ISSN:1813-1786 (Print) 2313-7770 (Online)

Feasibility and Data Analytics for Sustainable Water Consumption in Solar-Integrated Systems: A Case Study of Karachi, Pakistan

S. S. Ali[1], S. S. Hussain[2], K. Iqbal[3], S. A. A. Zaidi[4], U. E. Laila[5], S. Ali[6], M. Ali[7]

[1,2,6,7] *Faculty of Engineering Science and Technology, Iqra University, Karachi, Sindh, Pakistan*
[3] *Department of Computing, Faculty of Engineering Sciences and Technology, Hamdard University, Karachi, Sindh, Pakistan*
[4] *Department of Mechanical Engineering, Islamic University of Madinah, Madinah, 42351, Kingdom of Saudi Arabia*
[5] *Department of Computer Science, Institute of Business Management, Karachi, Sindh, Pakistan*

[1] saadali9210@gmail.com

Abstract- Water wastage damages reserves and irrigation systems. The distribution of dirty water in Karachi, the major economic hub of Pakistan, is one of the biggest challenges for drinking water and agriculture. This study provides techno-economic data analytics for a solar-powered efficient water management system. For techno-economic data analytics, RETScreen clean energy software was utilized for the solar-based economic analysis of major hub Karachi, Pakistan was considered for location analysis. The key contribution of this study is to examine the PV plant in Karachi, Pakistan, concentrating on the implementation of financial studies for renewable energy technologies to integrate with Electric Utilities to contribute clean energy to the national grid. For the data analytics study, Python (Jupyter notebook) was used to collect and process the data using computational methods. The study considered a 10kW power panel for energy generation. The proposed system provides payback for 15 years with a 93% reduction in tCO_2. The outcome shows that solar data analytics for the water consumption system is highly suggested for renewable energy integration to operate the water consumption system. This system purifies water for both drinking and irrigation applications by utilizing solar potential. Solar-based systems are recommended for higher efficiency without carbon emissions. Compared with conventional systems, this study integrated clean energy plants to generate power.

Keywords- Techno-economic, Water Consumption, Sustainable Water Management, Solar-Energy Integration, Statistical Study.

I. INTRODUCTION

World weather changes due to energy crises and extraordinary energy consumption of irrigation system greenhouse gas emissions. The system attains greenhouse efficiency and is an eco-friendly system that enhances the system power efficiency without gas emissions. This study used data from Shandong Province, China, to investigate solar efficiency and develop a model to indicate power generation. A technical economic study was conducted with a payback period of 6.25 years, and the outcome showed that approximately 46 tons of CO_2 emissions were reduced yearly [1]. This study presents a techno-economic analysis of solar-based electric vehicles for campus transportation. The main objective of this study was to integrate solar panels with lithium batteries and 4000-watt motors. The tests and experiments conducted to measure greenhouse gases and for economic analysis showed a return of 50% and an approximately 18% annual reduction in operational costs without emissions [2]. This study investigated the ecological and financial parameters of solar-integrated systems in Nigeria's energy sector. The challenges of the integration findings indicate that the adoption of photovoltaic systems reduces gas emissions by more than 60%. The initial investment is high, and the operational costs are low. Therefore, there is an urgent need to promote solar and other renewable energy technologies [3]. This study identifies the ecological problems associated with traditional greenhouse gas emissions by investigating a solar-integrated food manufacturing system. The real-time parameters and performance metrics were then calculated. The proposed system improves the return by 17% with lower carbon emissions [4]. The integration of solar power into grids is a sustainable approach to empowering clean energy technology. Solar power smart grid systems face major security challenges in terms of cyber security integration. This study demonstrates the challenges posed by different security threats that affect smart solar-integrated grid systems. These challenges include system instability due to

