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Assessing the Efficiency of Photovoltaic Panel Implementation in Riyadh's Residential Sector through Life Cycle Cost Analysis

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Abstract In recent decades, Saudi Arabia has seen remarkable growth, bringing along a wave of new opportunities. This surge has led to a population boom in major cities, driving up the demand for energy across the Kingdom. In line with its Vision 2030 plan, which aims for a more diverse economy and society, Saudi Arabia is keen on reducing its reliance on fossil fuels at home. And with plenty of local resources available, the idea of making our own solar components seems quite doable. But with more people using more energy, especially in homes where air conditioning is a big part of our lives, we need to find smarter ways to power our homes. Solar panels seem promising, but we're not sure if they're actually more cost-effective than our current electricity sources. So, we're embarking on a study to figure that out. We're going to compare the costs of using solar panels versus traditional electricity in Riyadh. We'll be looking at two similar residential buildings, considering things like their construction, size, and how much electricity they use. One of these buildings will get fitted with solar panels, while the other will stick to regular electricity. Then, we'll crunch the numbers and see which one ends up costing less over time. If solar panels turn out to be the cheaper option, it could be a game-changer, encouraging more people to go solar and make our energy consumption a bit greener.

Keywords Life Cycle Cost, life cycle Assessment, Building, Construction, Solar Energy, Self-manufacturing

1. Introduction

Saudi Arabia has undergone tremendous growth the last few decades, and with this growth comes new opportunities. And as a result, the population of its major cities has increased in population which is one of the major factors that has led to the rise in energy consumption in the Kingdom (Algarni & Nutter, 2013; Al-Surf et al., 2021). Therefore, as it works toward achieving a variety of economic and social goals under its Vision 2030 plan, Saudi Arabia aims to lessen its domestic dependency on fossil fuels. Due to the local accessibility of the majority of the raw materials, the goal of being self-sufficient in the production of solar components may be feasible (AlOtaibi & others, 2020). Since the residential sector consumes almost 49% of total electrical energy use, reducing it would be undoubtedly beneficial (Alardhi et al., 2022), and a significant portion of the electricity used by Saudi households is attributed to air conditioning that often exceeds 65% of the annual energy consumed by a non-insulated villa located in Riyadh (Krarti& others, 2020). Solar Panel systems have been shown to be effective, however, their economic value compared to current electrical sources in Saudi Arabia is unknown. The aim of this study is to compare the cost efficiency of solar panel systems compared to current electrical sources in Riyadh of the Kingdom. The research is applying an experimental method utilizing LCSA to measure the effectiveness of solar panels on the life cycle cost of the building. Starting by choosing two similar residential buildings in terms of (building type, construction materials, insulation, area of the building, number of occupants, average of electricity consumption). Solar panels are applied to one of the buildings. A life cycle assessment will be held to compare the cost of each building over the long term. If the study finds that the use of solar systems in the long run costs less than the current electrical source, as expected, this will motivate the residential consumer to use solar systems as a source of energy.

As the globe transitions from its reliance on fossil fuels to sustainable energy systems, renewable energy sources have been receiving more attention on a worldwide scale (AlOtaibi et al., 2020). As the energy savings of primary energy sources have increased by 19% between 2020 and 2021, the statistics also show an increase in electrical consumption, which is an increase of 1.42% on an individual level between the years 2022 and 2021. Specifically, .92% for the Residential Sector, 9.91% for the Commercial Sector and 5.19% for the Government Sector (Al-Sakkaf et al. 2021).

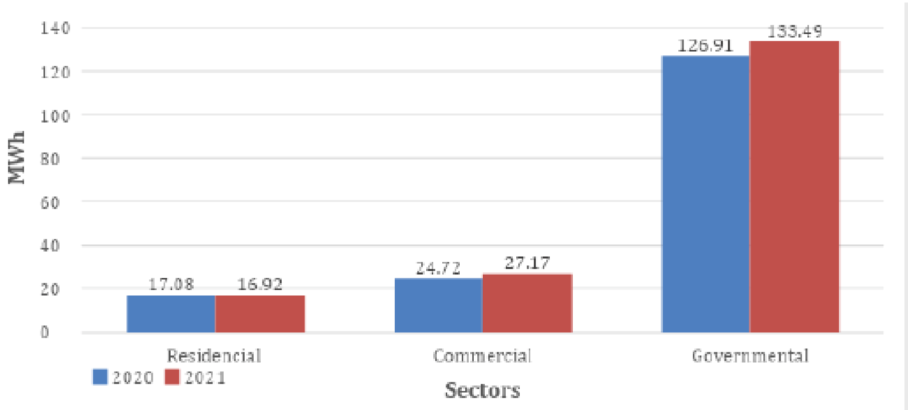

Figure 1: Electrical consumption statistics by individual (2021)

