often results in conflicting policies among the governmental bodies creating confusion and slowing the adoption of renewables [62, 63]. Local community resistance to renewable-energy projects present societal challenges to the adoption of renewable energy [64, 65].

The critical factors of social acceptance for solar PV rooftop system were studied through diffusion of innovations theory by Suppanich and Wangjiraniran [66]. The attributes of diffusion of innovations theory [67] are Relative Advantage, Observability, Complexity and Compatibility. To measure the above said attributes, Suppanich and Wangjiraniran have used various factors under the attributes. Under Relative Advantage, they have used revenue i.e. ability to sell solar electricity, environment protection, unlimited power, global warming, and technology development. Under observability, they have used factors such as facility to monitor income from selling electricity, neighbour attitudes, environmental protection image, power production monitoring, solar energy knowledge. Under Complexity the factors are installation space, availability of service providers, building location, difficultly in maintenance, building structure. Under Compatibility the factors are effect of the new system on the existing system, land use area, installation cost, global trends i.e. worldwide popularity of renewable energy and social value [66].

In a similar study [68], the authors have used Rogers' model of innovation diffusion framework [67]. They have identified drivers and barriers for SPVS adoption at household level. The categorization of drivers of solar adoption are presented as financial advantage and feasibility, reliability of technology, environment friendliness, independence from grid, energy security, and compatibility of SPVS with existing household wiring. The barriers for adoption among households is attributed to high initial cost, long payback period, perceived complexity of SPVS, maintenance, unforeseen troubles, performance efficiency drop, trialability - Return warranty over performance, other people opinions and experiences.

Solangi et al, [18] have considered various factors that affect public acceptance of solar energy. The factors were public knowledge, public awareness, subsidies and incentives, interest to the current environmental issues and global warming, cost of solar generated electricity, how households saved electricity bill, how low is the cost of SPVS and what other users' experience was.

In their study on "Assessing the Feasibility of Large-Scale Adoption of Solar Power in the Residential Sector", the authors [27] have considered payback period denoting the breakeven point for the customer, suitable tariffs and subsidies.

Walters et al., [69] studied about the Short-Term Initial Uptake and Long-Term Sustained Diffusion of solar PV system. The most influential factors for short-term diffusion are Market Maturity, Subsidies, and Knowledge of Technology while for Long-Term Diffusion, Environmental Stewardship, Understanding of Net-billing, Self-reliance and Cost Comparison are the influential factors.

Walters et al., [70] identified fourteen factors that acted as barriers to household solar investment. The fourteen factors are High Initial Costs, Uncertain Return on Investment (ROI), Subsidies, Reasonable Energy Price, Cost Comparison, Knowledge of Technology, Market Maturity, Understandable Net-billing, Daily Insolation Variability, Installation Quality, Grid Reliability, Self-reliance, Environmental Stewardship, and Carbon Footprint. These fourteen factors were in turn assigned into seven categories namely Financial Motivations, Energy Supply Motivations, Environmental Motivations, Decision Makers' Incomplete Knowledge, Technical Barriers, Financial Barriers, and Institutional Knowledge [70].

Salman Ahmad et al., [22] have used factors such as Perceived usefulness, Perceived ease of use, Attitude towards using solar PV system, and Behavioural intention for solar PV system. The measurement items under Perceived usefulness are Solar electricity serving individual/

households daily needs of electricity, lowering the electricity bill, complete tasks with same ease as normal power supply and confidence among the public that solar power can be a reliable source of electricity in future. Under Perceived ease of use, the measurement items are solar electricity being easy to use as source of electricity, easy to learn and use solar energy, easy to become skillful in using solar electricity, solar technology being easy and flexible to use, house being suitable for solar installations and technical obstacles in using solar electricity. In Attitude towards using solar PV system, the items are perception about solar electricity becoming a major source of electricity in future, idea of using clean source of electricity in house, right time to use solar electricity and Overall enjoyment in using solar technology as a source of electricity. The factor Behavioural intention is measured though intention to use solar electricity for house and an individual's plan to have some renewable energy technology for their house for generation of electricity

While many studies have studied about uptake of RE in rural areas, most have not studied about the uptake of SPVS for individual households with the objective of reducing the overall electricity consumption by those households thereby freeing up the energy available for industry. Also the researcher could not find any literature pertaining to the comparison of adoption of SPVS between rural and urban households with differing income levels.

