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***Research Article***

# Solar Energy Potential in Adana: Integrating Solar Panels in Agriculture for Sustainable Energy Solutions

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***Abstract*** – The study investigates the diverse range of renewable energy resources available in Adana, focusing on solar, wind, and hydropower. It emphasizes the importance of exploring innovative solutions to maximize the benefits of solar energy while minimizing its drawbacks, such as land use, intermittency, and grid integration. The paper delves into a detailed techno-economic assessment of different solar technologies, simulation results of solar power generation, and an evaluation of the ethical, environmental, and social impacts. Furthermore, it presents scenarios and strategies for solar energy production, with a particular focus on the application of agriculture. The potential for solar energy in Adana's agricultural sector is explored, highlighting how solar energy can enhance crop irrigation, cooling, and lighting, as well as increase land productivity and provide additional income for farmers. Additionally, the study examines the integration of solar panels in healthcare facilities to improve energy independence and reduce electricity costs, particularly during power outages. Drawing from an extensive literature review, the study emphasizes the global momentum towards solar energy as a sustainable, cost-effective, and environmentally beneficial alternative to fossil fuels. It references specific studies that have investigated the potential of solar energy in Adana, including its application in hospitals, agricultural lands, residential and industrial sectors, and university campuses. Adana presents an ideal opportunity for integrating sustainable energy solutions. Using the 4E's analysis framework (energy, exergy, economy, and environment) and RetScreen Software, this study provides a comprehensive analysis of the potential for integrating solar panels into agriculture to meet the city's energy demand sustainably.

*Keywords – Sustainable Energy, Solar Potential, Energy Demand, Agrivoltaics and Exergy.*

## I. INTRODUCTION

The global shift towards sustainable and renewable energy sources has sparked a significant transformation in the energy landscape. Amid this transition, solar energy has emerged as a prominent contender due to its abundance, cleanliness, and potential to fulfill the world's energy demands without adverse environmental impact. However, the integration of solar energy presents challenges related to land use, intermittency, and grid compatibility. As such, it is imperative to explore the potential of solar energy in various regions and sectors and devise innovative solutions to maximize its benefits while minimizing its drawbacks. In this context, our study aims to delve into the solar energy potential of Adana, a city situated in the Mediterranean region of Turkey. With its warm, sunny climate and a population exceeding 2 million, Adana stands as an ideal candidate for the adoption of renewable energy solutions. Moreover, as a major industrial center, the city exhibits a substantial energy demand, further underscoring the significance of exploring sustainable energy alternatives.

To conduct a comprehensive analysis of Adana's energy potential, we have employed the 4E's analysis framework, encompassing energy, exergy, economy, and environment, as well as utilized RetScreen Software for numerical data and simulations. Through this approach, we seek to advocate for the investment in renewable energy resources, particularly solar energy, to address Adana's energy needs sustainably. Geographically, Adana is well-positioned to harness energy from diverse renewable resources, including solar, wind, and hydropower. By examining the city's commitment to renewable energy and considering Turkey's escalating energy demand, we aim to present a compelling case for investment in Adana's energy sector. Our study will provide an in-depth exploration of the solar energy potential in Adana, encompassing a techno-economic assessment of various solar technologies, simulation results of solar power generation, an evaluation of ethical, environmental, and social impacts, as well as scenarios and strategies for solar energy production. Specifically, we will investigate how solar energy can augment the agricultural potential of Adana by providing irrigation, cooling, and lighting for crops, and how it can enhance the healthcare system by integrating solar panels across hospitals to ensure independence from the grid and reduce electricity demand and costs.

Informed by an extensive literature review, our study draws on existing research that underscores the viability of solar energy in Adana. Notably, prior studies have demonstrated the potential of solar energy to meet a significant portion of energy demand across various sectors, including residential, industrial, and institutional. Additionally, research has highlighted the potential of integrating solar panels into agricultural lands to bolster land productivity and provide an additional income source for farmers. The culmination of our study is aimed at providing valuable insights into the untapped potential of solar energy in Adana, offering a foundation for informed decision-making, policy formulation, and investment in sustainable energy solutions. Through our research, we seek to contribute to the burgeoning discourse on renewable energy and pave the way for the realization of a greener, more sustainable energy landscape in Adana and beyond.

## II. Materials and Method

In Adana, the shift towards eco-friendly farming practices is gaining momentum. This movement aligns perfectly with the principles of agrivoltaics, a sustainable farming method that combines agriculture with solar energy production. A study exploring the opportunity cost of conversion to eco-friendly farming in Adana revealed that the average farm incurs an opportunity cost of $4,454.3 for environmental protection [1]. However, the adoption of agrivoltaics could significantly reduce this cost by providing a renewable source of energy, thereby reducing reliance on fossil fuels. Despite the clear benefits, the study found that government environmental subsidies were not efficiently allocated, suggesting a need for more targeted support for solar agriculture initiatives. Interestingly, public support for solar development increases when energy and agricultural production are combined in an agrivoltaic system, with 81.8% of respondents indicating they would be more likely to support such initiatives. This suggests that agrivoltaics, by reducing the environmental impact of farming practices, could increase farmer satisfaction and public support. As such, agrivoltaics presents a promising solution for the future of farming in Adana, offering both economic and environmental benefits.

