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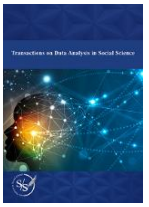

Challenges of Solar Energy Policy-Making in the Agricultural Sector

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ABSTRACT

The development of renewable energy policy frameworks, particularly for solar energy in agriculture, is vital to mitigate the environmental impacts of fossil fuel dependence. Most farmers still rely heavily on fossil fuels, which undermines sustainable agriculture and accelerates resource depletion, global warming, and water scarcity. Renewable energies, being environmentally compatible, are thus a strategic necessity for sustainable agricultural development. This study aimed to propose suitable policy frameworks for promoting solar energy use in Iran's agricultural sector. Using a mixed-method approach library and documentary review followed by a field survey the research identified key factors influencing policy implementation. In the first phase, interviews were conducted with policymakers and experts involved in national scientific and energy documents to refine the conceptual framework and identify major implementation barriers. In the second phase, a questionnaire quantified and weighted these barriers using a t-test (test value = 3) at a 95% confidence level. Findings revealed that financial support and incentives for farmers were the most crucial factors enabling solar energy adoption. Comparative analysis showed Iran's unfavorable position relative to developed countries, largely due to the absence of strategic vision. Hence, strategic foresight and applied research are essential to advance renewable energy use in Iran's agriculture.

1. INTRODUCTION

Today, energy represents one of the most critical and dominant global issues. As a fundamental component of modern society, it not only directly influences human activity but also plays a vital role in economic and social development and in improving the quality of life in all nations. The use of renewable energy sources is one of the key prerequisites for economic and social progress, as well as for enhancing living standards and promoting sustainable growth [1].

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Currently, renewable energy technologies have generated more employment opportunities worldwide than fossil-fuel-based technologies. According to the most recent estimates in 2017, approximately 10.3 million people are directly or indirectly employed in renewable energy industries [2].

Given the significance of the agricultural sector and its considerable potential for production and export in Iran, the application of renewable energy in this sector is of great importance. By utilizing such clean energies, it is possible to address challenges such as unemployment and high operational costs, while also increasing value-added and export capacities. The replacement of fossil fuel carriers with solar and other renewable energy sources as inexpensive and efficient fuels can create a major transformation in this sector. The adoption of modern technologies for the utilization of renewable energies such as biogas production from livestock and poultry waste, sewage, sludge, and agricultural residues can independently meet up to 45% of the energy demand in agriculture [3].

In particular, solar energy is widely applicable in agriculture for purposes such as greenhouse heating, solar-powered water pumping systems, and even in apiculture. Therefore, fostering the expansion of solar energy use in agriculture represents a long-term strategic necessity [3]. Solar energy can be harnessed in two main ways: through photovoltaic cells and solar panels for water heating. Furthermore, micro-hydroturbines can be used to generate power for mills, wind turbines can produce energy on farms, and geothermal energy can serve agricultural greenhouses, livestock farms, and aquaculture facilities. Altogether, these methods significantly reduce dependence on fossil fuels [3].

In Iran, several national policies and strategic documents including the General Policies on Consumption Pattern Reform, the National Energy Strategy Document (Vision 1414), the Ministry of Energy's Vision 1404, and the Sixth Development Plan emphasize the necessity of comprehensive, coordinated, and centralized government planning for energy management. These and other upstream policies such as the Long-Term Vision of the Oil and Gas Industry (1414), the General Policies of the Energy Sector, and the General Policies of the Resistance Economy highlight the optimization of energy supply and consumption, reduction of energy intensity, diversification of energy sources, environmental protection, increasing the share of renewable energy, and expanding regional energy cooperation. Achieving these goals requires integrated national energy planning with a sustainable development approach [4].

Energy planning is a continuous and systematic process aimed at balancing energy supply and demand within a defined policy framework to achieve sustainable development objectives in the future. Sustaining energy planning at the national level necessitates the establishment of a professional, centralized institution capable of modeling and planning, mobilizing expert networks, and ensuring stakeholder participation and coordination. Such an institution must guarantee the validity and quality of results, ensure that developed plans are implementable, align with national stakeholders, and provide policy advice, knowledge management, and dissemination of energy planning practices nationwide [4].