2. Methodology

The purpose of this paper is to investigate empirically the differences in the factors influencing the adoption of solar PVs among residents of rural and urban parts of Tamilnadu. The factors were clustered into six main heads such as a) perception of cost of installation of SPVS (PCS), b) electricity bill saving month on month (ROI), c) importance attached to uninterrupted power supply (UPS), d) environmental consciousness (EC), e) general willingness to adopt solar PV system (WA), f) willingness to adopt solar PV system with subsidy (WAS).

In order to explore the acceptance of solar PV system and to rank the acceptance of the same based on the locality of residence (rural (R) versus urban (U)), data was collected from 100 respondents out of which 50 were from rural areas and 50 were from urban areas. The respondents were selected based on their domicile nature, that is, whether they live in their own houses (o) or live in rented houses (r). Within this classification, it was ensured that varying income levels of the respondents was included. Thus in rural area, respondents living in rented houses and with a monthly income varying from INR 10,000 (coded as 1) to above INR 50,000 (coded as 5) was considered. The same was repeated with rural residents living in own houses, urban residents living in rented houses and urban residents living in own houses. Thus the coding given is as follows: for example, Rr1 means the participant from rural area, living in rented property and falling in income category of INR10,000.

A questionnaire was developed based on the five factors mentioned above and administered to respondents from different localities. The opinion of respondents about their willingness to adopt SPVS was sought on five point scale which ranged from strongly agree (rated as 5) to strongly disagree (rated as 1). After the responses were sought, initially, to understand the important criteria influencing the adoption of SPVS, simple average method of the ratings was used. Here, the average of the responses on individual factors for all the respondents was calculated to get overall opinion on each factor. Then, TOPSIS method was applied to rank the respondents based on their locality for their acceptance of SPVS. Weights for the various acceptance factors were assigned in order to apply TOPSIS. Then, based on the results obtained from TOPSIS, the different groups of residents were ranked for their acceptance of SPVS. In order to understand the importance of each and every criterion, the weights assigned to the individual criterion were varied and the corresponding ranking of the group of residents was obtained. Initially, equal weights were assigned to each criterion and later on, weights were varied in a systematic manner keeping the weight for one criterion constant and varying all other weights by a small amount between an upper bound of 0.3 and lower bound of 0.1. Like this, 30 sets of weights were taken to find their effect on the ranking of the respondents.

The basic principle of TOPSIS for ranking the alternatives considered is that the chosen solution should have the smallest distance from the ideal solution and the greatest distance from the negative ideal solution [71]. In TOPSIS, the decision maker has to express the weights of different criteria.

A Multi Criteria Decision Making problem is expressed as,

$$DM = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & . & . & . & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & . & . & . & x_{1n} \\ x_{21} & x_{22} & . & . & . & x_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_{m1} & x_{m2} & . & . & . & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

The weight matrix is given as,

$$W = [w_1 \quad w_2 \quad . \quad . \quad . \quad w_n] \tag{2}$$

where,

$A_1, A_2, \ldots, A_m$ are the different groups of respondents based on locality, domicile and income.

$C_1, C_2, \ldots, C_n$ are the SPVC adoption criteria.

x_{ij} is the rating given by A_i group of respondents with respect to criterion C_j.

w_j is the weight assigned to criterion C_j.

Let J be the set of criteria for which greater x_{ij} values are better and J' be the set of attributes for which lesser x_{ij} values are better.

Steps involved in TOPSIS method are presented below:

Step 1: Framing of normalized decision matrix:

Normalized decision matric is obtained by normalizing the scores using equation (3).

$$r_{ij} = \frac{x_{ij}}{\left(\sum_i x^2_{ij}\right)^{1/2}} \qquad for\ i = 1, ..., m;\ j = 1, ... n \tag{3}$$

Step 2: Framing the weighted normalized decision matrix:

The decision maker assigns a set of weights (w_i for j = 1…n) for each criterion based on the preference for each criterion. Each column of the normalized decision matrix is multiplied by its associated weight.

An element of the weighted normalized decision matrix is given by:

$$v_{ij} = w_j r_{ij} \tag{4}$$

Step 3: Estimation of ideal and negative ideal solutions:

Ideal solution is given by,

$$A^* = \left\{v_1^*, ... v_n^*\right\} \tag{5}$$

where

$$v_j^* = \max_i \left(v_{ij}\right); \quad if\ j \in J \tag{6}$$

For the adoption of SPVS,

A^* = {minimum value of Perception of Cost of system, maximum value of ROI, maximum value of Importance of UPS, maximum value of Environment conscious, maximum value of General Willingness to adopt, maximum value of Willingness to adopt with subsidy}.