Numerous cities with comparable weather conditions to Adana have successfully implemented solar energy systems in agriculture and healthcare sectors. In Egypt, the Ministry of Agriculture and Land Reclamation initiated a project to install solar panels in agricultural lands, aiming to generate electricity and reduce water evaporation [2]. Similarly, Saudi Arabia implemented a solar-powered irrigation system in agricultural lands to diminish water consumption and elevate crop yield [3]. A significant case study in Australia is the Warwick Solar Farm in Queensland, boasting a capacity of 154 MW and providing electricity to power 64,000 homes. Integrated with an existing irrigation system, the farm supports sustainable agriculture practices and offers an additional revenue stream for farmers [4]. In Morocco, the "Green Mosques" program was introduced to equip mosques with solar panels, effectively reducing energy consumption by up to 40% in over 600 mosques across the country [5]. In Japan, a solar-powered desalination plant in the city of Akita utilizes solar energy to desalinate seawater, providing a reliable source of water and reducing the city's dependence on imported water [6]. Additionally, in 2004, Akira Nagashima, a Japanese engineer, introduced the concept of "solar sharing". He designed test fields with varying shadowing rates based on each crop's light saturation point, which can be observed in Fig 1. The excess solar radiation, not used by the plants, was harnessed by photovoltaic systems to generate electricity.

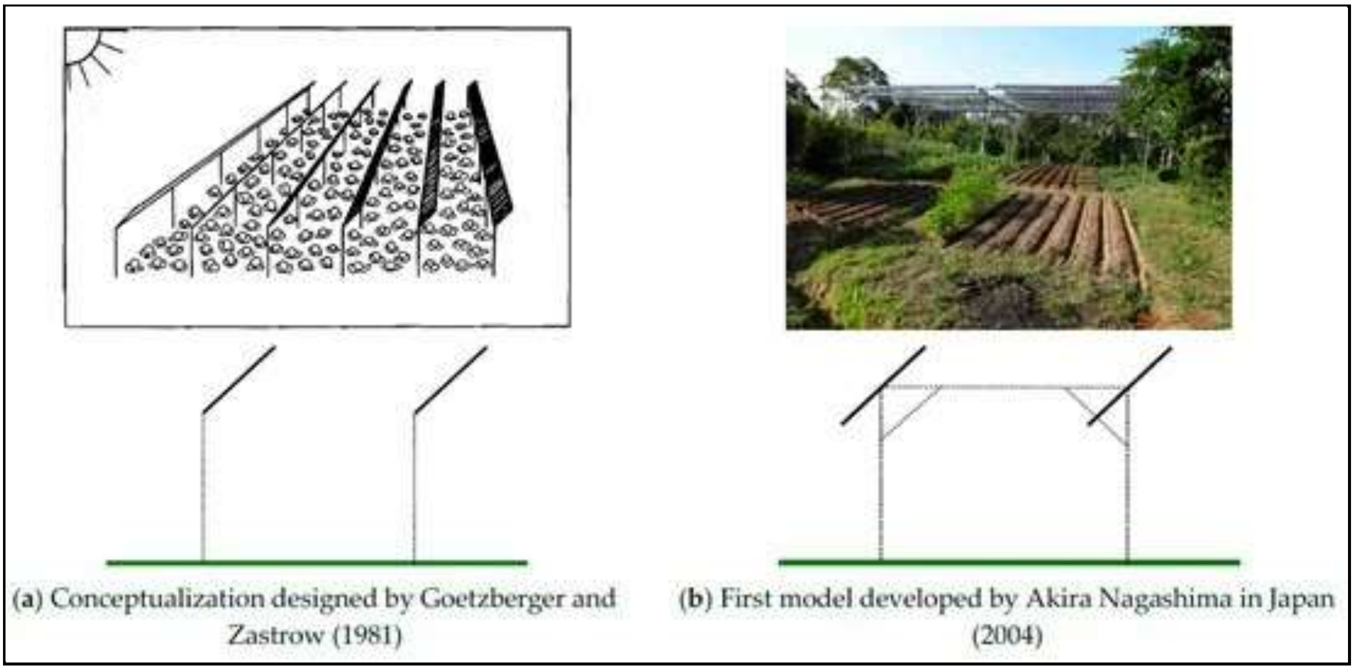


Fig. 1 First models of agrivoltaic systems.

*4Es Analysis Background*

To truly enhance system performance, we use the comprehensive 4Es Analysis. This approach includes Energy, Exergy, Economic, Environment, and Sustainability, offering a comprehensive view of a system. Each aspect of the 4E's Analysis provides unique insights into the system's efficiency, cost-effectiveness, environmental impact, and long-term viability.

Energy analysis helps us understand how efficiently a system is using its energy. Every system, whether it's a power plant, a manufacturing process, or a transportation network, consumes energy. But not all systems use this energy efficiently. Some may waste a significant portion of their energy due to inefficiencies in design or operation. By identifying where energy is being wasted, we can make changes to improve energy efficiency. This can lead to cost savings and is also better for the environment.

