Renewable and Sustainable Energy Reviews 78 (2017) 754–763

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Factors responsible for solar PV adoption at household level: A case of Lahore, Pakistan

Tahir Masood Qureshi[a,*], Kafait Ullah[b], Maarten J. Arentsen[a]

[a] Department of Governance and Technology for Sustainability (CSTM), Faculty of Behaviour, Management and Social Sciences (BMS), University of Twente, Enschede 7500 AE, The Netherlands

[b] US-Pakistan Centre for Advanced Studies in Energy (USPCASE), National University of Science and Technology (NUST), Islamabad, Pakistan

ARTICLE INFO

Keywords:
Solar photovoltaic (PV)
Household adoption decisions
Determinants
Innovation diffusion model
Pakistan

ABSTRACT

The crisis in electricity generation sector of Pakistan is causing load shedding. All sectors including household-domestic, commercial and industrial activities get severely affected by such power outages which could be minimized by adopting modern technologies such as solar PV. The use of solar PV system in many countries has become a promising solution to meet energy needs but in Pakistan its usage at household level still remains largely untapped despite huge potential. This study identifies the determinants that influence the household's decisions regarding solar PV adoption in Lahore, Pakistan. For this, initially, a generic list of significant determinants was extracted from literature. Later, detailed interviews (based on persuasion attributes of Roger's theory of Innovation Diffusion) of both adopters and non-adopters of solar PV system were conducted at household level to rank the determinants on the basis of their significance in solar PV adoption decision. The household's adoption of solar PV system faced many barriers regardless of the fact that it exceeds in advantages as compared to other conventional sources of electricity. The cost of solar PV system appeared to be the most significant barrier in the diffusion of solar PV system. Additionally, the absence of adequate financial support by government for the installation of small solar PV systems at household level further intensified the adoption decisions. Other important barriers included difficulty of using all appliances at the same time and shortage of reliable vendors as well the technicians. While, environment friendly feature of solar PV system along with its availability in local market appeared as significant driver of diffusion at household level.

1. Introduction

Like many other developing countries, Pakistan is also an energy deficient country. Demand for electricity remains unmet with existing supply. In year 2015, electricity shortfall reached 5500 MW with 15,500 MW supply out of 23000 MW installed capacity [1]. One reason of supply shortage is heavy reliance on thermal based power plants [2] which are costly to run all the time to meet the electricity demand. Dependence on thermal power added with a number of subsidies has plagued the power sector with inter-corporate circular debt which restricts it from functioning at full capacity [3]. This has put the social and economic life under intense pressure. This strain can be reduced by enhancing the access of subsidized sectors (e.g. household) to other than grid based and conventional energy resources.

Solar photovoltaic (PV) at household level has gained momentum as an alternate source of clean energy in many countries [4]. The PV module made up of silicon converts sunlight directly into DC electricity which is converted into ordinary power by inverter for its usage to operate appliances. For instance *Energiewende* program in Germany has widely transformed the traditional energy profile of the country.[1] Germany, as a result, is leading with its share of 32% of total world solar PV generation, followed by Italy and USA with 16% and 7.2% respectively [5]. Furthermore, the share of solar PV generated electricity is 7.9% in Italy, 7.1% in Germany, 3.4% in Spain and less than 1% in USA [6]. Similar to developed countries, many developing countries in Asia, Africa and South America are emphasizing the inclusion of solar power in their energy mix to lessen the burden on non-renewable and expensive sources of energy [7]. Despite huge potential, utilization of solar energy still remains in lacklustre in Pakistan that has not contributed markedly to energy mix of the country [8]. It is evident from a study [9] that the total electricity demand of Pakistan can be met by just installing solar PV of 20% efficiency on one percent of Baluchistan land. The annual average mean daily solar irradiation in Lahore ranges from 5.1 kWh/m^2 to 5.4 kWh/

* Corresponding author.
E-mail addresses: tmq33@hotmail.com, t.m.qureshi@student.utwente.nl (T.M. Qureshi).

[1] http://energytransition.de/

http://dx.doi.org/10.1016/j.rser.2017.04.020
Received 1 August 2016; Received in revised form 5 December 2016; Accepted 17 April 2017
Available online 10 May 2017

m^2 which is also promising for solar energy utilization [10].

Similar to other countries, adoption of solar PV at household can also relieve Pakistan from chronic electricity shortage. Household is important for solar PV adoption because it is a major electricity consumption sector in Pakistan and also a major receiver of subsidies [11]. Adoption at household level can provide off-grid and environment friendly solutions to electricity shortage. However, adoption of solar PV still faces hurdles in Pakistan that needs to be explored. There are few studies in the context of Pakistan which explored hurdles to the adoption of renewables in different parts of the country [8,12,13]. However, those studies mostly focussed on different aspects of renewables' diffusion and did not comprise a specialised investigation of the diffusion of solar PV technology particularly at household level under some authentic analytical framework. In this study, we tried to investigate the issue of diffusion of solar PV at household level by utilizing Rogers' Theory of Innovation Diffusion-a more systematic analytical framework [14].