cyberattacks by enemies of the country [5]. This study focuses on a solar-powered system integrated with different water purification techniques. This study focuses on integrating renewable technologies into the system to reduce emissions [6]. The wireless transmission of energy is one of the biggest challenges worldwide. This study provides energy transmission via induction methods to transmit power wirelessly [7]. Water challenges worldwide are due to unsustainable access to power and water management schemes. Solar-based pumping systems offer a sustainable solution for water supply in rural domestic regions. This study provides solar power efficiency via controller and battery integration with water schemes. This system comprises an ESP32 controller for real-time parameter measurements using water, level, and voltage/current sensors [8]. The irrigation system faces severe ecological challenges in producing energy that is emission-free. Sustainable power plants must be implemented and utilized in agricultural applications. IoT-based technologies improve system efficiency by observing parameters such as moisture, temperature, current, power, and voltage to measure the efficiency of agricultural systems. An economic analysis was conducted in this study to investigate the financial parameters of the proposed irrigation system [9]. Water filtration systems provide a sustainable solution for optimizing the water quality. Modern advances in water purification systems have demonstrated the removal of different materials to ensure water security [10]. The technical depth analysis for the solar region used RETScreen software for the economic analysis of photovoltaic technology. Further implementation of this study can improve the traditional system to a renewable system [11]. The implementation of renewable systems in Pakistan's water and agricultural systems increases sustainable practices. The study considered the financial parameters at 5-6 cents per kilowatt hour [12]. Water security is essential for the economic growth of a nation. The worldwide water requirement has increased owing to population growth and climate change. The Internet of Things (IoT) is utilized in smart urban areas to innovate water application. Modern technologies improve the system with IoT-integrated smart water optimal solutions that utilize controllers and sensors to design water applications [13]. Water flow recognizes leakages and waste in healthy water management systems. This study demonstrates the challenges of innovating water management using IoT-integrated systems. Real-time parameters and analysis were performed on data transmission via a cloud-based system. The utilization of controllers and sensors effectively achieves optimal water management [14]. This study provides the construction of a smart real data integrated water observing scheme to check water quality. The IoT-integrated solar-powered system uses a long-range wide-area network to share sensor details, including pH, turbidity, and temperature, with the cloud system [15]. Metropolitan supply corporations use conventional methods for water analyses. This study focuses on Internet of Things-based technologies for purifying water for public services. The system utilized a controller and sensor to build a small prototype, and the system was tested under several conditions [16]. Current agricultural schemes utilize traditional methods to produce energy from biomass. This study provides a solution for integrating solar systems with irrigation systems to provide a sustainable solution [17]. Water control for irrigation fields faces challenges. This study aimed to develop an IoT-based system integrated with solar energy. The system includes controllers, sensors, and pumps to control the system mechanism. The energy was transformed into electrical energy and stored in a 12V battery for water pump operation [18]. This study provides an artificial intelligence-based system implementation in water management schemes to improve water quality, optimal solutions, and predictions to improve water management. AI-based technologies [19]. Worldwide challenges due to climate change affect water quality and security. The effective utilization of innovative technologies uses sensors, equipment, and cloud computing-based systems to increase productivity by monitoring real-time parameters for irrigation applications. [20].

II. METHODOLOGY

This computable work utilizes a data analytics technique for measurement using computational simulation. The RETScreen software was used to conduct the feasibility analysis. Numerous engineers and power experts have utilized this tool for techno-economic analysis. This work utilized this software to analyze the cooling and power loads for the case study of Karachi, a major hub in Pakistan. This software calculates financial, location, climate, and emission analyses for Karachi and is engaged to integrate genuine climatic circumstances using the NASA database. The methodological approach used in the present study can be used to integrate climate and water data into the RETScreen software framework. The discussion related to the present research and its outcomes are discussed in the following section:

2.1. Study Area

The feasibility model selected for this study is Karachi, a major and densely populated city in Pakistan. The population of Karachi is estimated to be approximately 20.3 million, according to the Census 2023 conducted by the Government of Pakistan. In this case study, the seven districts selected were Central, East, South, West, Korangi,

Keamari, and Malir, and the population data of Karachi districts were obtained from the 2017 and 2023 censuses. The Karachi Water and Sewerage Board is responsible for the Karachi water distribution. The present arrangement of water sources is lower than the demand and is in crisis due to extreme requests from the increasing populace, trades, and productions. The current water distribution to Karachi, beginning from the River Indus via Kinjheer Lake and Hub River Dam, is approximately 650 million gallons per day, in contradiction of a request of 1080 million gallons per day, with a shortfall of 430 million gallons per day. The distribution of overall Karachi is managed by the KWSB, except for the Port Qasim Authority and the steel mill. The study location is shown in figure 1.