Due to the rapid growth of population, the need for clean, renewable energy substitutions is at an all-time high. And this is what motivated the kingdom to initiate innovative projects that aim to find multiple sources of renewable energy sources, for example, solar energy and wind energy (Al-Sakkaf et al. 2021).

Studies show that the percentage of homes connected to some kind of sources of electricity in the Kingdom is 99.9% where 98.4% of these connections are connected to the public network, 1.05% to a private network, .35% to a solar energy.13 are not connected to anything, and 12% from private generators (Al-Sakkaf et al. 2022).

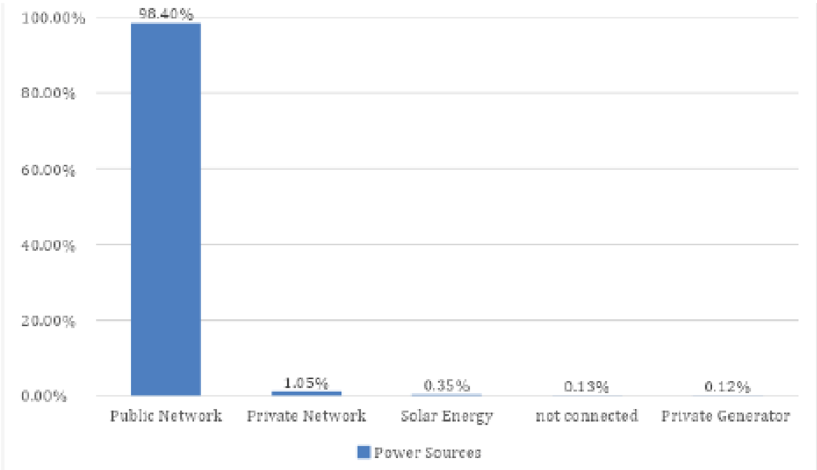

Figure 2: Interest families in electricity conservation in Saudi Arabia (2022).

Studies also show that families in Saudi Arabia have shown an increase interest in electricity conservation and this increase is about 39% between 2021 and 2022, while the percentage of families that actually apply energy conservation instructions in using electrical appliances have reached up to 86% (Al-Sakkaf et al. 2021).

In Saudi Arabia, 50% of energy consumed is attributed to the residential sector. A building stock model by (Krarti et al. 2020) has been represented for electricity used during 2018 in the residential sector shows that cooling has most of the total electricity use in houses (66%).

Regarding this issue, the Saudi government has set a target by 2030 to generate 58.7 GW of renewable energy benefitting from the potentials of solar and wind power (AlOtaibi et al. 2020). Solar energy is the most plentiful renewable energy source in the world which makes the current trend toward increasing utilization of it (Toosi et al. 2018). The ultimate objective of energy efficiency is to lower energy use while maintaining occupant comfort. In terms of sustainable development, cutting back on energy consumption also improves a building's economic performance and reduces operating expenses for building maintenance (Moesel, 2023). The advantages of leveraging solar energy are numerous, for example, minimizing the reliance on non-renewable sources of energy, improving air quality by reducing the spread of toxins in the air. Increase economic value by reducing electrical consumption, and last but not least, it provides alternative options for energy sources (Al-Sakkaf et al. 2021).

PV cells (also known as solar cells) can convert solar energy directly into electrical energy. These panels are an excellent choice for replacing fossil fuels in the production of electricity because they emit almost no pollutants while they are in use. Due to the sharp decline in photovoltaic cell charges and the increased demand for renewable energy sources worldwide in recent decades, interest in this technology has been rekindled (Muteri et al. 2020). Building surfaces, such as roofs or facades, can be fitted with PV systems that concurrently generate electricity while serving other structural needs. This combination can result in cost reductions when compared to large-scale PV power plants. The cost of the cladding could be the same at the price of the PV modules, particularly with costly facade systems (Hadi & Heidari, 2021). More focus is being put on the life cycle of buildings, which includes a calculation of the potential environmental effects and resource use of structures. Environmental impact of buildings is becoming more widely acknowledged, and assessment techniques are becoming more widely accessible (Nwodo, 2019). Regarding this study, life cycle cost assessment can determine the efficiency of PV cells by analyzing the cost of energy payback time compared to current consumption of electricity. The aim of this study is to investigate the cost efficiency of solar panel systems compared to current electrical sources in the residential sector in Riyadh City through life cycle cost assessment (LCCA) of PV panels. The study starts by filtering 34 references, and it is conducted by the following objectives:

