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"Using Solar Lighting Devices as Renewable Energy Applications"

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Abstract:

This study explores the direct relationship between sunlight and silicon photovoltaic cells that convert light into electrical energy. The feasibility of using renewable energy alternatives is assessed after calculating the savings and payback, comparing the LCC (life-cycle cost) of the existing electricity system and alternatives proposed during its life span. This design introduces a broader perspective to compare the alternative renewable energy systems in the campus facilities after estimating the total energy consumption in several buildings and infrastructures. This study also demonstrates the importance of having a systematic perspective and providing possible future production scenarios, considering the evaluation of the solar energy applications conducted for several years, in which the energy production system may change.

Keywords: Solar lighting; Photovoltaic panels; Solar energy; Renewable resource; Fence solar lighting devices; Electrical lighting device; Life-cycle cost.

Solar energy represents one of the natural renewable energy resources supporting sustainable development in the Kingdom of Saudi Arabia as supporting for kingdom vision. It is used in many applications to reduce dependence on electrical energy, the primary source of energy in the Kingdom. A critical application that supports reducing the dependence of universities on the public electrical grid is exploiting solar energy devices. The exploitation of this solar energy has been studied since 2014. Rapid deployment of renewable energy, energy efficiency, and technological diversification of energy sources result in significant energy security and economic benefits, reducing environmental pollution, such as air pollution from burning fossil fuels, and improving public health.

The annual solar radiation rate in the Kingdom of Saudi Arabia is about 2,100 to 2,400 kWh/m^2 annually (Figure 1). At King Faisal University in Hofuf, the solar radiation rate reaches approximately 5.6 to 5.7 kWh/m^2 daily. Like other countries, Saudi Arabia aims to determine alternative energy production sources to support Saudi Vision 2030. The national Renewable Energy Program (Figure 2) was launched under the Saudi Vision 2030 and the National Transformation Program.

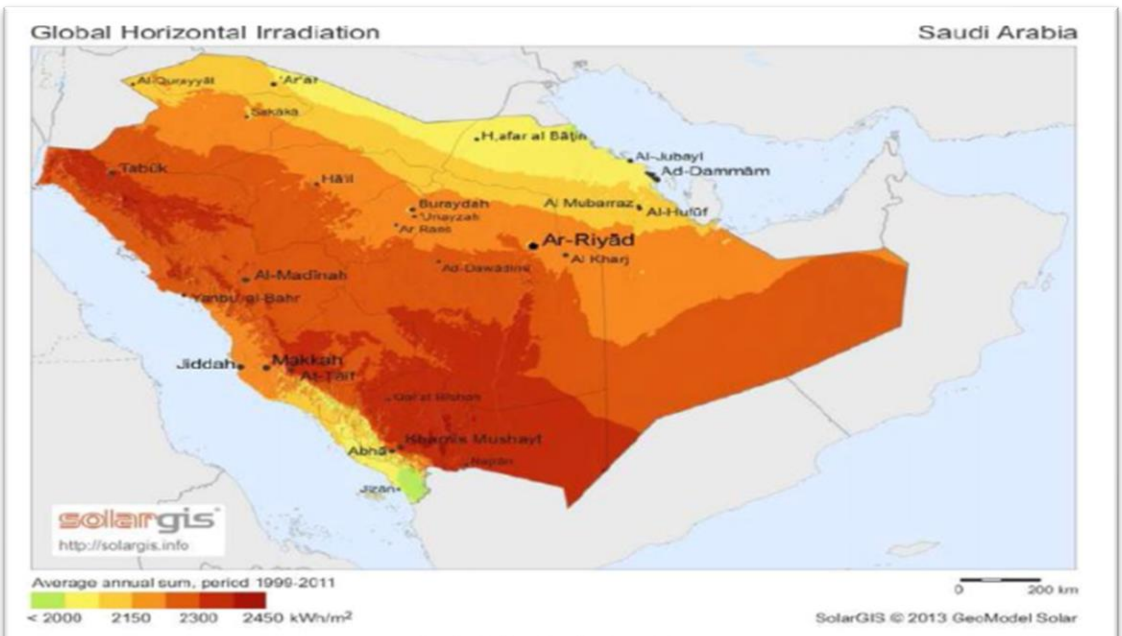

Fig 1. Solar Radiation Map

Figure 2
National Renewable Energy Program Logo

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Problem Statement

How can renewable energy (solar lighting) be implemented to provide possible future production plans for saving energy from the campus facilities? The feasibility of using renewable energy alternatives is assessed after calculating the savings and payback, comparing the LCC of the existing electricity system and alternatives proposed during its life span [Ellabban,2014]

Scope of Research

This research explores developing cost estimates and returns for energy alternatives compared to the electric current over 25 years by selecting campus facilities (solar lighting devices for fencing). Then, the total annual energy consumption and feasibility of using renewable energy alternatives after calculating the savings and payback are estimated.