The Negative ideal solution is given by,

$$A' = \left\{v_1', ... v_n'\right\} \tag{7}$$

where,

$$v_j' = \min_i \left(v_{ij}\right); \quad if\ j \in J' \tag{8}$$

Here, A' = {maximum value of Perception of Cost of system, minimum value of ROI, minimum value of Importance of UPS, minimum value of Environment conscious, minimum value of General Willingness to adopt, minimum value of Willingness to adopt with subsidy}.

Step 4: Computing the separation measures for each alternative:

Distance from the ideal solution is,

$$SI_i^* = \left[\sum_j \left(v_j^* - v_{ij}\right)^2\right]^{\frac{1}{2}} \qquad for\ i = 1, ... m \tag{9}$$

Likewise, the distance from the negative ideal solution is,

$$SI_i' = \left[\sum_j \left(v_j' - v_{ij}\right)^2\right]^{\frac{1}{2}} \qquad for\ i = 1, ... m \tag{10}$$

Step 5: Estimation of the relative nearness to the ideal solution C_i^*:

$$C_i^* = \frac{SI_i'}{\left(SI_i^* + SI_i'\right)} \qquad 0 < C_i^* < 1 \tag{11}$$

The alternative with C_i^* closest to 1 is the best group for adopting SPVS.

3. Results And Discussion

This research is conducted to find out the factors that are considered to be important in influencing the adoption of solar photo voltaic system among the general public for residential use so that fruitful policy decisions could be made by the government for the proliferation of solar PV. These factors were decided based upon previous researches in various countries such as Malaysia, Ghana, Pakistan etc.

The average of ratings given by different categories of respondents was calculated and is recorded in Table 1.

Table 1. Simple Average of Ratings by Respondents

Factors / Domicile	PCS*	ROI*	UPS*	EC*	WA*	WAS*
Ro1	5	4.6	1.6	1.4	1	2.6
Ro2	5	4.8	1.4	2	1	2.6
Ro3	5	5	3.4	2.2	2	2.4
Ro4	2.4	5	3	2.6	3.4	3.8
Ro5	1.2	5	3.8	4	4.4	4.8
Rr1	5	5	1.2	1.2	1	1.2
Rr2	5	4.8	1.2	2	1	1.4
Rr3	4.6	4.6	2.4	1.4	1	1.6
Rr4	3	4.8	4.4	3.6	1.6	2
Rr5	1.4	5	4.6	5	1.4	1.8
Uo1	5	4.6	1.4	3.2	2	3
Uo2	4.8	4.8	1.8	4.4	3.2	3.6
Uo3	3.4	5	3.4	4.4	4.6	4.4
Uo4	2.2	5	4.6	4.6	4.4	4.6
Uo5	1.2	5	5	4.8	4.6	4.8
Ur1	5	5	1.2	4.4	1	1
Ur2	4.6	4.8	1.6	4.8	1.6	1.6
Ur3	4.6	4.6	2.2	4.4	1.6	1.6
Ur4	4	4.8	4.4	4.6	1.4	1.4
Ur5	1.8	5	5	4.6	1.6	1.6

* Respondents opinion where, 1is Low rating and 5 is High rating

From the outcome of simple averages (Table 1), it can be seen that the respondents living in rented houses and with lower income both in the rural and urban areas feel that the cost of SPVS is high. But those in the higher income group irrespective of the status of accommodation or domicile feel that the cost of SPVS is acceptable.

