Deployment of Rooftop Solar Photovoltaic Electrification for Residential Buildings in an Industrial City: A Study on Public Perception and Acceptance

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Abstract- Solar-based power generation is gaining attention worldwide as it is environment-friendly, and highly sustainable. Saudi Arabia is bestowed with vast solar energy availability. This should be the driving force for generating solar electricity to the optimal. However, the installation of solar photovoltaic (PV) is not as widespread as expected. As purposed-built cities emerged from the Kingdom's new economic development and renewable energy initiatives, they should lead the way for solar energy utilization. This paper aims to investigate the public perception and acceptance towards rooftop solar electrification in such cities in Saudi Arabia. Survey questionnaires were distributed to a sample population of Yanbu Industrial City to measure the perception, and readiness towards installing rooftop solar systems and gauge the populace's concerns. The outcome shows a variation of awareness levels, positive perception, and mix-readiness towards installation. The main barriers are the relatively low cost of fossil fuel-based electricity and the lack of clear incentives from authorities. Homeowners are more willing to invest in solar electricity for long term gain. Household income also has significant effects on the willingness for investment. The scenario analysis indicated that less than six years of payback could be achieved with the PV system which can be an attraction.

Keywords Solar photovoltaic, public awareness, environmental impact, renewable energy policy, investment readiness

1. Introduction

Saudi Arabia is one of the solar belt countries having extended hours of intense sunlight. The amount of solar energy received can be used to generate electricity by solar photovoltaic, which could exceed local consumption. This makes the Kingdom a potential net exporter of solar electricity. Most areas in the country receive more than 2400 kWh/m^2 of solar energy every year [1,2]. In addition to generating electricity, solar energy can also be utilized as an energy supplement to the oil-related industries such as petrochemical process heat and steam generation in power plant [3]. Combining both electricity and thermal generation can significantly improve energy conversion efficiency [4]. However, due to highly subsidized electrical energy prices, resulting in low tariffs, the consumption behavior is high compared to the world average. Energy consumption in the Kingdom has been relatively high and thereby threatening oil export and revenue while at the same time contributed to greenhouse gases accumulation. The per capita electricity consumption in the Kingdom increased by over 100% from 1996 to 2016 [5]. Consequently, Saudi Arabia is one of the countries with high spending on oil subsidies [6]. In order to mitigate this, a proper strategy and national plan to integrate renewabele energy is crucial [7]

In the 70's there were two major cities established and developed by the Kingdom: Yanbu Industrial City and Jubail Industrial City. Yanbu Industrial City was established in 1975 by the Royal Commission of Jubail and Yanbu, Saudi Arabia, to provide a township for oil, gas, and petrochemical-related heavy industries. Located on the coastal area of the Red Sea, 350 km north of Jeddah, this city is inhabited by almost 130,000 people in over 20,000 residential units of villas, houses, apartments, and dormitories. The total population of Yanbu Industrial City is 123,440, of which 56% are Saudi nationals, and 44% are expatriates, according to the 2017 Royal Commission of Jubail and Yanbu census [8]. The electricity is supplied from a 1030 MW power plant operating on two steam turbines of 277 MW each and nine gas turbines with 513 MW total capacity. They are fueled with fossil heavy fuel oil and natural gas. This kind of city establishment is spreading in Saudi Arabia in recent years in areas like Jizan, Rabigh, Madinah, Makkah, Taif, and Neom. Therefore, understanding the public reaction from such a unique population can help establish effective strategies for deploying solar electrification both at large scale and residential scale.

Currently, in Saudi Arabia, the total share of renewable energy sources accounts for less than 1% of the total electricity generation. However, this share of renewable energy sources is expected to increase very significantly following Saudi Arabia's new policies as part of the Kingdom's Vision 2030. Renewable energy initiatives can be traced back to the mid 90's. In 1994 Saudi government also established joint venture research and development for the measurement of solar radiation (atlas) between the National Research Energy Laboratory (NREL) of USA, Energy Research Institute (ERI) of King Abdulaziz City of Science and Technology (KACST) to help the renewable energy sector development [9]. Over the last few years, the Saudi government adopted favorable renewable energy policies and launched a campaign to promote renewable energy in Saudi Arabia. The government strategy is to diversify the energy mix and increase renewable energy generation capacity to cut its oil consumption and build a sustainable future. The government level's critical policies include launching the National Renewable Energy Program to create renewable energy policies and facilitate the successful development of renewable energy projects.

The action areas highlighted by Saudi Arabia under the Nationally Determined Contributions (NDC) of the Paris Agreement include renewable energies, energy efficiency, and gas (United Nations Framework Convention on Climate Change 2019). Moreover, under the framework of Vision 2030 and the National Transformation Program 2020 (NTP), Saudi Arabia announced an ambitious plan to invest more than 100 billion dollars and targets to generate 60 GW of power from renewable energy, including 43 GW from solar energy, and 16 GW from wind energy by 2030 as Fig. 1. depicted [10]. This clean energy will contribute more than 50% of the country's energy demand. The renewable energy development aims for economic benefit as well as environmental benefits such as reducing domestic fossil fuel consumption and allowing the reduction of the country's greenhouse gas emissions as part of the Paris Accord on climate change [11].

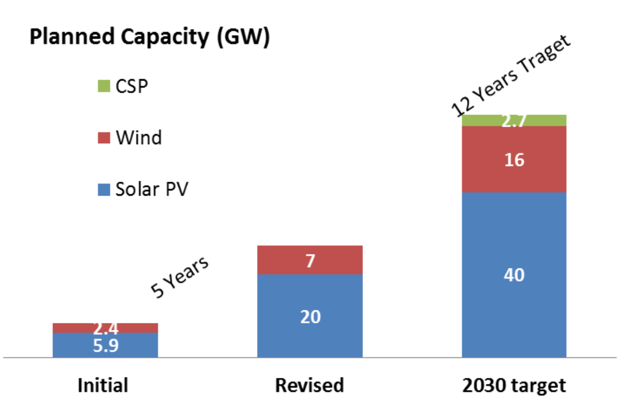

Fig.1. Saudi Arabia's renewable energy installation plan [12]