2. A brief review of factors responsible for innovation diffusion

A decision regarding the adoption of solar PV at a household level, is based on many factors including endogenous (e.g. technology awareness and intention of conserving energy) and exogenous factors such as cost, characteristics of PV system, market system, etc. A study found that electricity generation at household level through solar PV is socially an acceptable technology due to its environmental value but its adoption success is mainly based on its economic feasibility [15]. It is revealed from a cost-benefit study on different micro-generation options in UK which concluded that electricity production by micro-generation was unsuccessful even in the presence of incentive system due to long payback periods [16]. It was further identified that current market structure in which the energy prices are not accounted for the externalities of climate change and limited availability of fossil fuels is a barrier to the adoption of renewables [12].

Another aspect is consumers' willingness to pay for better life [17]. This study revealed that consumers are usually willing to pay more for better quality of life, and solar PV system is appearing as one of the reliable and clean sources of electricity for households. Therefore, in general, some of the households are willing to pay more for better and reliable services. Further, a study on the socio-economic contexts of solar PV usage in Pakistan concluded that solar technology can enhance the consumer quality of life in the urban areas of Pakistan [18]. Moreover, solar technology utilization is the best available technology on the basis of comparative cost analysis and user friendliness. The research also acknowledged the huge potential (65%) of solar technology in mitigating the country's energy crisis. A number of studies [19,20] revealed that higher income and higher education level have correlation with the adoption decision of solar PV as an alternative source of energy. It was also found that higher income have direct relation as it may overcome the cost barrier but the correlation between education and adoption decision is less clear.

Unavailability of grid connection in developing countries provides an opportunity to solar PV diffusion among potential users more rapidly [21]. The unreliable electricity supply from grid in Pakistan and frequent load shedding is being experienced by household including commercial and industry in various parts of the country, thus putting pressure on urban households to switch to another reliable electricity source like solar PV. This situation is eventually driving the solar PV diffusion in the local context. A recent study [17] on the decision making factors for the adoption of solar PV system among households of Netherlands revealed four factors (components). These factors included perceived relative advantage of technology, complexity of the innovation, social influence and knowledge about grants and costs. It concluded that cost of PV system was the main element behind the adoption decision for both adopters and non-adopters of PV system.

A number of studies found that consumers give more importance to cost aspect than environmental concerns [22,23] for selecting solar PV system. These studies revealed that solar PV technology is not compatible with personnel priorities of household users because most of them are interested in technology just to reduce the cost and save money rather than environmental consciousness. For meeting the challenge of high up-front cost of solar PV system and promotion of renewable energy projects in Pakistan, State Bank of Pakistan is providing loans to potential adopters of solar PV system. However, the loan provision under Financing Scheme for Renewable Energy is valid only for electricity producers between 4 kW and 50 MW [24]. Since adoption of solar PV is also geared up by environmental concerns, however accumulative impact of solar PV utilization over environment is minor due to limited usage of solar PV [25]. However, a study conducted in the Pakistan context identified that a 5 kW standalone solar PV system can minimize the net annual Greenhouse Gases (GHG) by 2.9 t to 3 t of CO_2 [10].

Lack of technology awareness among the users was also identified as a key barrier in developing countries [21]. [26] also supported this fact that lack of awareness resulted in the dissemination of misinformation among the potential adopters about the technology benefits. She also mentioned that high cost phobia among potential adopters of solar PV usually paralyzed the diffusion process at initial stages of adoption decision. [4] identified that the fear of adoption of new technology is one of the major barriers among the people of Pakistan.

A study conducted in Pakistan identified (a) high initial cost of PV system (b) unawareness of local community (c) inadequate availability of technical expertise (d) inadequate renewable energy policy as the main barriers in widespread solar PV utilization [27]. Another study [28] identified and categorized (i) policy barriers (ii) institutional barriers (iii) financial barriers (iv)market related barriers (v) technological barriers and (vi) social barriers as the renewable technology adoption barriers in the context of Pakistan. Whereas [29], identified inadequate policies, component failure, lack of solar compliant buildings and problem of research and development as diffusion barriers in African context. However, the common diffusion barrier found in the literature is high capital cost of solar PV system for households in most developing countries. In Pakistan, average cost of a 1 kW good quality solar PV system (panel, inverter, controller and energy meter) without battery backup is around 280,000 to 330,000 PKR. Whereas, the cost of 2 kW and 3 kW capacity solar PV system ranges from 530,000 to 800,000 PKR. However, the battery backup of 3 h increases the cost at the rate of nearly 70,000 PKR per kW for the above mentioned solar PV systems [30].

Similarly, a study about the barriers in renewable energy penetration came up with a large number of barriers of seven different categories based on their type [31]. These categories included i) market failure/imperfection ii) market distortions iii) economic & financial iv) institutional v) technical vi) social, cultural and behavioural and vii) other barriers. In Indian context, economic and financial barriers were found as the most influencing for diffusion of solar PV at household level [32].