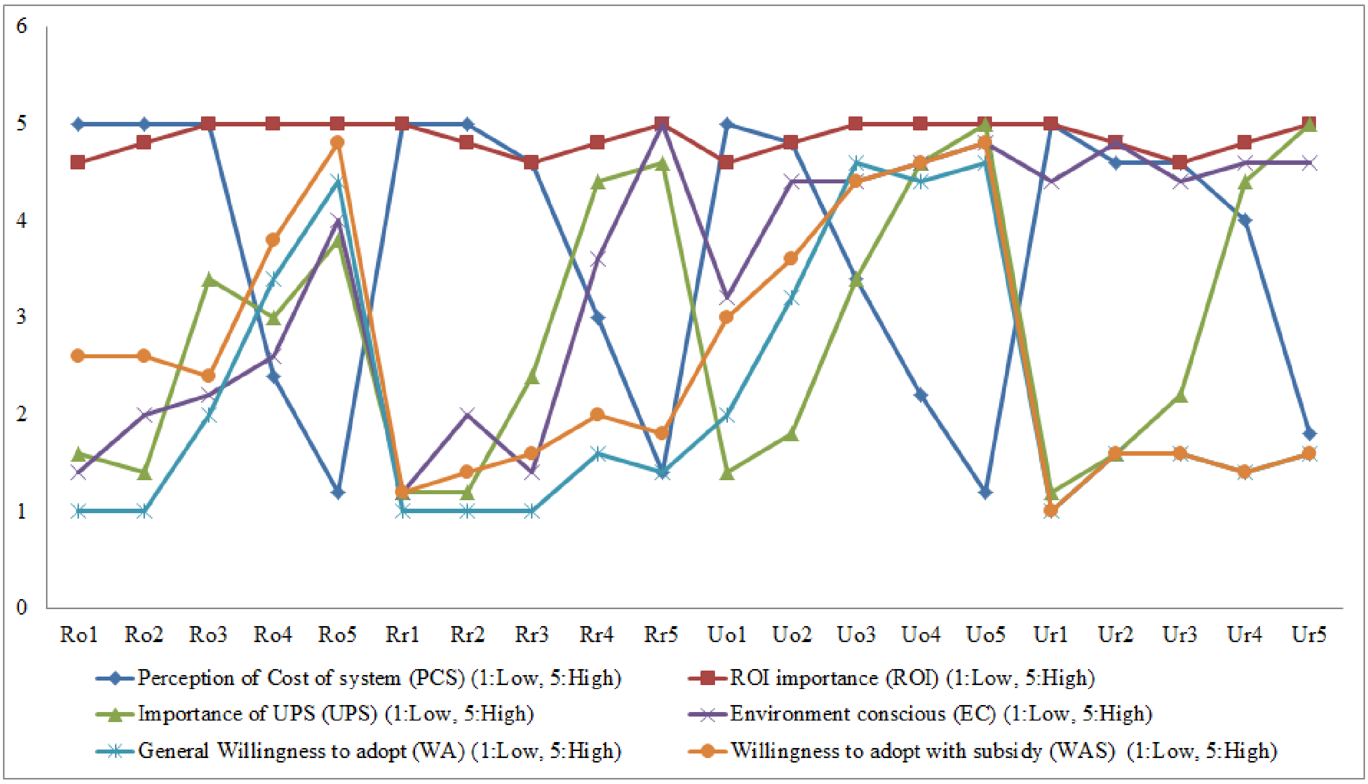

Fig. 1. Perception of the factors considered among different categories of rural and urban residents differentiated on income

There is a clear divide among those residing in own property compared with those residing in rented houses. Understandably those in the rented houses are far less inclined to adopt solar PV. The opinion among those in the rented houses is that the solar PV becomes an additional burden when they plan to shift houses. Thus to lessen the domestic demand on the grid, the house owners may be motivated to install solar PV in their property so that it can be useful to anybody who occupies the house.

In this analysis it is also found that cost involved in the purchase and installation of off grid solar systems for homes is the most important factor which influences the attitude on this system. During interaction with the respondents, it was found that almost all of the respondents' initial enquiry to the idea of installing solar PV was about the price of the product. There is a general perception that the SPVS is costly, which is not completely unfounded. The cost of 1kW SPVS (Solar PV, inverter and batteries) is INR 1,20,000 or USD 1600, price of 0.5kW is INR 72,000. India's per capita income was recorded to be INR 1,13,500 in Financial Year 2017-2018 [72]. Households with higher monthly income whether in rural or urban areas, generally use high power rating electrical appliances and will require 1kW system. These households can afford for solar PV. Most of these households are concentrated in pockets of urban and rural areas. Rest of the population both in urban and rural areas which use low power rated electrical appliances require only 0.5kW system but these households have less per capita income, hence they hesitate to adopt SPVS.

One interesting feature that can be observed from the study is that, irrespective of the income level or the place of residence, almost all of the respondents are very particular about the return on investment (ROI) they get from the solar PV. All of the respondents were very keen to know the cost savings they may get by installing solar PV. They were calculating the monthly interest rate for the investment and were keen to know about the payback period for the same. Also many households in the lower income group use less electricity and don't need to pay electricity charges since it is free as per the Tamilnadu government policy directives for provision of free electricity of 100 units bimonthly to all domestic consumers in all slabs [73].

When enquired about the importance attached to UPS, households in the lower per capita income do not find UPS to be important, while households in the higher per capita income category attach more importance to UPS. This is true for both urban and rural residents, whether they are in rented or own houses.