Besides the initiatives and policy drives to improve renewable energy utilization, the Kingdom has adopted a comprehensive policy framework and renewable energy support and subsidy strategies [13]. Asif asserted that despite the global success of implementing solar photovoltaic in residential houses, the focus is still on large scale renewable energy projects in Saudi Arabia [14]. Several studies had highlighted the high potentials of implementing rooftop solar photovoltaic arrays in Saudi Arabia [13-18]. Installation of rooftop solar panel may have a number of disadvantages. These include requirement for roof structure to withstand higher weight, more challenging to access for cleaning and maintenance, and they may trap heat between roof and panels. Most houses in Saudi Arabia has a flat rooftop with 4 feet walls. The solar panel should be erected higher than the walls in order to avoid shading as well as heat trap. Nahiduzzaman et al. studied the behavioral pattern of male and female citizens of households of Khobar city in Saudi Arabia with respect to awareness of household energy consumption and renewable energy facilities [15]. The results revealed that the number of adults in the family and education level profoundly influences the households' energy consumption behavior. More than the awareness, the selection of location considering different aspects of required facilities, as well as geographical importance, is critical for the success of any renewable energy project. Hassan and Anjali have recently touched upon this aspect, especially for Saudi Arabia, and proposed a Geographical Information System (GIS)- Analytical Hierarchy Process (AHP) approach for the best selection of sites [16]. As per the approach, Yanbu Industrial city can be considered one of the best locations for a solar or renewable energy project in Saudi Arabia. The same group studied different cities in Saudi Arabia on account of solar irradiance, temperature, tilt, and azimuth angles in order to identify the best locations later [17]. As per their analysis, Yanbu is considered an excellent place for solar energy projects. However, owing to the best resources available in Yanbu Industrial city and the future potential for the city and region, we consider Yanbu a strategic location for renewable energy projects and solar energy utilization.

The use of rooftops for solar PV installation and power generation is very important for the future of energy conservation and sustainability. A team of researchers led by Khan in the eastern region of Saudi Arabia analyzed the possibility of the installation of solar PV modules on rooftops of university housing units recently [18]. It was estimated that around 30% of the domestic electricity needs could be generated from the rooftop installation; however, necessary policy changes and an increase in awareness have to be undertaken by the respective stakeholders. Another important study on the efficacy of using unregulated building rooftops for the generation of electricity is done considering the apartments and villas in the Al-Khobar region recently [19]. It is interesting to note that only a quarter of the total units fit the effective production of power from PV installations. In order to improve the use of rooftops certain policy-changes and awareness among the public are recommended by the authors. A pilot study on the use of mosque rooftops for installing solar PV is done by Elshurafa et al. [20]. The techno-economic study estimated that the total cost for electricity is reduced to 50% or so after installing solar PV. It is envisioned that proper planning could lead the cost reduction to even 100%.

The social perception of installing residential solar photovoltaic in Saudi Arabia lacks solid data because fewer studies or reports exist. The first is done by Alrashoud and Tokimatsu using a web-based survey from a cross-section of individuals inside the country [21]. The study revealed mixed feelings on acceptance, knowledge about solar energy, safety aspects, job opportunities, and cost-effectiveness. Authors recommended policy changes and cost reduction through subsidies, low-interest loans for individuals to purchase the components etc. The same authors reported an improved version of the study with a more prudent questionnaire [22]. Within a short span of time, the respondents' awareness level increased due to the new plans (Vision 2030) and Net Metering facilities. Moreover, people are aware of the environmental issues arising out of fossil fuels, and more sustainable solutions are acceptable to them even though the initial cost of installation is pretty high.

The current study builds on the previous studies by focusing on the social aspect, public perception, of implementing solar photovoltaic arrays at an urban scale [23]. However, this study is unique compared to the afore-mentioned. It is focused on a well-planned industrial city with an advanced residential setting, comprehensive infrastructure, population distribution, education levels, and income levels compared to most cities in the country. Therefore, this might lead to different results.

1.1 Solar energy initiatives in Yanbu industrial city

In line with the Vision 2030 initiatives, the Royal Commission administration has laid out a renewable energy plan to install a solar- power plant with up to 400 MW capacity. In order to showcase the feasibility of this project, RC has initiated a pilot solar-powered residential project to demonstrate solar PV on residential rooftop systems with grid connectivity as an option. A 15 kW grid-connected rooftop solar system that is mounted on top of a 3-bedroom single-floor house in Aljabriah district to offset the electricity demand for that resident. Polycrystalline solar modules were used in this project. They are made by Canadian Solar, with an efficiency of 16.40% and 320W as maximum power. These solar PV modules have high performance at low irradiance approximately above 96%, and positive power tolerance up to 5 W above the rated power. The PV system comprises 16 PV modules connected in series to increase the DC voltage output and form a string to ensure that the open-circuit Voltage (Voc) of the PV array is within the Maximum Power Point Tracking (MPPT) operational window of the paired inverter [24]. Then, three strings are connected in parallel to increase the output current to the desired value. These strings are connected to a 3 phase Alternating Current (AC) string inverter. The inverter uses a proprietary MPPT technology to harvest the maximum energy from the solar array and convert the DC into AC power [25]. Then the inverter's AC power goes directly to a safety breaker then to the main panel. This project also includes a flush mount system and a 10-degree tilt racking system on a flat roof. The azimuth angle of the plant is 175°C South-East following the orientation of the building.

The layout of the PV plant was calculated carefully to install as many as possible panels in the available roof area, avoid inter-row shading, and maximize the plant's performance. This PV plant will feed its produced power into the existing house network. The grid connection point is the main switchboard located on the ground floor. An additional safety breaker of 40 A was added to this distribution panel, which will act as the interconnection point. A monitoring system has also been installed to ensure the control of the system remotely and monitor system performance and power production.

The system has produced a maximum power of 15360 W in perfect weather conditions, which can rarely be the case in real life because of DC to AC conversion losses, temperature losses, mismatch losses other losses. However, in Yanbu, the solar yield is 2,200 kWh per kW solar irradiance for the south-pointing array at a low tilt. That means a 15 kW solar array can produce approximately 33,000 kWh per year and provides power to 6 units of 18,000 Btu/hr air conditioner units, 40 units of 25 W light bulbs, and all the appliances for the resident. These potential promises that installing a solar PV system on residential houses available in this city can be a viable renewable energy option for its residence.