One of the key reasons for establishing a renewable energy policy framework particularly in the agricultural sector is the detrimental environmental and climatic impact of fossil fuel use. Today, most farmers depend heavily on fossil energy, which represents one of the major challenges to sustainable agriculture. The use of fossil fuels not only contradicts sustainable development principles but also leads to the depletion of valuable resources and causes adverse consequences such as global warming, agricultural degradation, water scarcity, forest loss, and sea-level rise. Consequently, renewable energies, given their environmental compatibility and alignment with sustainable development goals, represent an essential strategic direction for the agricultural sector [4].

Fadaei et al. [5] examined Iran's renewable energy potential and assessed the current status of industries related to renewable energy, emphasizing the country's performance in achieving the targets outlined in the Fourth National Development Plan. Their study identified several major barriers, including ineffective planning in executive bodies, lack of clarity in administrative and operational responsibilities, weak cooperation between industry specialists and regulatory bodies, and inadequate utilization of skilled professionals and technicians.

Similarly, Hosseini et al. [6] investigated the role of solar energy in the conservation and rehabilitation of rangelands in arid regions. Their findings revealed that the rural participants expressed a strong willingness to adopt solar energy as a clean and modern energy source in the coming years, recognizing its potential to significantly improve their income levels. The study also found that the participants' awareness of solar energy and its benefits was high, and that ongoing engagement with natural resource extension agents, regular visits to renewable energy

centers, and educational programs were the most influential promotional activities for introducing and popularizing renewable energy in these regions.

Nejat et al. [7] explored the status, achievements, and policies of renewable energy development in Iran during the Fourth Development Plan, comparing national trends with global patterns. Their results indicated that Iran's renewable energy development trajectory remains far behind global standards, primarily due to the country's extensive reliance on fossil fuel reserves.

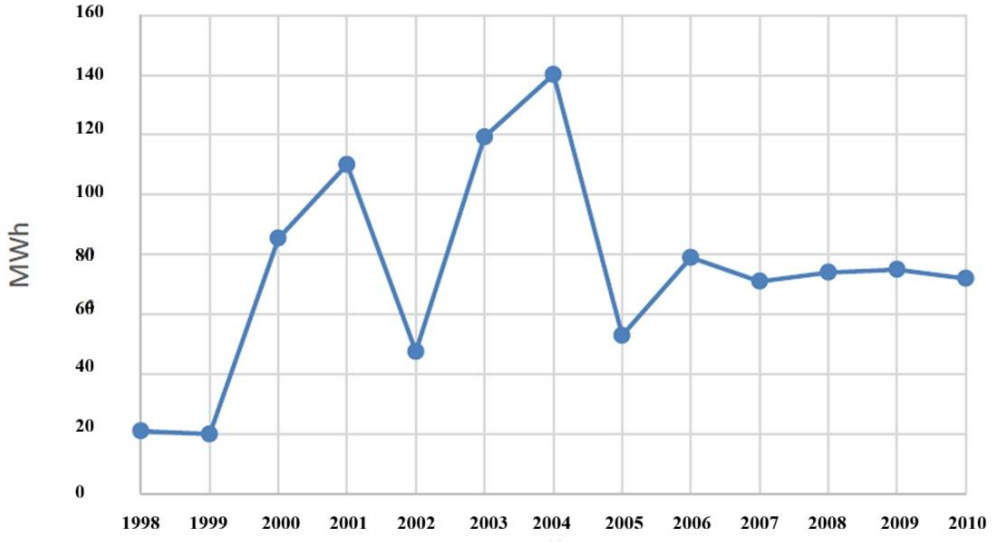

Fig. 1. Trend of Solar Power Generation in Iran (1999–2010)

Ghaemi Rad and Shahin [8] analyzed the factors influencing the development of solar energy technologies in Iran using SWOT and DEMATEL methods. In this study, the strengths, weaknesses, opportunities, and threats (SWOT) of solar energy technologies were identified and then the influential and influenced indicators were determined through the DEMATEL technique. According to the findings, the most significant factors hindering the development of these technologies included the low cost of fossil fuels and energy carriers in Iran, the lack of awareness and understanding among policymakers, insufficient motivation for private sector participation, and the absence of effective policies and adequate governmental incentives.