While energy analysis looks at the quantity of energy, exergy analysis focuses on the quality or usefulness of that energy. Not all forms of energy are equally useful; some can do more work than others. For example, electrical energy is a high-quality form of energy because it can be converted into other forms of energy with very little loss. On the other hand, thermal energy is a lower-quality form of energy because a lot of it is usually wasted as heat. By conducting an exergy analysis, we can understand where the system is wasting high-quality energy and suggest improvements. It helps us identify where improvements can be made to make better use of the available energy. This can increase the overall efficiency of the system and reduce waste.

Economic analysis helps us understand how efficiently a system is using its resources. Every system has a limited amount of resources. But not all systems use these resources efficiently. Some may waste a significant portion of their resources due to inefficiencies in design or operation. By identifying where resources are being wasted, we can make changes to improve economic efficiency. This can lead to cost savings.

Environmental analysis focuses on assessing the environmental impact of a system's operations. It's not just about the quantity or quality of resources used, but also about the emissions and waste produced by the system. For example, it evaluates the carbon footprint of a product or a process, helping to identify the key points where the most significant emissions occur and how to improve it.

Sustainability analysis is an in-depth process that does not just focus on the immediate consumption of resources, but also considers the long-term effects of such usage.

*4E's Analysis of Agricultural Application in Adana*

Adana, located in the Çukurova Region of Turkey, has rich agricultural resources. The region is enriched and irritable with the silt carried by Seyhan (the ancient Sarus River), Ceyhan, and Berdan rivers. The city dedicates 38% of its 1,403,000 ha (hectares) to agricultural land, with 73% of it irrigated, making it a fertile ground for diverse crop production. Adana leads in the production of citrus, watermelon, soya, grapefruit, peanut, and many other crops in Turkey. Furthermore, since 2018, sustainable practices have been adopted with 167 farmers practicing Organic Agriculture on 100.000 acres of land, focusing mainly on olive, sunflower, pomegranate, and citrus fruits. In terms of export value, TURKSTAT data from 2018 shows that food and agricultural products produced in Adana had an export value of $536,306,845, marking a 9.1% increase from the previous year and doubling the rate of food and agricultural exports in Turkey.

Adana has much potential for renewable energy. The region has a high solar potential, with an average of 2,800 hours of sunshine per year. There is also a significant potential for wind energy, with average wind speeds of 5.5 to 6.5 meters per second. Additionally, there is a potential for geothermal energy, with temperatures of up to 100 degrees Celsius. Currently, the main sources of energy in Adana are oil, gas, and coal. However, the use of renewable energy sources is increasing in the region, and there is much potential for further development.

Adana has an average of 300 sunny days per year, which makes it an ideal location for solar energy. According to our calculations, Adana has a solar potential of 30,000 GWh per year, which is equivalent to the energy produced by ten nuclear power plants. If Adana were to harness just 10% of this potential, it would be able to generate 3,000 GWh of electricity per year.

Below, Figure 2 shows the geographical map of Adana for solar radiation, highlighting the areas with the highest potential for solar energy generation. It displays the amount of solar energy received by different parts of Adana, making it easier for users to determine the most suitable locations for solar panel installation. This information can be valuable for those looking to invest in solar energy in Adana or for those interested in sustainable energy solutions.


Fig. 2 Adana Solar Radiation Map: A Geographical Overview [12].

Fig. 3 demonstrates the global radiation values (in Kn), sunbathing times (in hours), and potential energy (in kWh/year) that can be produced in Adana, Turkey. The first graph shows that the highest global radiation values occur in June, July, and August, while the second graph shows that the highest sunbathing times occur in June and July. The table displays the amount of energy that can be produced per year using different types of solar panels (monocrystalline, polycrystalline, film series, and shapeless silicon) in a specific area (in m2). The values in the table range from 28,000 to 12,000 KWh/year.

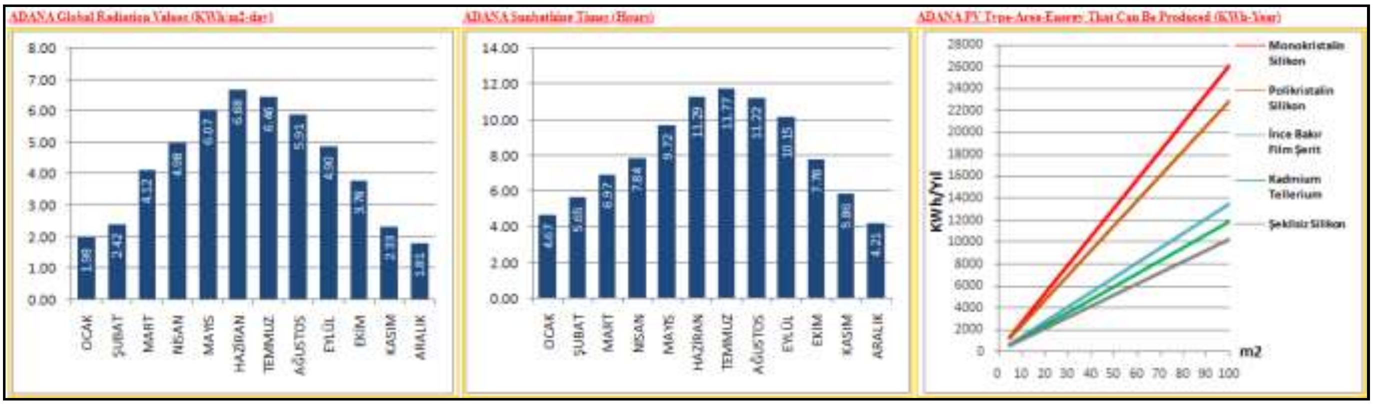


Fig. 3 Adana Solar Energy Production and Sunbathing Hours with Radiation Values [12].