1.2 Solar energy potential in the Yanbu region

For the Yanbu region, the annual average daily solar irradiation exceeds more than 2200 kWh/m^2 [26, 27]. This can be seen in Fig. 2. The KACST meteorological stationed at Yanbu Research Center measures real-time weather data of Yanbu Industrial City since 2014, which include Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), Global Horizontal Irradiance (GHI), ambient temperature, wind speed, wind direction, humidity, and atmospheric pressure. On an annual basis, Yanbu received solar irradiation on average of 6.56 kWh/m^2 per day. This varies from months to months, with the lowest in December (4.68 kWh/m^2/day) and highest in June (7.48 kWh/m^2/day), as shown in Fig. 3. While Fig. 4 shows the annual average daily solar radiation at Yanbu is as low as 100 W/m^2 and dusk and dawn. It can reach a maximum of 1050 W/m^2 at around 11.00 hrs and 12.00 hrs. The available radiation spans over a period of 14 hours each day.

Given the potential of solar electricity generation and the local authority initiatives to promote the use of renewable energy power, there is a need to understand the perception and readiness of residents towards its implementation. In this work, we conducted a public perception study performed on about 1% of the Yanbu Industrial City population through the survey method. No such study has been done in such a unique population demographic in Saudi Arabia since the Yanbu Industrial City is a well-planned city occupied by a diverse international population with a high average level of education, high-income levels, and well-planned city infrastructure.

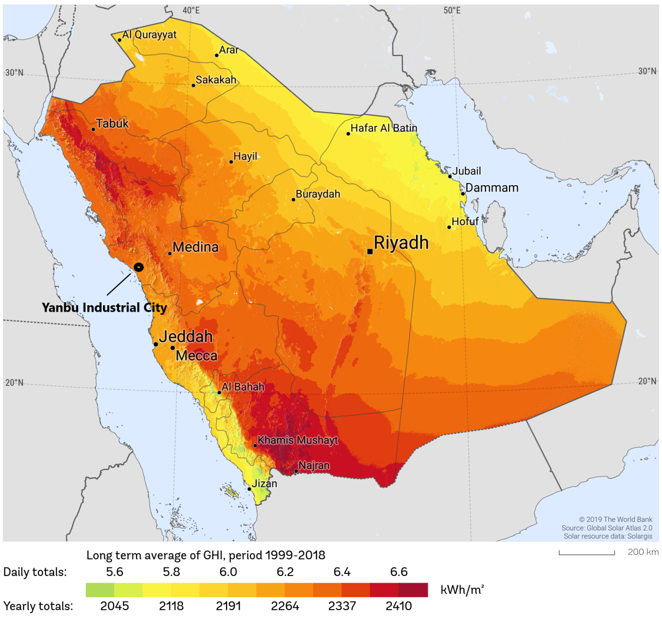

Fig. 2. Annual average daily solar irradiation Yanbu Industrial City and surrounding areas [28]

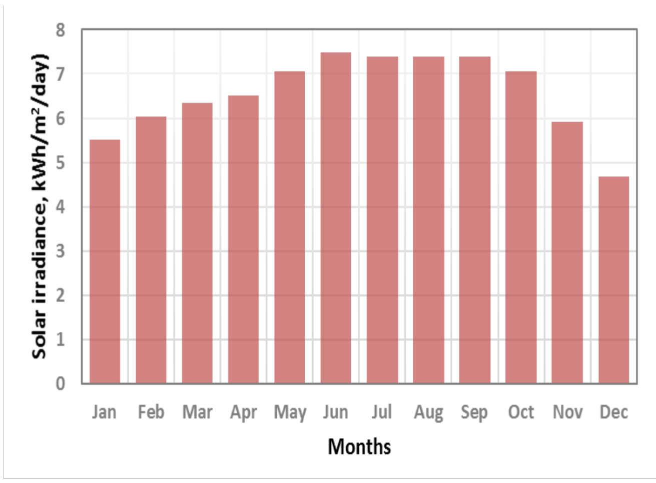

Fig. 3. Monthly average daily solar irradiation at Yanbu Industrial City (2015-2016)

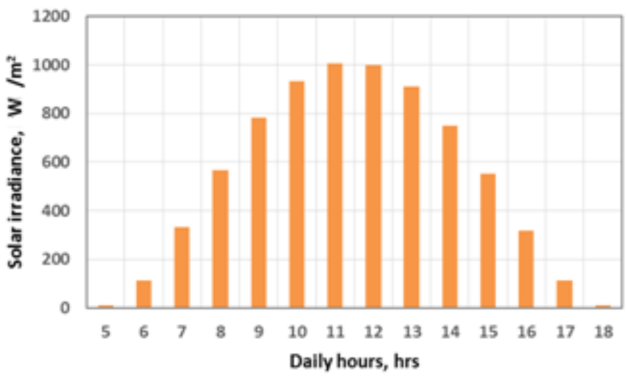

Fig. 4. Annual average hourly solar irradiance incident at Yanbu Industrial City

2. Methods

The study adopted two stages in examining the public perception towards the deployment of solar panels in Saudi Arabia. The first stage is reviewing relevant literature and official documents to ascertain the current adoption of renewable energy in Saudi Arabia and the prevailing initiatives and policies. The review gave insight into the gap in knowledge and the suitable research instrument for undertaking the study. Consequently, some concerns and barriers in the implementation of this renewable energy initiative were understood. They were then used to construct the survey questionnaires. The second stage involves the administration of questionnaires to capture the perception of the residents in Yanbu.

2.1 Survey design

Questionnaires were sent to a selected population of Yanbu Industrial City to solicit responses on PV adoption. A survey questionnaire was developed to assess demographic information, knowledge about renewable energy, its applications and advantages, investment readiness, and its deterrent factors. These questions were short format and grouped by their similarities to make the questionnaire easier to respond to and make the respondent feel more comfortable answering the questions. The survey questionnaire was in English and Arabic to better understand the terminology to the local residents. Apart from gender, education levels, and family size, participants were grouped into five age groups: 20–25 years, 26–35 years, 36–45 years, 46–55 years, and 56 years old or higher. The residential was divided into four sub-categories; apartment, villas, townhouses, and others. Other categories include types of employment (government, private, own business, and others), income brackets (less than SAR 5000 to over SAR 25,000), and house ownership or provision. Additional background questions measure the participants' knowledge and the type of renewable energy they are familiar with. Details are shown in Table 1.