Khani et al. [9] presented an optimized model aimed at achieving low-cost and environmentally friendly energy sources by outlining a desirable sustainability scenario across technical, economic, and environmental dimensions over a 100- to 500-year horizon. Their results indicated that, in the short term, fossil fuels dominate energy supply due to the stronger influence of financial indices compared to environmental ones. However, in the long term, more than half of the total energy supply would be provided by renewable sources. The availability of technological infrastructure, coupled with adequate governmental support and policy formulation, were identified as the most critical factors influencing the expansion of renewable energy use in the agricultural sector.

2. MATERIALS AND METHODS

The present study is applied in purpose and field-based in nature, based on the degree of control and supervision. The main instruments for data collection and document analysis included interviews and questionnaires.

Sampling was carried out using a purposive sampling method. In some cases, it becomes necessary to collect information from specific individuals or groups who possess unique knowledge or experiences relevant to the study. These individuals are considered capable of providing the required information or meeting criteria defined by the researchers. Such a sampling design is known as purposive sampling.

The research was conducted in two stages:

1. **First stage:** Interviews were conducted with the executors and drafters of the National Scientific Master Plan as a national document, along with three sectoral organizations the Renewable Energy and Energy Efficiency Organization (SATBA), the Department of Environment (DOE), and the Tavanir Power Generation, Transmission and Distribution Company. These interviews aimed to identify the key obstacles to implementing renewable energy policies, particularly solar energy, in Iran's agricultural sector.

2. **Second stage:** To determine the relative weight of the identified barriers, a **questionnaire** was employed. In selecting the experts, efforts were made to include a broad spectrum of policymakers and practitioners involved in policy formulation and implementation at various levels from macro to micro who had accumulated valuable practical experience.

The collected data from expert interviews and questionnaires were analyzed using the SWOT analytical framework and the SPSS software package.

3. 3. RESEARCH FINDINGS

The highest age frequency among participants belonged to the 35–45 years age group, while the lowest frequency corresponded to the 55–65 years group. According to Table 1, the majority of respondents held master's or doctoral degrees, while the smallest proportion held bachelor's degrees. Additionally, respondents had between 5 and 25 years of professional experience in their respective fields.

Table 1. Individual Characteristics and Opinions of Respondents

Gender	Age Range (Years)	Education Level	Work Experience (Years)
23 (Male)	5 participants (25–35)	7 participants (Bachelor's)	4 participants (5–10)
7 (Female)	16 participants (35–45)	15 participants (Master's)	11 participants (10–15)
Total: 30 participants	7 participants (45–55)	8 participants (PhD)	9 participants (15–20)
	2 participants (55–65)		6 participants (20–25)

The various sections of the questionnaire, along with the number of items and the Cronbach's alpha coefficients calculated for each section, are presented in Table 2. The questionnaire comprised four sections Opportunities, Threats, Strengths, and Weaknesses each containing five items. The Cronbach's alpha values for each section ranged between 0.88 and 0.95, indicating a high level of internal consistency and reliability.

Table 2. Cronbach's Alpha Coefficients for the Study Variables

Questionnaire Section	Number of Items	Cronbach's Alpha
Opportunities	5	0.95
Threats	5	0.92
Strengths	5	0.88
Weaknesses	5	0.90

The ranking and coefficient of variation of factors influencing the use of solar energy among farmers were categorized into four groups Opportunities, Strengths, Weaknesses, and Threats and are presented in Table 3.

Among the opportunities, the factor "policy-making for the implementation of solar energy as an economic opportunity" ranked first, while "the excessive concentration of more than 90% of the country's power plants on renewable energy" ranked last within this group.