Environmental consciousness is more prevalent among urban residents irrespective of the per capita income of the households. This may be because there is more air pollution in the urban areas due to higher density of automobiles in general. In rural areas the density of automobiles is lesser and thus the rural residents don't feel the impact of pollution and consequently have less cognizance of the same. When asked if they will adopt solar PV to mitigate pollution caused by thermal power stations, most of the urban households were positive irrespective of their domicile while most of the rural households had opinion otherwise.

Willingness to adopt solar PV seems to be a factor independent of households' opinion on other factors such as environmental consciousness or ROI. It is clearly evident that only households with higher income in both urban and rural areas, living in their own houses are willing to adopt solar PV.

Further there is a clear divide observed with the willingness to adopt solar PV among rented or own house dwellers with or without subsidy. Most of the respondents living in their own house are more open for adoption of SPVS. Almost all of the respondents in rented houses irrespective of urban or rural dwelling and per capita income are not willing to adopt SPVS.

Another main aspect for non-adoption attitude is that there is no power deficit in Tamilnadu and the state has witnessed surplus power in the financial year 2018-19 and has continued to move forward with adequate plans for surplus power in the forthcoming years [50]. Further it should also be noted that almost all of the households both in the rural and urban areas already have inverters. This coupled with the factor that the state has little power cut contribute to the lower adoption of Solar PV.

In order to rank the different groups of respondents (based on domicile and per capita income) on the six factors influencing the adoption of SPVS, TOPSIS was applied.

The respondents' mean rating of groups of respondents A_i with respect to criterion C_j is given as,

$$x = \begin{array}{cc} & \begin{array}{cccccc} PCS & ROI & UPS & EC & WA & WAS \end{array} \\ \begin{array}{c} Ro1 \\ Ro2 \\ Ro3 \\ Ro4 \\ Ro5 \\ Rr1 \\ Rr2 \\ Rr3 \\ Rr4 \\ Rr5 \\ Uo1 \\ Uo2 \\ Uo3 \\ Uo4 \\ Uo5 \\ Ur1 \\ Ur2 \\ Ur3 \\ Ur4 \\ Ur5 \end{array} & \begin{bmatrix} 5.0000 & 4.6000 & 1.6000 & 1.4000 & 1.0000 & 2.6000 \\ 5.0000 & 4.8000 & 1.4000 & 2.0000 & 1.0000 & 2.6000 \\ 5.0000 & 5.0000 & 3.4000 & 2.2000 & 2.0000 & 2.4000 \\ 2.4000 & 5.0000 & 3.0000 & 2.6000 & 3.4000 & 3.8000 \\ 1.2000 & 5.0000 & 3.8000 & 4.0000 & 4.8000 & 4.6000 \\ 5.0000 & 5.0000 & 1.2000 & 1.2000 & 1.0000 & 1.2000 \\ 5.0000 & 4.8000 & 1.2000 & 2.0000 & 1.0000 & 1.4000 \\ 4.6000 & 4.6000 & 2.4000 & 1.4000 & 1.0000 & 1.6000 \\ 3.0000 & 4.8000 & 4.4000 & 3.6000 & 1.6000 & 2.0000 \\ 1.4000 & 5.0000 & 4.6000 & 5.0000 & 1.4000 & 1.8000 \\ 5.0000 & 4.6000 & 1.4000 & 5.0000 & 2.0000 & 3.0000 \\ 4.8000 & 4.8000 & 1.8000 & 4.4000 & 3.2000 & 3.6000 \\ 3.4000 & 5.0000 & 3.4000 & 4.4000 & 4.6000 & 4.4000 \\ 2.2000 & 5.0000 & 4.6000 & 4.6000 & 4.4000 & 4.6000 \\ 1.2000 & 5.0000 & 5.0000 & 4.8000 & 4.6000 & 4.8000 \\ 5.0000 & 5.0000 & 1.2000 & 4.4000 & 1.0000 & 1.0000 \\ 4.6000 & 4.8000 & 1.6000 & 4.8000 & 1.6000 & 1.6000 \\ 4.6000 & 4.6000 & 2.2000 & 4.4000 & 1.6000 & 1.6000 \\ 4.0000 & 4.8000 & 4.4000 & 4.6000 & 1.4000 & 1.4000 \\ 1.8000 & 5.0000 & 5.0000 & 4.6000 & 1.6000 & 1.6000 \end{bmatrix} \end{array}$$