Figure 1. Study Location

Five filtration plants have been installed to filter the water supplied to Karachi, as shown in Table 1 and figure 2.

Table-1. Filtration Plants [1]

Sr.#	Site Name	MGD
1.	COD Filter Plants	115
2.	Pipri Filter Plants	100
3.	NEK Filter Plants	125
4.	Hub Filter Plant	80
5.	Gharo Filter Plant	20
	Total	440

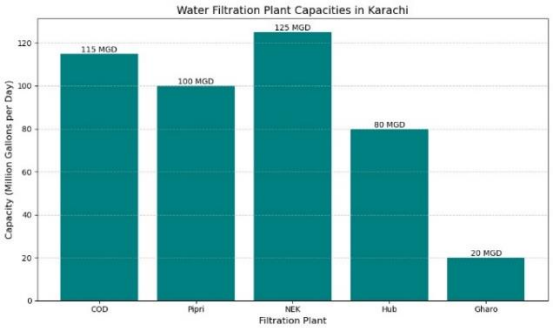


Figure 2. Karachi Filteration Capacity

The locations of the main water sites in Karachi are listed in Table 1. The bulk distribution system shown in figure 3 is for the Karachi water distribution.

Table-2. Karachi Water Sites Coordinates

Sr.#	Site Name	Site Coordinates
1.	Kinjheer Lake	24.957220367673546, 68.04526068894184
2.	Hub River Dam	25.249365071256143, 67.11262606241225



Figure 3. Bulk Transmission System Map Karachi Water Board [1]

2.2. Feasibility Studies

This study utilized the RETSCREEN software for power, load, emission, economic, climate, and facility analyses. These tools and techniques were used to determine the initial and operating costs of the proposed system. The present study demonstrates a purification system for the water potential available in Karachi, Pakistan. The district-wise population was calculated to analyze the water requirements for the selected city Karachi. Based on the study, according to the last census conducted by the Government of Pakistan, the total population is 20, 382, 881. This study was conducted in seven districts of Karachi. The highest population district is District East, Karachi, with 3,950,031 people. For the district central 3,822,325 populations, district Korangi 3,128,971 populations, district west 2,679,380, district Malir 2,403,959, district south 2,329,764, district Keasmari 2,068,451. In addition, the feasibility of this information was conducted for the water analysis of the solar-powered water consumption scheme. The Cash flow in RETScreen is designed by considering the scheme's income, functioning costs, and investments. The net periodic currency flow study can be measured using:

Net Cash Flow = Revenue + Savings - Operating Costs - Capital Costs ---------- (1)

The profit savings time in RETScreen is calculated as follows:

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Annual net cash flow}} \text{-------} \quad (2)$$

The Emission Analysis investments in RETScreen

measure the reduction in power consumption and the production of renewable energy associated with traditional power sources. The emission analysis was performed using the following formulations:

CO_2 Savings = Energy Savings × Emissions Factor----------(3)

Figure 4 shows the district-wise population statistics for the selected city.

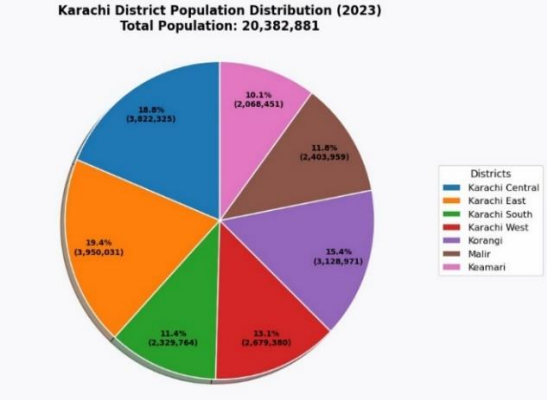


Figure 4. Population Statistics (Census 2023)

III. Results and Discussion

The outcomes of the feasibility studies are deliberated in this section for the solar-powered water consumption system. The feasibility analysis utilized a 10 KW solar-based system to conduct the feasibility studies. The feasibility analysis determined the water quality and energy potential for the most economical urban city, Karachi, for solar-based renewable technologies. The dam linked to Karachi was selected for the case study. The two official water sites, Kinjheer Lake and Hub River Dam, were considered for the feasibility studies.

