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Feasibility Study of Air Conditioners Operated by Solar Energy in Saudi Arabia

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Abstract—Solar energy has become currently the subject of attention around the world and is undergoing many researches and studies. Using solar energy, which is a renewable energy, is aligned with the Saudi Vision 2030. People are more aware of it and are starting to use it more for environmental and economical reasons. A questionnaire was conducted in this paper to measure the awareness of people in Saudi Arabia regarding solar energy and their attitude towards it. Then, two kinds of air conditioners (one powered by electricity only and one powered by solar panels and electricity) are compared in terms of their cost over a period of 20 years. This will help the users to decide which kind of device to use depending on its cost. The result shows that as the electricity tariffs in Saudi Arabia increases, depending on the sector, the solar air conditioner is cheaper. In fact, if the tariff in the future increases to reach 50 Halalah/kWh, the solar air conditioner is more economical. This will influence users to buy more solar powered devices, and it will decrease the consumption of electricity. Therefore, the dependence on oil will decrease.

Keywords—Air conditioner, solar energy, photovoltaic cells, present value.

I. Introduction

THERE has been a search for other alternative sources of energy different from oil for many reasons, such as the high price of oil and the fact that oil is not renewable. Therefore, the renewable energy such as the solar energy has received a great attention from governments, companies and researchers. As a result, many agreements have been signed as well as research and studies conducted for the solar energy.

The high rate of population and economic growth in Saudi Arabia result in high-energy consumption. In order to conserve existing resources such as oil and gas, Saudi Arabia has made the decision to use renewable energy resources. Therefore, the government initiated the National Renewable Energy Program (NREP) under the Saudi Vision 2030 and the King Salman Renewable Energy Initiative. The program aims to maximize the potential of renewable energy in Saudi Arabia [1]. King Abdullah City for Atomic and Renewable Energy (KACARE) was established in 2010 and its head quartered is in Riyadh. It announced the implementation of a national project aimed at measuring and mapping renewable energy resources in Saudi Arabia. Through KACARE, Saudi Arabia seeks to develop a system of sustainable renewable atomic energy to produce electricity [2].

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Regarding generating sufficient energy for the lives of neighborhoods and cities, some challenges and difficulties are encountered, for example, solar cells are fragile and are often protected by placing a glass layer over them, but remain sensitive to weather factors. Dust is one of the most important problems that affect the use of solar energy because it reduces its efficiency [3] and may disrupt it completely. This happens especially in the desert areas, which are best suited to exploit the glare of the abundant continuous sun. The design of solar power stations is an engineering challenge because they must be set up in open areas not surrounded by any buildings or high terrain that shadow on the panels during the day. The problem is also the photoelectric system, which depends entirely on the sun. Which means that there is no energy produced during the night. To create a balanced energy system using solar panels during the day and night, it is necessary to provide a type of energy storage systems during the day for night consumption. This problem also applies to the means of transport that are intended to run on solar energy.

Mathematical modeling facilitates many tasks, as studies may be done on devices available in the market using equations and mathematical programs such as MATLAB, to compare them in terms of price and quality. It also allows us to test multiple cases and know the result without wasting time, effort and money. Therefore, there have been many studies regarding mathematical modeling of solar energy, in particular photovoltaic (PV) cells [4]–[9]. In particular, [9] studied the effect the impact of environmental conditions, which include varying the temperature, solar irradiation. The operating temperature increase leads to a decrease in the power output. On the other hand, the greater the irradiation the greater the energy, which give the maximum power.

Mathematical modeling is also used to compare the efficiency of solar powered devices in terms of the price. Equations provide the ability to compare the cost of a regular devise with a one powered by PV cells and electricity. The result depend on the electricity tariffs, cost of the devices. The study is applied to the prices is Saudi Arabia. The break-even point and the future value of both devices will be compared to decide which one is more economical in the long run. The result of this study helps the user decide whether to buy solar powered product or not depending on the cost.

In the second section, a questionnaire will be presented for a random sample of the community regarding solar energy. Then, in Section III, a comparison of a partially solar-powered air conditioner is compared with a regular one to find which one is economical in the long run. Finally, the conclusion is in Section IV.