Table 1. provides a comprehensive overview of the potential, current usage, key facts, benefits, and challenges of other types of renewable energy sources in Adana: wind, geothermal, and hydro energy. The information presented aims to provide insights into the opportunities and challenges in harnessing these resources, contributing to a sustainable and clean energy future for Adana.

Table 1. Energy Sources Potential, Key Facts, and Challenges in Adana, Turkey.

| Energy Source | Potential | Key Facts | Challenges |
|---|---|---|---|
| Wind Energy | 30,000 GWh/year | Turkiye ranks 7th in Europe and 12th in the world for installed wind power plant capacity. Adana has an average wind speed of 5.5 m/s, making it suitable for wind energy [7]. | Wind power must compete with other low-cost energy sources. |
| Hydro Energy | 1,500 GWh/year | Adana is home to several rivers and dams that contribute to its significant hydro-energy potential. Notably, the Seyhan River, which flows through the city, is harnessed by the Seyhan Dam. Other dams in the region include the Eski Baraj, Adana Kadincik Baraji, and Nergizlik Barajı These water resources make Adana a suitable location for hydro energy generation [8]. | Hydro energy projects in Adana are complicated by its earthquake-prone location, requiring careful planning and safety measures to mitigate seismic risks, potentially increasing project complexity and costs. |
| Geothermal Energy | 1,200 MW/year | Adana is located in a region with significant geothermal potential. The General Directorate of Mineral Research and Exploration (MTA) of Türkiye is planning to drill a geothermal exploration well in the Adana province Karaisali district [9]. | Geothermal energy in Adana is challenged by high start-up costs and the risk of induced seismic activity due to its earthquake-prone location, which could lead to stricter drilling regulations. |

The 4ES analysis, which considers the four dimensions of Energy, Exergy, Economic, Environment, and Sustainability, was applied to the agricultural sectors in Adana. This comprehensive analysis provided a different view of the potential impact and benefits of harnessing renewable energy sources in these areas, considering not only the energy generation potential but also the economic, environmental impact, and the sustainability.

According to calculations and simulations, a 10kW solar panel array designed for agricultural applications in Adana is estimated to generate approximately 19,500 kWh of electricity annually. This estimation is derived by multiplying the power generated per day (10kW) by the number of operational hours per day (5.30 hours), and then by the total number of days in a year.

The projected exergy efficiency of the solar panel array is approximately 10%, with a corresponding levelized cost of energy (LCOE) of \$0.096/kWh. According to research from the National Renewable Energy Laboratory (NREL), the life cycle greenhouse gas emissions from solar photovoltaic (PV) systems are estimated to be around 40 g CO2eq/kWh. As a result, the anticipated carbon footprint of the solar panel array is calculated to be 780,000 g CO2eq/year or 780 metric tons of CO2eq/year based on an annual energy production of 19,500 kWh/year.

The analysis provides a comprehensive exploration of solar energy utilization, focusing on crucial parameters including solar radiation data and the technical specifications of a bifacial solar panel system. The photovoltaic setup, equipped with a tracking system with a capacity of 10 kW, operates within a dynamic range of daily solar radiation, averaging at 6.05 kWh/m². Annual solar radiation figures for both horizontal and tilted systems emphasize the system's efficiency, measuring at 203,573 and 228,085 MWh/m², respectively.

The focus of this study shifts to the advanced bifacial solar cells, known for their performance-driven characteristics. The 10kW system, consisting of 18 units and utilizing mono-S cells, achieves an impressive efficiency rate of 22.26% with a temperature coefficient of -0.30%. The TommaTech TT575 144TN10 bifacial solar panel system is highlighted for its exceptional conversion efficiency and durability. Equipped with self-cleaning, reflection-reducing glass featuring a specialized coating, it ensures consistent power output even in challenging conditions. Designed to withstand environmental pressures, it demonstrates resilience against wind loads of up to 2,400 Pa and snow loads of 5,400 Pa. With a positive power tolerance of 0 to +5W, straightforward installation, and supported by a 15 year product warranty and 30 year performance guarantee, this system exemplifies reliability and longevity in sustainable energy solutions.