3.1 RETSCREEN Software

This study used the RETSCREEN software for feasibility analysis. The study includes a virtual energy analyzer to calculate the performance based on location and climate data using a benchmark technique. The second part is the main part feasibility for the proposed system, which includes project investment, savings, and emission analysis. The research workflow is shown in figure 5 and 6.

3.2 Data Analytics

Data analytics were conducted using Python (Jupyter nootbook). Statistical data from the tables and figures were used for the analysis. The main purpose of this analytics is to collect and preprocess data via computational methods. Figure 7 shows the software interface for the implementation of this study.



Figure 5. Research Workflow

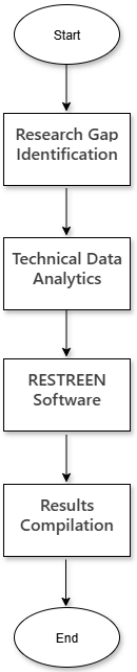


Figure 6. System flow

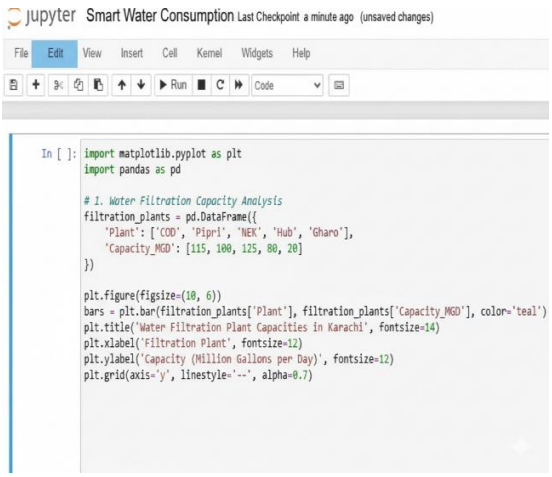


Figure 7. Data Analytics

3.3 Location & Climate Analysis

The RETSCREEN software utilizes NASA-based climate data for the location and climate analysis of the proposed system. Figure 8 shows the climate analysis for the proposed city.

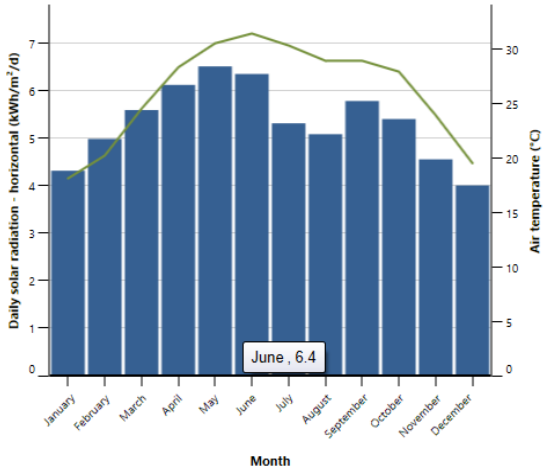


Figure 8. Climate Statistics

3.4 Facility Analysis

To conduct the facility analysis for the 10 KW solar-based system, the data utilized in RETSCREEN are shown in Table 3.

Table-3. Facility Analysis

1.	Load Type	Heating Load
2.	Description	Mono- Si
3.	Manufacturer	Apin Solar
4.	Model	SPP280
5.	Capacity per unit	280 Watt
6.	Number of units	10.08
7.	Efficiency	14.4%

3.5 Energy Analysis:

The input parameters used in this study were obtained using the RETSCREEN software for solar facility and energy analysis. This study utilized solar radiation for power production. Figure 9 shows the cooling load facility for the proposed system.

