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Effect of the Residential Photovoltaic Systems Evolution on Electricity and Thermal Energy Usage in Jordan

Nabil Beithou[1], Mohammad A. Mansour[2,3], Nasser Abdellatif[3,4], Sameh Alsaqoor[1,3,4*], Sultan Tarawneh[4,5], Ala H. Jaber[6], Artur Andruszkiewicz[7], Moh'd Alsqour[8], Gabriel Borowski[9], Ali Alahmer[1,10], Julia Siderska[11]

[1] Department of Mechanical Engineering, Tafila Technical University, 179, 66110 Tafila, Jordan
[2] Department of Mechanical and Industrial Engineering, Applied Science Private University, Amman, Jordan
[3] MEU Research Unit, Middle East University, Amman, Jordan
[4] Electrical Engineering Department, Applied Science Private University, Amman, Jordan
[5] Civil Engineering Department, Applied Science Private University, Amman, Jordan
[6] Mechanical Engineering Department, Zarqa University, Zarqa, Jordan
[7] Department of Thermal Science, Wrocław University of Science and Technology, ul. Wybrzeże Wyspiańskiego 27, 50-370, Wrocław, Poland
[8] Department of Accounting, Irbid National University, PO. Box 2600, Irbid, Jordan
[9] Faculty of Environmental Engineering, Lublin University of Technology, ul. Nadbystrzycka 40B, 20-618 Lublin, Poland
[10] Department of Industrial and Systems Engineering, Auburn University, Auburn, USA
[11] Faculty of Engineering Management, Bialystok University of Technology, ul. Wiejska 45A, 15-351 Bialystok, Poland
* Corresponding author's e-mail: sameh@ttu.edu.jo

ABSTRACT

The aim of this study was to improve the residential photovoltaic systems (RPVS) sector, using surveys as the research method. The research was carried out in four selected districts in Jordan, taking into account the largest population. The prepared sets of questionnaires covered a wide range of topics, divided into three parts and seven sections. The results showed that the highest use of solar energy for heating was in the Amman district, while in the Irbid and Zarqa districts photovoltaic (PV) system installations can potentially be more prospective because of high electricity and thermal energy usage. This study found the willingness of people to have a combined on-grid/off-grid PV systems, made by European and American manufacturers. However, those respondents were afraid of the high maintenance cost, the unclear lifespan of the system, doubtful reliability, and unclear warrantee of the PV systems.

Keywords: residential photovoltaic, renewable electricity, thermal energy, on-grid systems.

INTRODUCTION

In the last decade, the photovoltaic (PV) panel prices have been dropped down, which makes the use of PV panels for electric generation much more feasible. Jordan is one of the first countries in the Middle East that adopted the implementation of on-grid PV systems for electricity generation. Almost 2 GW of electricity is generated from renewable energy resources, most from PV systems [1]. The maximum electricity demand in Jordan in 2020 was in the range of 3.6 GW [2]. Different researchers have studied the electricity situation in Jordan, the executed PV projects, energy production and the reliability of the PV systems [3–5]. To supply the business sector with valuable information that helps in the evolution of the PV industry and minimize the dependency