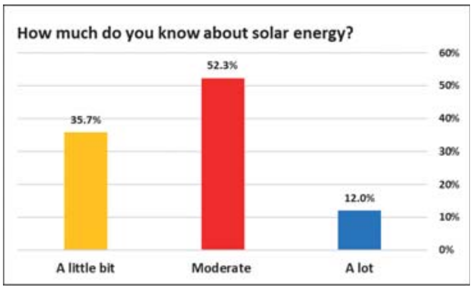

Fig. 1 Responses for the first question in the questionnaire

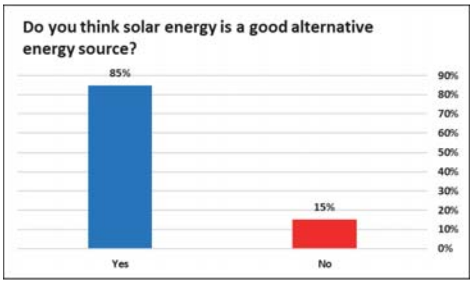

Fig. 2 Responses for the second question in the questionnaire

II. A Questionnaire

This questionnaire has been conducted with 1000 random participants in Saudi Arabia to measure the awareness of people towards the importance of the solar energy and its future. Fig. 1 represents the responses of the participants regarding the knowledge about solar energy. The figure shows that 52.3% has a medium knowledge while 35.7% has a little bit of knowledge, and 12% has a lot of knowledge. Also, it was found that 15% believed that solar energy is not a good alternative to the current energy used, while the rest (85%) believed that it is a good alternative as shown in Fig. 2. The survey also shows that 26% has purchased a solar-powered product previously while the remaining did not as shown in Fig. 3. Some 83% of respondents expressed their opinion that they will use solar energy, if the electricity tariff is increased, while 17% will not use it as shown in Fig. 4. Regarding whether solar energy is economical in the long run or not, the majority of the sample (92.5%) chose yes while the rest did not believe that as shown in Fig. 5. Finally, in line with the Saudi Vision 2030, 92% predicted that the use of solar energy would contribute to it as shown in Fig. 6. In conclusion, from this questionnaire, it was found that the community began to realize the importance of solar energy and believes that it is a good alternative to the energy currently used.

III. Comparison between the Cost of Regular and Solar Air Conditioners

In this section, a comparison between the cost of a regular air conditioner (AC) powered by electricity only and an AC powered by electricity and solar panels (solar AC) is introduced. This will be done to know which is more economical over a period of 20 years. The present value formula and a linear function will be used. First, the equation of the present value of the annuity, cooling capacity, and

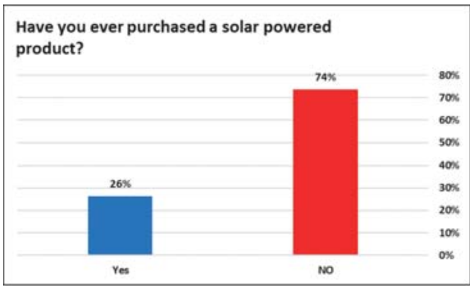

Fig. 3 Responses for the third question in the questionnaire

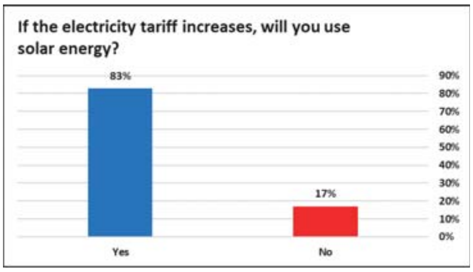

Fig. 4 Responses for the fourth question in the questionnaire.

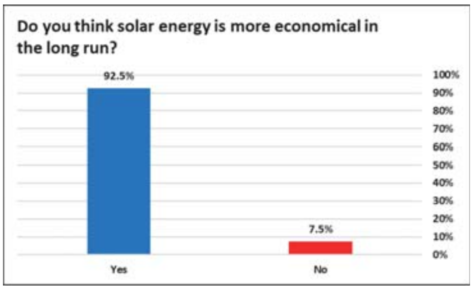

Fig. 5 Responses for the fifth question in the questionnaire

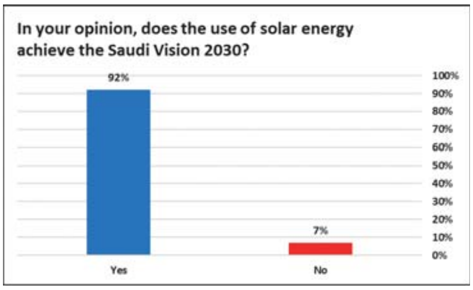

Fig. 6 Responses for the sixth question in the questionnaire

the electricity tariffs from the Saudi Electricity Company are given.