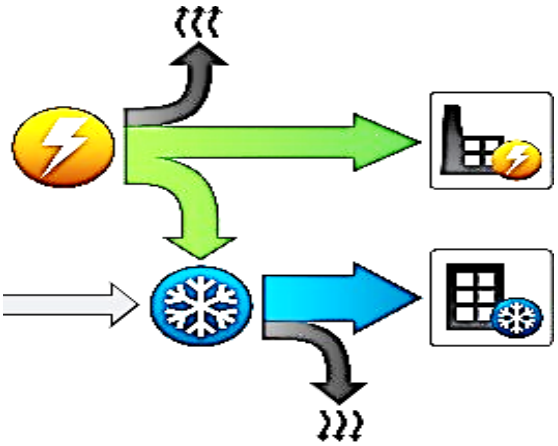


Figure 9. Energy Model

3.6 Emission Analysis

Solar photovoltaic cells achieved a 93% emission reduction using the proposed strategy. The comparative bar graph in figure 10 shows the proposed and base cases for the selected facility. The black area specifies the remaining emissions, and the green area shows the emission reduction.

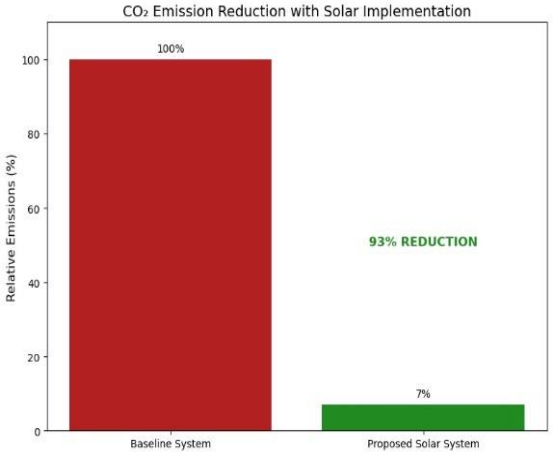


Figure 10. Emission Analysis

3.7 Cost Analysis

The cost analysis shows the maintenance and operation costs to calculate the initial investment required to implement the system. Table 4 shows the cost parameters for the selected solar facility.

Table-4. Facility Analysis

1.	Description	Mono- Si
2.	Manufacturer	Apin Solar
3.	Model	SPP280
4.	Initial Cost	2,880$
5.	Operation Cost	150$ Annually
6	Payback Period	15 Years

3.8 Financial Analysis

The financial parameters comprise the inflation rate of Pakistan at 6.10%, and the project life span is 15 years (2025-2040). The debt nation ratio considered for the study was 71.4% (ratio of national debt to GDP). The cumulative cash flow is an economic analysis that proves the remaining amount of cash in the method of revenues and expenditures. Cash flows are influenced by the functioning efficiency of the photovoltaic scheme, which comprises maintenance costs, petroleum costs, and power production capability. The cumulative cash flow curve was generated using RETSCREEN software for the financial performance of the proposed project. The seven years are the initial years to cover the initial investment in the project. The eight–nine year is the simple payback time, and the later period indicates the long-term financial payback for the proposed system. The financial analysis is shown in Figure 11 and 12.