Specific questions were asked to understand better respondents' knowledge about renewable energy in general and solar PV rooftop in particular. These questions included why or why not they will install solar systems on their single-family home or the likelihood they will adopt this technology as a power source. The second group of questions was related to the participants' willingness to use environmentally friendly energy to replace fossil fuels, affordability, availability of this technology, and trust in the solar industry. To further understand the public attitudes and beliefs, participants were asked about the difficulties they encountered that prevented them from utilizing solar energy and prompted them to consider PV installation on their rooftops, such as renewable energy incentives and related government policies. It asked if they are waiting for a price reduction or technology improvements. If solar equipment's space requirement is a limiting factor for using solar energy was another question. A review of sitting issues, loss of aesthetic value concerns, or Not In My Backyard (NIMBY) was also part of the assessment. Details of these questions are shown in Table 2.

Table 1. Survey questionnaires Part A

Survey on public perception towards solar electrification (Solar PV) installation in residential buildings in Yanbu Alsinaiyah, Saudi Arabia

Part A Background information

Gender
a) Male
b) Female

Age
a) 20-25
b) 26-35
c) 36-45
d) 46-55
e) 55 and above

What is your highest education level?
a) Elementary school
b) High school
c) Diploma
d) Bachelor degree
e) Post graduate (Master or PhD)

What type of residence do you live in?
a) Apartment
b) Villa
c) Townhouse (attached units)
d) Others

What is your household size?
a) 1-3 persons
b) 4-6 persons
c) 7-10 persons
d) More than 10

What is your employment status?
a) Employed – Government sector
b) Employed - Private sector
c) Own Business
d) Others

What is the total household monthly income?
a) Under SAR 5,000
b) SAR 5,000 - 10,000
c) SAR 10,000 – 15,000
d) SAR 15,000 - 25,000
e) SAR 25,000 and above
f) Prefer not to answer

The residence I am living at the moment is..
a) Rented
b) Owned
c) Provided by employer

Select the terms you are familiar with;
a) Renewable energy
b) Solar Water Heater
c) Solar Photovoltaic
d) Energy efficiency
e) Greenhouse gases
f) None of above

Table 2. Survey questionnaires Part B

Survey on public perception towards solar electrification (Solar PV) installation in residential buildings in Yanbu Alsinaiyah, Saudi Arabia

Part B Perception, acceptance and deterrent factors

	Items	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagre
1	We should increase the use of solar energy					
2	Enough information is available on solar energy and its technologies					
3	Energy produced from solar energy can replace the use of fossil fuels					
4	Solar PV can reduce your electricity bills.					
5	I would be more interested in buying a home with solar PV installed					
6	Solar PV system can be installed on a building rooftops.					
7	Solar PV can help to improve the environment.					
8	I am willing to pay more for electricity coming from solar than from fossil fuels for environmental reason					
9	Solar energy can help improve the economy.					
10	Renewable energy is too costly for me to consider for my home					
11	Excess electricity from solar PV can be sold to electricity companies					
12	The government is encouraging the use of solar energy for houses					
13	There exist policy to support solar PV installation for residential buildings					
14	Financial incentives for solar PV installation are available					

If you are not likely to set up any Renewable Energy technology in your home, what would be the most probable reasons? Rank you answers (1 – most important, 7 – least important)

- They are unappealing /They would deface my property ☐
- Lack of space ☐
- The installations will be too costly ☐
- There no issue with the current electricity cost ☐
- Limited knowledge on how they work ☐
- Lack of knowledge about regulatory procedure ☐
- Other, please specify ☐

2.2 Sampling and data collection

Using Google Form application, this online survey was distributed through social network applications such as emails, Twitter, and WhatsApp to ensure that this survey reaches as many residents as possible [29, 30]. Online survey shows significant advantages over other formats to reach the maximum number of people [31, 32]. Data was collected between September and December 2019. The survey was distributed to Royal Commission staff, private companies' staff, and others mainly through official email, Twitter, and WhatsApp network.

It is important to ensure the sampling size is reliable for such a survey. According to the social survey method by Crano and Brewer, the minimum sampling size was determined by the following relation [33]:

$$n = \frac{Nn'}{N+n'} n = \frac{Nn'}{N+n'} \qquad \text{(Eq. 1)}$$

$$n' = \frac{p(1-p)}{(SE)^2} n' = \frac{p(1-p)}{(SE)^2} \qquad \text{(Eq. 2)}$$

Where,

n is the required sample size
N is the population size (the Yanbu Industrial City population in 2017 is 123,440)
n' is the first estimated sample
p is the estimated proportion to participants (assumed as 0.05 to gain maximum sample size)
SE is the standard error (assumed 2.5%)

Based on Eq. 1 and Eq. 2, the sample size required for this survey was calculated to be about 76 respondents. The number of participants completed the questionnaire survey is 134, twice the required value, thus ensuring the sampling size's reliability.

A Kruskal-Wallis test was applied to determine the difference in respondents' perception (dependent variable) on the deployment of rooftop solar photovoltaic electrification for residential buildings with regard to house ownership, education level, and income (independent variables). The possible scenarios of the adoption of renewable energy in the case study were evaluated and discussed.

3. Results and Discussion

A total of 134 participants responded to the survey, of which 120 (89%) are males, and the remaining are females (11%), as shown in Fig. 5. The range of the respondents' age is from 24 to 60 years old. They represent the working class of the local community. The majority of the respondents (35%) are in the age group between 46 and 55 years old. Almost 60% of them aged between 36 and 55 years old. The household size can be divided into three major groups; 44% have household occupants between 4 and 6 people, 33% between 1 and 3, and 22% between 7 and 10 people. A small percentage represents the household size of more than 10 people.

Fig. 6 shows the respondents' educational background, indicating 38% of the participants are qualified with post-graduate qualifications (Masters and Ph.D.), 35% with bachelor's degrees, and 15% with diplomas, while the remaining 12% with high school and elementary school certificates. The majority of the participants are with highest educational qualifications, while the minority only passed high school. The respondents were all adults and residents of Yanbu Industrial City.

Employment and housing information are shown in Fig. 7. Over eighty percent of these respondents are employed by either the government sector (50%) or private companies (33%), and 2% are business owners while the remaining 15% have other income sources. Out of the total, 36% live in housing provided by the employers. These houses are mainly villas (59%) and apartment (27%). The remaining 14% are townhouses and other types of residents. Of these, 73% (villa and townhouse residents) have rooftop spaces possible for PV installation. Only 85% of the respondents indicate their monthly income brackets, while the remaining 15% prefer not to disclose this information. About 15% of respondents received SAR 5000 less per month, 15% between SAR 5000 and SAR 10000, 16% between SAR 10000 and SAR 15000, 19% receive between SAR 15000 and SAR 25000, and the remaining 17% get more than SAR 25000. The distribution between salary groups is almost evenly represented among the participants.