The present value of an annuity is the amount that should be deposited in one lump sum today (at the same compound interest rate) to produce exactly the same balance at the end of n years [10]. The present value P of an annuity for n years, where R is the annual payment and i is the annual interest rate is

$$P = R\left[\frac{1-(1+i)^{-n}}{i}\right]. \quad (1)$$

Cooling Capacity is measured as the number of British Thermal Units (BTUs) per hour of heat that the unit can

TABLE I
COOLING CAPACITY OF THE INDICATED ROOM SIZE

Room size (square meter)	AC capacity (ton)
14	1
23	1.5
37	2
70	3.5

Note that the value for the room with size 70 m^2 is estimated based on the previous values.

remove from the air. A BTU is the amount of heat required to raise 1 pound of water by 1° Fahrenheit. [11]. The cooling capacity is also measured in ton (one ton equals 12,000 BTUh). Table I shows the cooling capacity in tons for different sizes of rooms [12].

The cost of a regular AC and a solar AC (both are 3.5ton) for a period of 20 years will be compared by two methods: present value and linear function, to know which is more economical. Note that, 20 years is chosen because the life span of a solar panel is about 20 years [13]. The present value is calculated by using 1, where the interest rate i is 5% and $n = 20$ years. R is the annual invoice of the AC. For the regular AC: the annual invoice is the multiplication of the daily consumption, 365, and the electricity tariff from Table II. The latter will depend on the category. Note that a new category is added, which represents an increase in the tariff to reach 50 Halalah/kWh as given in Table III. This might happen in the future to encourage people to use solar energy more and reduce the consumption of electricity. If the daily use of the AC is 18 hours and the actual consumption of the AC is 3.5 kWh per hour for a 3.5 ton AC [14], then the daily consumption is equal to 18×3.5. Therefore, for the regular AC, the annual invoices $R = 18 \times 3.5 \times 365 \times$tariff. On the other hand, the solar AC will be partially powered by 12 solar panels each producing 0.3 kW. If the peak sunlight hours per day is 5.5 hours [15], then each day the panels production is $12 \times 5.5 \times 0.3$. Therefore, the annual invoice of the solar AC will be the difference between the daily consumption and the daily production of the solar panels multiplied by 365 and the tariff ($R = (18 \times 3.5 - 5.5 \times 12 \times 0.3) \times 365 \times$tariff). Thus, after calculating the annual invoice, Eq. 1 is used to find the present value for a period of 20 years for six different categories of electricity tariffs as in Table III. The result is given in Table IV. Note that, the cost of buying each AC is added to the present value in this table, where the regular AC cost about 6600 SR and the solar AC cost about 9596 SR plus the cost of the 12 solar panels which is 12000 SR.

Now a comparison between the two ACs will be done by a simple linear equation for the total cost C for the AC over a period of 20 years: $C = Rn + b$. Here R is the annual invoice, n is the years, and b is the price of the AC. This equation adds the cost of buying the AC to the annual electricity invoice over 20 years. Note that the annual invoice and the cost of the AC are the same as the previous comparison. The importance of this equation is that it calculates the break-even point for six categories of electricity tariffs from Table III. The break-even

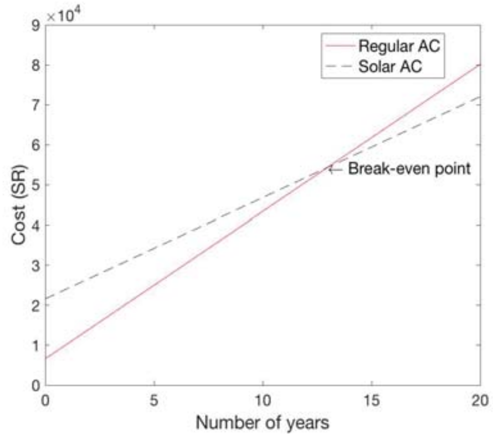

Fig. 7 For 16 Halalah/kWh the break-even point is at approximately 13 years. This means that the cost of both ACs is the same and after 13 years the solar AC will be cheaper (the annual electricity invoice is cheaper)