3. Rogers' model of innovation diffusion–an analytical framework

According to Roger's (2003) theoretical model, the potential adopter passes through a number of steps before accepting or rejecting an innovation. Since, the potential adopter has a lot of uncertainties about new product or service, therefore this model helps them to make a final decision [14]. The Roger's diffusion of innovation in a society is a process by which new technology adoption is communicated over time by utilizing various channels. This diffusion process has been modelled and theorized over time. It assumes that potential adopters get interested in new innovation only when they start collecting knowledge of innovation. That knowledge guides the individuals to persuade them

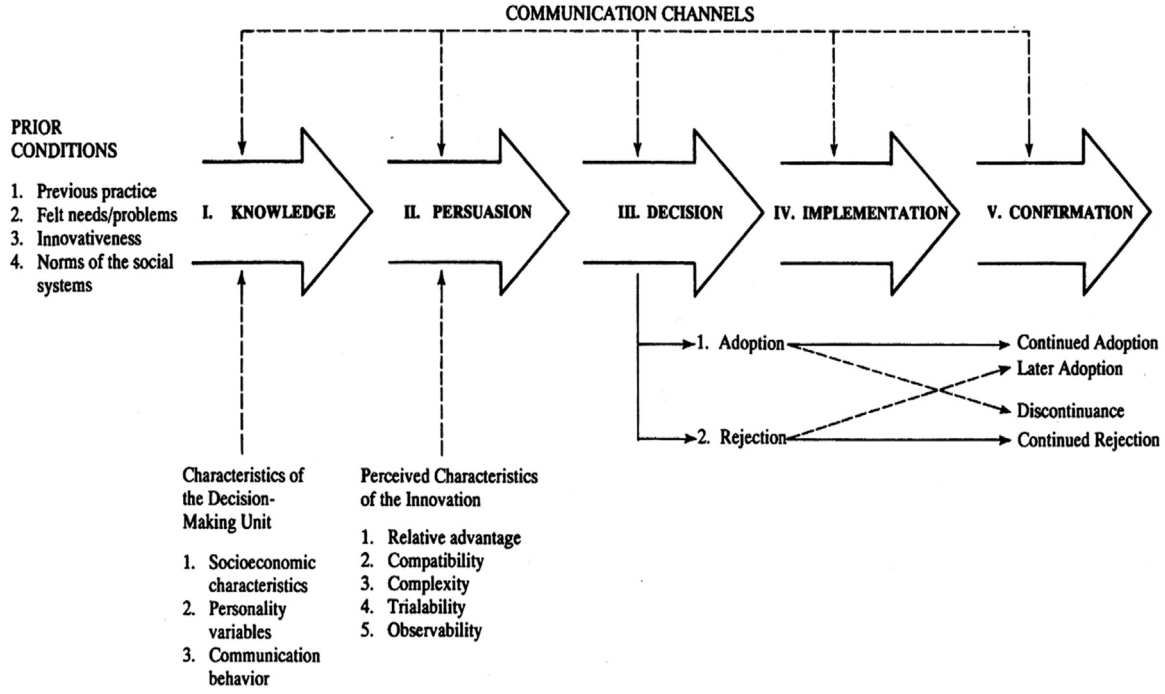

Fig. 1. Roger Model for Innovation Decision Process. Source: Rogers, E.M., Elements of diffusion. Diffusion of innovations, 2003.

to accept or reject the technology. However, the personality, communication behaviour and socioeconomic conditions are the prior to knowledge characteristics of the individuals. The detail of communication channels/stages of the model can be found in Fig. 1. Whereas, persuasion is based on five attributes of the innovation i.e. relative advantage, compatibility, complexity, trialability and observability that eventually may determine the success and failure of innovation's diffusion. Following are the details of each attribute which affects the rate of innovation adoption.

- ***Relative advantage***: It is a degree to which an innovation is considered better than its contemporaries. The determinants of relative advantage measurement can be economic, social, convenience and satisfaction. Rate of adoption is directly proportional to relative advantage of the innovation.
- ***Compatibility***: Compatibility is the degree of consistency of the innovation with existing values, past experiences and needs of potential adopters. The innovation which is incompatible with social norms will not be adopted rapidly, rather its adoption will be a relatively slow process.
- ***Complexity***: It is a perception about understanding and usage of innovation. Few innovations are readily understandable by society while others are more complicated and diffuse slowly.
- ***Trialability***: It is the degree of experiencing the innovation on trial basis. The ideas or innovation tried in the form of projects are generally adopted more rapidly than those are not visible. Trialable innovations possess less uncertainty to adopters and enables learning by doing.
- ***Observability***: Observability is the visibility of innovations to others in order to see the results of innovation adopted by friends, peers and neighbours. Visibility stimulates the peer discussions regarding innovation.

The innovation having greater relative advantage, compatibility, trialability, observability, and less complexity are adopted more rapidly. Further, the relative advantage in this model does not have absolute rule, however it depends on the perception of households and need of solar PV as innovation.

4. Methodology

4.1. Study site

Pakistan is facing energy crises and household in urban areas using various energy sources to meet their electricity demands. However, for this research study, Lahore has been selected as a case study because of the following reasons:

- Lahore is an important economic hub of Pakistan and long blackouts of electricity disturbing the business and households life adversely
- Households are looking for alternative sources of reliable electricity supply
- Easy accessibility to solar PV system supplier and vendors as most are located in Lahore

The targeted population is residential users and nonusers of solar PV system and the selection of respondents for this study are subject to the above criteria.

4.2. Study design

In the context of this study, the Roger decision model persuasion attributes i.e. relative advantage, compatibility, complexity, trialability and observability are used to understand the decision making on solar PV adoption at household level. A solar PV system considered in this study is comprised of PV module, inverter, mounting and charge controller. Thus, at first step, a literature survey is conducted to identify the significant determinants in solar PV diffusion at broader level. The initial literature survey provided useful knowledge of drivers and barriers of solar PV diffusion in a broader perspective and to identify the suitable data collection methods and patterns. Later, semi structured questionnaire based interviews are used as a tool for data collection among the households of Lahore. The questionnaire used for interviews is comprised of closed as well as open ended questions. The open ended questions enabled the respondents to give their own answers. Although the city has big population but only a few households have standalone solar PV system that restricted and justified the sample size to 36 households located in the vicinity of Lahore city.