Regarding threats, "the alignment of solar energy development with the government's targeted subsidy reform plan" was identified as the primary threat, while "higher employment generation potential in renewable energy compared to fossil fuels" was ranked as the least significant threat.

In terms of strengths, "independence from oil resources and resilience against international sanctions through solar energy technology" was recognized as the top strength, whereas "the reduced water consumption of solar power plants compared to fossil-fuel power plants that use water for cooling" was placed last among the strength factors.

Table 3. Ranking and Coefficient of Variation of Factors Influencing the Adoption of Solar Energy Among Farmers

Factor	Variable	Rank	Coefficient of Variation
Opportunity	Policy-making for the implementation of solar energy represents an economic opportunity.	1	0.323
	Given the country's geographical conditions, electricity generation from solar energy exceeds that of many European countries.	2	0.541
	The expansion of this technology toward reducing greenhouse gas emissions and promoting a green economy represents an environmental opportunity.	3	0.617
	The excessive concentration of more than 90% of the nation's power plants toward renewable energy represents an economic opportunity.	4	0.091
	The expansion of solar energy technology represents a scientific and technological opportunity.	5	0.128
Threat	The movement of solar energy development in alignment with targeted subsidy programs represents a threat.	1	0.714
	The advancement of solar energy technology poses a threat to the fossil fuel industry.	2	0.190
	The global upward trend in this industry represents a potential threat.	3	0.871
	The higher employment generation potential of renewable energy compared to fossil fuels poses a threat.	4	0.289
	The rapid establishment of solar power plants represents a potential threat.	5	0.761
Strength	Considering international sanctions on solar technology and reducing dependence on oil represents a major strength.	1	0.650
	Solar energy technology is economically advantageous.	2	0.756
	The capability to generate electricity from solar energy in remote rural areas is a significant strength.	3	0.432
	Article 129 of the Development Law supporting the establishment of solar power plants is a political strength.	4	0.876
	Reduced water consumption in solar power plants compared with fossil-fuel plants that require water for cooling represents a strength.	5	0.543
Weakness	The possible scenario of fossil fuel price reductions due to neighboring countries' shift toward solar energy represents a weakness.	1	0.435
	The emission of greenhouse gases from solar power plants represents a weakness.	2	0.329
	The increase in fossil fuel consumption for electricity generation reduces the country's export share and negatively affects political influence.	3	0.567
	Generating electricity from solar power plants that contributes to savings in production and transmission is considered a weakness.	4	0.432
	The relatively easy recyclability of photovoltaic products poses an environmental weakness.	5	0.911

The key factors influencing the implementation of solar energy policy in agriculture are illustrated within a conceptual framework in Figure 1. These critical factors are essential for the effective execution of solar energy policies in the agricultural sector. By addressing each of these factors, the policy can be successfully operationalized and integrated into sustainable agricultural practices.