The primary objective is to select the optimum energy system for campus facilities, specifically the King Faisal University (KFU) lighting fence, regarding operational and financial aspects that achieve the sustainability requirements. The secondary objectives include the following:

- Reducing the total cost of energy consumption;
- Choosing environmentally friendly energy systems;
- Applying this study to similar projects under the same conditions, such as the KFU hospital fence, landscape projects, and streets;
- Maintaining the environment using sustainable energy;
- Assessing the efficiency of renewable energy systems considering the regional climate and environment;
- Decreasing electrical consumption by approaching the new technology of renewable energy considering the climatic and topographical criteria of the campus project in Eastern Saudi Arabia for the least energy consumption;
- Using modern alternative energy technology;
- Clarifying the implementation constraints of renewable energy and processing mechanisms to maintain efficiency;
- Comparing the technical and financial aspects of alternative energy based on engineering and environmental criteria;
- Recognizing new energy technology and the possibility of implementing this study or adding recommendations for the future;
- Determining the study feasibility of using renewable energy system infrastructure through the comparison of the LCCs of electrical power systems and renewable energy;
- Choosing the appropriate architectural form of solar lighting devices in proportion to the fencing.

Methodology

The design methodology focuses on the economic effects of replacing electrical power lighting with renewable energy. It also focuses on the design of systems that can be used based on the environmental and climatic standards of the location. The most important of these systems is the photovoltaic (PV) panel. A modern application uses light-emitting diodes (LEDs) in lighting systems due to the high yield of the resulting lumens.

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Solar Lighting Devices for the University Fence

Figure 3 depicts the plan for the main fence of the university with a length of 13 km, where the approximate total cost of installing ordinary electrical lighting devices is more than 13 million SAR. We include the cost of the cables and extensions, transformer substations, medium-voltage cable installation, duct banks, and connections (Table 1). In addition, we include the cost of energy consumption from the network and maintenance costs, estimated at one million riyals annually.

Figure 3
Outer Fence of the University (Marked Red)

Installation Conditions

Crucial points to consider when using solar lighting devices for 3,200 poles are the suitability for the fence shape, the required energy, practical installation methods, the electricity cost, maintenance cost reductions, economic costs, the architectural shape, and the ease of installation (Figure 4).

Figure 4
Photos of Solar Lighting Systems for the Fence

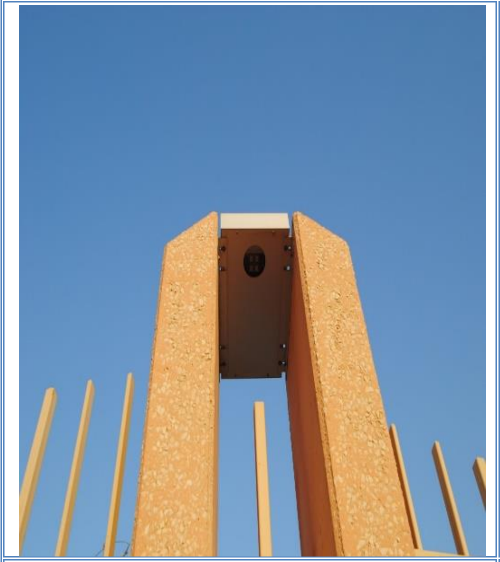
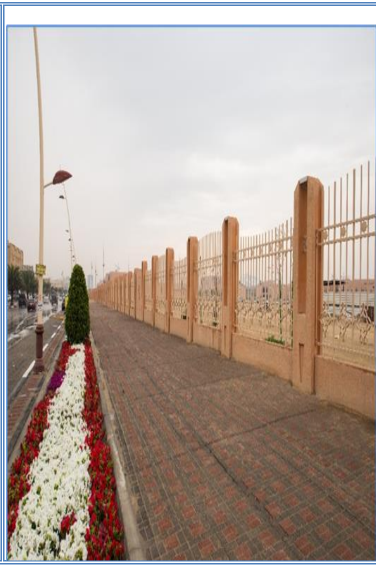
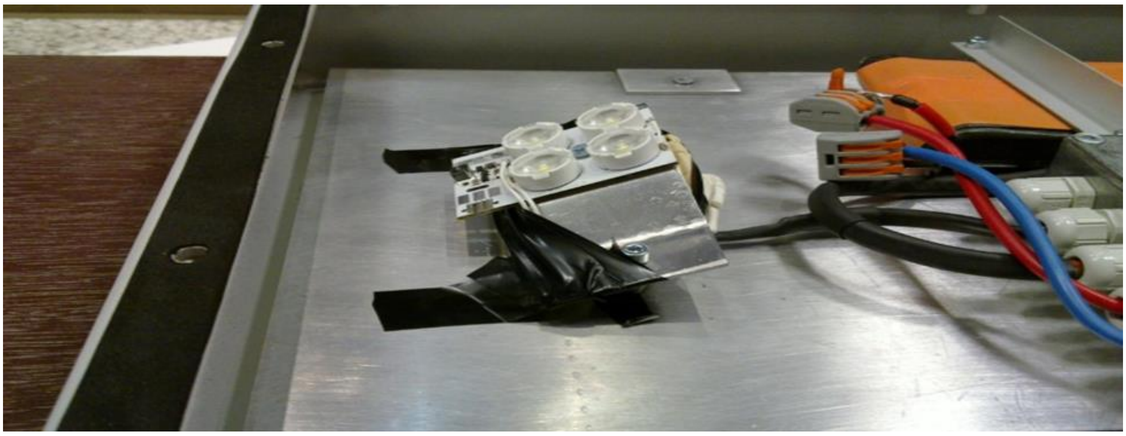
		