Using step 1 of TOPSIS, the normalized decision matrix is obtained as:

$$r = \begin{array}{cc} & \begin{array}{cccccc} PCS & ROI & UPS & EC & WA & WAS \end{array} \\ \begin{array}{c} Ro1 \\ Ro2 \\ Ro3 \\ Ro4 \\ Ro5 \\ Rr1 \\ Rr2 \\ Rr3 \\ Rr4 \\ Rr5 \\ Uo1 \\ Uo2 \\ Uo3 \\ Uo4 \\ Uo5 \\ Ur1 \\ Ur2 \\ Ur3 \\ Ur4 \\ Ur5 \end{array} & \begin{bmatrix} 0.2809 & 0.2115 & 0.1118 & 0.0821 & 0.0862 & 0.2029 \\ 0.2809 & 0.2207 & 0.0978 & 0.1173 & 0.0862 & 0.2029 \\ 0.2809 & 0.2299 & 0.2376 & 0.1290 & 0.1723 & 0.1873 \\ 0.1348 & 0.2299 & 0.2096 & 0.1524 & 0.2930 & 0.2965 \\ 0.0674 & 0.2299 & 0.2655 & 0.2345 & 0.4136 & 0.3589 \\ 0.2809 & 0.2299 & 0.0839 & 0.0704 & 0.0862 & 0.0936 \\ 0.2809 & 0.2207 & 0.0839 & 0.1173 & 0.0862 & 0.1092 \\ 0.2585 & 0.2115 & 0.1677 & 0.0821 & 0.0862 & 0.1248 \\ 0.1686 & 0.2207 & 0.3075 & 0.2111 & 0.1379 & 0.1561 \\ 0.0787 & 0.2299 & 0.3214 & 0.2931 & 0.1206 & 0.1405 \\ 0.2809 & 0.2115 & 0.0978 & 0.2931 & 0.1723 & 0.2341 \\ 0.2697 & 0.2207 & 0.1258 & 0.2580 & 0.2757 & 0.2809 \\ 0.1910 & 0.2299 & 0.2376 & 0.2580 & 0.3964 & 0.3433 \\ 0.1236 & 0.2299 & 0.3214 & 0.2697 & 0.3791 & 0.3589 \\ 0.0674 & 0.2299 & 0.3494 & 0.2814 & 0.3964 & 0.3745 \\ 0.2809 & 0.2299 & 0.0839 & 0.2580 & 0.0862 & 0.0780 \\ 0.2585 & 0.2207 & 0.1118 & 0.2814 & 0.1379 & 0.1248 \\ 0.2585 & 0.2115 & 0.1537 & 0.2580 & 0.1379 & 0.1248 \\ 0.2247 & 0.2207 & 0.3075 & 0.2697 & 0.1206 & 0.1092 \\ 0.1011 & 0.2299 & 0.3494 & 0.2697 & 0.1379 & 0.1248 \end{bmatrix} \end{array}$$

As the next step in TOPSIS, weights are assigned to all SPVS adoption attributes. Different weights are assigned to the attributes to signify varied importance given to those attributes and to rank the respondents. About 30 combinations of weights were assigned to the attributes and the results were ranked to identify those residents who had the most willingness to adopt SPVS. One of the 30 sets of weights assigned to the attributes is shown in Table 2 and their corresponding computations are presented below.

Table 2. A Sample of Weights Assigned for the Various SPVS Adoption Attributes

SPVS Adoption Factors	**Weight (w_j)**
Perception of Cost of SPVS (PCS)	0.1
ROI importance (ROI)	0.2
Importance of UPS (UPS)	0.2
Environment consciousness (EC)	0.2
General Willingness to adopt SPVS (WA)	0.1
Willingness to adopt SPVS with subsidy (WAS)	0.2

From step 2 of TOPSIS, the weighted normalized decision matrix considering the above weights is obtained as,