on fossil fuels, the promoting area of the PV systems should be investigated. The PV system's market has been studied long ago. In 1986, Ivan Chambouleyron discussed the third world view of the PV system market; it was clarified that a high competition of other fuels, such as diesel and electrical grid, were available [6], which was due the high cost of the PV panels at that time. Nevertheless, researchers continue work on the PV systems for their valuable contribution in reducing global warming. In 1994, a survey was conducted to ascertain the awareness of the industrial sector to the potential of renewable energy in supplying industrial energy needs. The survey considered the heavy/industrial and service utilities companies. Low level of awareness was recorded in UK [7]. Time passed and lessons were learned from the Japanese/Australian experience in the Residential Photovoltaic Systems (RPVS) market. As mentioned by Parker, P. in 2008, there was a need for capital incentive to facilitate the industrial growth [8]. The main obstacles of the PVS market It was also stressed on, including high initial cost and country regulations. The search for an evolution in the PVS marked was continued, researchers concentrated on the factors that affect the RPVS market, various studies have been performed in different countries, such as USA, India, Greece and China [9–12]. These factors were summarized in the income level, awareness, government support and weather conditions. Throughout these difficulties, the PV systems were used in other applications, other than electricity generation: solar cooling, solar oven and indoor PV cells are some of these applications [13–15], the use of PV system in such applications was encouraging, regardless of the cost. The sea water desalination and hydrogen generation were also promising applications of the PV systems [16, 17]. Recently the, cost of the PV systems was largely reduced and the use of the PVS in industry has become highly profitable with payback periods as short as three years. Most of the companies and factors that are consuming a large amount of electricity are already using on-grid PVS. The problem is concentrated now in the residential market of the PVS. To overcome the low demand of the PVS in residential sector, researchers and companies proposed alternative substitutional solutions, such as hybrid PV-Thermal (PV-T) systems as proposed by El Sayed [18]. The PV-T systems were also used to increase the efficiency of the PV solar system and supply hot water in the industries requiring both electricity and hot water [19, 20]. The performance and economic evaluation of a PV-T solar system for residential applications was analyzed late in 2013 by Petros et al. [21]; they found that the PV-T system can cover a significant portion of the domestic hot water load, while simultaneously feeding the grid with electrical energy. It is also noted that the installation of a PV-T system is a more advantageous investment when the auxiliary water heating energy is from electricity, followed by heating oil and then natural gas. Other approaches in modifying the use of a PVS are analyzed, such as new PV technologies with future prospects, smart charging and discharging and the centralized district PV system in rural areas [22–24].

The surveys were performed throughout the different districts of Jordan to investigate the factors affecting the evolution of the RPVS sector. It was found that this evolution has a great impact on the reduction of energy consumption, including electricity and heating.

QUESTIONNAIRE DESIGN

Research area

Jordan is a Middle Eastern Asian country with a population about 10.4 million, 42% of the population lives in the capital Amman city, 18.5% at north region in Irbid cities, 14.5% at the central region in Zarqa city and 5.8% in Mafraq, the rest are in the other cities with percent range 1–3% each (Fig. 1).

The area of study covered of four districts listed in Table 1. The selected districts: Amman, Irbid, Zarqa and Mafraq, represent more than 80% of Jordan population. This area characterized by high solar intensity all over the year, with sun shine more than 330 days per year. Figure 2 represents the global solar radiation on a horizontal surface.

Table 1. The population of selected districts

District	Population	City population intensity factor
Amman	4,430,700	0.420
Irbid	1,957,000	0.185
Zarqa	1,509,000	0.143
Mafraq	608,000	0.058
Total	10,554,000	–

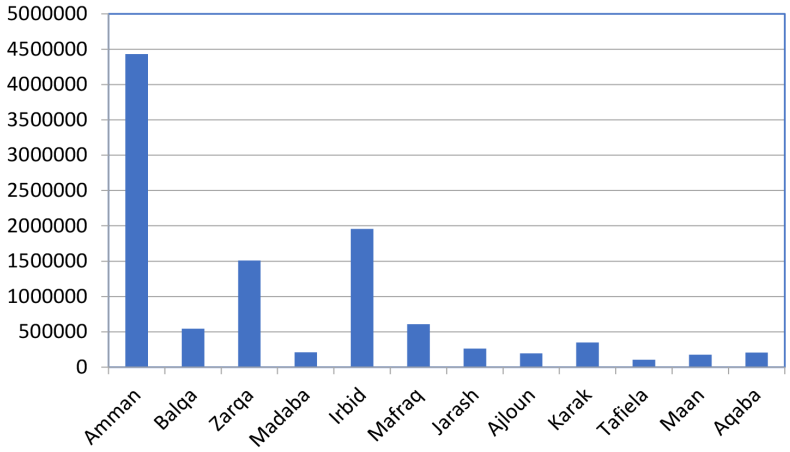

Fig. 1. The population distribution in the different districts of Jordan

Each city assigned a population intensity factor defined as:

$$CPIF = \frac{PD}{TP} \tag{1}$$

where: *CPIF* – city population intensity factor,
PD – population of the district,
TP – total population.