Table 1
Overview of responses with type of PV users and nonusers.

Number of Interview Responses				
PV Users Types		**PV Nonusers Types**		**Total**
Standalone PV	Partial PV	Grid+other sources	Grid	
9	9	9	9	36

The households selected for interviews are of both types; users and nonusers of solar PV system in order to get comprehensive picture of determinants in solar PV diffusion. The selection of the interviewees is based on the fact that the interviewee must be the person who is responsible for the household decision regarding solar PV adoption. Further, it is kept in mind to select the interviewees from various parts of Lahore for comprehensive coverage of households of different socioeconomic conditions as no individual households is willing to share his/her monthly average income. Therefore, for mixed sample of different socio economic types of households, WAPDA Town, Defence Housing Authority, Johar Town, Township, Allama Iqbal Town, Shaadbagh, Elite Town, Izmir Town, Harbanspura, Shalimar Town, Canal View Colony, Azam Garden, UET Society and Punjab Cooperative Housing Society are included in this study. Table 1 shows the overview of respondents in each of the 4 types of solar PV system users and nonusers.

The data collected from the households is on the basis of Roger's diffusion attributes (relative advantage, compatibility, complexity, trialability and observability) which positively and negatively influence its diffusion. Since each attribute has its own relative role in the diffusion of solar PV system among households, therefore, the influence of these five attributes is studied at household level in order to identify the key determinants in solar PV diffusion. These attributes covered all the determinants included in the study. For each household type, a list of determinants have been given to all respondents and asked them to indicate their level of agreement or disagreement on a five point Likert scale. The main purpose behind these attributes data is to seek the perception of users and nonusers of solar PV system on drivers that motivate and barriers that prevent them from using solar PV system. Table 2 shows the categorization of Roger's adoption attributes with regard to key determinants of adoption decision.

For ranking of determinants which comprised of drivers and barriers, the response of each statement of each type of user and non-user is coded on a five point scale (2,1, 0,−1, and −2) where 2 represents strong agreement while −2 stand for strong disagreement with the statement. Since this method is easy and appropriate to this study therefore researchers prefers to use this technique to get significance to each determinant. After normalizing the weighted score for each determinant (statement), we found the average weighted score of each determinant for all different types of households.

Table 2
Categorization of adoption attributes and determinants.

Adoption Decision Attributes	Determinants Categorizations
Relative advantage	• Financial viability • Environment friendliness • Socially acceptable • Independence from Grid • Energy security • Technological reliability
Compatibility	• Cost(initial cost) • Social norms • Habits and routines • Household residence
Complexity	• Knowledge of technology • Operation & Maintenance • Solar PV expert availability • Unforeseen troubles
Trialability	• Return warranty over performance
Observability	• People opinions & experiences

5. Results and discussion

Data on various determinants actually depend on local circumstances which reveals in below mentioned results with respect to five attributes. First section of results presents and discusses ranking of different determinants under each attribute while second section presents the rankings of overall drivers and barriers for solar PV adoption.

5.1. Determinants by attributes

5.1.1. Determinants regarding relative advantage

The main drivers under relative advantage attribute are varied. More than 94% of the respondents considered that solar PV system are easily available in the market and in existing energy deficit conditions; it is a best alternate to grid provided electricity as agreed by 27 respondents from a total of 36 sampled. The solar PV available in market are both types (mono and poly crystalline PV technology) and qualities depending on the demand of potential adopter. However, 8% respondent believe that it is not a best alternative to grid provided electricity in current circumstances. Whereas, around 17% have neutral opinion in respect to best alternative choice.

The economic viability is an important driver in the adoption decision of solar PVs. All of the respondents strongly agreed (11), agreed (15) and neutral (10) about savings of household money in shorter or longer period in terms of reduction in electricity bills after using solar PV system.

Some people don't consider high electricity tariff as a driver for solar PV adoption when compared with the energy security issue in Lahore. Only 67% respondents have the opinion that high energy prices are the driving factor for solar PV installation, while 86% of sample reflect, consistent supply of energy is the major advantage of solar panel in house. However, it is a fact that all of the interviewees have grid connection regardless of other sources of electricity which include solar PV, UPS and power generator. The presence of other sources is an indicator of inhabitants distrust over standalone PV system. The presence of other sources is an indicator of inhabitants distrust over standalone PV system. However in general, users and nonusers of solar PV system believe that independency from grid although a diffusion driver but it primarily depends on the size of the solar PV system and the household's electricity needs.

Table 3 shows the detailed responses of each respondent in four different categories of user and nonusers of solar PV system.

5.1.2. Determinants regarding compatibility

The high initial cost and inability to finance the solar PV system is the most significant barrier identified by all respondents regardless of their solar PV usage status (user or nonuser). Each respondent has his/her own criteria of solar PV system (with batteries or without batteries), therefore the response regarding high upfront cost cannot distinguish the cost of solar PV system with battery backup or without it. Despite the fact of battery condition, the cost of solar PV system still remains the most significant barrier as per the perception of respondents. On the issue of long payback period, the entire sample households have mixed opinions. Almost 39% of respondents have neutral opinion because they don't have any idea about payback period despite the fact they know solar PV system is cheap in longer period. 15 respondents are agreed with lengthy payback period for solar PV system whereas 7 respondents have disagreement with longer payback period. Apart from these responses, it is a fact that financial saving plays an important role in forming a part of their decision whether to install or not [14].