a) Identify the average electricity consumption per person for the residential sector in Riyadh City.
b) Identify and estimate the LCCA of PV panels applied to the case study building -a villa in Riyadh City.
c) Identify the impact of PV panels on the environment.
d) Conduct a comparative analysis to determine the efficiency of utilizing PV panels in Riyadh City, especially for residential buildings.

Literature Review

Although the kingdom of Saudi Arabia heavily relies on oil and fossil fuels as energy sources, it is experiencing the need for a shift in this mindset due to the population growth and economic development, especially in the last two decades. And with this growth and new modern lifestyle, the kingdom has witnessed an annual increase of 7% in fuel consumption in the years between 2006-2016 which sparked a governmental initiative to reverse the country’s dependence on a single source of energy. And among the many different technologies that generate renewable energy, Solar Photovoltaic (PV) is one of the most successful (Alghamdi, 2019; Asif et al., 2019).

Influencing Factors

Studies have shown that there are a few factors that influence the performance of the PV panels. These factors are panel orientation and title, dust accumulation, temperature, and last but not least the Location on which the system is installed in.

Panel Orientation and Title

In one study, the author chose a case study that is located in Yanbu, Saudi Arabia where in the base-case model the panels were horizontally fixed. The first model, on the other hand, the year was divided into periods consisting of a fixed number of days, whereas the second model was designed with a flexibility in assigning the number of days to each period. The results showed that by increasing the number of adjustments throughout the year, better proficiency is achieved but is economically infeasible (Ramli et al., 2021). Compared to a case study done in Jeddah analyzed the influence adjusting the tilt angle of a solar panel has on the harvested energy. It was found that changing the title monthly will increase harvested energy by 7.74% and for a seasonal change it increases by 6.38%. Additionally, performing fewer adjustments of PV tilt angle will reduce manpower or tracker motors costs (Kaddoura et al., 2016). In addition, a case study done in the city of Dhahran analyzed the influence of adjusting the tilt angle of a solar panel on its energy output and found that including an annually optimal tilt angle of 24.50˚ , increased the energy output by 7% compared to the conventional flat-plate PV panel. And when incorporating a monthly optimal tilt, the energy output increased to 14% (Abdulsalam et al., 2017). Also, in a study where the author tries to find the best PV application solution for buildings with roof area. Three scenarios were conducted to compare the different panel tilt angles. The first scenario uses the optimum tile angle that also provides the largest amount of energy; however, it can only be used in cases where the area is unlimited. In the second scenario where the tilt was reduced to 15˚to accommodate the limited roof area, however, the energy produced was lowered. Therefore a third scenario was offered by using the first sting of PV panels with an angle of 20˚ and the rest with a tilt of 15˚ to accommodate the area while increasing the amount of energy produced compared to the second scenario (Al-Quraan et al., 2022). In another study the author believed that the performance of a solar-powered device can be enhanced by finding the appropriate tilt angle on a monthly, seasonally, and annual basis. The main findings were that the ideal tilt angle is higher in the winter than in the summer. And for Najran, 20.97˚ is the optimum title angle annually. In addition, the author found that to maximize solar radiation absorption, the panel surface should be tilted at a monthly or seasonally when possible (Alqaed et al., 2023).

Dust Accumulation

In a study where the objective of this study was to design a PV panels cleaning system using water for a case study that is located in Khobar, Saudi Arabia. The results show that after cleaning, the solar panels had an efficiency increase of 6-12% at nominal temperature of 27˚ C. in addition to an increase of power output of 35% during the day time (Nader et al., 2020). In addition to another study where the author implemented an Electrodynamic cleaning system (EDS) that is an automatic, water-free system where the soiling rate is reduced can be up to 95.7% with an average of 32.1% (Faes et al., 2019).