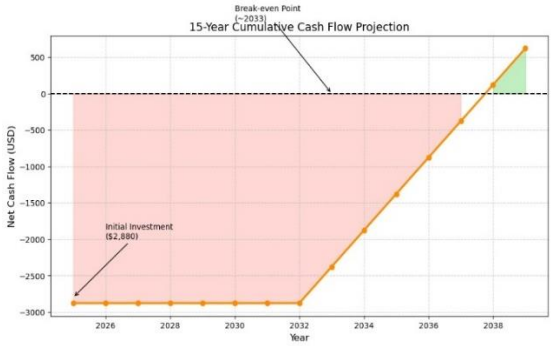


Figure 11. Cumulative Cash Flow Analysis

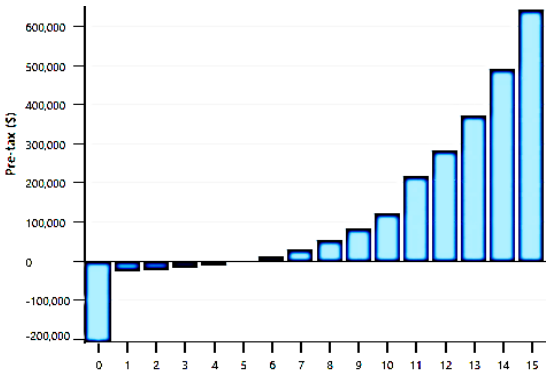


Figure 12. Cash Flow Analysis

These cash flows examine the entire price for the photovoltaic system with US 2,880$ for the early stage and the US 150$ for the functioning and maintenance. Cash flow provides identification of periodic changes where the scheme might face economic upturns and downturns. The study uses an inflation rate of 6.10%, and the scheme life is 15 years (2025-2040). The debt ratio of Pakistan measured for this study was 71.4%. Overall, cash flows demonstrate the financial analysis to determine the initial, operational, and maintenance costs. The financial aspects are enhanced by integrating inflation and debt ratios. Variations in inflation affect profits and savings and impact project costs.

IV. Conclusion

Based on the recommendations, the initial study plan to initiate the proposed case study provides greater cash flow through clean energy generation. This study focuses on the major challenge of water purification via solar-based technologies in Karachi, Pakistan. Feasibility studies were conducted in this study for the Karachi case study. The Karachi Water and Sewerage Board uses two water sites for water potential. The two sites include Kinjheer Lake and the Hub River Dam for the overall distribution in Karachi, except Port Qasim and the Steel Mill. A reformed energy model with a 10 KW solar potential was used to operate the smart water consumption system. RETScreen technology demonstrates a simple profit period of 15 years with a 93% reduction in CO_2 Emissions. The following key findings were obtained from this study:

1. The projected cooling load constructed scheme Connection of 10 KW energy production plant for Karachi is a perfect model for water usage and local authorization of the Karachi water sector.
2. In this Study, seven districts were deliberated: Central, East, South, West, Korangi, Keamari, and Malir. The population information for the Karachi districts was imported from the 2023 census. Karachi has seven districts, District East, Karachi, with a population of 3, 950, 031. For the district central 3,822,325 populations, district Korangi 3,128,971 populations, district west 2,679,380, district Malir 2,403,959, district south 2,329,764, district Keasmari 2,068,451.
3. The feasibility study resulted in a 93% emission reduction. This indicates that the proposed system produces fewer emissions.
4. The photovoltaic system initial cost was US 2,880$ and the US 150$ for the operational and maintenance.

Numerous recommendations suggest incorporating a technical oriental strategy to provide a sustainable solution with operations and maintenance to implement studies in Karachi using renewable energy technologies.

References

[1] Y. Liu, C. Zhou, and A. Riaz, “Optimization design and techno-economic assessment of integrated solar photovoltaic thermal systems for modern agricultural greenhouses,” SSRN, no. 5360968, 2025.

[2] K. Srasuay, J. Thongpron, A. Namin, K. Nakaiam, N. Panlawan, M. Ngaodet, W. Muangjai, T. Somsak, and N. Patchaprakiti, “A techno-economic analysis of 48V mini shuttle electric vehicle with solar assisted system for carbon-neutral green campus,” Jpn. J. Appl. Phys., Jun. 2, 2025.

[3] H. C. Unegbu, D. S. Yawas, B. Dan-asabe, A. A. Alabi, and R. C. Vedad, “Assessing the environmental and economic benefits of integrating solar energy in Nigerian construction,” Discov. Civ. Eng., vol. 2, no. 1, p. 114, Jun. 17, 2025.

[4] Y. Alvari, M. Zandi, A. Jahangiri, M. Ameri, A. Gholami, P. Shahidi, and S. A. Mousavi, “BIPV-driven smart vertical greenhouses: A water-energy-food-environment nexus framework for sustainable urban agriculture,” Energy Nexus, Art. no. 100473, Jul. 12, 2025.

[5] M. A. Hossain and F. Mahjabeen, “Ensuring cybersecurity and resilience in solar smart

grids: Challenges and solutions," SSRN Electron. J., no. 5243029, Apr. 21, 2025.

[6] R. Manimaran, "A comprehensive review of solar-assisted technologies in India for clean water and clean energy," Clean Energy, vol. 9, no. 2, pp. 12–36, Apr. 2025.

