RESEARCH ARTICLE

International Journal of Agriculture, Environment and Food Sciences 2023; 7(1): 156-162
DOI: https://doi.org/10.31015/jaefs.2023.1.19

Techno-economic analysis of a solar-powered agricultural irrigation system using PV*Sol software: A case study in Konya

Mehmet Ali Biberci[1]

[1] Mechanical Engineering Department, Engineering Faculty, Cankiri, Türkiye

Citation: Biberci, M.A. (2023). Techno-economic analysis of a solar-powered agricultural irrigation system using PV*Sol software: A case study in Konya. International Journal of Agriculture, Environment and Food Sciences, 7 (1), 156-162

Received: 29 January 2023
Revised: 24 February 2023
Accepted: 26 February 2023
Published Online: 12 March 2023

Correspondence: Mehmet Ali Biberci
E-mail: m.alibiberci@karatekin.edu.tr

Abstract

Agricultural irrigation is essential for crop growth and yield, but traditional irrigation systems are often associated with high costs, energy consumption, and negative environmental impacts. The development of alternative irrigation systems, such as solar-powered systems, has gained increasing attention in recent years. In this study, a techno-economic analysis of a grid-connected solar photovoltaic (PV) system was carried out for the electrical energy needed in irrigation of an agricultural area located in Konya, Turkiye. The electrical energy produced by the solar energy system was used to meet the energy needs of the electrical equipment and the water pumping system required for agricultural irrigation. According to the simulation results, the annual energy requirement for agricultural irrigation is 6,735 kWh and the peak load is 2.1 kW. In addition, in line with the simulation results, the PV system can feed the load with a self-consumption of 15.9%, a self-sufficiency level of 46.6% and a performance rate of 83% when the desired rate is set as 115% for a year reference period. When the financial analysis of the simulation is examined, it is estimated (or computed) that an asset return of 9.14% and a depreciation period of 8.7 years. The annual gain loss of the energy system due to shading is 1.5% and the annual CO_2 emission prevented by the system is 9.201 kg. Considering these results, it could be stated that the proposed energy system is technically and economically appropriate for agricultural irrigation systems. At the same time, these results might provide valuable insights for farmers and policymakers seeking to adopt sustainable and cost-effective irrigation systems for agricultural production.

Keywords: Agricultural irrigation, Solar-powered systems, PV*Sol, Techno-economic analysis

INTRODUCTION

Agriculture is a critical sector for the economies of many countries and water for irrigated agriculture is essential for crop growth and increasing yield (Mancosu et al., 2015; Özhüner, 2020a, 2020b, 2022). Agricultural irrigation is, thus, an essential part of agricultural production in arid and semi-arid regions where rainfall is limited, and it accounts for over 70% of global water use (Deng et al., 2006; Wallace, 2000). Traditional irrigation systems such as flood irrigation, furrow irrigation and sprinkler irrigation have been used for centuries to provide water to crops (Hassanli et al., 2010; Jensen, 2007). However, these methods have several drawbacks including high water loss due to evaporation and runoff, high energy consumption and dependence on unreliable power sources. In recent years, solar-powered irrigation systems have emerged as an alternative solution that can overcome some of these challenges. The photovoltaic design and simulation (PV*Sol) program is a tool that can be used to design and analyze the techno-economic feasibility of solar-powered agricultural irrigation systems (Arnell, 1999; Nkuriyingoma et al., 2022).

Traditional irrigation systems involve the application of water to crops using gravity or pumps. Flood irrigation which is the oldest and simplest method involves flooding the fields with water and allowing it to infiltre in. However, this method is highly inefficient due to fact that much of the water is lost by evaporation and runoff (Kamwamba-Mtethiwa et al., 2016; McNabb, 2019). Furrow irrigation is also similar to flood irrigation, but water is applied through trenches or furrows. Sprinkler irrigation involves the use of sprinklers to distribute water over the crops. This method is more efficient than flood and furrow irrigation but still suffers from high water loss due to evaporation and wind drift (Fahong et al., 2004; Fahong et al., 2004). Some irrigation systems require energy using electricity or diesel and this is quite expensive (Hassan and Kamran, 2018). In contrast, solar-powered irrigation systems use solar energy to power water pumps, which can significantly reduce operating costs and increase water availability for agriculture. These systems consist of photovoltaic (PV) panels that convert solar energy into electrical energy, which is used to power the water pumps. The PV*Sol program is a simulation software tool that can be used to design and analyze the technical and economic feasibility of such systems (Kazem et al., 2017; Ikram et al., 2021).