LED solar light	**Perimeter fence at KFU**	

Figure 5
Testing Module for Lenses Type and Tilt of the LED and Color Light

Design



Criteria

In practice, after studying and designing LED solar lighting devices, devices must be optimally installed, calibrating the angle to obtain the highest flux from lighting on the sidewalk projection and in all directions [Costa,2009] [El-Faouri,2016]. The Austrian company Conlux was awarded the job due to the company's global experience in this field for more than eight years, meeting the requirements. Most importantly [Dalal,1977], the raw material quality and device testing regarding intensity, lighting, and other factors in the Al-Hassa region, were considered before supplying these devices after the KFU administration visited the factory.

This project uses solar energy at King Faisal University; therefore, the experience and quality requirements must be met before manufacturing numerous devices. The coordinator of the electricity department, Professor Fallaha, and the chief operating of the Conlux factory, engineer Karl Gartner, did many tests in the field on the fence to assess the lens type, light color, tilt of the LED light, and the best method to reflect the light on the desired surface.

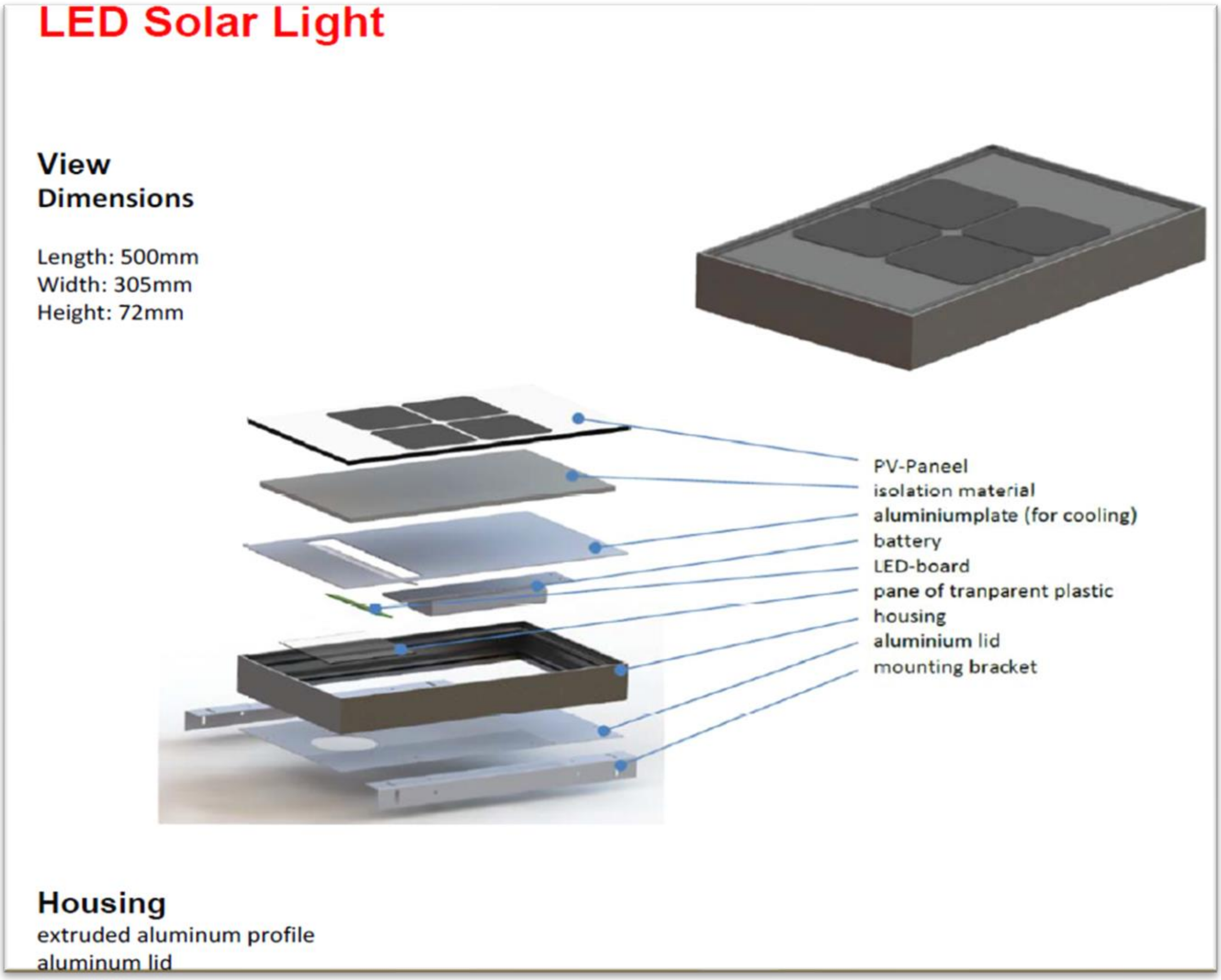
Finally, we assessed fixing the tilt of the LED light (with four pieces) and the LED (4x2 Watts) for the production line with robotic applicators and a plug connector. We assessed the following raw materials for all parts of the lighting device using the tests [Kozak,2009] [Lin,2012]:

- All designed and developed electronic boards,
- Optical lenses provided by Conlux in Austria,
- LED lights from Cree in the USA,
- PV cells from SunPower in the USA and,
- Batteries and controllers from Luna Tone in Austria (Figure 5).

Solar LED Light Technical Specifications

The company implementing these devices was assessed, and the best solar lighting devices were selected. The necessary technical specifications were developed following the best technology. The specifications were confirmed as the first projects applied in the Kingdom due to the technological progress in producing lighting control devices from cells to batteries for LEDs. Then, we installed the devices in the best locations [Guha,2007]. The voltage of the solar panel in operation (panel in the sunlight) was 2.0 to 2.2 V. The amperes during charging from the solar panel were approximately 4 to 5 A, and the battery voltage should be 3.2 to 3.7 V. Conlux specialized in integrating these elements to form a luminescent device that works through monocrystalline silicon cells well insulated and coated with a durable, insulated glass panel. Figure 6 illustrates all parts of the LED solar light.

Figure (5) Solar LED Technical Specifications



Results

Financial Study and Resulting Savings

Initial Costs

The financial assessment determined the savings after installing the appropriate solar lighting device equipment at about 7.36 million SAR, compared with ordinary lighting devices at about 13.225 million SAR, saving 5.86 million SAR or 44.3% of the total cost (Table 1). The cost of electric lighting devices minus the cost of solar lighting devices is 13.225 million - 7.3 million, saving 5.865 million SAR.

Table 1
Cost of Ordinary Lighting Devices and Comparison with Solar Energy Devices

Subject	Electrical Lighting Device Cost			Solar Lighting Device Cost	
Items	Qty	Unit Price	Total Price in SAR	Solar Unit Price	Solar Energy Device Price
Installation and supply of four 75-W electrical bulb lighting devices with accessories, extensions, and pipes	3200	500	1,600.000	2300	7,360.000
Low voltage cable with plates and pipes (10 mm^2)	2000	300	600.000	-	-
Low voltage cable with pipes (6 mm^2)	15000	175	2,625.000	-	-
Medium voltage cable with duct bank (13.8 kV)	7000	800	5,600.000	-	-
Transformer stations with bases (13.8 kV/400 V)	14	200,000	2,800.000	-	-
Total		13,225,000 SAR		7,360,000 SAR	
Savings	5,865,000 SAR				

Continuous Costs

Regarding the life spans for solar lighting devices, solar panels are expected to work for 25 years, batteries for eight years, control devices for 25 years, and LED devices for 50,000 h. Costs were provided for continuous use for one year and over 25 years, as the default ordinary electric system ranges from three years and then is replaced. In addition, heat emission from the unit and electricity consumption savings compared to the ordinary electric devices for 10 hours daily were calculated as follows:

Daily consumption = unit consumption x by units x 10 h,

Annual consumption = 300 W x 3200 x 10 h x 360 days x 0.9 = 3,110,400 kWh, and

Annual Savings = 3,110,400 X 0.3 SAR = 933,120.0 SAR.