[7] S. Ali, S. Ali, K. Iqbal, S. Munawwar, B. Raza, A. A. Almani, M. Jawad, and A. B. Iqbal, "Design and control of efficient wireless electrical energy transfer," Policy Res. J., vol. 3, no. 7, pp. 512–520, Jul. 23, 2025.

[8] Z. M. Rumbayan, I. Pundoko, S. R. Sompie, and D. G. Ruindungan, "Integration of smart water management and photovoltaic pumping system to supply domestic water for rural communities," Results Eng., vol. 25, Art. no. 103966, Mar. 1, 2025.

[9] M. A. Abdelhamid, T. K. Abdelkader, H. A. A. Sayed, Z. Zhang, X. Zhao, and M. F. Atia, "Design and evaluation of a solar powered smart irrigation system for sustainable urban agriculture," Sci. Rep., vol. 15, no. 1, p. 11761, 2025.

[10] R. Namdeti, D. S. M. S. Al-Kathiri, G. B. Rao, A. H. Khan, and H. A. M. Alshehri, "A critical review of smart materials for efficient water purification: Towards sustainable clean water solutions," J. Membr. Sci. Res., vol. 11, no. 1, 2025.

[11] M. Irandoostshahrestani and D. R. Rousse, "Status of photovoltaic water pumping systems in Iran: A comprehensive review," Water Science & Technology, vol. 89, no. 12, pp. 3270–3308, 2024, doi: 10.2166/wst.2024.149.

[12] Y. Aziz, A. K. Janjua, M. Hassan, M. Anwar, S. Kanwal, and M. Yousif, "Techno-economic analysis of PV systems installed by using innovative strategies for smart sustainable agriculture farms, "Environment, Development and Sustainability, vol. 26, no. 2, pp. 5003–5024, Feb. 2024, doi: 10.1007/s10668-023-02919-5.

[13] N. J. Okoli and B. Kabaso, "Building a smart water city: IoT smart water technologies, applications, and future directions," Water, vol. 16, no. 4, p. 557, 2024.

[14] N. Bawankar, A. Kriti, S. S. Chouhan, and S. Chaudhari, "IoT-enabled water monitoring in smart cities with retrofit and solar-based energy harvesting," *IEEE Access*, vol. 12, pp. 58222–58238, Apr. 2024, doi: 10.1109/ACCESS.2024.3392852.

[15] W. A. Jabbar, T. M. Ting, M. F. I. Hamidun, A. H. C. Kamarudin, W. Wu, J. Sultan, A. A. Alsewari, and M. A. H. Ali, "Development of LoRaWAN-based IoT system for water quality monitoring in rural areas," Expert Syst. Appl., vol. 242, p. 122862, 2024.

[16] C. Axiotidis, E. Konstantopoulou, and N. Sklavos, "A wireless sensor network IoT platform for consumption and quality monitoring of drinking water," Discov. Appl. Sci., vol. 7, no. 1, p. 15, 2024.

[17] S. S. Ali, S. Ali, J. Khan, Z. Khan, M. T. Saleem, S. Munawwar, and H. Khawer, "Design and implementation of a sustainable microcontroller-based solar power automatic water irrigation control and monitoring system," Pak. J. Eng. Technol. Sci., vol. 12, no. 1, pp. 78–90, 2024.

[18] P. K. Dey, S. Banu, S. R. Milufarzana, N. C. Mazumdar, and M. S. N. K. Samsuzzaman, "IoT-based solar-powered smart irrigation system with solar tracker for rice fields," Precis. Agric., vol. 6, p. 60, 2024.

[19] L. Abdulameer, N. M. L. Al Maimuri, A. H. Nama, F. L. Rashid, and A. N. Al-Dujaili, "The role of artificial intelligence in managing sustainable water resources: A review of smart solution implementations," Water Conserv. Manag., vol. 9, no. 2, pp. 181–191, 2025.

[20] A. Bhardwaj, M. Kumar, M. Alshehri, I. Keshta, A. Abugabah, and S. K. Sharma, "Smart water management framework for irrigation in agriculture," Environ. Technol., vol. 45, no. 12, pp. 2320–2334, 2024.