Table 3
Relative advantage of solar PV system by its users and nonusers.

Determinant	Determinant Type	Number of Interview Responses																								
		Strongly Agree					*Agree*					*Neutral*					*Disagree*					*Strongly Disagree*				
		Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**
Availability in market	Driver	6	4	3	1	**14**	3	5	6	6	**20**	0	0	0	2	**2**	0	0	0	0	**0**	0	0	0	0	**0**
Economical viable	Driver	3	5	2	1	**11**	5	2	4	4	**15**	1	2	3	4	**10**	0	0	0	0	**0**	0	0	0	0	**0**
Environment friendly	Driver	6	4	4	5	**19**	3	4	2	4	**13**	0	1	3	0	**4**	0	0	0	0	**0**	0	0	0	0	**0**
Energy security	Driver	6	2	3	2	**13**	2	5	6	5	**18**	1	2	0	2	**5**	0	0	0	0	**0**	0	0	0	0	**0**
Independence from grid	Driver	4	2	2	0	**8**	2	4	2	3	**11**	3	2	5	5	**15**	0	1	0	1	**2**	0	0	0	0	**0**
Best alternative	Driver	4	4	2	3	**13**	2	5	4	3	**14**	2	0	2	2	**6**	1	0	1	1	**3**	0	0	0	0	**0**
Social acceptability	Driver	4	3	2	2	**11**	4	5	6	3	**18**	1	1	1	4	**7**	0	0	0	0	**0**	0	0	0	0	**0**
High energy tariff	Driver	1	2	3	3	**9**	5	4	3	3	**15**	2	2	1	3	**8**	1	1	2	0	**4**	0	0	0	0	**0**

As far as the solar PV system compatibility is concerned, 92% (33) of respondents have consent with it as the geographic position and weather conditions of Lahore are in the favour of solar energy production through PV installation. At the same time 23 out of 36 respondents disagree with the barrier related to major renovation of house for installing solar PV system. Only 2 respondents consider the renovation in house as barrier for PV installation.

From Table 4, it can be seen that 14 out of 36 respondents agree that installation of solar PV system changes their behaviour in sustainable way about electricity consumption routine which ultimately reduces the household electricity bills. Whereas, a perceptible number (12) of interviewees have neutral opinion in respect of behaviour change due to lack of solar PV usage experience. The inflexibility of using all the appliances simultaneously entirely depends upon the size of solar PV system and demand of households' electricity as 25% don't have any opinion. However, in general, majority 67% of respondents agree with this as barrier in solar PV diffusion.

5.1.3. Determinants regarding complexity

The usage and installation of solar PV system is not a complicated process rather a simple practice as more than 44% respondents have disagreement with this statement including 36% of neutral opinion. The reason of less complication and speedy installation of solar PV system is generally due to already installed separate electrical wiring for other electrical backup sources (i.e. UPS) in most houses. This already installed electrical wiring can also be used for solar PV system. Insufficient supply from solar PV system is also examined to understand its importance in adoption decision. 20 respondents identify it a barrier while other 16 have mixed opinions in which 7 respondents are in the opposition of taking it as a barrier, while remaining have the neutral opinion.

Majority (28) of respondents believe that inadequate financial support from government is one of the significant factors in the slow diffusion of solar PV system among households in Lahore. It has been shared by few respondents that government is only providing loans for installing solar PV system but not giving incentives in monetary terms to small potential adopter. While other barriers like hard accessibility of well reputed vendors and/or technical experts is mainly agreed by 22 users and nonusers of solar PV system followed by 8 neutral opinions and 6 disagreements.

For proper assessment of complexity attribute, another aspect of high maintenance and service requirement for solar PV is also enquired. Only 5 among 36 respondents mention the high demand of maintenance and service while majority (15) are against this proclamation followed by 9 neutral opinions including 3 of no answer to this barrier due to no experience of solar PV system usage. Table 5 shows the detail responses of each respondent in four different categories of user and nonusers of solar PV system. As far as the solar PV performance efficiency drop is concerned, mostly (17) don't have any opinion. On the other hand, 13 believe in performance efficiency drop with time.

5.1.4. Determinants regarding observability and trialability

The attributes of Observability and Trialability are hard to assess under this research study scenario. However, the literature revealed that observability and Trialability play positively in the diffusion of solar PV system as both attributes motivate inhabitants to adopt it. For these attributes, it has been asked to the sampled population about friends, family members and pears' opinions that may have influence on their final decision of adopting solar PV system. In response, almost all of the interviewee have mentioned that everyone is in the favour and recommend to install it if there are no financial constraints. Additionally, one of the users has stated that it is recommended by other influencing persons to go for cost impact of solar PV first and then take decision regarding its adoption. The second important recommendation is the selection of reliable vendor/technical expert

Table 4
Compatibility of solar PV system by its users and nonusers.