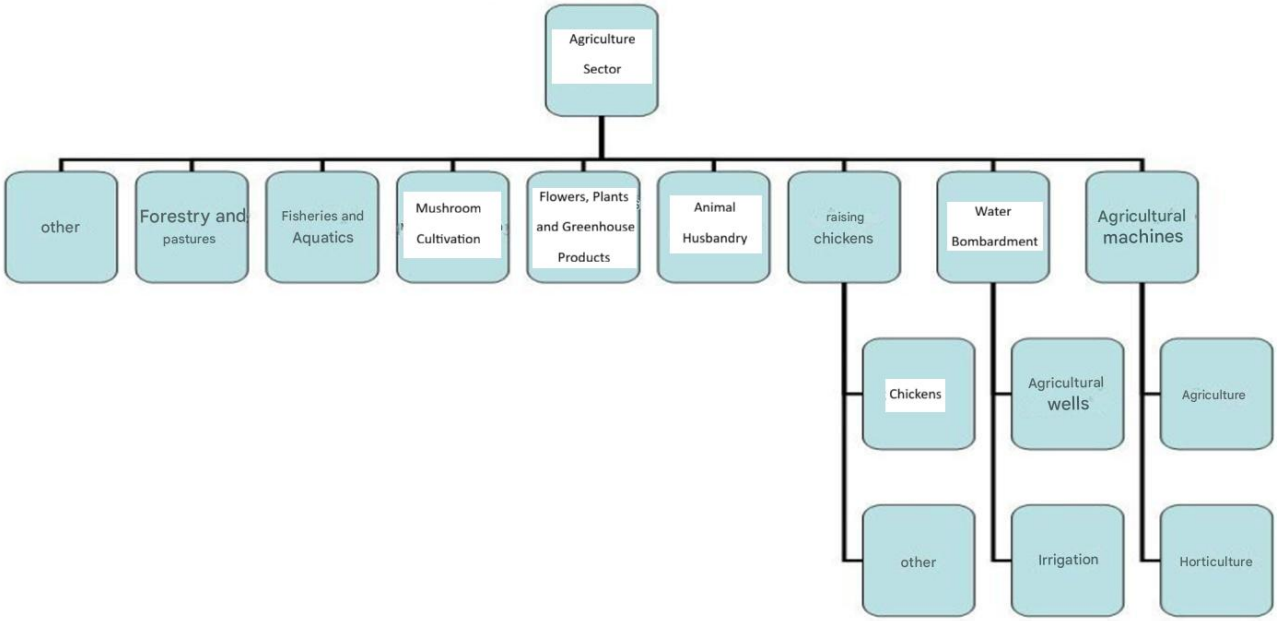

Fig. 1. Structure of the Components of Iran's Agricultural Sector for Estimating Energy Demand

In general, the main factors influencing energy demand in the agricultural sector include the following [10]:

- Volume of activity (e.g., cultivated area, amount of water extracted from wells, capacity of poultry farms, etc.) and level of utilization (e.g., hours of machinery operation, practical capacity of poultry or dairy farms, etc.) within sub-sectors.
- Energy carrier prices.
- Energy consumption intensity in each activity.
- Technological efficiency and its expected rate of change.
- Degree of mechanization and the extent of machinery utilization.
- Standards, regulations, and policies governing the sector.

As shown in Figure 2, several essential factors play a decisive role in the successful implementation of solar energy policy in agriculture. These include: determining an appropriate budget and subsidy structure, ensuring effective management and strong regulatory guarantees, establishing a system for monitoring and evaluation, and providing training for specialists and renewable energy experts. Furthermore, encouraging private sector participation, developing suitable infrastructures such as necessary equipment and facilities, educating farmers on renewable energy technologies and their benefits, and building trust among agricultural stakeholders are among the most critical and influential components in achieving effective implementation of solar energy policies in agriculture.