Temperature

There was a study where the author focused on gathering data that reflects the monthly and yearly optimum PV panel tilt that generates the maximum power while considering the ambient temperatures. The study found a correlation between power output and air temperature where the higher temperature reduces the power generated from the PV cells (Mansour et al., 2021). In another study the author analyzed the effect of temperature on the performance of a PV cell system and found a decrease when the surface temperature of the PV panels increased where the highest energy yield was observed at 35.8˚ C of the surface temperature of the PV panels at approximately 6H and a rapid decrease in energy yield followed during the first few hours and then relatively small towards the end of the day (Rehman & El-Amin, 2012). In addition to a study that aimed at examining the effect of temperature on PV cell panels where the results showed that temps above 25˚ C give a power output 20% less and when the temperature drops to below 25˚ C, the power output increases by about 6% and 11.5% for corresponding temperatures of 15˚ C and 5˚ C respectively (Badi et al., 2022, Al-Sakkaf et al., 2022).

Location

In one study where the author investigated 44 locations within Riyadh were part of a techno-economic feasibility of installing moderate 10 MW grid connected PV power plants to estimate the annual energy yield. The study found that Based on the present analysis Bisha and Najran are found to be the best sites while Sulayel and Tabuk the worst sites. The study recommended that the government should provide a subsidy and clean energy development incentives of 30–70% for attractive payback periods of 12 to 5 years (Al-Sakkaf et al., 2021; Rehman et al., 2017).

Electric Consumption

According to one study that was done where two Villas in Jeddah with the exact characteristics, size, facilities, and number of occupants are compared after one of the villas had a PV system installed and found that the energy consumption was reduced by 80%. While introducing FiT with the same tariff as import tariff would reduce the payback period to around 4.6 years The researcher stated that future studies can be done to further investigate the financial benefits of the suggested solution (Alghamdi, 2019). Additionally, one study investigated the influence of rooftop PV on residential buildings in terms of energy saving and power output. A total of 70 buildings were selected from a residential compound. A satellite image analysis was done and found that the area of about 21% can be used for apartments and 28% for villas which results in an annual irradiance reduction of 13%. It is found in this study that solar PV can offset 19% of the electricity demand when 25% of the building roof is utilized, in addition to a cooling load reduction of 2% due to the shading effect of panels (Dehwah & Asif, 2019; Al-Sakkaf, 2020). In another study, the researcher aimed at calculating the electric conservation of the PV panels from the shading it provides to the building. The results show it saves about 23% on energy that is used for cooling loads (Zubair et al., 2018).

Economic Value

PV panels are typically thought to have a 25-year lifespan. PV panels are expected to last this long because the industry standard for warranties is between 25 and 30 years. It is expected that inverters need to be changed every eight years. Inverter costs are thought to be discounted at a rate of 4% annually. After being converted to net present value, the cost of replacing inverters is allocated to yearly operating expenses. The initial O&M costs are increased by these expenses (Asif et al., 2019). In one study based in Abha, Saudi Arabia where the aim was to perform a techno-economic feasibility study for a Photovoltaic (PV) panels system that incorporates a battery backup to meet a small load for a camping site in Saudi Arabia.it was found that the battery storage capacity cost has an important role in the overall cost of the PV system. Also, the cost of energy from the PV system was 29% cheaper than the diesel-generating set (Rehman et al., 2006; Al-Sakkaf & Ahmed, 2021).

Performance Optimization

Presently, an abundance of solar energy is converted into electricity using flat-plate solar panels (PV installations). Commercial products featuring tilted solar panel installations have long been on the market, allowing for the utilization of solar energy, which is a renewable resource. The solar modules in these systems are exposed to solar radiation through one or more flat-plate surfaces that: (i) track the sun continuously at a fixed tilt angle rotated on a vertical axis; (ii) continuously track the sun at a fixed tilt angle rotated on a system with two axes (one vertical and one horizontal); this ensures that the receiving surface is always normal to the solar rays. Fixed-tilt systems, as these installations are called, are becoming increasingly common because they require a smaller investment for the supporting frame. Mode installations, also referred to as single-axis systems, offer more solar energy on inclined surfaces but come with a slightly higher cost due to the requirement for moving part maintenance. Mode installations, sometimes referred to as 2-, double-, or dual-axis systems, are thought to be the most efficient. They are more efficient, but because they require more moving parts, they also come with higher maintenance costs (Kambezidis et al., 2021; Eweda et al. 2021). In addition, one study investigated the optimum title angle and it to be 20°, 25° and 30° towards the south for most cities in KSA (Farahat et al., 2021). In addition to the fact that solar PV and battery energy storage cannot meet all of Saudi Arabia's primary energy needs, photovoltaic (PV) requires more than just batteries—it is not a viable solution for the country's future.