The PV*Sol program takes into account variables such as solar irradiation, temperature, and shading effects to predict the output power and energy yields of the PV system. This tool enables designers to assess the expected performance of PV systems under different climatic conditions geographical locations (Dondariya et al., 2018; Milosavljević et al., 2022). The PV*Sol program can be used to determine the optimal design and configuration of the PV system including the sizing and selection of PV modules, inverters, batteries, and other components (Alsadi & Khatib, 2018; Mohanty et al., 2016). Additionally, the PV*Sol program can be used to estimate the energy demand for pumping water for irrigation and the resulting cost savings compared to traditional irrigation methods. The use of solar-powered irrigation systems with the PV*Sol program has several advantages over traditional irrigation methods. Solar-powered irrigation systems are more efficient and have lower energy consumption compared to traditional methods. Additionally, these systems are environmentally friendly, as they do not produce any greenhouse gas emissions. Furthermore, solar-powered irrigation systems can reduce dependence on unreliable power sources and provide a reliable source of water for agriculture (Biberci et al., 2018; Deveci et al., 2015; Grant et al., 2022).

This study presents a techno-economic analysis of a solar-powered agricultural irrigation system using the PV*Sol program. The PV*Sol program was used to model the energy output of the solar panels, estimate the water requirements of the crop and determine the economic feasibility of the system. The results of the study provide valuable insights into the feasibility and economic benefits of solar-powered irrigation systems for farmers.

MATERIALS AND METHODS

Selection of the energy system simulator

Techno-economic analysis of a solar-powered agricultural irrigation system was made using the PV*Sol program. The design concept is important in the selection of the simulation program. Because some functional tools are needed to simulate and optimize the designed system. PV*Sol software offers many advanced structures to simulate the generated energy system. While it enables us to model the electrical and mechanical structure of the energy system in detail, it also provides detailed technical specifications. Many engineers, planners, architects, installers and technicians around the world use PV*Sol software to design and build efficient PV energy systems (Bocullo et al., 2023).

Energy system location

The place where the photovoltaic system will be installed depends on certain parameters. These parameters can be determined as solar radiation value, amount

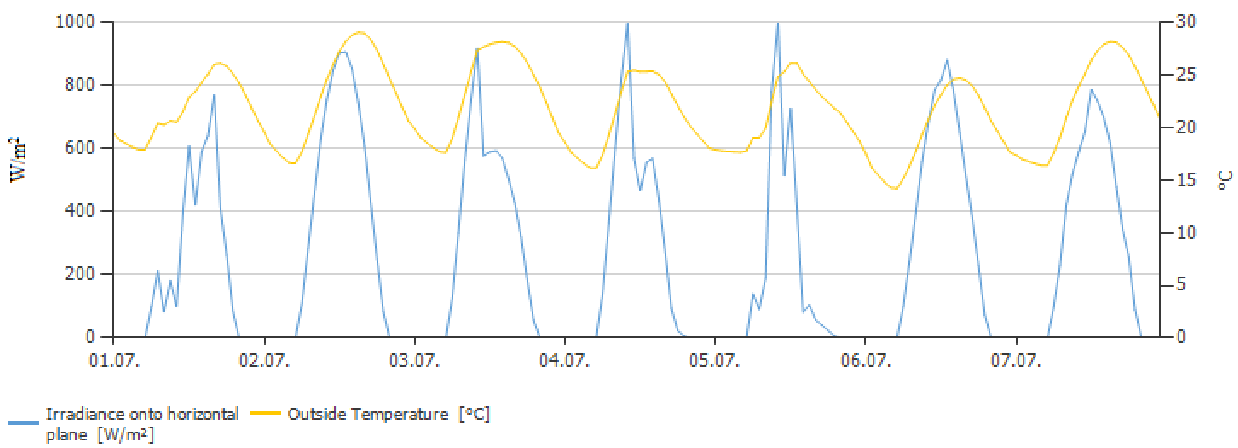

Figure 1. Horizontal radiation and outside temperature values for the first week of July for the selected location.

of shading and proximity to the consumer. For this reason, the location where the system will be installed is very important in terms of performance and efficiency (Kayhan et al., 2015).