The second set of questions in part A concerns respondent familiarity with energy efficiency, renewable energy, and environmental terms. As shown in Fig. 8, the respondents' most familiar term is "renewable energy," with 81 (60.45%) responses. This is followed by "energy efficiency" 75 (55.97%), and "solar water heater" 72 (53.73%). "Renewable energy" and Energy efficiency" terms are commonly used and discussed by the city's working community. "Solar water heater," on the other hand, has been installed in some residential buildings at the beginning of Yanbu Industrial City establishment, even though most of them are not in working condition for the last 10 to 15 years. The more scientific terms are less common amongst the participants; "solar photovoltaic" with 63 replies (47.01%) and "greenhouse gases" 46 replies (34.33%). These terms are more familiar amongst higher learning institutions staff and research personnel who constitute a significant portion of the survey respondents. Surprisingly, 20 respondents (14.92%) are not familiar with any of the terms listed, which may correlate to the fact that 12% of respondents are qualified with school certificates.

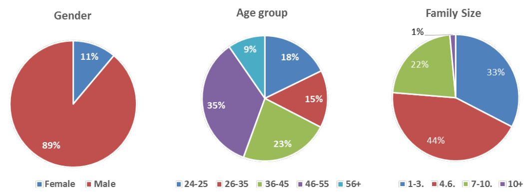

Fig. 5. Respondents basic information

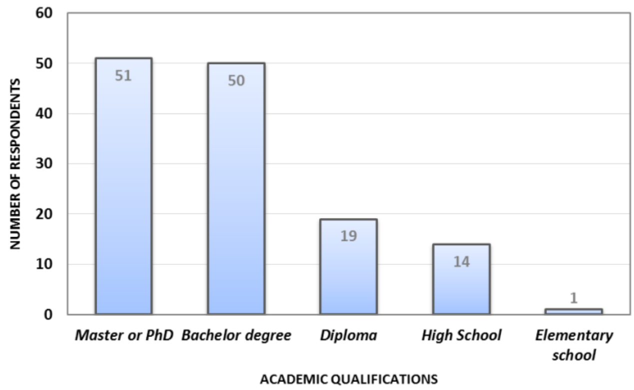

Fig. 6. Respondents education levels

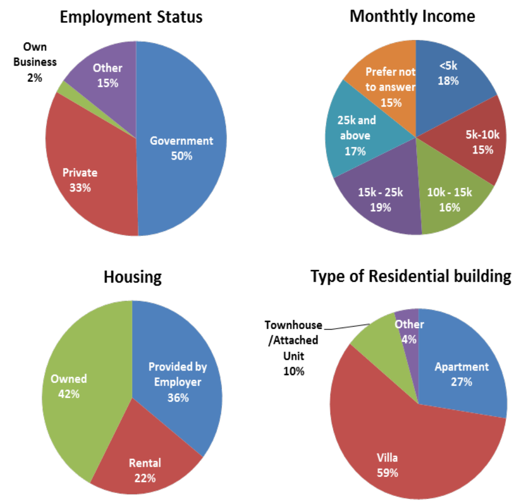

Fig. 7. Respondents employment and housing

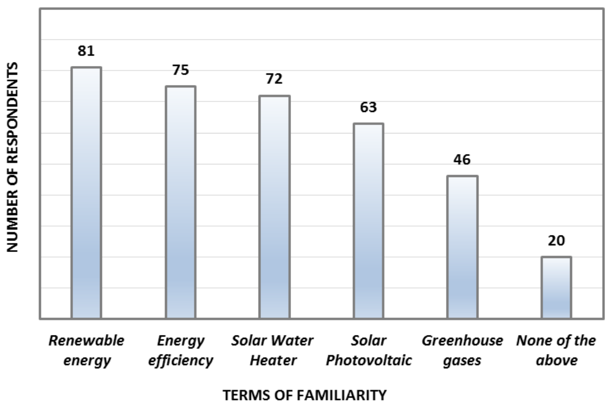

Fig. 8. Energy-related terms respondents are familiar with

In the second part of the survey, Part B, the aim was to understand barriers in adopting solar PV for the residential sector. As shown in Fig. 9, the survey identifies several barriers and various interrelated factors that are holding back the use of rooftop solar PV for electricity generation. Technical barriers, including lack of space, grid integration issues, and lack of knowledge, have been identified as the most significant challenges to adapt rooftop solar technology in Yanbu Industrial City. Social acceptance, market factors, economic and financing barriers such as high initial capital cost, long payback period, limiting financing opportunities, and aesthetic concerns are other significant barriers to implementing a rooftop solar energy system for Yanbu residents. Lack of a clear renewable energy policy, lack of standards, and regulatory barriers are also other key barriers to installing solar rooftops. The survey also revealed that significantly low fossil fuel prices in this region are probably the major challenges that could hinder solar rooftops' deployment. As shown in Fig. 9, according to the findings, the main barrier is satisfaction with the current electricity cost (15%). The electricity cost in the city as well as Saudi Arabia, in general, has been below the world average for a long time – USD 0.05/kWh compared to USD 0.14/kWh world average [34]. As discussed in the earlier section, almost six in ten (58%) of respondents do not own the building; they either live in residence provided by their employers as part of their employment or in rented properties. That is why they are very unlikely to be willing to invest in installing a solar electricity system on the rooftop of domestic properties.

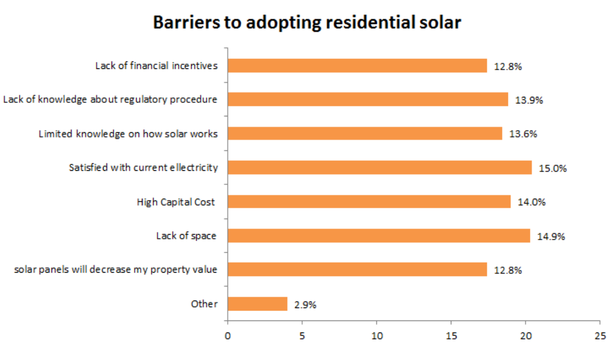

Fig. 9. Barriers to adopting solar rooftop system in Yanbu

The respondents' limited space usable for solar panels installation is the second most commonly mentioned (14.9%). The rooftop spaces are only available for those living in villas and townhouses, whereas residents of apartments would have to share the space. In order to fulfill the energy needs and get the return you expected on the investment, a certain size of available rooftop space allocated for solar panels is crucial. The average home in Saudi Arabia has around 125 to 175 square meters of roof space. While this is adequate space suitable for solar systems, most of the time, less than 50% of this space is available to use. Most of the residents use all or large proportions of the roof for different purposes, such as entertainment and social gathering.