Furthermore, compared to PV, enclosed trough systems with a single trough saltwater condenser experience significantly less sand, dust, humidity, salt, and extreme temperatures in Saudi Arabia. PV in Saudi Arabia generally suffers greatly from the numerous problems that are impeding their adoption. Because of the high temperature and the rapidly forming layer of dust, the solar energy collected by the panels is reduced significantly, and less electricity is produced. In addition, rust and cracks cause the panels to fail (Boretti et al., 2020; Elshaboury et al. 2022). As observed from the literature, there seems to be a lack of studies that address the economical long-term value of solar panels compared to the value of the electrical that is used nowadays in the kingdom of Saudi Arabia for residential buildings. It is important to address this issue since the call to find renewable resources is on the rise and with the evidence this paper would provide, it would motivate the end users – occupants of residential homes in Saudi Arabia– to appreciate the economic value of installing PV panels in existing and new residential buildings.

Methodology

This research is adopting analytical descriptive methodology. Initially, a review of thirty-four references was conducted to investigate the effectiveness of photovoltaic panels. The second step includes defining the research problem and the key variables that could affect the research solution. Statistics regarding the average electricity consumption in Riyadh City's residential sector have been gathered for a subsequent comparative analysis during the practical portion of the study.

In the second phase, a villa in Riyadh City has been chosen as a case study for this research to perform an LCCA for the PV panels located within the structure. The payback period for PV panels has been estimated using a Return-on-Investment Analysis (ROI). In order to ascertain the effectiveness of this type of energy sources in buildings in Riyadh City, residential buildings specifically, a comparative analysis has been carried out on the current conditions of residential buildings in Riyadh and the case study building.

Statistics on Average Use of Electricity in Riyadh Houses

The residential sector in 2021 accounted for 47.25% of the total electric energy consumption in KSA, per capita share of electrical energy consumption recorded an increase of 6.98% in 2021, reaching 8,841 kWh/person, after it was 8,263 kWh/person in 2020 (Electric Energy Statistics Publication, 2021).

Table 1: Main indicators of energy statistics (GASTAT, 2021).

Indicators	Unit	2020	2021
Total electric energy consumption	TWh	289	302
Per capita share of electric energy consumption	KWh/person	8,263	8,841
Subscriber share of electric energy consumption	KWh/subscriber	28,527	28,662

In Figure 3, the electricity consumption in Riyadh Housing units reached 48,810 kWh in 2022 according to the GASTAT Statistical Database (Housing units electrical energy consumption by season and region, 2022).

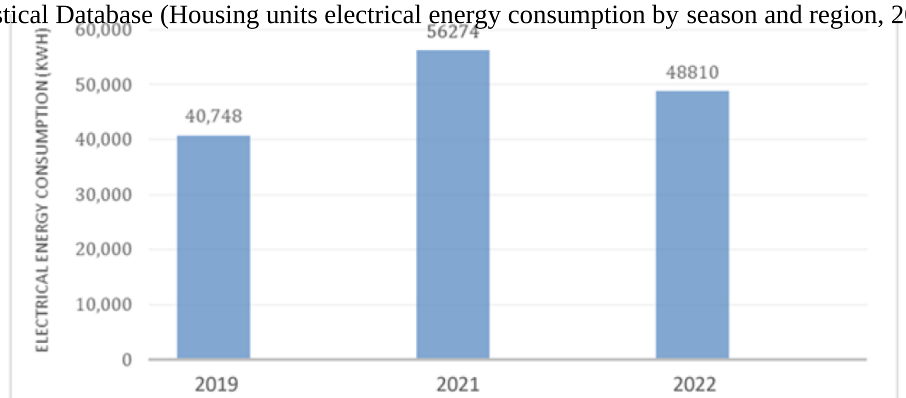

Figure 3: Housing units electrical energy consumption by season and region (GASTAT, 2022).

In 2021, the percentage of households using solar energy in Riyadh reached 3.34% of more than 3 million housing units as shown in Figure 4.

Table 2: Households with solar energy usage by region (GASTAT, 2021).