The solar energy system to be established in this study was realized in Karatay district of Konya province. The reason for choosing this location is that it has an average temperature of 12 °C, and a high solar radiation value of 1763kWh/m^2 (Nkuriyingoma et al., 2022; *Climate Data (Calculation) :: PV*SOL® Help*, n.d.). At the same time, the lack of slope of the installed land is an important parameter in choosing the determined location. Horizontal radiation and outside temperature values for the first week of July for the selected location are shown in Figure 1.

Load Profile

Load profiles are usually determined by the hourly or demanded energy needs (Kamber et al., 2021). Within the scope of this study, the annual energy consumption of 6735 kWh required to irrigate an area of approximately 36 ha between April and September has been determined as the amount of consumption. The load profile distribution for the specified time interval is given in Figure 2.

Energy system configuration

Photovoltaic panels are a component that converts solar energy into direct current (Tunçer, 2022). Photovoltaic panel selection is usually made by taking into account the demanded power and losses. For this study, panel layout configuration was made using the model mounting section in the PV*Sol software, and 48 panels of ECSOLAR ECS-250P60 model with 250 W power were selected as the PV panel. The inverter, which is another component of modulation, converts the direct current (DC) coming from the PV modules to alternating current (AC) and supplies the systems working with AC current (Yinanç, 2022). Three Schneider Electric Conext RL 3000E brand inverters were selected as inverters. In Figure 3, the circuit diagram including these components as well as wiring and other electrical equipment is given in detail.

Financial analysis

Financial analysis is made to decide whether the

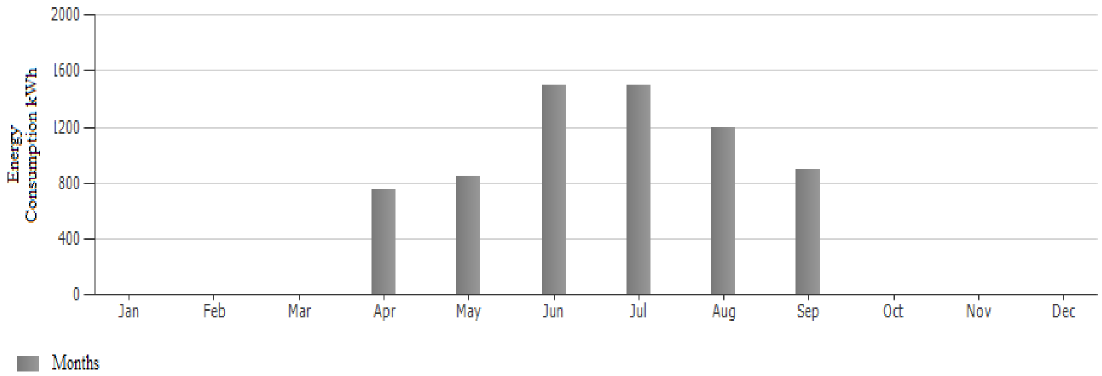

Figure 2. The load profile distribution for the specified time interval.