Furthermore, most of the residential properties in Saudi Arabia have many installations on the roof that reduce available installation space to use for solar panels such as skylights, tall parapet walls (1 m), balustrades (1.8 m), air-conditioning units, secure staircase rooms, chimneys, TV aerials, satellite dishes, and water tanks [35]. If these objects are near the solar panels, they can cast a shadow and obstruct the sunlight that solar panels are entirely dependent on producing electricity. Also, the Saudi building code and National Electrical Code require 0.9 to 1.2 meters setbacks from each existing object as well as at least 2 meters wide access path for skylights and roof hatches. Hence, these items occupy a considerable roof area and dramatically reduce the available footprint space for a solar rooftop system. This doesn't consider the required row spacing to avoid inter-row shading nor consider nearby tall buildings, trees, or other objects that might cast shadow to the rooftop area, which further will be subtracted from the usable space.

Next, it is found that financial and economic barriers were the third most common concern among the responses. The questions that were asked by the participants include whether the high initial capital cost and lack of incentive are their concern and if these are the obstacles that are confronting the expansion of clean solar energy. About (14%) said upfront cost is a huge issue. Additionally, contributing to this issue, 12.8% of the respondents agree that inadequate government incentives and subsidies are important barriers for residential solar PV.

Although solar panels have positive impacts on residential and commercial buildings and can indeed increase the home's value by more than 4%, according to numerous studies [36], a significant portion of the response shows an opposite sentiment. Nearly 13% of the respondents expressed that installing solar PV on their houses can negatively impact the home's appearance, and as a consequence, could decrease the value of the house. Lastly, 13.6% of the participants believe that lack of knowledge and solar training is a significant barrier. It is one of the things that are holding back the implementation of rooftop solar energy systems for electricity generation in Yanbu, particularly and in Saudi Arabia in general.

The final part of the questionnaires' results is shown in Fig. 10 summarizes the opinions, attitudes, traits, and thoughts of individual respondents and their perspective on the topic of utilizing solar energy. There are 14 variables formed as a

Likert scale on a five-point scale, which is used to allow the participants to express how much they disagree or agree with a particular simple statement. The Likert scale that is used in this survey to measure each variable is strongly agree, agree, neutral, disagree, and strongly disagree.

The responses were processed and analyzed, showing that a large percentage of statements have a repetitive outcome of agreement or strong agreement. For instance, the majority of respondents with the highest percentage (>78%) chose strongly agree with several statements, such as whether we should adopt and increase the use of solar energy technologies and the possibility of installing solar PV on residential rooftops. Where solar energy has the potential to improve and provide substantial benefits to our environment and public health. This strong wide agreement was followed by those who choose to agree, while very few choose neutral.

Moreover, more than half (>51%) of those surveyed strongly agree that solar renewable energy has important attractive economic benefits, including the potential of reducing electric bills by selling the excess power generated to the utility company. The second option is those who choose to agree, while neutral is the third-ranking option. Solar does not only save money for you but also may generate an income for you. The survey results showed that a good number of respondents believe that it's a magnificent idea to install solar panels or buy a house with solar PV power already installed. The majority also agree that the government is doing its part by initiating, fostering, and spurring these emerging renewable technologies.

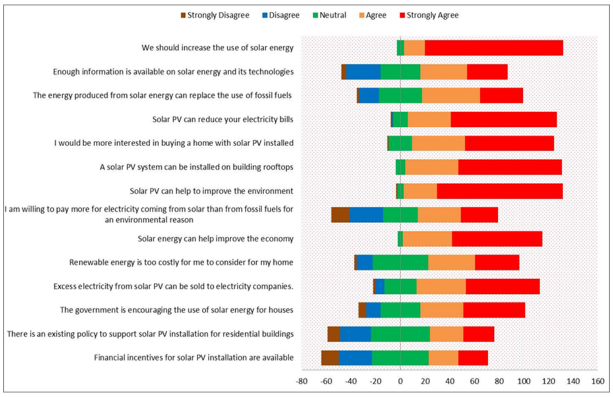

Fig. 10. Miscellaneous perceptions towards solar and renewable energy usage and benefit

Based on the survey, there was also considerable support among the participants for the view that energy produced from solar panels with the help of other renewable energy sources has the potential to supply a significant amount of power and can effectively replace the nonrenewable fossil fuels. Although about a little over (30%) chose neutral, there is also a comprehensive agreement that solar electricity is expensive. Likewise, in the statements of whether enough information is available on solar energy and its technology, the highest percentage (28%) chose neutral, followed by the agreed option. In contrast, the fewest individuals chose to disagree and strongly disagree.

On the other hand, the survey showed a mixed perception of many issues. A high percentage can see these respondents choosing disagreement options. The first issue is whether there are any incentives for solar that you can take advantage of and whether there is an existing national policy supporting developing solar PV. For these questions, the respondents may or may not have enough information to answer. However, the highest respondents chose somewhat (neutral), followed by disagreeing, agree, and strongly agree, while the least chose strongly disagree. Secondly, the availability of financial incentives to assist the new installation issue has as many as neutral standing and the first issue has more negative responses. This is well understood because there is no clear information on this issue as the solar energy installation initiatives in this country are more focused on large-scale power plant establishment. The third issue with significant disagreement is the willingness to invest in solar energy installation for an environmental reason. It shows that even realizing that solar energy has tremendous benefits to the environment, the lack of supportive national policy and financial incentive ceases people's readiness to invest in this renewable energy installation.

The results of the Kruskal-Wallis test indicated that house non-owners and house owners are found significantly different in their perception of the cost of renewable energy (Chi square=3.965, P value=0.04646). The summary of these can be found in Table 3 and Table 4. Respondents with bachelor's, diploma, and lower certificates are found significantly different in their willingness to buy a home with solar PV installed than those with post-graduate degrees (Chi square=8.119, P value=.01725). Similarly, the groups are also significantly different in their perception of renewable energy cost (Chi square=7.567, P value=.02274). High income and low-income groups are found significantly different from high-middle class and low-middle class groups on renewable energy cost as too high to consider for their home (Chi square=9.099, P value=.028). The box plots show further details of the results (including medians and percentiles) in Fig. 11, Fig. 12, Fig. 13, and Fig. 14.