Region	2019	2021
Riyadh	1.82	3.34
Grand Total	1.82	3.34

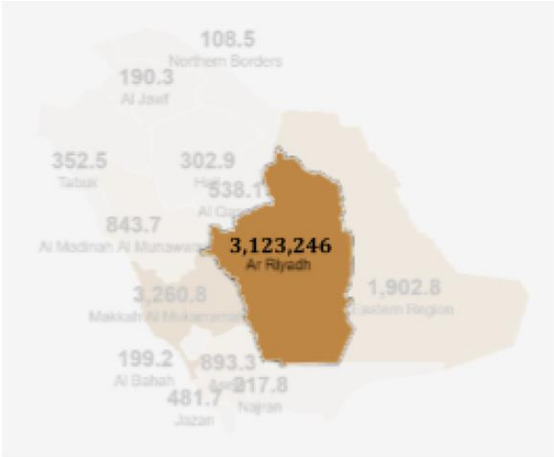

Figure 4: Dwellings in Riyadh Region (Saudi Census, 2023)

The Case Study - Eng. Hisham Samarkandi Palace

The case study chosen is for a villa house in Riyadh City, Qurtuba District. All data about the case is provided by Solar Land Company. The building consists of 3 storeys, basement, besides 2 annexed buildings, with an area of 950 m2. Insulation systems follow electricity company requirements (info are not available for insulation). The number of occupants in the house is 7. PV panels had been installed prior to occupancy in the building, and the study of PV panels by the company has continued for 6 months. Regarding PV installation, 60 panels -Jinko brand, monocrystalline 460WP- of total capacity 27.6 KW, were installed tilted 25 degrees towards the south, with an inverter -SMA inverter 25 KW-, and a control device integrated online to the system to monitor the performance. The time required to complete this project was five days after supplying to the site as shown in Figure 5.

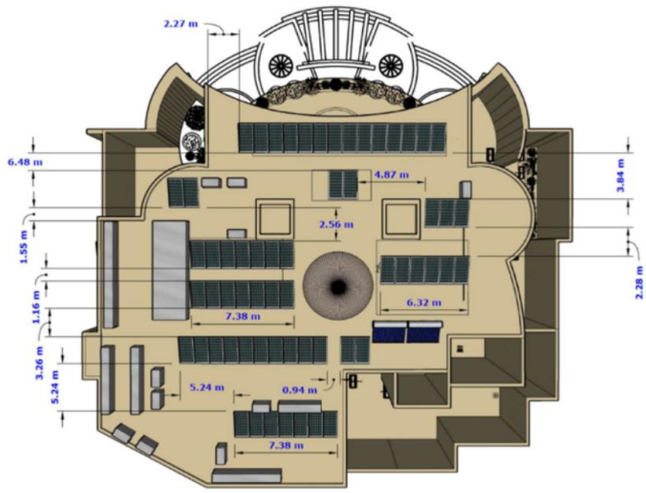

Figure 5: Case study House Roof Plan, provided by Solar Land Company

Return on Investment (ROI) and Payback Period Calculation

ROI: it refers to calculation of the monetary value of an investment versus its cost. In this case, the measure of PV panel LCC compared to the saving in electricity bills, -all data provided by Solar Land Company.

a) Initial Cost: it includes total cost of PV panels, installation, operation, and other auxiliary equipment and accessories (inverter, DC cables, AC cables, and concrete base), as mentioned in the project document by Solar Land Company = 78,000 SAR.

b) Lifetime Period: usually refers to the period of full effectiveness of the panels, which is often considered to be 25 years, noting that after this period PV panels still preserve 80% of their effectiveness.
c) Maintenance Fees: during the first 10 years, almost no maintenance fees are required. After 10 years, usually fees are assigned for changing the inverter, and this equals 16,000SR.
d) Total Cost: total cost includes sum of initial cost, adding to it the maintenance, and any other extra fees over the lifespan of the panels, in this case it equals to: 78,000 + 16,000 = 94,000SR.
e) Net benefit: it refers to the sum of all benefits subtracting from it the sum of all costs of a project. In this case, it is the total amount one saved on electric bills over the PV panels lifespan -this factor is estimated by the executing agency per-, and it is represented in the following equation:

Total benefit (annual savings on electric bill x lifespan period) - total cost
= (6,715.92 x 25) – 94,000SR
= 167,898 – 94,000SR
= 73,898SR

ROI = (Net benefit / Total Cost) x 100%
= 73,898 / 94,000 x 100%
= 0.78 x 100%
= 78%
This means that the Return on Investment is 78%.