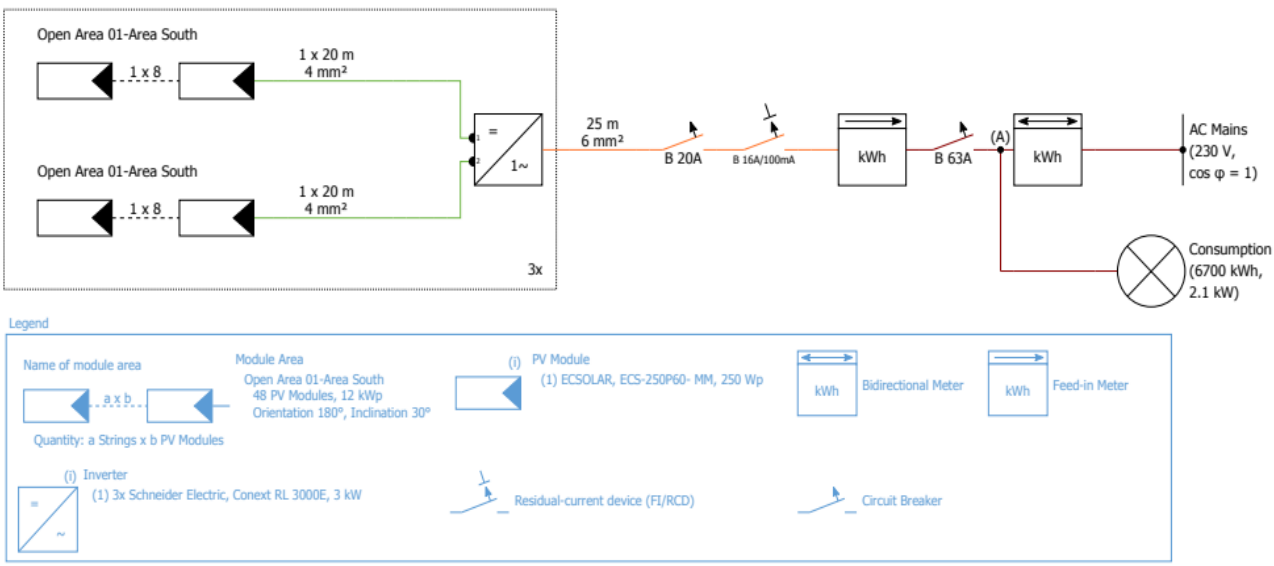

Figure 3. Circuit diagram including these components as well as wiring and other electrical equipment.

investment in the solar energy system is economically worthwhile. PV*Sol software allows financial analysis for the specified system. Financial analysis can be, thus, made by entering the price of electricity sold, net metering tariffs, inflation rate for energy price and general installation and operating costs into the software. The financial analysis parameters used in this study are given in Table 1.

Table1. Financial analysis parameters.

Economic life	20 year
Outgoing cost of system setup parts and labor	775 US$/kWp
Operation and maintenance cost	1% of investment
Net metering tariffs (energy sale price to the consumer)	Consumption type: residential (0.19 US$/kWh)
Inflation rate for energy price	2.7%/year

of solar radiation, the impact of shading on the solar panels, and the availability of water resources. These factors can have a significant impact on the performance and cost-effectiveness of the system, and should be carefully considered when evaluating the feasibility of a solar-powered irrigation system.

The solar energy system is designed as Grid-connected PV System with Electrical Applications type in order to meet the energy need for agricultural irrigation and to sell the excess energy to the grid. A design configuration specific to the determined location has been created. In this direction, the system that was first installed was chosen in a place close to the consumer. When the Konya region is examined, irrigation costs increase due to the fact that agricultural irrigation is too much, in this case, it is reflected in the producer costs. Thus, the energy costs used increase the price and cost of the product considerably. For this reason, in this study, a solar energy system was modeled and simulated to meet the electrical energy needs of two 10 horsepower (hp) irrigation pumps used for irrigation of an agricultural area of 36 ha. All of the excess energy produced in this simulated system feeds the grid. A general summary of the simulation results is presented in Table 2.

RESULTS AND DISCUSSION

The use of solar power for agricultural irrigation systems has several advantages, including reduced reliance on fossil fuels, lower operating costs, and reduced greenhouse gas emissions. However, the initial capital cost of setting up a solar-powered system can be a barrier for many farmers, particularly those in developing countries. The techno-economic analysis presented in this study provides useful information for farmers and policymakers in evaluating the feasibility and cost-effectiveness of a solar-powered irrigation system (Guno and Agaton, 2022).

The use of the PV*Sol program to conduct the techno-economic analysis is an effective approach, as it provides a detailed assessment of the system's performance and costs. However, the analysis could be further improved by considering additional factors, such as the variability

Table 2. Simulation results of total system.