Cost of Electrical Lighting Devices

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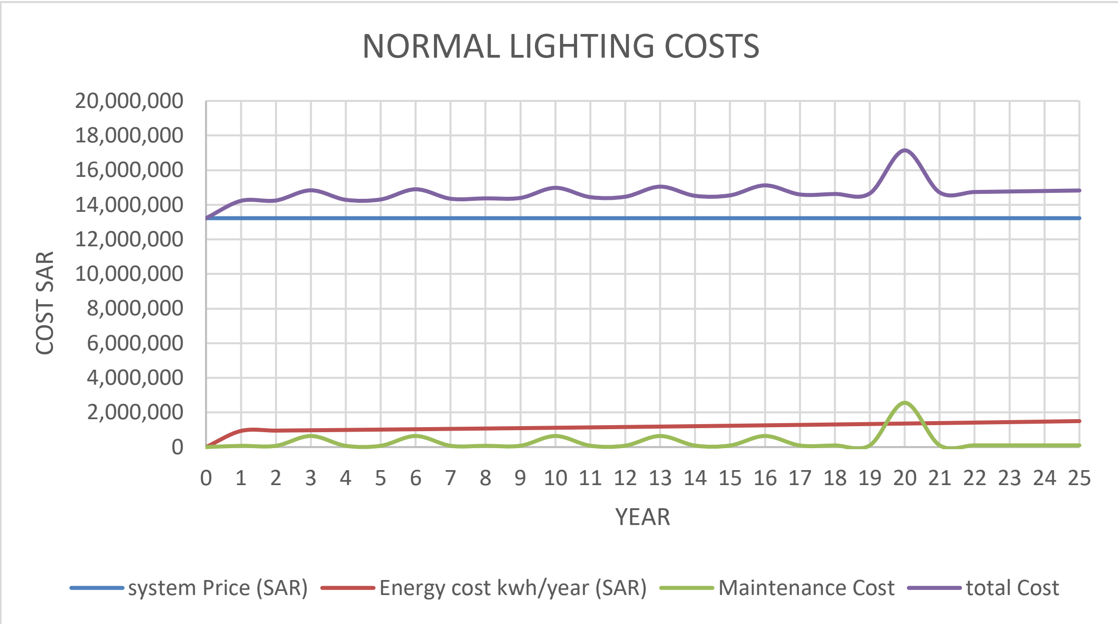
The annual energy consumption cost at 0.3 SAR/kWh is 933,000 SAR. The maintenance cost for electrical lighting devices, transformers, breakers, and connections as a percentage of the contract value annually is about 0.5%, approximately 70,000 riyals. For the replacement parts, bulbs are replaced every three years at 640,000 riyals for 3,200 devices at 200 riyals. The cost of replacing the device after 20 years is 2.56 million riyals for 3,200 devices at 800 riyals (Figure 7).

Figure 7
Cost of the Electrical Lighting Project for 25 Years



Cost of the Solar Lighting Project

The fixed project cost is 7.36 million SAR. The maintenance cost is approximately 10,000 riyals annually. The life span of replacing luminaires and basic parts for a solar lighting system is every five years for batteries and every 10 years for LED over 25 years compared to a regular system is every three years for bulbs. The cost of spare parts every five years for batteries is 320,000 riyals, and every 10 years, the cost of LED lamps is 5,000 riyals (Figure 8).

Figure 8
Cost of the Solar Lighting Project for 25 Years

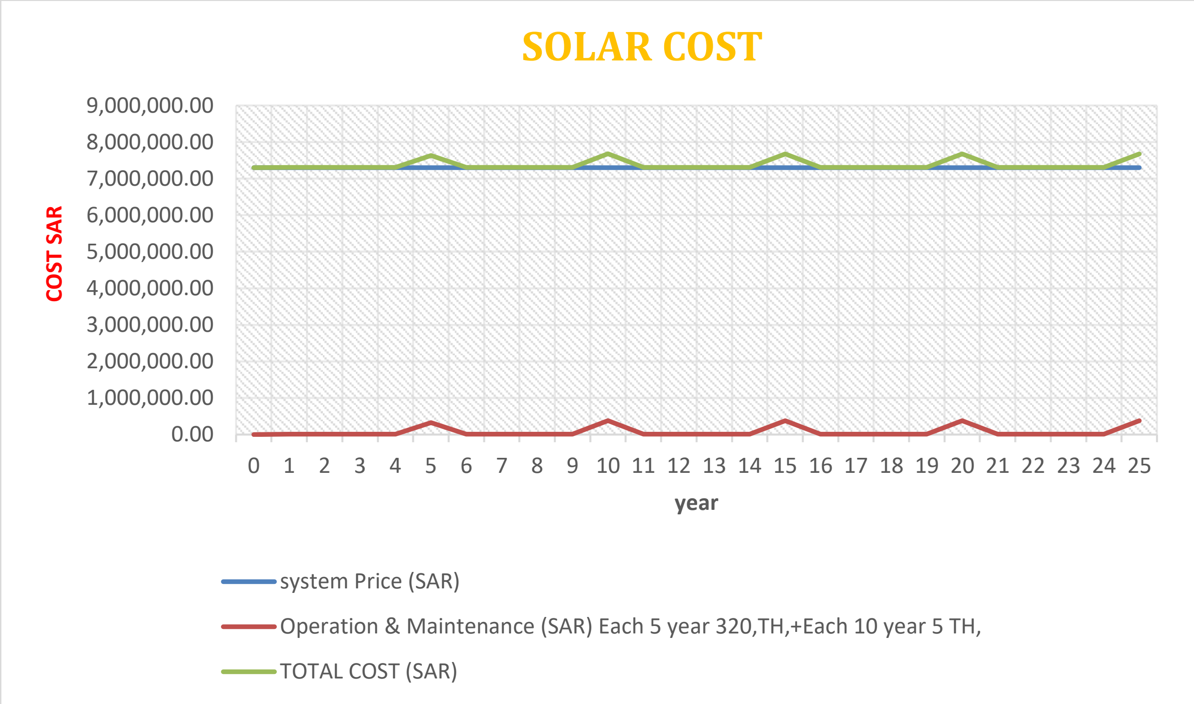
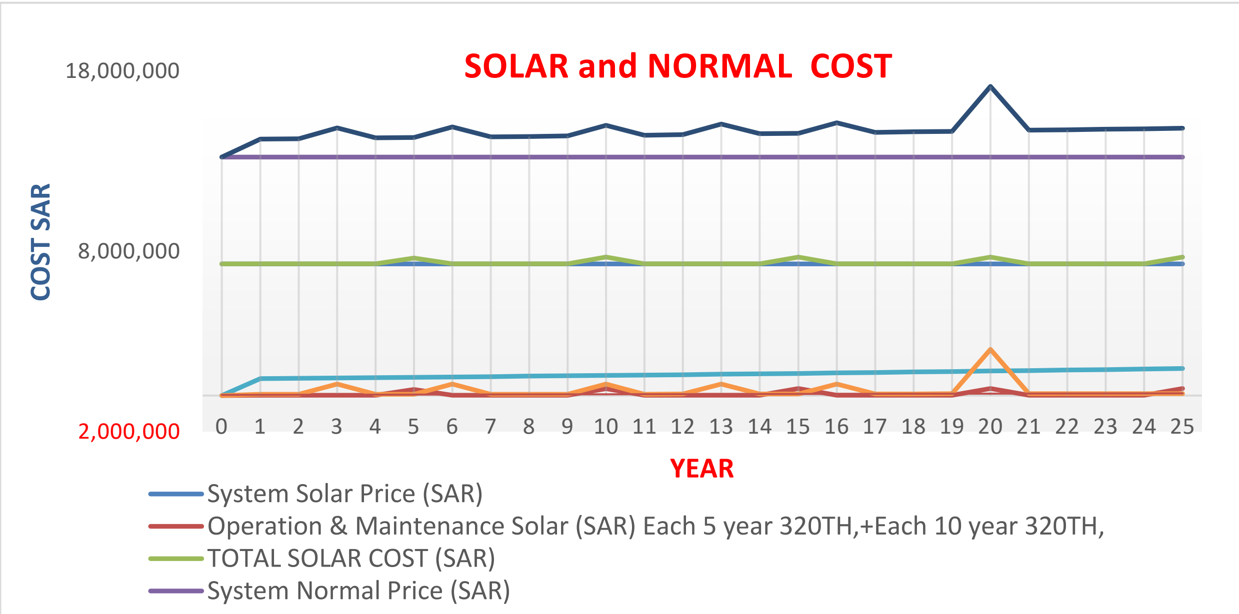