Survey scope and topics

The number of respondents assigned to each city was proportional to its population. Before the survey started, the respondents were introduced on PV systems in order to supply an approximate cost and area of installation required, calculated by the equations:

$$A = Mr \cdot 0.0444 \tag{2}$$

where: *A* – area, m^2; *Mr* – monthly rate, kWh.

$$C = Mr \cdot 8 \tag{3}$$

where: *C* – cost, JD.

Moreover, the respondents were introduced to the scope and topics involved in the questionnaire.

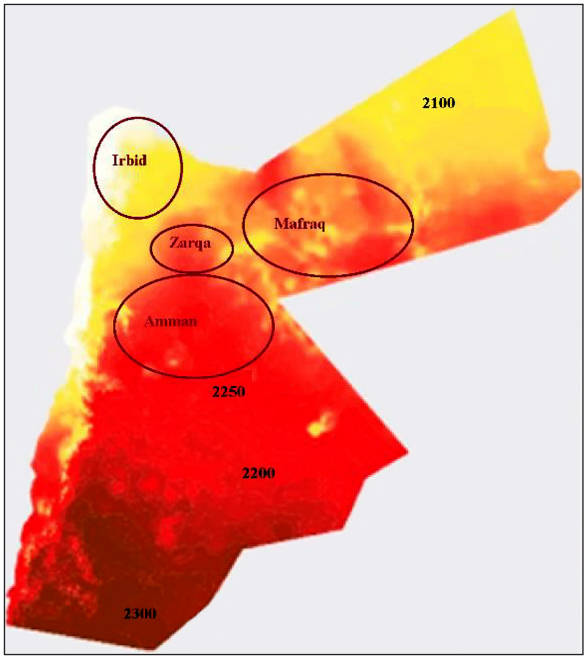

Fig. 2. Jordan annual solar radiation (kWh/m^2), and selected research areas

The survey was divided into three parts and seven sections, as shown in Table 2.

Table 2. The survey scope and topics

Part	Section	Topic description
Part one	Living standards	Related level of education, dwelling type (independent, apartment or rent) and the consumed electrical power per month
	Current level of awareness	Thermal energy usage/heating system (fuel type, insulation, water heating…)
	Prospects	Thermal energy/heating systems (heating system, system type, usage and financial power)
Part two	Current residential status	Electricity consumption, area available, air conditioner usage and usage type
	PV system related issues	Manufacturer, maintenance, preferable system properties
Part three	Obstacles: system related	Maintenance, life, stability reliability and security
	Obstacles: cost related	Payback period, life, maintenance and trust

About four hundred family residences were included in this survey, men and women are usually taking the decision of implementing solar systems. The respondents were divided in accordance to percentages with the city intensity factor, people from newly-married to old ages were included in the survey, without and advantage of males over females in decision making.

ANALYSIS OF THE RESULTS

The living standards of selected districts

One of the factors investigated was the standard of the life of the community. These studies were performed on the basis of education, dwelling type, and electricity consumption (Figure 3). These parameters can give an overview of the living standards for the districts discussed.

From Figure 3 some of information was obtained, as below:

- Amman shows the highest education level, with the lowest area available for PV systems.
- Mafraq has the highest available area for PV system installation but with a lowest dwelling.
- Irbid and Zarqa districts have very good education levels, fairly high available area for PV system installation and high electricity consumption.