Determinant	Determinant Type	Number of Interview Responses																									
		Strongly Agree					***Agree***					***Neutral***					***Disagree***					***Strongly Disagree***				
		Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**
High Initial Cost	Barrier	6	7	6	6	**25**	2	2	3	3	**10**	0	0	0	0	**0**	1	0	0	0	**1**	0	0	0	0	**0**
Long payback Period	Barrier	2	0	3	2	**7**	1	3	3	1	**8**	3	5	1	5	**14**	3	1	2	1	**7**	0	0	0	0	**0**
Renovation in House	Barrier	0	1	0	0	**1**	0	0	0	1	**1**	1	2	5	3	**11**	8	6	4	5	**23**	0	0	0	0	**0**
Inflexibility to use all appliances	Barrier	1	2	0	1	**4**	6	4	3	7	**20**	2	1	5	1	**9**	0	1	1	0	**2**	0	1	0	0	**1**
Behaviour changes-sustainability (less Consumption)	Driver	0	0	0	1	**1**	4	5	3	1	**13**	3	2	4	3	**12**	2	1	2	4	**9**	0	1	0	0	**1**
Technology compatibility	Driver	3	5	1	1	**10**	6	3	7	7	**23**	0	1	1	1	**3**	0	0	0	0	**0**	0	0	0	0	**0**

Table 5
Complexity of solar PV system by its users and nonusers.

Determinant	Determinant Type	Number of Interview Responses																								
		Strongly Agree					***Agree***					***Neutral***					***Disagree***					***Strongly Disagree***				
		Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**
Complex and Complicated	Barrier	0	0	0	0	**0**	0	1	3	3	**7**	3	3	2	5	**13**	4	5	4	1	**14**	2	0	0	0	**2**
High Maintenance and Service	Barrier	0	0	0	1	**1**	0	0	2	2	**4**	0	2	4	3	**9**	4	6	3	2	**15**	5	1	0	1	**7**
Insufficient Supply from Solar PV system	Barrier	1	0	0	0	**1**	2	6	5	6	**19**	3	1	3	2	**9**	3	1	1	1	**6**	0	1	0	0	**1**
Inadequate Government Financial Support	Barrier	2	4	4	2	**12**	3	3	4	6	**16**	4	2	1	1	**8**	0	0	0	0	**0**	0	0	0	0	**0**
Hard Access of Vendor/ Expert	Barrier	2	1	0	1	**4**	3	4	5	6	**18**	3	2	1	2	**8**	1	2	3	0	**6**	0	0	0	0	**0**
Performance Efficiency Drop	Barrier	1	2	0	0	**3**	3	3	2	2	**10**	2	2	6	7	**17**	3	1	0	0	**4**	0	1	1	0	**2**

Table 6
Trialability of solar PV system by its users and nonusers.

Determinant	**Determinant Type**	**Number of Interview Responses**																								
		Strongly Agree					***Agree***					***Neutral***					***Disagree***					***Strongly Disagree***				
		Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**	Stand-alone PV	Partial PV	Grid +other	Grid	**Total**
Trial Performance Warranty	Driver	1	0	1	2	**4**	2	3	2	1	**8**	1	1	2	4	**8**	4	3	3	2	**12**	1	2	1	0	**4**

for the installation of solar PV system.

The response of the targeted population regarding trialability attribute is shown below in Table 6.

The respondents have mix views about the trial performance warranty of solar PV system. 12 out of 36 respondents are agreed with the provision of performance warranty by supplier/installer. However, majority (16) completely disagree with the provision of trial warranty. This is the only aspect in which mixed responses have been received from all types of users and nonusers. However, it is mentioned by respondents that trial performance warranty only available on solar PV panels and other accompanies gadgets of complete system are exclude from warranty. One of the respondents mention that an installed working solar PV system in a house has been shown by his contacted supplier/installer before taking adoption decision. The observability and then provision of trial performance warranty by installer resulted in minimize the uncertainties of solar PV system in household's mind.

5.2. Ranking of determinants for significance

5.2.1. Accumulative significance of drivers

In this section each identified driver is ranked in order to get its accumulative importance in solar PV system adoption decision for households of Lahore under current local conditions. The significant drivers which motivate the households to use solar PV system has been identified as follow in Table 7.

The accumulative weighted average score of 2.13 shows that environmental benefits of solar PV system as compared to other conventional sources of electricity are more as affirmed by the respondents. The reduction in carbon emissions by using solar PV system has been ranked top most significant motivating factors for households to adopt solar PV system.

The presence of solar PV systems in market appeared as the 2nd most significant factor that actually facilitates the household to go for solar PV system. The availability of technology in market have positive influence in the diffusion of technology otherwise it behaves like a barrier as acknowledged in a study by [28] about renewable technology adoption in Pakistan. The 3rd most significant driver of solar PV diffusion among households is the best alternative for consistent supply of electricity. The electricity load shedding from national grid along with other local conditions distinguished the solar PV system as the best alternative to meet their electricity needs without polluting the environment significantly [21].

The social acceptability is another major determinant which is not only important for the diffusion but also for the sustainability of the solar PV system. The respondents provided much significance to social acceptability as it ranked 4th in the adoption decision drivers.

Unexpectedly, the high energy tariff has not been appeared a significant driver (ranked at 8th position) as households want to have uninterrupted electricity despite the price of grid electricity in this energy deficit city. However [13], argued that increasing energy tariff in Pakistan will motivate the inhabitants in near future to adopt solar PV system once the price of solar panels reduced.