PV System	Value	Unit
PV Generator Output	12	kWp
Spec. Annual Yield	1,631.38	kWh/kWp
Performance Ratio (PR)	83.0	%
Yield Reduction due to Shading	1.5	%/Year
PV Generator Energy (AC grid)	19,612	kWh/Year
Down-regulation at Feed-in Point	0	kWh/Year
CO_2 Emissions Avoided	9,201	kg / year
Appliances	Value	Unit
Appliances	6,700	kWh/Year
Standby Consumption (Inverter)	35	kWh/Year
Total Consumption	6,735	kWh/Year
Power Surplus	12,876.6	kWh
Solar Fraction	291.2	%
Level of Self-sufficiency	Value	Unit
Total Consumption	6,735	kWh/Year
Covered by Grid	3,596	kWh/Year
Level of Self-sufficiency	46.6	%

Agricultural irrigation activities are carried out in the selected region in April-September. The realized PV energy system is configured to meet the amount of energy demanded by the consumer even when the sunshine duration is low and the least energy is produced. In addition, shading analyzes were made during the design and it was ensured that shading was at the minimum level. The selection of each part used in the PV energy system has been optimized and thus the best efficiency has been obtained from each part. At the same time, each of the parts used with the benefit of optimization has been selected to meet the minimum needs of the system. In this case, it allows us to avoid excessive parts costs. The parts list is given in Table 3.

Table 3. Part list of PV*Sol system.

Number	Type	Manufacturer	Name	Quantity	Unit
1	PV Module	ECSOLAR	ECS-250P60- MM	48	Piece
2	Inverter	Schneider Electric	Conext RL 3000E	3	Piece
3	Cable		String Cable 4 mm^2 Copper	120	m
4	Cable		AC cables 1-phase 6 mm^2 Copper	75	m
5	Components		Feed-in Meter	1	Piece
6	Components		Circuit Breaker B 63A	1	Piece
7	Components		Bidirectional Meter	1	Piece
8	Components		Circuit Breaker B 20A	3	Piece
9	Components		Circuit Breaker B 20A	3	Piece

In this study, the annual energy requirement for agricultural irrigation is 6,735 kWh and the peak load is 2.1 kW. In addition, when the PV system is determined as 115% in accordance with the simulation carried out, the simulation gives the most appopriate and optimum results. In line with these results, the PV system can feed the load with a self-consumption of 15.9%, a self-sufficiency level of 46.6% and a performance rate of 83% for a one-year reference period. According to the result of the financial analysis of the simulation, it could be stated that there is a return on assets of 9.14% and a depreciation period of 8.7 years. The annual energy loss of the energy system due to shading is 1.5% and the annual CO_2 emission eliminated by the system is 9,201 kg.

The amount of consumption (load) demanded by the consumer was directly requested from the energy system. The grid was fed continuously with the excess electrical energy produced by the energy system. The energy flow of the system is shown in Figure 4.

Considering the simulation results, considering that the life of the PV energy system is 20 years, the depreciation period of 8.7 years is quite appropriate. Figure 5 shows the cash flow.

The change in energy cost developments by years before the PV system was installed (in blue) and after it was installed (in yellow) is shown in Figure 6. When Figure 6 is examined, it is observed that the energy cost has increased significantly over the years before the PV system was installed. After the PV system is installed, it is seen that the increase in energy costs has increased almost negligibly over the years.

CONCLUSION

In this study, the electrical and mechanical structures of the PV solar energy system required for an agricultural irrigation system were designed and simulated with PV*Sol software. For the system created, Karatay district of Konya province was selected. This location was chosen because of the high need for agricultural irrigation in this region. The excess of agricultural irrigation in the region increases the demand for electricity and energy costs. The load profile consists of two 10 hp irrigation pumps. The electrical energy needed for the pumps is required in April-September. On the day of irrigation, the pumps operate for 10 hours a day. Therefore, the annual energy requirement for agricultural irrigation is 6,735 kWh and the peak load is 2.1 kW. According to the simulation results, the PV system can feed the load with a self-consumption of 15.9%, a self-sufficiency level of 46.6% and a performance rate of 83% when the desired rate is set as 115% for a reference period of one year. When the financial analysis of the simulation is examined, it is seen that there is a return on assets of 9.14% and a depreciation period of 8.7 years. The annual gain loss of the energy system due to shading is 1.5% and the annual CO_2 emission prevented by the system is 9,201 kg.

The results of the techno-economic analysis presented in this study demonstrate the feasibility and cost-effectiveness of a solar-powered agricultural irrigation system. The PV*Sol program provides a valuable tool for evaluating the performance and costs of such systems, and can help farmers and policymakers make informed decisions about adopting renewable energy solutions for agricultural irrigation. Further research is needed to refine the analysis and to better understand the factors that can impact the performance and cost-effectiveness of solar-powered irrigation systems. Overall, this study highlights the potential of solar power to support sustainable agriculture and reduce greenhouse gas emissions in the agricultural sector.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

Funding

No financial support was received for this study.