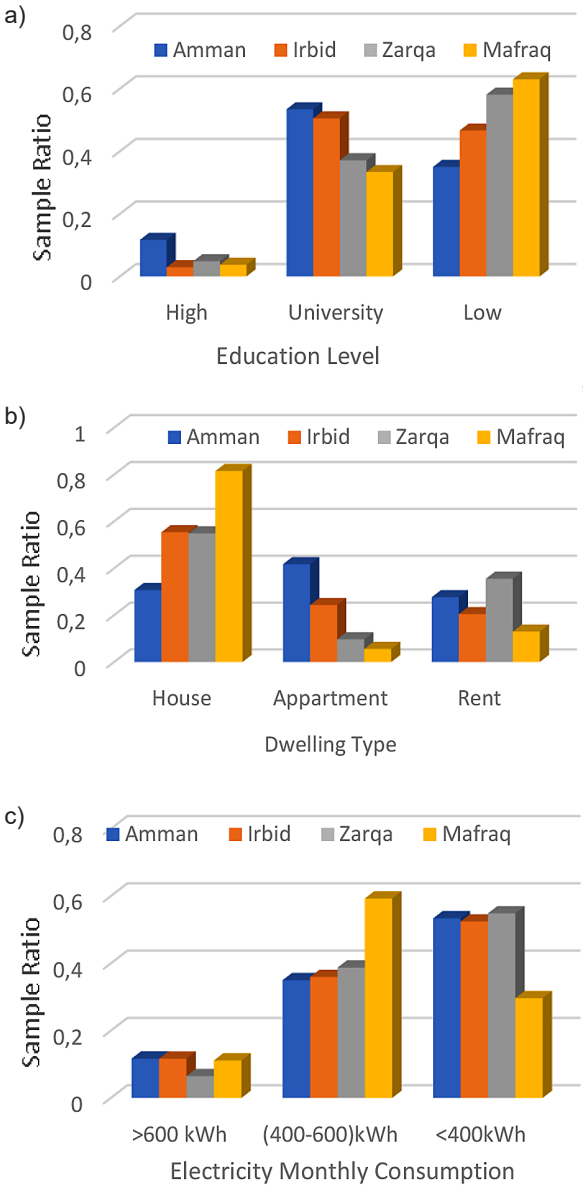

Fig. 3. Living standards of the selected districts: (a) education, (b) dwelling type, (c) electricity consumption

Level of awareness

The current level of awareness of the respondents has been investigated in the four selected districts. This was possible by asking questions related to renewable energy and its application, as well thermal energy usage, the heating system implemented, fuel type used, insulation and water heating type.

Figure 4a shows that most of respondents are willing to use fossil fuels or electricity for heating purposes. This result shows the importance of implementing the renewable energy in the life of the Jordanian people. The Amman district shows the highest use of solar energy in heating. Figure 4b gives the indication on the type of the heating system used in the residential buildings. It is clear that most of the buildings are still using the portable heaters as their heating system. This is due to the low cost of fossil fuels; the usage of fossil fuels for heating purposes in closed areas created a large increase in the respiratory diseases especially among mothers and kids who rarely leave homes during winter. The move to clean energy low-cost system such as solar assisted underfloor heating system has great benefits. Figure 4c shows the energy source for water heating systems, most residents used electricity for heating water. This is due to simplicity of electrical heater installation and low initial cost. High electrical bills appear in winter which affects the family's economic situation for the rest of the year. Some regulations from the municipal will correct such behavior.

Figure 5 shows that a residential home can consume about 20–50 JD per month under normal conditions. The use of 50–100 JD electric bills by about 35% of the four district residential buildings is an indicator of the miss use of electricity.