Table 3. Kruskal-Wallis test result

	Kruskal-Wallis chi-squared	**df**	**p-value**
House Ownership –Overall Perception on PV	4.1101	1	0.04263
Education Level –Overall Perception on PV	9.2071	2	01002
Income –Overall Perception on PV	2.2116	3	0.5297

Table 4. Kruskal-Wallis test result

Variables	**Kruskal-Wallis chi-squared**	**df**	**p-value**
House Ownership-Solar PV can reduce your electricity bills	1.7085	1	0.1912

House Ownership-I would be more interested in buying a home with solar PV installed	1.5366	1	0.2151
House Ownership-Solar PV can help to improve the environment	0.80176	1	0.3706
House Ownership -I am willing to pay more for electricity coming from solar than from fossil fuels for environmental reason	1.3549	1	0.2444
House Ownership -Renewable energy is too costly for me to consider for my home	3.965	1	0.04646
House Ownership -Excess electricity from solar PV can be sold to electricity companies	0.93965	1	0.3324
Education Level- Solar PV can reduce your electricity bills	3.7297	2	0.1549
Education Level – I would be more interested in buying a home with solar PV installed	8.1195	2	0.01725
Education Level -Solar PV can help to improve the environment	2.1662	2	0.3386
Education Level- I am willing to pay more for electricity coming from solar than from fossil fuels for environmental reason	3.0674	2	0.2157
Education Level -Renewable energy is too costly for me to consider for my home	7.5674	2	0.02274
Education Level -Excess electricity from solar PV can be sold to electricity companies	1.1187	2	0.5716
Income- Solar PV can reduce your electricity bills	2.2799	3	0.5164
Income -I would be more interested in buying a home with solar PV installed	4.2773	3	0.233
Income -Solar PV can help to improve the environment	1.8918	3	0.5952
Income - I am willing to pay more for electricity coming from solar than from fossil fuels for environmental reason	2.3745	3	0.4984
Income - Renewable energy is too costly for me to consider for my home	9.0995	3	0.028
Income - Excess electricity from solar PV can be sold to electricity companies	1.3386	3	0.72

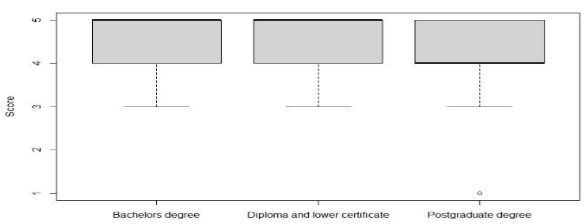

Fig. 11. Scores of the responses to the question on interest in buying a home with solar PV

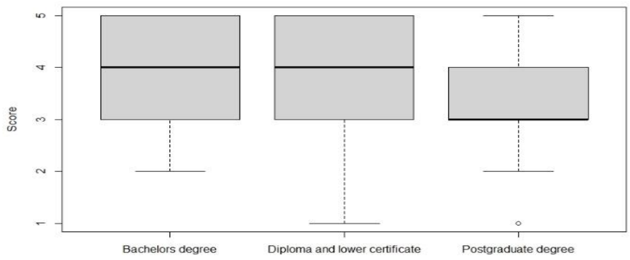

Fig. 12. Scores of the responses to the question on renewable energy being too costly (Education background)

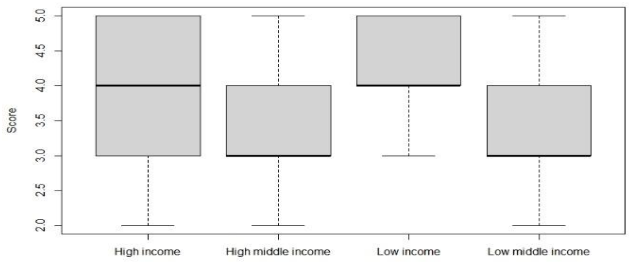

Fig. 13. Scores of the responses to the question on renewable energy being too costly (Income level)

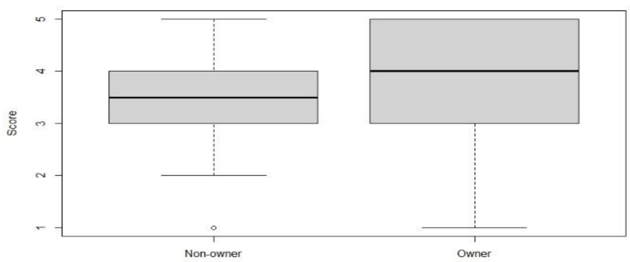

Fig. 14. Scores of the responses to the question on renewable energy being too costly (Homeownership)

4. Case scenario

As of the end of 2019, roughly 634 MW of solar photovoltaic had been installed in Saudi Arabia. Around 98% of this cumulative installed capacity comes from large utility-scale installations with greater than 2 MW, while solar rooftops represented just less than 2%. This is much lower than the developed countries' where more initiatives are taken to solarize every household with a rooftop solar PV system. As Fig. 15 illustrates, many countries have made incredible development in utility-scale and distributed-scale solar generation despite most of them receiving way less solar radiation than Saudi Arabia. Saudi Arabia's solar power generation represents an insignificant fraction of the country's current energy mix and the worldwide installed capacity even though the environmental performance of a PV array in Saudi Arabia is remarkable and acknowledged. For example, typical rooftop solar PV has a less than 2-year energy payback, meaning they have produced enough energy in 2 years to offset the energy required to extract and process raw materials, finish manufacturing products, and transport products to the site. Given the more intense sunlight in the region but the added manufacturing effort for the power electronics and Balance of System (BoS), it probably is reasonable to assume the 2-year energy payback is valid for the entire system deployed in the sunnier regions of Saudi Arabia. From the financial point of view, the rooftop systems' financial performance depends primarily on the utility's cost of power, the electric household consumption, and of course, the initial purchase price of the PV equipment. Few scenarios were evaluated in this study.