Data availability

Not applicable.

Consent for publication

Not applicable.

REFERENCES

Alsadi, S., & Khatib, T. (2018). Photovoltaic Power Systems Optimization Research Status: A Review of Criteria, Constrains, Models, Techniques, and Software Tools. *Applied Sciences*, *8*(10), Article 10. https://doi.org/10.3390/app8101761

Arnell, N. W. (1999). Climate change and global water resources. *Global Environmental Change*, *9*, 31–S49. https://doi.org/10.1016/S0959-3780(99)00017-5

Biberci, M. A., Özhüner, E., & Çelik, M. B. (2018). Yenilenebilir Enerji Kaynaklarının Belediyelerde Kullanımı. *Şehir Düşünce Dergisi*, *11*, 80–93. (in Turkish)

Bocullo, V., Martišauskas, L., Pupeikis, D., Gatautis, R., Venčaitis, R., & Bakas, R. (2023). UAV Photogrammetry Application for Determining the Influence of Shading on Solar Photovoltaic Array Energy Efficiency. *Energies*, *16*(3), Article 3. https://doi.org/10.3390/en16031292

*Climate data (Calculation): PV*SOL® help*. (n.d.). Retrieved February 17, 2023, Retrieved from https://help.valentin-software.com/pvsol/en/calculation/irradiation/climate-data/

Deng, X.-P., Shan, L., Zhang, H., & Turner, N. C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. *Agricultural Water Management*, *80*(1), 23–40. https://doi.org/10.1016/j.agwat.2005.07.021

Deveci, O., Onkol, M., Unver, H. O., & Ozturk, Z. (2015). Design and development of a low-cost solar powered drip irrigation system using Systems Modeling Language. *Journal of Cleaner Production*, *102*, 529–544. https://doi.org/10.1016/j.jclepro.2015.04.124

Dondariya, C., Porwal, D., Awasthi, A., Shukla, A. K., Sudhakar, K., S.r., M. M., & Bhimte, A. (2018). Performance simulation of grid-connected rooftop solar PV system for small households: A case study of Ujjain, India. *Energy Reports*, *4*, 546–553. https://doi.org/10.1016/j.egyr.2018.08.002

Fahong, W., Xuqing, W., & Sayre, K. (2004). Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. *Field Crops Research*, *87*(1), 35–42. https://doi.org/10.1016/j.fcr.2003.09.003

Grant, F., Sheline, C., Sokol, J., Amrose, S., Brownell, E., Nangia, V., & Winter, A. G. (2022). Creating a Solar-Powered Drip Irrigation Optimal Performance model (SDrOP) to lower the cost of drip irrigation systems for smallholder farmers. *Applied Energy*, *323*, 119563. https://doi.org/10.1016/j.apenergy.2022.119563

Guno, C. S., & Agaton, C. B. (2022). Socio-economic and environmental analyses of solar irrigation systems for sustainable agricultural production. Sustainability, 14(11), 6834. https://doi.org/10.3390/su14116834

Hassan, W., & Kamran, F. (2018). A hybrid PV/utility powered irrigation water pumping system for rural agricultural areas. Cogent Engineering, 5(1), 1466383. https://doi.org/10.1080/23311916.2018.1466383

Hassanli, A. M., Ahmadirad, S., & Beecham, S. (2010). Evaluation of the influence of irrigation methods and water quality on sugar beet yield and water use efficiency. *Agricultural Water Management*, *97*(2), 357–362. https://doi.org/10.1016/j.agwat.2009.10.010

Ikram, H., Javed, A., Mehmood, M., Shah, M., Ali, M., & Waqas, A. (2021). Techno-economic evaluation of a solar PV integrated refrigeration system for a cold storage facility. *Sustainable Energy Technologies and Assessments*, *44*, 101063. https://doi.org/10.1016/j.seta.2021.101063

Jensen, M. E. (2007). Beyond irrigation efficiency. *Irrigation Science*, *25*(3), 233–245. https://doi.org/10.1007/s00271-007-0060-5

Kamber, E., Körpüz, S., Melih, C. A. N., Aydoğmuş, H. Y., & Gümüş, M. (2021). Yapay Sinir Ağlarina Dayali Kisa Dönemli Elektrik Yükü Tahmini. *Endüstri Mühendisliği*, *32*(2), 364–379.