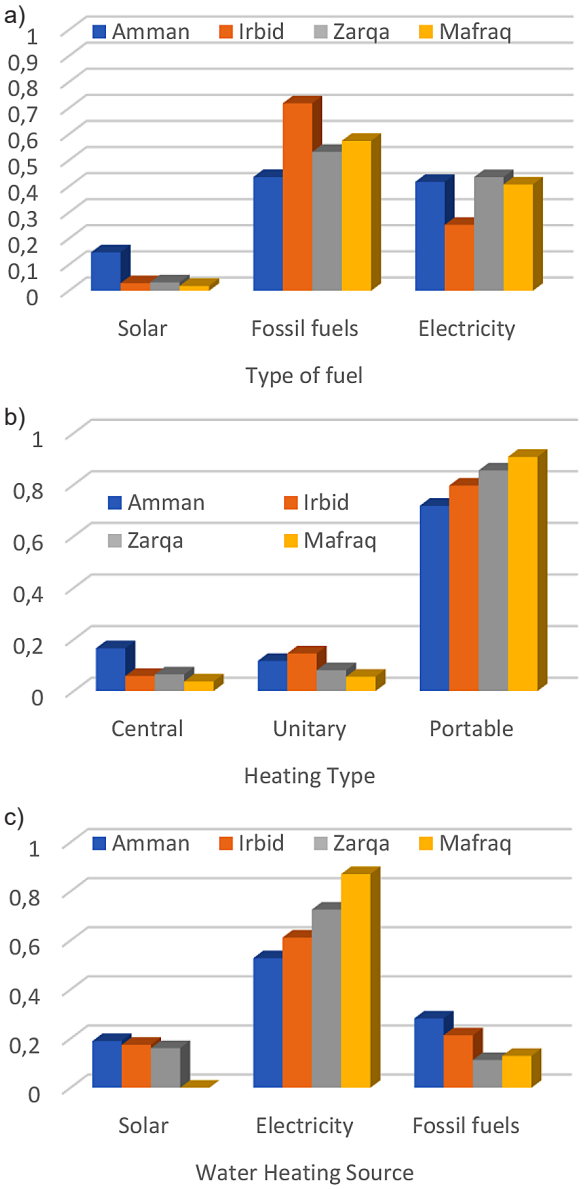

Fig. 4. Level of awareness of the four selected districts: (a) fuel type, (b) heating type, (c) source of water heating

Again, here is another indicator that shows the need for implementing renewable energy. The insulation if applied both wall and windows are mostly used (Fig. 5).

The awareness of the respondents to the renewable energy usage was quite low. There is a great need to use media and especially the governmental media to increase the awareness of people to renewable energy. Such awareness will be reflected on the government in a reduction in the needs of importing fossil fuels from outside.

Prospective of solar energy using

Figure 6 shows that solar plates are the most common used as water heater, this is due to its low maintenance cost and long life. In turn, Figure 7 shows the prospect of using solar energy for the selected districts. This prospect has been drawn through the usage type, the system type and the nature of the system used. According to Figure 7, the water heating usage type is mostly for both house heating and water heating, the majority of people selected solar plates as the heat supply system, general heating systems received the highest choice because of the low knowledge on the centralized systems.

Residential buildings status

In order to investigate the RPVS, the status of the residential buildings was analyzed. Figure 8 shows the results of area availability and the air conditioning used in the different districts. Most of the respondents that have air conditioners, in a certain manner have an adequate area of PV installation, especially in Amman, Irbid and Zarqa.

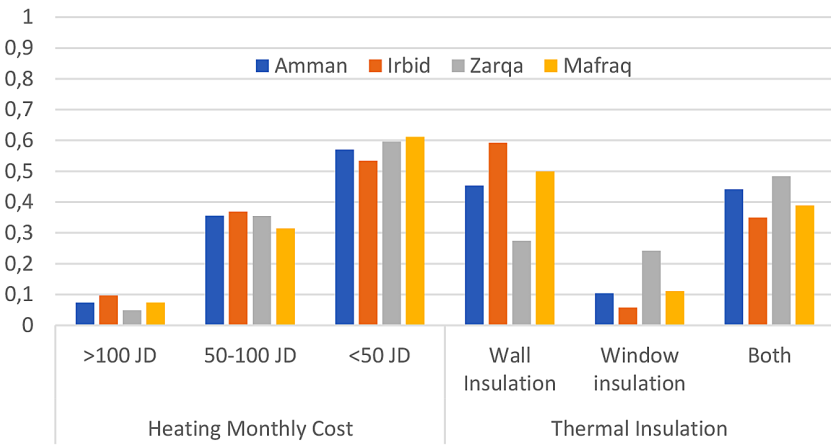

Fig. 5. Thermal insulation and monthly electricity bills for the four discussed districts

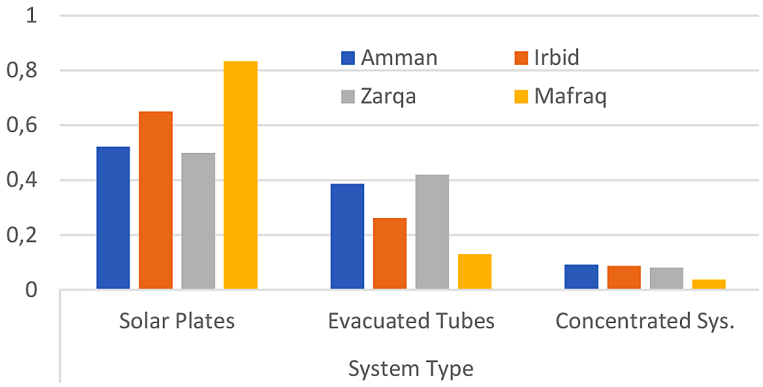

Fig. 6. Solar system type preferred for water heating in the four selected districts