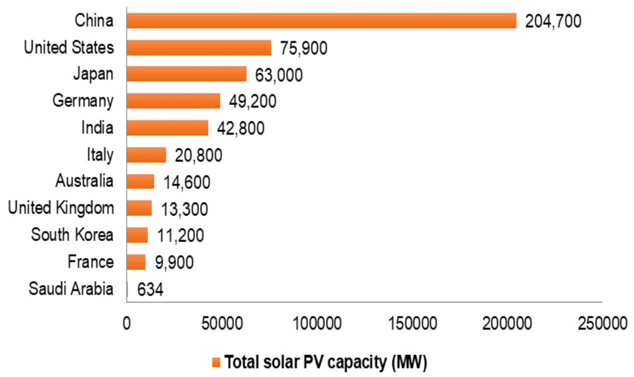

Fig. 15. Saudi Arabia's total solar PV capacity in comparison to other economies

Although the pricing still varies considerably based on the size of the purchase, as Table 5 indicates, and the installation location, the pricing for PV equipment has dropped significantly over the last several years [37]. It is also expected to drop furthermore over the next few years due to PV cells' performance enhancement and technology advances. In the Kingdom, electricity tariffs were increased in the last few years. Currently, the rates are 0.18 SAR/kWh or USUSD0.048 for the first 6,000 kWh consumed and SAR0.30/kWh or USD0.08/kWh for any following kWh consumed according to the Council of Ministers' decree dated 12/12/2017. This electricity price further increased when 15% of the value-added tax was introduced on July 1, 2020. The average consumption of electricity in the western region of Saudi Arabia is 2,300 to 3000 kWh per household per month.

On the other hand, the sale price of surplus energy from residential solar rooftops was set by Electricity and Co-generation Regulatory Authority (ECRA) to SAR0.07/kWh or USD0.019/kWh. Installing a solar rooftop for this scenario that offsets 100% of the energy usage will result in a 14-year straight-line payback, as Fig. 16 depicted and a Levelized Cost of Energy (LCoE) of about USD0.065/kWh. Besides, the system owner will be paying more for PV electricity for the first eight years and then less than utility rates for the rest of the system's 25 to 30 years life expectancy.

Considering another scenario where utility electricity cost is USD0.10/kWh or the sale price of PV surplus energy increases to SAR0.14/kWh. The owner will save money, and the payback will be less than six years, and the cost of PV electricity is significantly lower than the utility starting from day one. So it is clear that the financial viability of a residential PV rooftop installation, as well as a PV industry for Saudi Arabia, is almost completely based on the real cost of electricity created by burning bunker oil and the price of the surplus energy. This analysis ignores the environmental benefits of PV-based electricity and ecological lifestyle, as well as the marketing and public relations advantages.

Table 5. Solar PV system purchase estimate

Component	Approximate System Size (DC STC)			
	<100 kW	500 kW	1 MW	>10 MW
	Cost in USD			
Modules	0.75	0.56	0.49	0.34
Inverters	0.23	0.17	0.15	0.11
Racking (roof)	0.23	0.17	0.11	0.08
Balance of Materials (BOM)	0.08	0.06	0.04	0.02
Monitoring System	0.08	0.06	0.04	0.02
VAT	0.22	0.15	0.12	0.08
Labor	0.45	0.38	0.30	0.23
Direct Cost Estimate	2.02	1.54	1.25	0.87
EPC	50%	30%	20%	10%
	1.1 /W	0.45 /W	0.25 /W	0.09 /W
Total Estimate	3.03 /W	2.00 /W	1.50 /W	0.96 /W

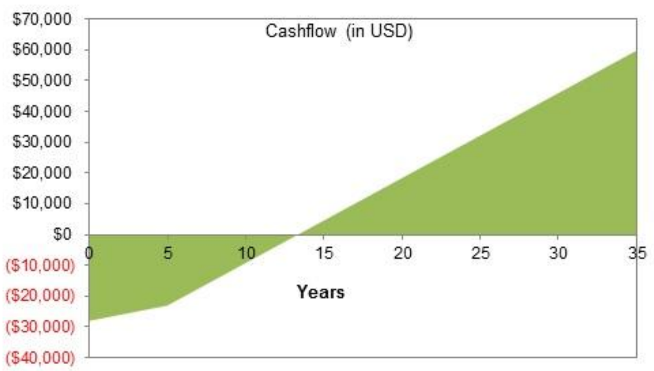

Fig. 16. Annual Accrued Cash Flow (Cash Balance)

5. Conclusion

The study on public perception towards rooftop solar PV deployment in the residential sector in Yanbu Industrial City, Saudi Arabia, was carried out, and results were analyzed and cross-related. A total of 134 population sample participated in this survey with evenly distributed income groups, high education levels, 50% homeowners, and 70% of these owners have sufficient rooftop space that can be installed solar system, and the following conclusions were derived:

1. Almost all respondents have a positive attitude towards rooftop photovoltaic installation. Even though none of the respondents have installed solar panels on their rooftops, a considerable number of the respondents, especially the homeowners, were interested in installing solar PV, or at least they have given serious thought to use solar PV to power their homes.

2. The majority of the respondents are aware that solar PV can reduce their overall electricity expenses plus its enormous advantage of less negative impact on the environment. They also perceive that the traditional power source is responsible for greenhouse gas emissions and other hazardous wastes. Thus, respondents' interest in solar PV reflects both financial benefits and environmental concerns.

3. However, it was found that the rooftop solar PV application is hampered by multiple barriers to adoption in the Kingdom of Saudi Arabia, according to the respondents. The main reason is the low cost of electricity, which is due to highly government subsidized. Some of the other socio-technical barriers that respondents showed they are concerned is lack of information, lack of knowledge, required space of solar panels, and the solar intermittent energy source.

4. The respondents also recognized several economic challenges that mainly pertain to initial system capital cost, lack of national renewable energy portfolio (RPS), lack of direct subsidies, and other favorable financial facilitation or government incentives.

5. Also, the survey data highlighted that government policies are crucial to the success of rooftop solar growth. Those essential policies that can provide substantial financial benefits and can significantly boost the usage of solar rooftop include establishing of Net Metering scheme and Feed-in tariffs policies. The net metering system allows the solar owners to sell the excess electricity they generate from their rooftop solar systems to the grid.The conclusion section should emphasize the main contribution of the article to literature. Authors may also explain why the work is important, what are the novelties or possible applications and extensions. Do not replicate the abstract or sentences given in the main text as the conclusion.

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