Using exergy efficiency as a quantitative metric, the project’s ability to transform available energy resources into productive labor can be evaluated, offering a comprehensive assessment of the system's sustainability and functionality. The calculation used to determine the exergy efficiency is expressed as

$$\eta = \text{useful power output} / \text{solar power}$$

In a specific scenario where the solar panel area ($A_{pv}$) is 100 square meters, the solar irradiance (G) is 1,000 W/m2, and the temperature coefficient is 0.5, the solar power ($P_{solar}$) is calculated as 50,000 W. With a useful power output ($P_{out}$) of 30,000 W, the exergy efficiency (η) is determined to be 60%. Consequently, the exergy efficiency of the solar power system in Adana is evaluated to be 60%, indicating the effective transformation of 60% of the available solar energy into useful energy output. This metric serves as a valuable tool for assessing the overall sustainability and functionality of the solar power system and for identifying potential areas for enhancement.

Based on our calculations and simulations, it is estimated that a 100-kW solar power plant in Adana has the potential to generate approximately 182,500 kWh of electricity per year, considering an operational period of 5 hours per day for 365 days. The exergy efficiency of the solar power plant is projected to be around 10%, with a corresponding levelized cost of energy (LCOE) of $0.123/kWh. The sustainability index, derived from the exergy efficiency is 0.11. Additionally, the life cycle greenhouse gas emissions from solar photovoltaic (PV) systems, as determined by the National Renewable Energy Laboratory (NREL), are found to be approximately 40 g CO2eq/kWh. Consequently, the estimated carbon footprint of the solar power plant is calculated to be 6,000,000 g CO2eq/year or 6tCO2eq/year based on an annual electricity generation of 150,000 kWh/year.

The economic assessment of the project is a critical step in the decision-making process, providing a comprehensive evaluation of its financial feasibility and potential impact. This process employs mathematical techniques to compare the costs and benefits of the project, considering commercial, economic, and social aspects. Return on Investment (ROI) serves as a performance measure used to evaluate the efficiency of an investment or compare the efficiency of a number of different investments. It tries to directly measure the amount of return on a particular investment, relative to the investment’s cost. The ROI is calculated using the formula:

$$\text{ROI} = (\text{Net Profit} / \text{Cost of Investment}) \times 100\%,$$

where Net Profit is the gain from the investment minus the cost of the investment, and Cost of Investment is the total money spent on the investment. The acquisition cost of the photovoltaic panels is based on a power rating of 15,000 /10,000 watts at $1.5 per watt, resulting in a total cost of $22,500 / $15,000. The inverter, facilitating the conversion of direct current (DC) to alternating current (AC), incurs an expense of

$3,587. The racks, which serve as the structural framework for mounting the solar panels, entail a cost of $1,375 / $1925 (5 / 7 racks at $275 each). Additionally, the labor cost and installation, valued at $600, are bundled with the purchase of the photovoltaic panels. The total initial investment cost is estimated to be $28,612 for the 15kW system and $20,562 for the 10kW system.

Fig. 4 provides information on our photovoltaic system, including its power capacity, manufacturer, model, number of units, capacity factor, initial costs, and O&M (Operations and Maintenance) costs savings. It also includes data on electricity export rates, annual electricity exported to the grid, and electricity export revenue. It includes an electricity export rate of $0.10 per kWh, resulting in an annual electricity export revenue of $1.950.