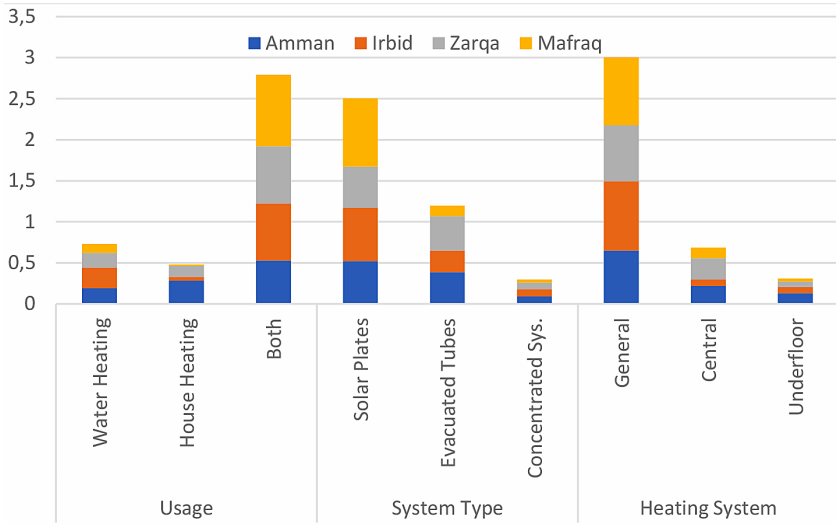

Fig. 7. Prospect of using solar energy in terms of usage, system and nature

Figure 9 show the preferred type of the RPVS weather on-grid or off-grid system and the electricity consumption in terms of high, medium, and low. Most of the residential buildings consume the high amounts of electricity; this designates a good potential for the needs of PV systems. The willingness of people to have a combined on-grid/off-grid system was also shown.

PV system related issues

To measure the tendency of people to install RPVS, the importance of some system parameters such as the manufacturer and maintenance have been surveyed. Most people preferred the US/EU manufacturers. The availability of maintenance is dependent on the district type (Fig. 10).

Next, the preferable RPVS type and nature have been analyzed in the survey. Figure 11 shows that the combined systems were preferred. Respondents wish to have a PV-T system having hot water and electricity, and also wish to have the option of being on-grid or of-grid. Such type of information may have a critical impact on the willingness to install the PV system.

Obstacles of PV system related

The PV system related obstacles that may affect the decision of the residential building owner, have been considered. Maintenance, life, reliability and stability of the system have been surveyed. The results obtained are shown in Figure 12. The main PV system related obstacles are the high maintenance cost, the unclear lifespan of the system, doubtful reliability, and unclear warrantee of the system.

CONCLUSIONS

It was found that the Amman district shows the highest use of solar energy in heating,

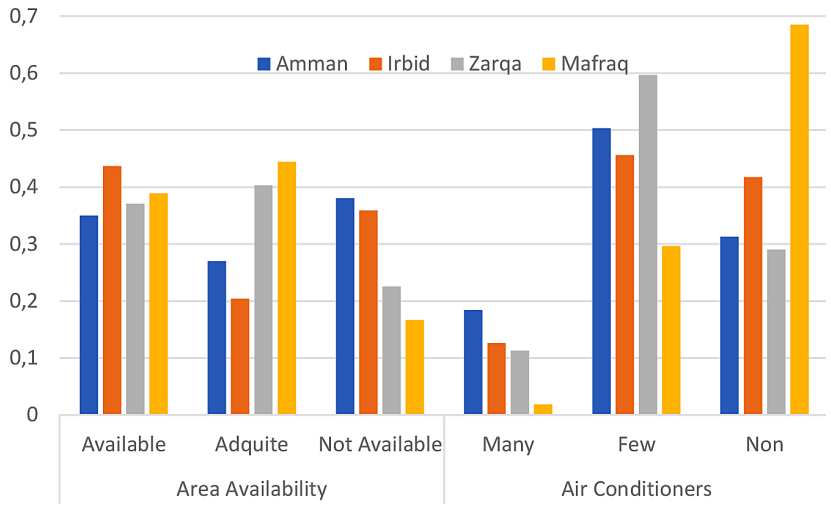

Fig. 8. The area availability and the air conditioning used in the selected districts