Figure 9 presents the chart for the total, fixed, and maintenance costs using solar lighting devices. The total cost scheme includes the fixed, maintenance, spare part, and annual electricity consumption costs using solar lighting.

Figure 9 Total Expected Normal and Solar Cost



Cumulative Revenue (SAR) for Fence Lighting

A cumulative revenue analysis using the above results (Figure 9), including the system, operation, and maintenance prices and the savings of 933,000 riyals in the annual electricity consumption over 25 years, is presented in Table 2. The cumulative revenue and payback study using this data on charting as the y-axis (for 25 years) and the x-axis (for cumulative revenue) are displayed in Figure 10. The repayment period is approximately eight years, and the repayment period begins to reach the value of 20.3 million riyals after 25 years [Boer,1978].

Table 2
System Cost, Savings for Electricity Consumption, and the Repayment Period

Year	System price (SAR)	Energy savings kWh/year	Operations & maintenance (SAR)	Savings (SAR)	Cumulative revenue (SAR)
0	7,300,000.00	0	0.00		-7,300,000.00
1	7,300,000.00	3,110,400.00	10,000.00	933,120.00	-6,376,880.00
2	7,300,000.00	3,172,608.00	10,200.00	951,782.40	-5,435,297.60
3	7,300,000.00	3,236,060.16	10,404.00	970,818.05	-4,474,883.55
4	7,300,000.00	3,300,781.36	10,612.08	990,234.41	-3,495,261.22
5	7,300,000.00	3,366,796.99	330,612.08	1,010,039.10	-2,815,834.21
6	7,300,000.00	3,434,132.93	10,000.00	1,030,239.88	-1,795,594.33
7	7,300,000.00	3,502,815.59	10,200.00	1,050,844.68	-754,949.65
8	7,300,000.00	3,572,871.90	10,404.00	1,071,861.57	306,507.92
9	7,300,000.00	3,644,329.34	10,612.08	1,093,298.80	1,389,194.64
10	7,300,000.00	3,717,215.93	380,612.08	1,115,164.78	2,123,747.34
11	7,300,000.00	3,791,560.24	10,200.00	1,137,468.07	3,251,015.41
12	7,300,000.00	3,867,391.45	10,200.00	1,160,217.43	4,401,032.85
13	7,300,000.00	3,944,739.28	10,200.00	1,183,421.78	5,574,254.63
14	7,300,000.00	4,023,634.06	10,200.00	1,207,090.22	6,771,144.85
15	7,300,000.00	4,104,106.74	380,200.00	1,231,232.02	7,622,176.87
16	7,300,000.00	4,186,188.88	10,200.00	1,255,856.66	8,867,833.54
17	7,300,000.00	4,269,912.66	10,404.00	1,280,973.80	10,138,403.33
18	7,300,000.00	4,355,310.91	10,404.00	1,306,593.27	11,434,592.61
19	7,300,000.00	4,442,417.13	10,404.00	1,332,725.14	12,756,913.75
20	7,300,000.00	4,531,265.47	380,200.00	1,359,379.64	13,736,093.39
21	7,300,000.00	4,621,890.78	10,200.00	1,372,973.44	15,098,866.82
22	7,300,000.00	4,714,328.60	10,404.00	1,386,703.17	16,475,166.00
23	7,300,000.00	4,808,615.17	10,612.08	1,400,570.20	17,865,124.12
24	7,300,000.00	4,904,787.47	10,824.32	1,414,575.91	19,268,875.70
25	7,300,000.00	5,002,883.22	380,200.00	1,428,721.66	20,317,397.37