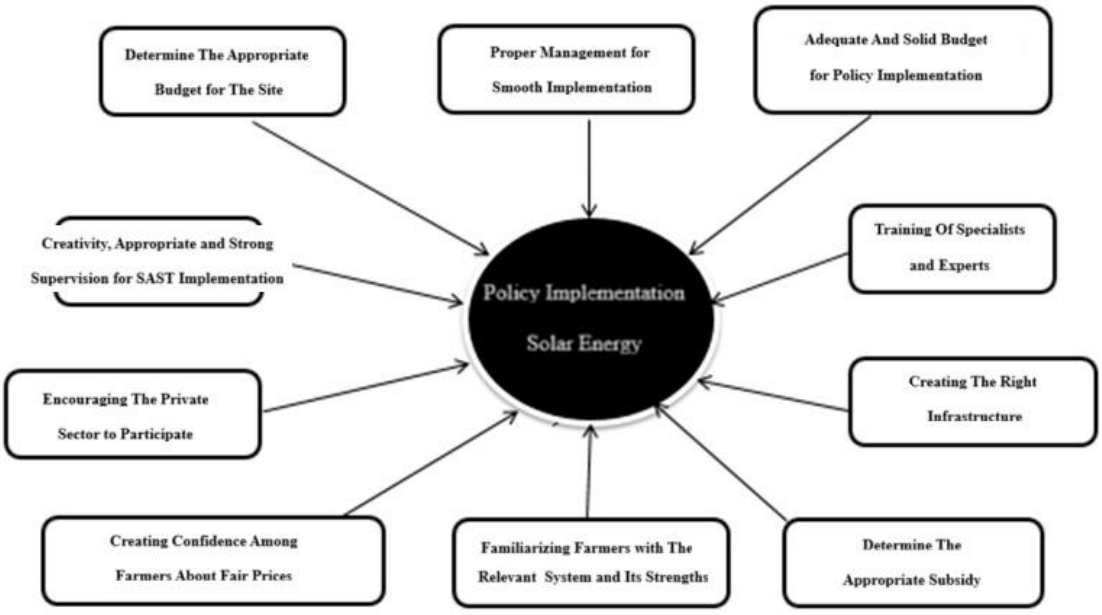

Fig. 2. Proposed Framework for the Key Factors Influencing the Implementation of Solar Energy Policy in Agriculture

The prioritization of factors affecting the implementation of solar energy policy, conducted using SPSS software, revealed that among the examined variables, economic factors play a more significant role than others. Allocating an appropriate budget for the implementation of this policy within the government's annual financial plan, determining the specific budget share for each sector in every region and province, and providing suitable subsidies for farmers were identified as the most essential and decisive factors for the effective execution of solar energy policies in the agricultural sector.

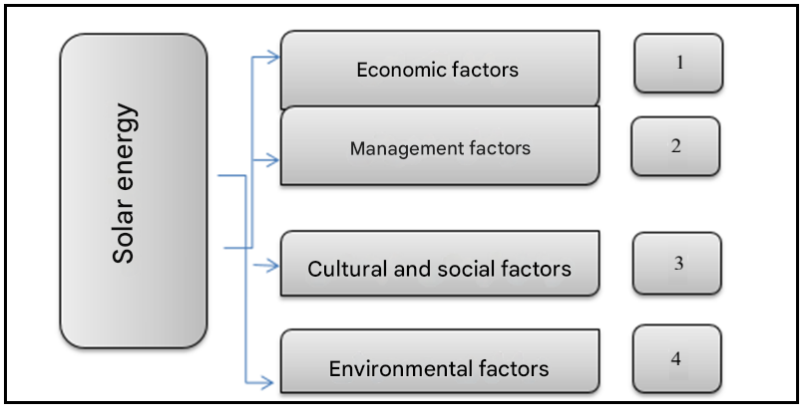

Fig. 3. Prioritization of Factors Influencing the Implementation of Solar Energy in Agriculture

4. CONCLUSION

The conceptual framework presented in this study, by integrating both top-down and bottom-up approaches to policy implementation, aims to provide a comprehensive perspective on the theoretical foundations of policy

execution. The top-down approach emphasizes the clarity of policies and suggests that the more ambiguous a stated policy is, the lower its chances of successful implementation. Conversely, the bottom-up approach highlights the participation of stakeholders and those directly affected by policy outcomes. Utilizing both perspectives, this study sought to identify the barriers to implementing the national science and technology policy documents in Iran.

The results of the correlation analysis indicated a significant and positive relationship between variables such as age, education level, work experience, and economic, research, educational, and socio-cultural requirements with the potential application of solar energy in the agricultural sector. Therefore, to expand and enhance the use of solar energy in agriculture, stakeholders must address the essential economic, research, educational, and socio-cultural requirements by engaging experienced, well-trained, and highly educated experts who possess adequate knowledge of the applications, advantages, and limitations of solar energy technologies in agriculture.

Furthermore, the multiple regression analysis demonstrated that among the significant variables, economic requirements, research requirements, work experience, and educational requirements entered the regression equation, collectively explaining 33% of the variance in the dependent variable the potential for using solar energy in agriculture. Based on these findings, it can be concluded that these factors play the most influential role in predicting the adoption of solar energy technologies. Consequently, financial incentives and facilities for farmers, as key economic requirements, are essential to promote solar energy utilization in the agricultural sector.