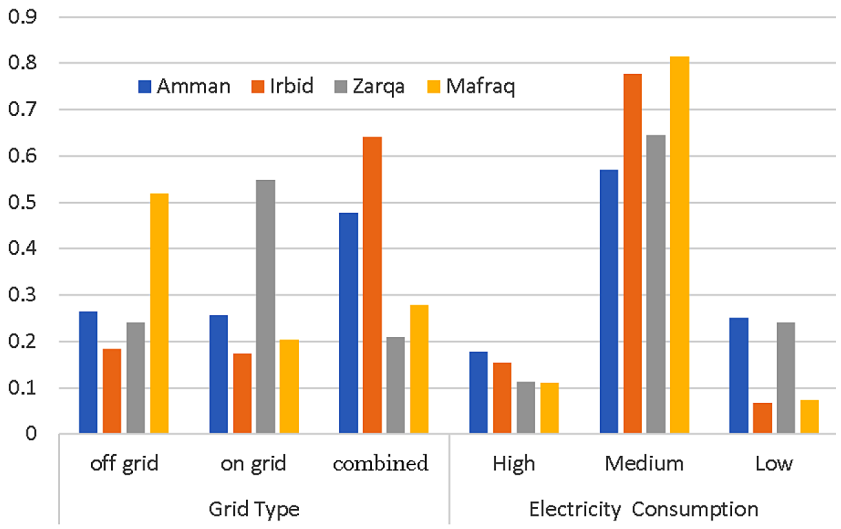

Fig. 9. PV system type and electricity consumption

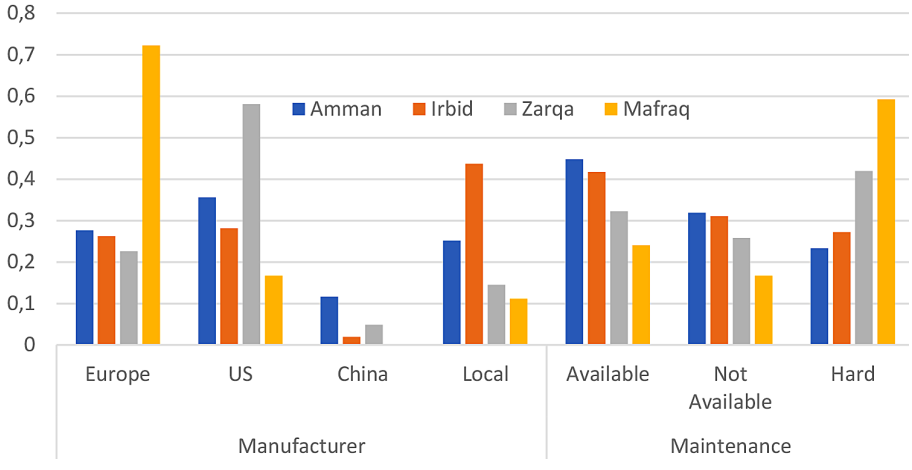

Fig. 10. RPVS related issues, manufacturer and maintenance

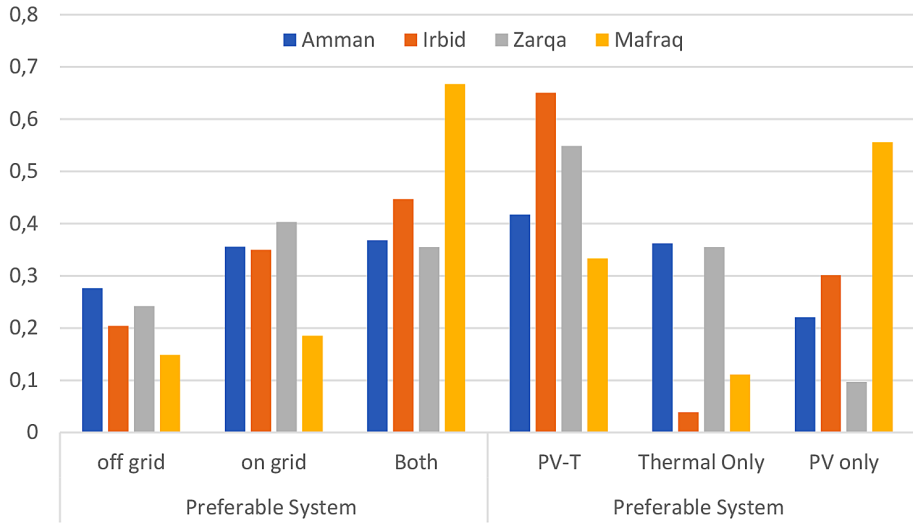

Fig. 11. RPVS related issues, preferable system type and system nature

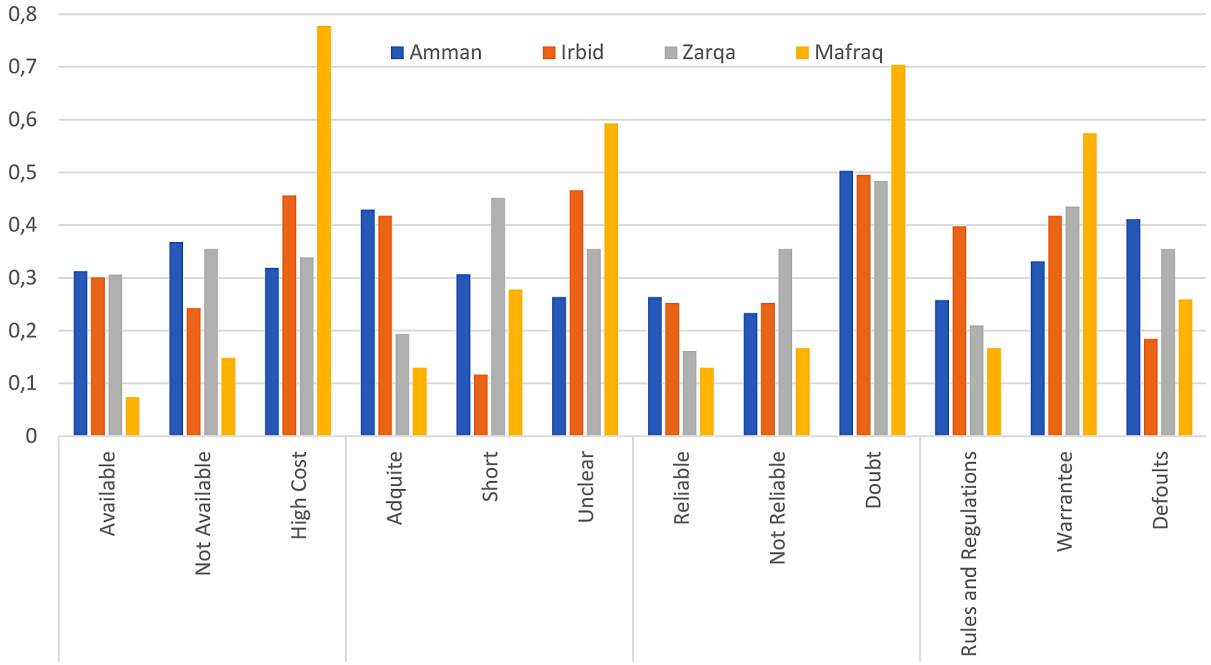

Fig. 12. RPVS related obstacles: maintenance, lifespan, reliability and stability

while the Irbid and Zarqa districts have the best pushing potential to install the PV systems for their high electricity and thermal energy usage. The results found that solar plates are the most commonly used as water heaters, heat supply systems, and general heating systems. The willingness of people to have a combined on-grid/off-grid systems was also shown. The awareness of respondents to the renewable energy usage was quite low, so intensive media dissemination was recommended. European and American manufacturers of combined PV systems were preferred for multi-objective and low maintenance. The main PV system related obstacles were the high maintenance cost, the unclear lifespan of the system, doubtful reliability, and unclear warrantee of the system.

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