$$v = \begin{array}{cc} & \begin{array}{cccccc} PCS & ROI & UPS & EC & WA & WAS \end{array} \\ \begin{array}{c} Ro1 \\ Ro2 \\ Ro3 \\ Ro4 \\ Ro5 \\ Rr1 \\ Rr2 \\ Rr3 \\ Rr4 \\ Rr5 \\ Uo1 \\ Uo2 \\ Uo3 \\ Uo4 \\ Uo5 \\ Ur1 \\ Ur2 \\ Ur3 \\ Ur4 \\ Ur5 \end{array} & \begin{bmatrix} 0.0281 & 0.0423 & 0.0224 & 0.0164 & 0.0086 & 0.0406 \\ 0.0281 & 0.0441 & 0.0196 & 0.0235 & 0.0086 & 0.0406 \\ 0.0281 & 0.0460 & 0.0475 & 0.0258 & 0.0172 & 0.0375 \\ 0.0135 & 0.0460 & 0.0419 & 0.0305 & 0.0293 & 0.0593 \\ 0.0067 & 0.0460 & 0.0531 & 0.0469 & 0.0414 & 0.0718 \\ 0.0281 & 0.0460 & 0.0168 & 0.0141 & 0.0086 & 0.0187 \\ 0.0281 & 0.0441 & 0.0168 & 0.0235 & 0.0086 & 0.0218 \\ 0.0258 & 0.0423 & 0.0335 & 0.0164 & 0.0086 & 0.0250 \\ 0.0169 & 0.0441 & 0.0615 & 0.0422 & 0.0138 & 0.0312 \\ 0.0079 & 0.0460 & 0.0643 & 0.0586 & 0.0121 & 0.0281 \\ 0.0281 & 0.0423 & 0.0196 & 0.0586 & 0.0172 & 0.0468 \\ 0.0270 & 0.0441 & 0.0252 & 0.0516 & 0.0276 & 0.0562 \\ 0.0191 & 0.0460 & 0.0475 & 0.0516 & 0.0396 & 0.0687 \\ 0.0124 & 0.0460 & 0.0643 & 0.0539 & 0.0379 & 0.0718 \\ 0.0067 & 0.0460 & 0.0699 & 0.0563 & 0.0396 & 0.0749 \\ 0.0281 & 0.0460 & 0.0168 & 0.0516 & 0.0086 & 0.0156 \\ 0.0258 & 0.0441 & 0.0224 & 0.0563 & 0.0138 & 0.0250 \\ 0.0258 & 0.0423 & 0.0307 & 0.0516 & 0.0138 & 0.0250 \\ 0.0225 & 0.0441 & 0.0615 & 0.0539 & 0.0121 & 0.0218 \\ 0.0101 & 0.0460 & 0.0699 & 0.0539 & 0.0138 & 0.0250 \end{bmatrix} \end{array}$$

From step 3, the ideal solution is found as,

$$A^{*} = [0.0067 \quad 0.0460 \quad 0.0699 \quad 0.0586 \quad 0.0414 \quad 0.0749]$$

and the negative ideal solution is

$$A' = [0.0281 \quad 0.0423 \quad 0.0168 \quad 0.0141 \quad 0.0086 \quad 0.0156]$$

Consequent to step 4, the separation from the ideal alternative is

$$SI_i^{*} = \begin{bmatrix} 0.0822 & 0.0805 & 0.0634 & 0.0448 & 0.0207 & & & \\ & 0.0974 & 0.0917 & 0.0839 & 0.0558 & 0.0555 & & \\ & & 0.0661 & 0.0548 & 0.0273 & 0.0103 & 0.0029 & \\ & & & 0.0890 & 0.0767 & 0.0722 & 0.0634 & 0.0573 \end{bmatrix}$$

and the separation from the negative ideal alternative is

$$SI_i' = \begin{bmatrix} 0.0257 & 0.0269 & 0.0406 & 0.0589 & 0.0842 & & & \\ & 0.0048 & 0.0114 & 0.0195 & 0.0565 & 0.0695 & & \\ & & 0.0552 & 0.0591 & 0.0789 & 0.0901 & 0.0977 & \\ & & & 0.0377 & 0.0440 & 0.0415 & 0.0606 & 0.0697 \end{bmatrix}$$

Finally using step 5, the comparative nearness to the ideal solution is

$$C_i^* = \begin{bmatrix} 0.2381 & 0.2504 & 0.3904 & 0.5678 & 0.8027 & & & \\ & 0.0472 & 0.1107 & 0.1883 & 0.5030 & 0.5560 & & \\ & & 0.4548 & 0.5187 & 0.7431 & 0.8973 & 0.9711 & \\ & & & 0.2977 & 0.3645 & 0.3650 & 0.4889 & 0.5487 \end{bmatrix}$$

An ordering of different respondents groups is done, where the group which is closest to the ideal solution A* is ranked first. The rankings obtained by the 20 groups of respondents after applying TOPSIS technique are shown in Table 3.