Figure 11 provides system cost analysis charts for 25 years, including the total cost and savings.

Figure 10
Cumulative Revenue (SAR) for Solar Fence Lighting Units

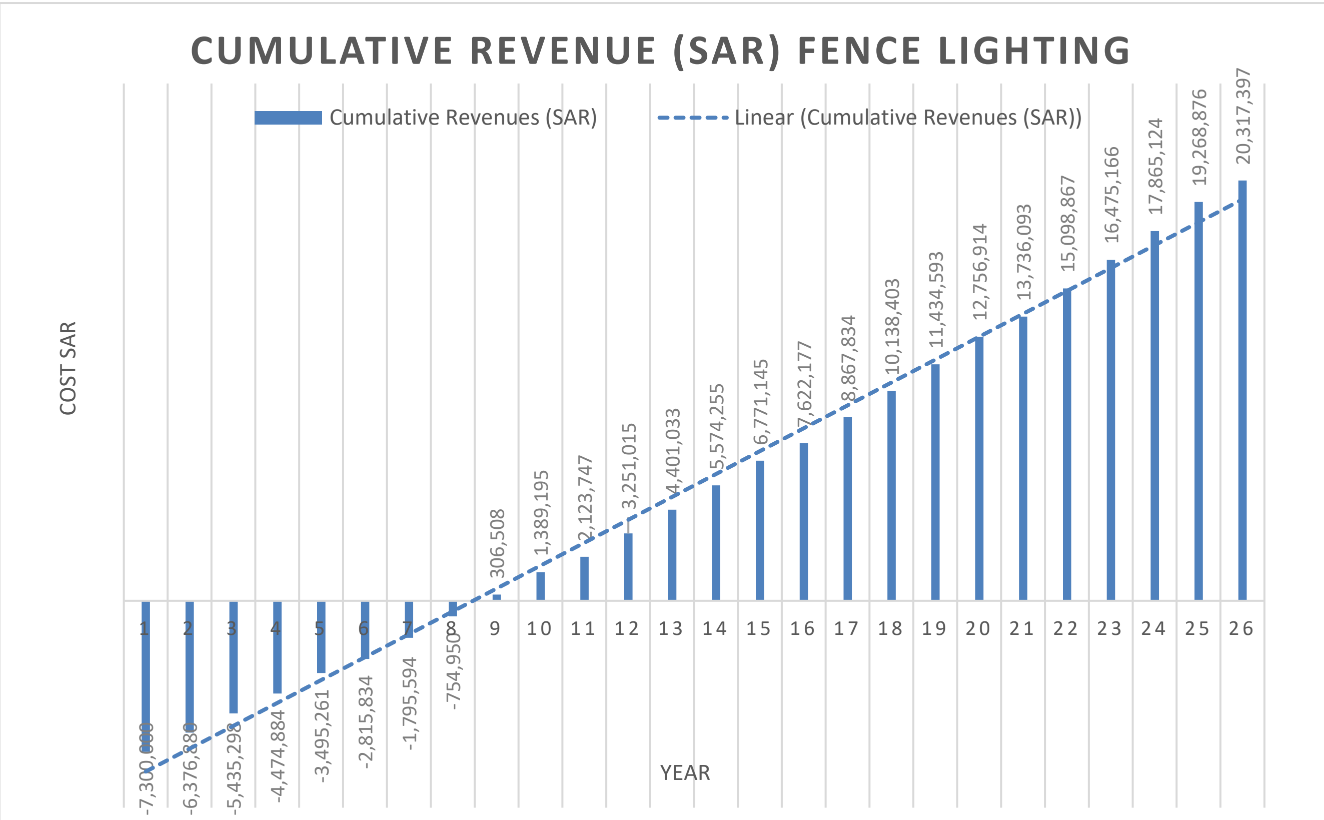


Figure 11
Cost Analysis Charts Over 25 Years

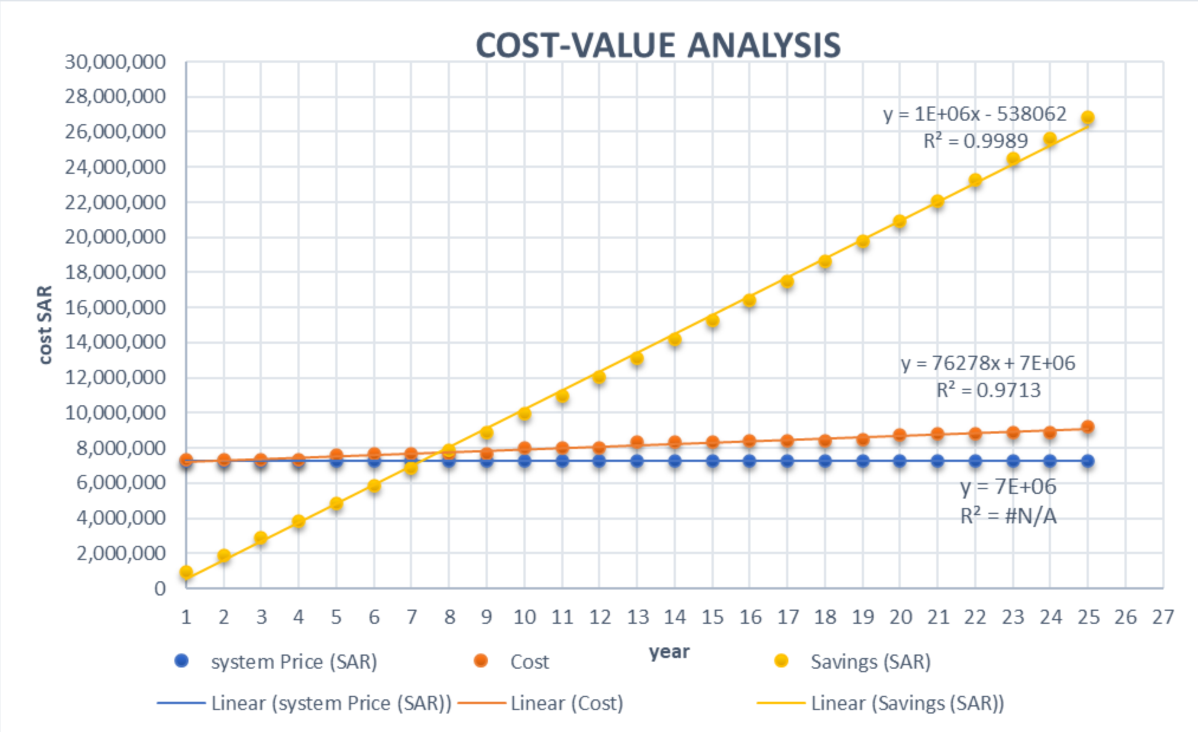


Figure 12
Solar Lighting System of the Fence

LED solar light	LED solar light at KFU at night

Conclusion

This study demonstrates one way to use solar lighting devices instead of regular devices for fence lighting, saving 5.865 million from the fixed cost value and 933,000 riyals in annual electricity consumption, where the results and tables reveal that the repayment period is approximately eight years. The results, tables, and curves for the total and fixed costs, maintenance costs, and spare part costs in this study indicate that solar lighting devices are much cheaper than regular devices. From the date of implementation in 2014 until the date of research preparation in 2023, through tests and monitoring, this system worked well without replacing any batteries, control panels, lighting, and LEDs.