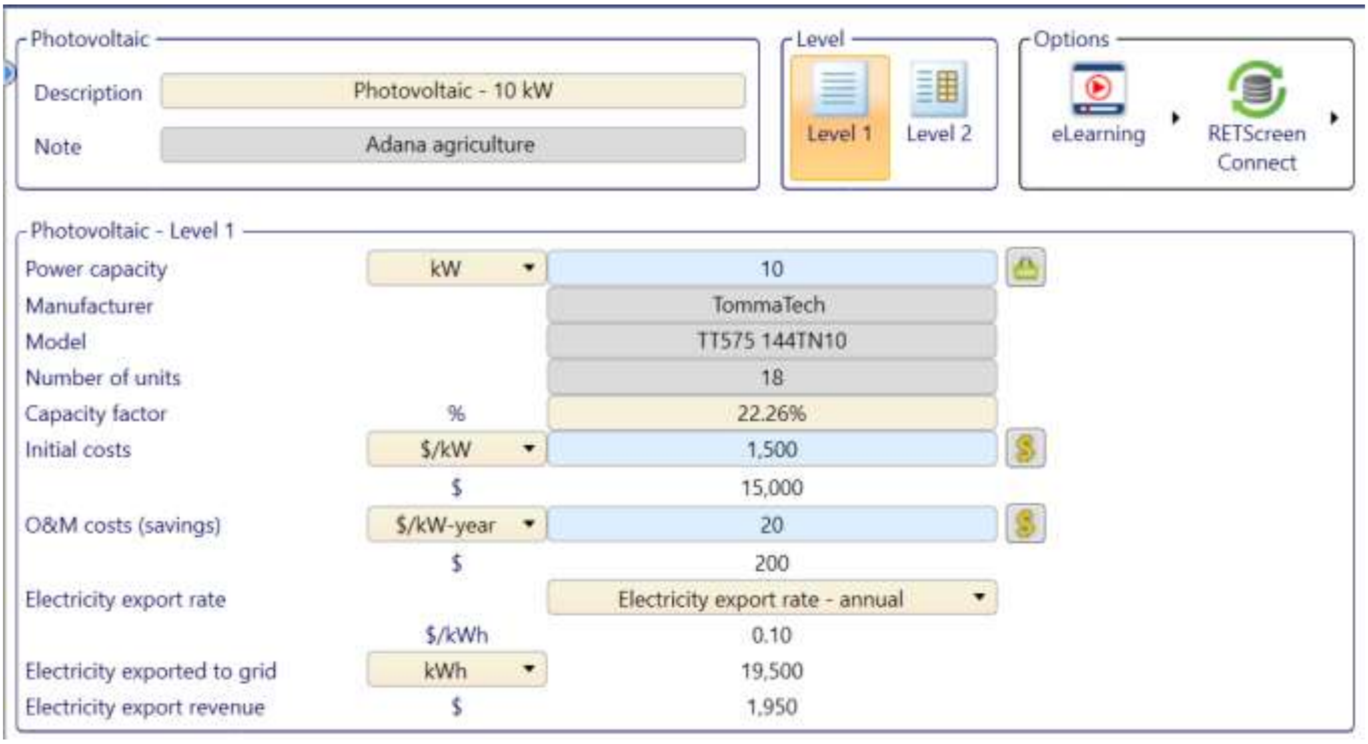


Fig. 4 Photovoltaic System Information and Financial Analysis.

Fig. 5 presents an emission analysis of the base case electricity system (Baseline) in the context of our research study focused on energy and environmental considerations. It specifically examines the electricity exported to the grid, encompassing all fuel types. The figure provides data on the GHG (Greenhouse Gas) emission factor (excluding T&D - Transmission and Distribution) in tCO2/MWh, which is measured at 0.464. Additionally, it indicates the GHG emissions for the base case, displaying the gross annual GHG emission reduction proposed in tCO2 and tCO2eq (CO2 equivalent) at 97 and 0.68 respectively. It further illustrates the reduction percentage in GHG emissions, which is recorded at 93%. It also includes details on T&D (Transmission and Distribution) losses, represented as a percentage (7.0%), and the corresponding GHG emission factor in tCO2/MWh, which is 0.499. The proposed case is also presented, featuring the GHG emissions and the gross annual GHG emission reduction, which stands at 0.68 tCO2 and 9.1 tCO2eq. Notably, the proposed case shows a 93% reduction in gross annual GHG emissions, as indicated in the legend. Furthermore, it provides context for the impact of the GHG emission reduction, stating that the reduction of 9.1 tCO2 is equivalent to the amount of emissions produced by cars and light trucks not being used.