Payback Period: it refers to the amount of time it takes to recover the cost of an investment. In this case, it is the length of time it takes to balance out the cost of utilizing PV panels with the value saved on electricity bills.

Annual Saving: as mentioned in the document provided by the executing agency, the total amount saved on the electric bills yearly = 6,715.92 SAR.

Payback Period = Total Cost / Annual Saving
= 94,000 / 6,715.92SR
= 13.9 Years
This means that it will take the owner approximately 14 years to make back the cost on the PV system installation.

In the case study of Samarkandi House, the annual savings on the electricity bill amounts approximately 6,715SR per year. On the other hand, through the "consumption tariff," consumption segments are measured according to (kWh/month) for the residential sector, which is divided into two segments; from 1 to 6,000 kilograms, and it costs 18 Halala/kwh, and from6,000 kilograms and above, it costs 30 Halala/kwh (The Saudi Electricity Company, 2023).

As mentioned previously, the electricity consumption per residential unit in Riyadh reached 48,810 KWh/year. According to the data of The Saudi Electricity Company, the lowest electricity cost of residential units is estimated at 8,785SR/year, while the highest cost is 14,643SR/year. The average was 11,714SR/year.

1) Cost average of electricity consumption per residential unit for 25 years = 292,850 SAR
2) Life cycle cost for PV panels= Initial Cost of PV panels + maintenance cost + (cost average of electricity consumption - annual saving x 25 years) =78,000 + 16,000 + (11,714 - 6,716 x 25) = 218,950 SAR.

Table 3: The cost of electricity consumption by residential units.

Residential unit Cost	Cost
Cost of electricity consumption in 25 years	292,850 SAR
Cost of electricity consumption with PV panels in 25 years	218,950 SAR

Comparison results show that PV panels can save up to 73,900SR in a life cycle of 25 years, which means that approximately 25.2% of cost is saved during the default lifespan of PV panels.

Conclusion

This paper presented a Construction and Demolition Waste (CDW) method to study and control the potential of demolition. In addition, buildings, like any other entity, have a limited lifespan of approximately 80-100 years.

Once a building reaches the end of its life cycle, plans for demolition must be carefully prepared to ensure safety measures are taken, hazardous materials are removed, and the building is surveyed before demolition. Unfortunately, this process often results in a significant amount of demolition waste that is usually deposited in landfills. The purpose of this article is to raise awareness and encourage the adoption of effective waste management plans in Saudi Arabia. The article is divided into two parts. The first part provides a general overview of Construction and Demolition Waste (CDW), waste management methods, and factors that contribute to CDW generation. The second part takes an economic perspective and focuses on CDW.

This study aimed to compare the cost of current electricity consumption with PV panels in the residential sector, through the case study (Eng. Hisham Samarkandi Palace) which analyzed life cycle cost assessment (LCCA) of PV panels and investigated the cost efficiency of both of them. And as a result of this study, the following main points can be concluded:

1. The average lifespan of the PV panels is 25 years. and this is the period where the panels have full effectiveness.
2. The average electric cost of a residential unit in Riyadh, Saudi Arabia, was 11,714SR/year and this means that it cost 292,850 SAR over a period of 25 years.
3. The total cost of installing PV panels for a 3-story residential villa with an area of 950 sqm is 94,000 SAR. This cost includes maintenance, and any other extra fees over the lifespan of the panels.
4. The life-cycle cost of installing PV panels for a 3-story residential villa with an area of 950 m^2 is 218,950 SAR.
5. When we compare the average cost of electricity for a residential unit in Riyadh, Saudi Arabia to the life-cycle cost of installing PV panels, we will find that installing PV panels can save the homeowner approximately 25.2% during the lifespan of the PV panels which is 25 years.

The current study gives an initial calculation of the life-cycle cost of installing PV panels for a 3-story residential villa in Riyadh, Saudi Arabia and compares it to the average cost of electricity of a villa without PV panels. and though these numbers are based on real-world circumstances, the latest statistical studies that were found, were for the year 2021. Another limitation was due to the age of the case study - newly built - authors were left without baseline values to compare the cost of the electric bills before and after installing the PV panels. Thus, the authors referred to the average cost of electric bills for villas located in Riyadh, Saudi Arabia and used those values as a baseline value, therefore accuracy might have been compromised.

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