This project implemented solar lighting for a university fence, supporting sustainable development processes and ease of installation, where cables, medium voltage 13.8Kv/400 voltage stations, drilling, electricity consumption costs, and maintenance workers are provided, which is considered clean energy. We recommend this solar lighting for all lighting projects on roads, corridors, squares, buildings, and outdoor systems. Because of these solar lighting device results, many lighting systems were installed on the university campus and in the hospital project. In addition, for the future project as well.

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ملخص:

تستكشف هذه الدراسة العلاقة المباشرة بين ضوء الشمس والخلايا الكهروضوئية السيليكونية التي تحول الضوء إلى طاقة كهربائية. ويتم تقييم جدوى استخدام بدائل الطاقة المتجددة بعد حساب الوفورات وفترة الاسترداد، ومقارنة *LCC* (تكلفة العمر الافتراضي) لنظام الكهرباء الحالي مع البدائل المقترحة خلال هذه الفترة. يقدم هذا التصميم منظورا أوسع لمقارنة أنظمة الطاقة المتجددة البديلة في مرافق الحرم الجامعي بعد تقدير إجمالي استهلاك الطاقة في العديد من المباني والبنى التحتية. وتوضح هذه الدراسة أيضا أهمية وجود منظور منهجي وتقديم سيناريوهات الإنتاج المستقبلية المحتملة، مع الأخذ في الاعتبار تقييم تطبيقات الطاقة الشمسية التي أجريت لعدة سنوات، والتي قد يتغير فيها نظام إنتاج الطاقة.

الكلمات المفتاحية: الإضاءة الشمسية؛ الألواح الكهروضوئية؛ الطاقة الشمسية؛ مصادر الطاقة المتجددة؛ أجهزة الإضاءة الشمسية للسور؛ جهاز إضاءة كهربائي؛ تكلفة دورة العمر الافتراضي