5.2.2. Accumulative significance of barriers

A commonly known diffusion barrier for user and nonuser of solar PV system is the high cost of solar PV system. The high cost of solar PV system has been mentioned by many researcher in past as a major barrier in the diffusion of new technologies like solar PV system [17,19,27]. However, no respondent has shared the accurate cost of solar PV system as many variables are involved in the cost estimation of solar PV system such as made, type, capacity and vendor. Even in the presence of less expensive Chinese made solar PV, it remains a most significant barrier to its uptake at household level.

The negative accumulative weighted average score of statements such as *Complex and Complicated*, *High Maintenance and Service* and *Renovation in House* reveals the respondents answer in disagreement

Table 7
Accumulative ranking of drivers in PV system adoption decision.

Ranking No.	Determinants	Determinant Type	Weighted Average Score				
			Standalone PV	Partial PV	Grid+Other Sources	Only Grid	Accumulative
1	Environment friendly	Driver	2.50	2.00	1.67	2.33	**2.13**
2	Availability in market	Driver	2.50	2.17	2.00	1.33	**2.00**
3	Energy security	Driver	2.33	1.50	2.00	1.50	**1.83**
4	Social acceptability	Driver	2.00	1.83	1.67	1.17	**1.67**
5	Best alternative	Driver	1.50	2.17	1.17	1.33	**1.54**
6	Economical viable	Driver	1.83	2.00	1.33	1.00	**1.54**
7	Technology compatibility	Driver	2.00	0.50	1.50	1.50	**1.38**
8	High energy tariff	Driver	1.00	1.17	1.17	1.50	**1.21**
9	Independence from grid	Driver	1.67	1.17	1.00	0.33	**1.04**
10	Behaviour changes- sustainability (less Consumption)	Driver	0.33	0.33	0.17	−0.17	**0.17**
11	Trail Performance Warranty	Driver	−0.33	−0.67	−0.17	0.50	**−0.17**

Table 8
Accumulative ranking of barriers in PV system adoption decision.

Ranking No.	Determinants	Determinant Type	Weighted Average Score				
			Standalone PV	Partial PV	Grid+Other Sources	Only Grid	Accumulative
1	High Initial Cost	Barrier	2.17	2.67	2.50	2.50	**2.46**
2	Inadequate Government Financial Support	Barrier	1.17	0.50	2.00	1.67	**1.33**
3	Hard Access of Vendor/Expert	Barrier	1.00	1.00	0.33	1.33	**0.92**
4	Inflexibility to use all appliances	Barrier	1.33	0.50	0.33	1.50	**0.92**
5	Long payback Period	Barrier	0.33	0.33	1.17	0.67	**0.63**
6	Insufficient Supply from Solar PV system	Barrier	0.17	0.50	0.67	0.83	**0.54**
7	Performance Efficiency Drop	Barrier	0.33	0.33	0.00	0.33	**0.25**
8	Complex and Complicated	Barrier	−1.33	−0.67	−0.17	0.33	**−0.46**
9	Renovation in House	Barrier	−1.33	−1.00	−0.67	−0.67	**−0.92**
10	High Maintenance and Service	Barrier	−2.33	−1.33	−0.17	0.00	**−0.96**

or against to the literature identified barriers under local conditions. Therefore, these three statements couldn't clearly describe the barrier impact in adoption decision. However, it could be interpreted that these three barriers have no significance in the adoption decision of solar PV system for households of Lahore. Table 8 shows the ranking of each barrier as per the respondents' reviews.

6. Conclusion

The study revealed that the diffusion or adoption of solar PV system in Lahore is not an easy process. From the adoption point of view, the cost of solar PV system is appeared to be the most important factor regardless of its clean and environmental friendly characteristics. The financial constraints in terms of high upfront cost of PV system further intensify due to the absence of any substantial financial support by government to small (< 4 kW) potential adopters. However, despite high upfront cost, few people are relatively more inclined towards solar PV system for uninterrupted supply of electricity which reveals that high cost and the demand of consistent supply of electricity polarized the potential adopter's consideration regarding its installation. On the other hand, the availability of PV system in local markets found as the substantial driver in its diffusion followed by a best alternative source for consistent supply of electricity.

By and large, the diffusion of solar PV system at household level can possibly be increased provided the identified significant barriers in adoption decision are addressed properly. Thus, following are few recommendations on the basis of identified factors which can stimulate the adoption rate of solar PV system (renewable energy technology). These policy actions may ultimately support the government to meet the energy security issues at one end and move towards to the future of clean energy in Pakistan on the other side.

- The factor of high upfront cost of solar PV system can be addressed by establishing a financial institute by government that provide loan/financial support to small potential adopters at zero or low interest rate for PV system purchase.
- The government must implement the concept of net metering for electricity trade-off which is not yet practically started in Lahore. The net metering can reduce the cost of full solar PV system as the major cost of batteries will be diminished from full system.
- Appropriate subsidies and reduction of import duty on all solar PV system components for supplier and household must be put in place to encourage the adoption of solar PV system.
- Every supportive effort for solar PV system diffusion will be useless until the households are not fully aware of solar PV technology benefits and drawbacks. The supplier, vendors and government along with other concern organizations must collectively start campaigns to aware public regarding solar PV system benefits and nominate the authentic shops from where people can purchase quality solar system.