Kamwamba-Mtethiwa, J., Weatherhead, K., & Knox, J. (2016). Assessing Performance of Small-Scale Pumped Irrigation Systems in sub-Saharan Africa: Evidence from a Systematic Review. *Irrigation and Drainage*, *65*(3), 308–318. https://doi.org/10.1002/ird.1950

Kayhan, V. A., Ulker, F., & Elma, O. (2015). Photovoltaic system design, feasibility and financial outcomes for different regions in Turkey. *2015 4th International Conference on Electric Power and Energy Conversion Systems (EPECS)*, 1–6. https://doi.org/10.1109/EPECS.2015.7368518

Kazem, H. A., Albadi, M. H., Al-Waeli, A. H., Al-Busaidi, A. H., & Chaichan, M. T. (2017). Techno-economic feasibility analysis of 1 MW photovoltaic grid connected system in Oman. Case studies in thermal engineering, 10, 131-141. https://doi.org/10.1016/j.csite.2017.05.008

Mancosu, N., Snyder, R. L., Kyriakakis, G., & Spano, D. (2015). Water Scarcity and Future Challenges for Food Production. *Water*, *7*(3), Article 3. https://doi.org/10.3390/w7030975

McNabb, D. E. (2019). Agriculture and Inefficient Water Use. In D. E. McNabb (Ed.), *Global Pathways to Water Sustainability* (pp. 99–115). Springer International Publishing. https://doi.org/10.1007/978-3-030-04085-7_7

Milosavljević, D. D., Kevkić, T. S., & Jovanović, S. J. (2022). Review and validation of photovoltaic solar simulation tools/software based on case study. *Open Physics*, *20*(1), 431–

451. https://doi.org/10.1515/phys-2022-0042

Mohanty, P., Muneer, T., Gago, E. J., & Kotak, Y. (2016). Solar Radiation Fundamentals and PV System Components. In P. Mohanty, T. Muneer, & M. Kolhe (Eds.), Solar Photovoltaic System Applications: A Guidebook for Off-Grid Electrification (pp. 7–47). Springer International Publishing. https://doi.org/10.1007/978-3-319-14663-8_2

Nkuriyingoma, O., Özdemir, E., & Sezen, S. (2022). Techno-economic analysis of a PV system with a battery energy storage system for small households: A case study in Rwanda. *Frontiers in Energy Research*, *10*.

Özhüner, E. (2020a). Bitkilerde kuraklık stres cevabında mikroRNA'ların rolü, 3. Uluslararası Mühendislik Bilimleri Ve Multidisipliner Yaklaşımlar Kongresi. (in Turkish)

Özhüner, E. (2020b). Tarımsal ve hayvansal ürünlerde biyoteknolojik uygulamalar. 9.Uluslararası Bilimsel Araştırmalar Kongresi. Ankara. (in Turkish)

Özhüner, E., K. Özrenk (Ed.) ve E.Küçüker, (Ed.) (2022), *CRISPR/CAS genome editing: Recent advances in abiotic stress response in plants*. Current Research in Agriculture, Forestry and Aquaculture (s. 43-57). Gece Kitaplığı Yaynevi.

Tunçer, B. (2022). Şebeke bağlantılı fotovoltaik güç sistemlerinin analizi, benzetimi ve boyutlandırılması [Master's Thesis]. Pamukkale Üniversitesi Fen Bilimleri Enstitüsü. (in Turkish)

Yinanç, D. M. (2022). Ordu İlinde Fotovoltaik Sistemin Zamana Bağlı Verim Değişimi ve Su Pompalama Kapasitesi Üzerine Etkilerinin Belirlenmesi [Master's Thesis]. Fen Bilimleri Enstitüsü. (in Turkish)

Wallace, J. S. (2000). Increasing agricultural water use efficiency to meet future food production. Agriculture, ecosystems & environment, 82(1-3), 105-119. https://doi.org/10.1016/S0167-8809(00)00220-6