Table 3. Values Close to Ideal Solution, Associated Ranking and Domicile

Closeness to ideal solution	Rank	Respondent Group
0.9711	1	Uo5
0.8973	2	Uo4
0.8027	3	Ro5
0.7431	4	Uo3
0.5678	5	Ro4
0.556	6	Rr5
0.5487	7	Ur5
0.5187	8	Uo2
0.503	9	Rr4
0.4889	10	Ur4
0.4548	11	Uo1
0.3904	12	Ro3
0.365	13	Ur3
0.3645	14	Ur2
0.2977	15	Ur1
0.2504	16	Ro2
0.2381	17	Ro1
0.1883	18	Rr3
0.1107	19	Rr2
0.0472	20	Rr1

It was observed from the results of TOPSIS that, for all the weight combinations, Uo5 ranks first, showing that the respondents with high income, residing in their own houses in urban areas are more open to adopt SPVS. Based on the number of ranking occurrences, Uo4 is considered to be the next group of respondents who are willing to adopt SPVS. Similarly rural respondents with higher income and living in their own houses are also willing to adopt SPVS. Observing the rankings in Table 3, it can be seen that the respondents with higher income and own houses whether in urban or rural areas are positive to the idea of adoption of SPVS. Further, it was also observed that Rr1 (rural, rented, low income) group of respondents showed the lowest willingness to adopt SPVS.

The approximate cost of 1kW SPVS is INR 1,20,000 (USD 1600) which includes lead acid batteries for power backup. In an average household, the approximate bimonthly electricity bill would be around INR 2000 (USD 27). After installation of SPVS the bimonthly electricity bill is reduced to INR 500 (USD 6.7), effectively saving INR 1500 (USD 20) for two months. This will lead to a yearly saving of INR 9000. This means that the cost of SPVS can be realized in 12-13 years. The life of SPVS is 25 years and above. Thus households can enjoy electricity at lower cost after this period.

If the government provides subsidy for SPVS and if it is available for INR 60,000 (USD 800), then the payback for SPVS will be reduced to 6-7 years. This will be more attractive to prospective users of SPVS, and many will be willing to adopt SPVS readily, thereby reducing overall consumption of electricity from grid and reduction of greenhouse gases.

4. Conclusion

This paper aimed at finding out the factors that are considered to be important in influencing the adoption of solar photo voltaic system for individual households. The paper also aimed to find out if there is any difference in the adoption of SPVS among the households with differing income levels and their place of residence namely rural and urban areas; and ranking the groups of households accordingly using TOPSIS. It is found that there is a clear divide among people on the adoption of SPVS based on their place of residence (rural/urban), status of residence (owned house/rented) and income level. It is observed that, people with higher income levels were generally more open to the idea of adopting SPVS. Further there is a very clear divide between people living in rented houses compared to those living in own property. People in rented facility are very reluctant to spend money on SPVS. It can be observed that the general willingness to adopt SPVS among the people living in rented houses is very less. This is true even if the SPVS is offered with subsidy. Thus there is no big difference on the opinion on adoption of SPVS among people living in rented houses, whether rural or urban.

It is also observed that people living in urban areas were more environmentally conscious, but even when they were environmentally conscious, those living in rented houses are reluctant to adopt SPVS. Further, people with lesser income were not very particular about having uninterrupted power supply in their homes in contrast to people with higher income. Almost all of the households were very particular about the return on investment from the SPVS. Almost all of the households with lower to mid income had the perception that SPVS is expensive and that they cannot afford one.

The outcome of TOPSIS shows that the respondents with high income, residing in their own houses in urban areas are more open to adopt SPVS. Further, urban residents in own houses with a monthly income of INR 40,000 are considered to be the next group of respondents who are willing to adopt SPVS. The ranking by TOPSIS also shows that rural respondents with higher income and living in their own houses are also willing to adopt SPVS. It can be seen from the results that the respondents with higher income and own houses whether in urban or rural areas are positive to the idea of adoption of SPVS. Further it was also observed that rural, rented, low income group of respondents showed the lowest willingness to adopt SPVS.

Out of the installed 2.1 GW rooftop solar power in the country, 70% is accounted by industrial production. This shows that the adoption of SPVS by domestic households is very less in the country. It is thus recommended that apart from providing subsidies for domestic SPVS, the government should also actively promote the idea of installing SPVS by house owners through popular media such as television and print and educate the domestic SPVS users about the long term benefits of the same. This will ensure better adoption of SPVS by the domestic households. The production and consumption of household electricity requirement, if met through solar PV system can free up much of the precious electricity requirement for the industry and provide an environmentally friendly, green energy source thus providing clean and green energy for households.. Thus production of electricity through solar PV by the households could be encouraged.

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