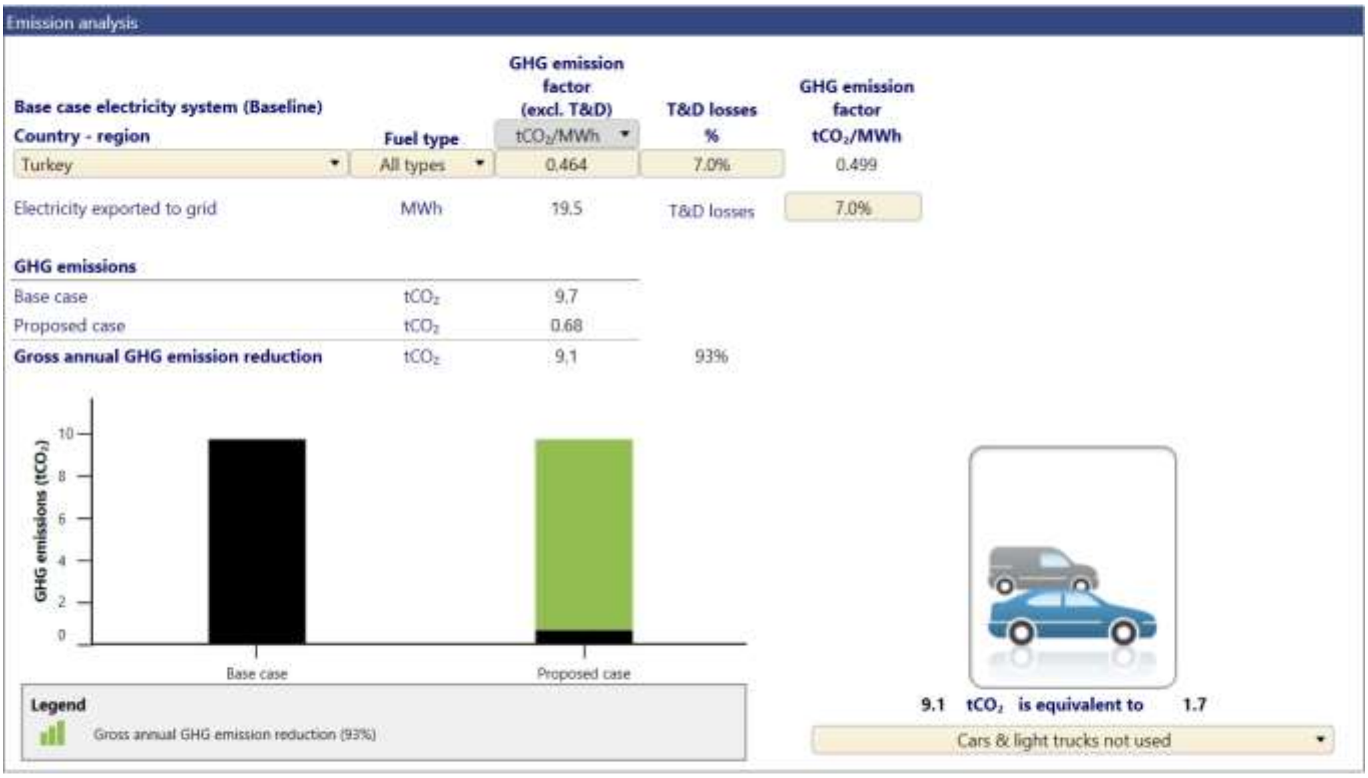

Fig. 5 Base Case Electricity System GHG Emission Reduction.

Fig. 6 provides a financial analysis for our study, including data on debt, equity, debt interest rate, debt term, and debt payments. It also includes income tax analysis data. Additionally, the table shows annual savings and revenue, including electricity export revenue, GHG reduction savings, and clean energy production revenue. The total annual savings and revenue are calculated, as well as the net yearly cash flow for Year 1. The financial viability of the project is analysed using pre-tax IRR (Internal Rate of Return), pre-tax MIRR (Modified Internal Rate of Return), simple payback, equity payback, net present value (NPV), and benefit-cost (B/C ratio). It also includes data on debt service coverage, GHG reduction costs, and energy production costs. The data is provided for the first 20 years of the project.

| Financial parameters | | |
|---|---|---|
| **General** | | |
| Fuel cost escalation rate | | 0% |
| Inflation rate | % | 2% |
| Discount rate | % | 9% |
| Reinvestment rate | % | 9% |
| Project life | yr | 20 |
| **Finance** | | |
| Incentives and grants | $ | 0 |
| Debt ratio | % | 7% |
| Debt | $ | 1,050 |
| Equity | $ | 13,950 |
| Debt interest rate | % | 7% |
| Debt term | yr | 20 |
| Debt payments | $/yr | 99.11 |
| **Income tax analysis** | | ☐ |

| Annual savings and revenue | | |
|---|---|---|
| **Electricity export revenue** | | |
| Electricity exported to grid | kWh | 19,500 |
| Electricity export rate | $/kWh | 0.10 |
| Electricity export revenue | $ | 1,950 |
| Electricity export escalation rate | % | 2% |
| **GHG reduction savings** | | |
| Gross GHG reduction | $tCO_2/yr$ | 9 |

| Costs \| Savings \| Revenue | | | |
|---|---|---|---|
| **Initial costs** | | | |
| Initial cost | 100% | $ | 15,000 |
| **Total initial costs** | **100%** | **$** | **15,000** |
| **Yearly cash flows - Year 1** | | | |
| **Annual costs and debt payments** | | | |
| O&M costs (savings) | | $ | 200 |
| Debt payments - 20 yrs | | $ | 99 |
| **Total annual costs** | | **$** | **299** |
| **Annual savings and revenue** | | | |
| Electricity export revenue | | $ | 1,950 |
| GHG reduction savings | | $ | 0 |
| CE production revenue | | $ | 0 |
| **Total annual savings and revenue** | | **$** | **1,950** |
| **Net yearly cash flow - Year 1** | | **$** | **1,651** |

| Financial viability | | |
|---|---|---|
| Pre-tax IRR - equity | % | 12.4% |
| Pre-tax MIRR - equity | % | 10.4% |
| Pre-tax IRR - assets | % | 11.4% |
| Pre-tax MIRR - assets | % | 10% |
| Simple payback | yr | 8.6 |
| Equity payback | yr | 7.7 |

| Yearly cash flows | | |
|---|---|---|
| **Year** | **Pre-tax** | **Cumulative** |
| # | $ | $ |
| 0 | -13,950 | -13,950 |
| 1 | 1,686 | -12,264 |
| 2 | 1,722 | -10,543 |
| 3 | 1,758 | -8,785 |
| 4 | 1,795 | -6,989 |
| 5 | 1,833 | -5,156 |
| 6 | 1,872 | -3,285 |
| 7 | 1,911 | -1,374 |
| 8 | 1,951 | 577 |
| 9 | 1,992 | 2,570 |
| 10 | 2,034 | 4,604 |
| 11 | 2,077 | 6,681 |
| 12 | 2,120 | 8,801 |
| 13 | 2,165 | 10,966 |
| 14 | 2,210 | 13,176 |
| 15 | 2,256 | 15,432 |
| 16 | 2,303 | 17,735 |
| 17 | 2,351 | 20,086 |
| 18 | 2,400 | 22,486 |
| 19 | 2,450 | 24,937 |
| 20 | 2,501 | 27,438 |

Fig. 6 Financial Analysis.