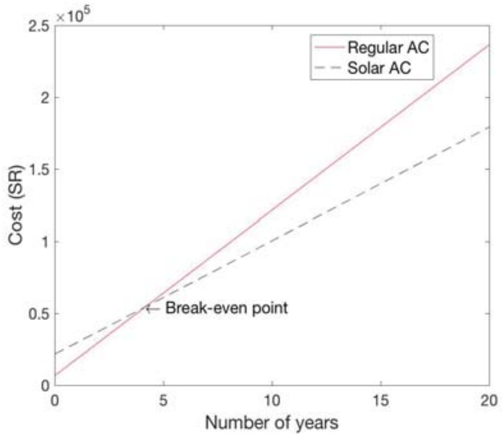

Fig. 8 For 50 Halalah/kWh, the break-even point is at approximately 4 years

point indicates which year both ACs cost the same amount of money. Then, after this year, the solar AC costs less than the regular AC. Figs. 7 and 8 represent the linear function for the two ACs for category 1 and category 6, respectively. As the tariff increases, the break-even point decreases; and thus it is cheaper to buy a solar AC.

Table IV shows the results of each category for the regular and solar ACs. The present value of the solar AC is less than the regular AC in general. The difference between them increases when the electricity tariff increases. Also, the break-even point decreases as the electricity tariff increases. This shows that if the electricity tariff increases more people might buy solar ACs as it is cheaper than regular AC. However, the current electricity tariffs might not encourage people to switch to solar energy specially the residential sector that uses less than 6000 kWh per month. The table shows that the break-even point is about 12 years. This might not be worth switching to a solar device.

IV. CONCLUSION

In this paper, the cost of a solar powered device and its impact on the future is studied. We surveyed a random sample

TABLE II
CONSUMPTION TARIFFS IN SAUDI ARABIA APPLIED FROM 1/1/2018 [16]

Consumption categories (kWh)	Residential (Halalah/kWh)	Commercial (Halalah/ kWh)	Agricultural and charities (Halalah/kWh)	Governmental (Halalah/kWh)	Industrial, private educational facilities, and private medical facilities (Halalah/ kWh)
1-6000	18	20	16	32	18
More than 6000	30	30	20		

TABLE III
THE SIX CATEGORIES OF ELECTRICITY TARIFFS

Categories	Electricity tariffs (Halalah/kWh)
1	16
2	18
3	20
4	30
5	32
6	50

Refer to Table II regarding the corresponding sector for each category. Category 6 represents an increase in the tariff to reach 50 Halalah/kWh.

TABLE IV
RESULTS FOR EACH CATEGORY

Present value (approximately)			Linear function
Category	Regular AC	Solar AC	Break-even point (approximately)
1	52451 SR	53037 SR	13 years
2	58182 SR	56967 SR	12 years
3	63914 SR	60897 SR	10 years
4	92571 SR	80547 SR	7 years
5	98302 SR	84477 SR	6 years
6	149884 SR	119848 SR	4 years

of the community, which showed that they are aware of the importance of solar energy and willing to switch to solar devices in the future. The other part of this study consists of the comparison of two types of air conditioners (regular and solar) in terms of their cost. The aim was to know which one is more economical over the period of 20 years (approximately the life span of the AC and solar panels). The results show that if the electricity tariff is 30 Halalah/kWh or more, the solar AC is cheaper as the break-even point is about 7 years or less. Thus, the residential (which uses more than 6000 kWh per month), commercial, and governmental sectors will benefit from using a solar AC. Another important result is that increasing the electricity tariff in the future will lead the consumers from all sectors to use solar energy more and reduce the dependence on electricity. This will reduce the consumption of petrol; and this is in alignment with the Saudi Vision 2030. In addition to this, as the demand on solar devices increase, the prices will be more competitive. This study is applied to the current prices of the ACs, solar panels, and electricity tariffs in Saudi Arabia and it can be applied to any other case as the calculations are provided.

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