However, achieving this goal requires coordination and joint decision-making among the Ministry of Agriculture-Jihad, the Ministry of Energy, and the banking system to establish the necessary regulations and operational guidelines. Providing special facilities, low-interest loans, and specific credit packages for investment and equipment purchase, along with suitable energy pricing policies particularly gradual increases in fossil fuel prices can significantly enhance the feasibility of adopting solar energy in agriculture. Another important factor is allocating research funds to advance studies on renewable energy applications in the agricultural sector.

Conducting such research and utilizing its outcomes can contribute substantially to the establishment of a sustainable agricultural system and its sub-components. The results also revealed that educational requirements play a key role in increasing the feasibility of solar energy use. Therefore, needs assessments, curriculum design, and specialized training programs for agricultural experts, extension agents, and farmers are essential. Given the relatively new nature of solar energy applications, this need is even more pronounced. The shortage of specialized and professional consultants in both public and private sectors for implementing solar energy projects in agriculture is evident. To address this issue, training programs and workshops can be effective short-term solutions.

Nevertheless, prior to such interventions, it is crucial to raise awareness among stakeholders about the consequences of fossil fuel consumption and the benefits and opportunities of renewable energy sources. Utilizing mass media platforms such as radio, television, the internet, social networks, and field visits to successful international projects can effectively improve the knowledge, attitudes, and practical understanding of policymakers, planners, and farmers regarding the potential of solar energy in agriculture.

Given that the adoption of solar energy in Iran's agricultural sector is considered an innovation, it is recommended that its use first be tested on a pilot scale in various domains. This approach will help determine the regional suitability of solar technologies and their adaptability to specific agricultural activities. Implementing such pilot projects will also allow farmers to observe the relative advantages and practical ease of using these systems. Providing the identified requirements can greatly enhance the feasibility of employing solar energy in agriculture. However, it must be noted that the broader development of solar energy in this sector requires additional prerequisites that were beyond the scope of the present study, representing one of its major limitations.

5. RECOMMENDATIONS

The Ministry of Agriculture-Jihad, through the implementation of an operational policy and planning framework for solar energy in agriculture, should develop guidelines in collaboration with the Ministry of Energy for installing solar panels in rural and agricultural areas with high solar potential. According to the guaranteed electricity purchase regulation of the Ministry of Energy, the electricity generated by farmers' solar systems should be purchased by the

government, while farmers pay reduced rates for their consumed electricity creating a mutually beneficial economic opportunity for both ministries.

Under Article 12 of the Law on Removing Production Barriers, each ministry may develop energy-saving and investment projects. Currently, the Ministry of Energy, in cooperation with the Fuel Conservation Company of the Ministry of Petroleum, has initiated projects to electrify agricultural wells. One of its priorities is to utilize solar energy for this purpose. A five-party memorandum of understanding among the Ministry of Energy, the Ministry of Agriculture-Jihad, the Ministry of Petroleum (Fuel Distribution Company), Tavanir, and the Water Resources Management Company outlines four technical approaches: solar energy, wind turbines, distributed gas generator plants (DGI), and grid connection. This initiative represents an important economic opportunity for the Ministry of Agriculture-Jihad to reduce dependence on fossil fuels and thus lower greenhouse gas emissions and protect the environment.

The Ministry of Agriculture-Jihad should motivate and encourage farmers through incentive programs and financial support to adopt solar energy technologies, helping them recognize the economic and environmental benefits of these systems. For instance, poultry farms and greenhouses can achieve substantial long-term cost savings by adopting solar networks.

The Ministry of Agriculture Jihad should formulate strategies for the development of renewable energies in the agricultural sector particularly solar energy conduct a comprehensive assessment of existing challenges, and prioritize the formulation and implementation of laws and regulations that promote the expansion of renewable energy within the government's policy agenda.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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