The implementation of solar energy systems in agriculture and healthcare sectors can yield substantial environmental and social impacts. Solar panels have the potential to reduce greenhouse gas emissions, lower water consumption, and enhance land productivity. However, the installation of solar panels may also present challenges such as land-use conflicts, soil degradation, and wildlife displacement. In the healthcare sector, the integration of solar panels can ensure uninterrupted power supply during outages, reduce energy costs, and enhance the quality of healthcare services. Nonetheless, the installation of solar panels may entail high initial costs, ongoing maintenance expenses, and the need for technical expertise.

## III. Results

These results provide valuable insights into the potential of solar energy in Adana and lay the groundwork for further research and development in this area. The results of our study indicate that Adana possesses significant potential for renewable energy, particularly solar, wind, and geothermal energy. With an average of 2,800 hours of sunshine per year and average wind speeds of 5.5 to 6.5 meters per second, Adana presents a promising environment for harnessing solar and wind energy. Additionally, the region's geothermal energy potential, with temperatures reaching up to 100 degrees Celsius, further adds to its diverse range of energy resources for sustainable energy production.

Furthermore, our techno-economic assessment of different solar technologies, including photovoltaic (PV) and concentrated solar power (CSP) systems, revealed that PV systems are more cost-effective than CSP systems for solar energy production in Adana. The assessment factored in capital cost, operating cost, and levelized cost of electricity (LCOE) for each technology. The simulation results using RetScreen Software demonstrated that Adana has the potential to generate approximately 30,000 GWh of electricity per year from solar energy. This amount is equivalent to the energy output of ten nuclear power plants. Even harnessing just 10% of this potential could yield 3,000 GWh of electricity per year, showcasing the substantial solar energy generation capacity of the region. In evaluating the environmental and social impacts of solar energy production in Adana, our study found that solar energy production has minimal environmental impact compared to traditional energy sources such as coal and gas. The assessment considered factors such as land use, water consumption, and carbon emissions. Additionally, solar energy production has the potential to create job opportunities and enhance the quality of life for the local population.

## IV. DISCUSSION

The findings of this study present a significant advancement in understanding the potential of solar energy integration in Adana, Turkey. The results demonstrate the feasibility and benefits of incorporating solar energy technologies in various sectors, including agriculture, healthcare, residential, industrial, and educational institutions. The comprehensive analysis of Adana's solar energy potential using the 4E's analysis framework and RetScreen Software has provided valuable insights into the energy, exergy, economic, and environmental aspects of solar energy utilization in the region.

Comparing these findings with prior research indicates a consistent trend towards recognizing solar energy as a viable and sustainable alternative to traditional energy sources. The literature review revealed similar studies that highlighted the potential of solar energy in Adana, particularly in the context of agricultural land use and its capacity for solar energy generation. The results of this study align with previous research, emphasizing the significant energy and environmental benefits of integrating solar panels into agricultural practices. Moreover, the examination of solar energy applications in hospitals, residential areas, industrial sectors, and educational institutions corroborates the potential for solar energy to meet a substantial portion of energy demand across diverse sectors in Adana.

Furthermore, the findings of this study contribute to the broader scientific understanding of solar energy integration by presenting a holistic assessment of various technological, ethical, environmental, and social implications. The discussion of integrating solar energy in agriculture for irrigation, cooling, and lighting, as well as its potential to enhance healthcare facilities and reduce electricity costs, underscores the multifaceted advantages of solar energy beyond electricity generation. These interpretations provide a clear step forward in scientific understanding by emphasizing the need for innovative solutions to maximize the benefits and mitigate the challenges associated with solar energy utilization.

## V. CONCLUSION

Our study has demonstrated the significant potential for solar energy integration in Adana with an average of 2,800 hours of sunshine per year, particularly in the agricultural sector. The analysis conducted using the 4E's framework and RetScreen Software has highlighted the economic feasibility, environmental benefits, and energy optimization potential of solar energy in meeting the city's energy demand. The literature review has provided valuable insights into existing research on solar energy in Adana, emphasizing the diverse range of sectors that can benefit from solar energy integration. It has also underlined the potential of agrivoltaics in Adana, showcasing how the integration of solar panels in agricultural lands can not only contribute to renewable energy generation but also enhance land productivity and provide an additional source of income for farmers. Furthermore, the investigation into integrating solar panels in healthcare facilities has revealed the potential for energy independence and cost reduction, emphasizing the broader societal impact of solar energy integration.

The findings of this study underscore the importance of exploring innovative solutions to maximize the benefits of solar energy while addressing its challenges. The geographical positioning of Adana provides a compelling case for investment in solar energy infrastructure, given its abundant solar resources and growing energy demand. The diverse applications of solar energy presented in this study highlight the multifaceted advantages of solar energy integration, encompassing economic, environmental, and social dimensions.

In conclusion, this study serves as a comprehensive guide for stakeholders and policymakers in Adana to recognize the potential of solar energy and formulate strategies for its effective integration. By leveraging solar energy solutions, Adana can move towards a more sustainable and resilient energy future, while simultaneously fostering economic development and environmental conservation. The insights provided in this study lay the groundwork for further research, development, and implementation of solar energy projects in Adana, contributing to the broader goal of transitioning towards a more sustainable energy landscape.

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