Acknowledgements

The authors wish to acknowledge the support of the Department of Governance and Technology for Sustainability (CSTM), Faculty of Behaviour, Management and Social Sciences (BMS), University of Twente, Enschede 7500 AE, The Netherlands. Further, authors would like to acknowledge all the interviewees' who generously contributed in the success of this research study.

References

[1] NEPRA . State of industry report, national electric power and regulatory authority. Government of Pakistan; 2015.

[2] NTDC, Power System Statistics, Planning Power, NTDC, Islamabad; 2015.
[3] PC/USAID, The Causes and Impacts of Power Sector Circular Debt in Pakistan. Report jointly prepared by Planning Commission of Pakistan and United States Agency for International Development, Islamabad; 2013.
[4] Bhutto AW, Bazmi AA, Zahedi G. Greener energy: issues and challenges for Pakistan-solar energy prospective. Renew Sustain Energy Rev 2012;16(5):2762–80.
[5] REN21, Renewables 2013. 2013, Global Status Report, Paris ⟨http://www.ren21.net/portals/0/documents/resources/gsr/2013/gsr2013_lowres.pdf⟩.
[6] IEA . Snapshot of Global PV Markets (1992–2014): photovoltaic Power Systems Programme. International Energy Agency; 2015, [Available at] ⟨http://www.iea-pvps.org/fileadmin/dam/public/report/technical/PVPS_report-A_Snapshot_of_Global_PV-1992-2014.pdf⟩.
[7] Ondraczek J. Are we there yet? Improving solar PV economics and power planning in developing countries: the case of Kenya. Renew Sustain Energy Rev 2014;30:604–15.
[8] Khalil H, Zaidi S. Energy crisis and potential of solar energy in Pakistan. Renew Sustain Energy Rev 2014;31:194–201.
[9] Katz M. The feasibility of renewable energy in Pakistan. TBL Spec CSR J 2008(2):14–6.
[10] Mehmood A, et al. Stand-alone PV system assessment for major cities of Pakistan based on simulated results: a comparative study. NUST J Eng Sci 2013;6(1):33–7.
[11] Kessides IN. Chaos in power: Pakistan's electricity crisis. Energy Policy 2013;55(0):271–85.
[12] Nowsherwan K. et al. Identification and removal of barriers for renewable energy technologies in Pakistan. In: Proceedings of the 2nd international conference on emerging technologies. Peshawar: IEEE-ICET; 2006.
[13] Khalid A, Junaidi H. Study of economic viability of photovoltaic electric power for Quetta–Pakistan. Renew Energy 2013;50:253–8.
[14] Rogers EM, Elements of diffusion. Diffusion of innovations, vol. 5; 2003. p. 1–38.
[15] Jacobsson S, Lauber V. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy 2006;34(3):256–76.
[16] Allen S, Hammond G, McManus M. Prospects for and barriers to domestic micro-generation: a United Kingdom perspective. Appl Energy 2008;85(6):528–44.
[17] Vasseur V, Kemp R. The adoption of PV in the Netherlands: a statistical analysis of adoption factors. Renew Sustain Energy Rev 2015;41:483–94.
[18] Jabeen M, et al. Socio-economic prospects of solar technology utilization in Abbottabad, Pakistan. Renew Sustain Energy Rev 2014;39:1164–72.
[19] Reddy S, Painuly JP. Diffusion of renewable energy technologies - barriers and stakeholders' perspectives. Renew Energy 2004;29(9):1431–47.
[20] Claudy MC, et al. Consumer awareness in the adoption of microgeneration technologies: an empirical investigation in the Republic of Ireland. Renew Sustain Energy Rev 2010;14(7):2154–60.
[21] Muntasser M, et al. Photovoltaic marketing in developing countries. Appl Energy 2000;65(1):67–72.
[22] Palm J, Tengvard M. Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. Sustain: Sci Pract Policy 2011;7(1).
[23] Berger W. Catalysts for the diffusion of photovoltaics—a review of selected programmes. Progress Photovolt: Res Appl 2001;9(2):145–60.
[24] SBP, Revised Scheme for Financing Power Plants Using Renewable Energy, S.B.o. Pakistan, editor; 2016: ⟨http://www.sbp.org.pk/smefd/circulars/2016/C3.htm⟩.
[25] Faiers A, Neame C. Consumer attitudes towards domestic solar power systems. Energy Policy 2006;34(14):1797–806.
[26] Wamukonya N. Power sector reform in developing countries: mismatched agendas. Energy Policy 2003;31(12):1273–89.
[27] Khan MA, Latif N. Environmental friendly solar energy in Pakistan's scenario. Renew Sustain Energy Rev 2010;14(8):2179–81.
[28] Mirza UK, et al. Identifying and addressing barriers to renewable energy development in Pakistan. Renew Sustain Energy Rev 2009;13(4):927–31.
[29] Akinboro F, Adejumobi L, Makinde V. Solar energy installation in Nigeria: observations, prospect, problems and solution. Transnatl J Sci Technol 2012;2(4):73–84.
[30] AEDB, Alternate Energy Development Board, Ministry of Water & Power, Government of Pakistan; 2016.
[31] Painuly JP. Barriers to renewable energy penetration; a framework for analysis. Renew Energy 2001;24(1):73–89.
[32] Eltawil AM, Zhao Z. Grid-connected photovoltaic power systems: technical and potential problems—a review. Renew Sustain Energy Rev 2010;14(1):112–29.