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الجدوى الاقتصادية لتكنولوجيات الطاقة المتجددة في الزراعة المصرية والتنمية الريفية

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المستخلص

تهدف هذه الورقة البحثية إلى دراسة الجدوى الاقتصادية لتقنيات الطاقة المتجددة كالطاقة الشمسية والغاز الحيوي في المناطق الريفية المصرية، وخاصة قطاع الزراع حيث تعاني مصر من ارتفاع معدل استهلاك الطاقة الذي يتجاوز معدل إنتاج الطاقة، ومن المتوقع أنه مع النمو السكاني السريع، سيستمر الطلب على الطاقة في الزيادة ويؤدي إلى نقص الطاقة في المستقبل وتكون المناطق الريفية الأكثر عرضه لهذا الخطر. اعتمدت الدراسة على نسبة المنافع للتكاليف، وفترة الاسترداد، ومعدل العائد الداخلي، والموازنة الجزئية. أظهرت النتائج أن أنظمة الألواح الشمسية المنزلية تعد خيارا قابلا للتطبيق بشكل هامشي للأسر الريفية من حيث فترة استرداد تبلغ 6 سنوات مع معدل عائد داخلي بنسبة 4٪، كما أن محطات الغاز الحيوي هي أيضا خيار مجد اقتصاديا للمزارعين المصريين من حيث فترة استرداد مدتها 3 سنوات مع عائد داخلي 40٪، وهو أعلى من سعر الفائدة التجارية البالغ 27٪. لذلك، اقترحت الدراسة أن تتبنى الحكومة المصرية سياسة جديدة تؤدي إلى تثبيط الاعتماد على الطاقة التقليدية، وخفض دعم الطاقة، وتشجيع المزيد من الاعتماد على تقنيات الطاقة المتجددة، وزيادة الوعي بفوائد استخدام تقنياتها.

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Economic Viability of Renewable Energy Technologies in Egyptian Agriculture and Rural Development

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ABSTRACT

The paper aims to examine the economic viability of renewable energy technologies (solar and biogas) in rural Egypt, particularly the agriculture sector since Egypt is suffering from a high rate of energy consumption that exceeds the rate of energy production, and it is expected that with rapid population growth, the demand for energy will keep increasing and lead to energy shortages in the future and rural areas are most exposed to this risk. The study relied on cost-benefit analysis, payback period, internal rate of return (IRR), and partial budgeting. The results showed that home solar panel systems are a marginally viable option for rural households in terms of a payback period of 6 years with an IRR of 4%, and biogas plants are also an economically viable option for Egyptian farmers in terms of a payback period of 3 years with an IRR of 40%, which is higher than the commercial interest rate of 27%. So, the study suggested that the Egyptian government should adopt a new policy that leads to discouraging reliance on traditional energy, decreasing energy subsidies, encouraging more reliance on renewable energy technologies, and increasing awareness of the using its technologies.

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1. Introduction

Energy acts as the engine of economic and social development in Egypt, and without sufficient access to modern energy services, Egypt will suffer from social instability and economic underdevelopment. Energy is a basic need for the Egyptian farmers, as it is essential to meet their daily activities like food production, cooking, lighting, and water heating. In terms of agricultural activities, energy is essential as an input for irrigation, fertilization, refrigeration, land preparation, livestock, drying agricultural products, and other activities to produce food. In this context, Egypt is suffering from a high rate of energy consumption that exceeds the rate of energy production, and it is expected that with rapid population growth, the demand for energy will keep increasing and lead to energy shortages in the future. Egypt is the larget number of population among MENA countries, with one of the highest growing populations in the world. The rapid population growth leads to an increase in energy demand, and that puts more and continuous pressure on Egypt's domestic energy resources, along with the increasing demand for energy input to agriculture, which leads to a decrease in productivity and food security levels. So, the energy sector is a cornerstone of Egypt's economic development and represents about 13.1% of the overall GDP.

The Egyptian government has adopted a new energy diversification strategy called the Integrated Sustainable Energy Strategy (ISES) that aims to achieve continuous energy supply security and stability via adopting new renewable energy technology and increasing energy efficiency as a part of reform and maintenance programs in the power sector. Egypt produces about 3.45 quadrillion BTU of energy that covers only 86% of annual energy consumption needs, in which it consumed 4.01 quadrillion BTU of energy. Therefore, the Egyptian government targets to meet 42% of overall power generation from renewable energy technologies by 2035. The paper aims to examine the economic viability of renewable energy technologies (solar and biogas) in rural Egypt, particularly in the agriculture sector, by exploring the potential of renewable energy technologies in Egypt and figuring out the economic viability of using renewable energy technologies in rural areas. So, the potential of the renewable energy sector and technologies, along with the economic viability of using renewable energy technologies in the Egyptian agriculture sector and rural areas, are analyzed in this paper via a literature review and cost-benefit analyses. Moreover, internal rates of return, payback periods, and partial budgeting are also

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used to examine the economic viability of these technologies in providing energy services to the farmers in rural Egypt.

Despite the abundance of renewable energy resources in Egypt, there are many barriers that limit the promotion of renewable energy technologies like solar and biogas energies in rural Egypt. Those barriers can be divided into 4 main groups: (1) Institutional and policy barriers due to lack of cooperation between different institution at national-level in collecting and analyze the data related to the energy sector, (2) Economic and financial barriers due to absence of a supportive financial environment to reduce high initial costs of renewable energy technologies, (3) Awareness and information barriers due to unavailability or unreliable of database related to renewable energy resources especially at the rural and remote areas, and (4) Technical barriers due to lack of local expertise, manufacturers, companies and equipment standardization. This paper contributes to the scarce literature in Egypt by conducting a comparative study of the economic viability of the different renewable energy technologies to explore the potential of using these technologies in the agriculture sector. The main limitation of this study is that only secondary data has been used. Surveying governorates could have more depth to such a study, but it was avoided due to the high costs required to collect data.

2. Literature review

Many studies have pointed out the economic viability of renewable energy technologies like solar, wind, and biogas energies in Egypt, particularly in the rural and remote areas. Previous studies focused on solar water heating technologies. Sorour and Ghoneim (1994) examined the feasibility of solar water heating and cooling systems; Abdrabo and Soliman (2008) investigated the economic solar water heater technology aspects; Sharma (2017) assessed the solar industrial heating; Shiqwarah (2020) focused on the potential of solar water heater usage; and Hassan (2021) evaluated the productivity and enviro-economics of hybrid solar distillers using direct salty water. In the same context of the economic viability of solar energy, studies like Abou Rayan (2001) focused on the feasibility of installing solar desalination units; Ahmad and Schmid (2002) examined the feasibility of Photovoltaics technologies on desalinating brackish water; Lamei (2008) carried out a cost analysis for solar desalination units based on both solar thermal and Photovoltaics technologies; Moser (2011) assessed the integrated hybrid

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concentrating solar power and seawater desalination system in Egypt; Abo Zaid (2015) investigated the stand-alone reverse osmosis desalination unit powered by PV systems; and Moharram (2021) conducted a feasibility analysis for integrating a concentrating solar power plant with water desalination systems.

Other studies have pointed out the economic viability of wind and biogas energy in Egypt such as Ahmed and Abouzeid (2001) evaluated the economical and feasible implementations for wind energy in coastal and remote areas; El-Sayed (2002) focused on a cost analysis of a wind farm with 600 MW capacity located in El-Zafarana area; Hamid (2011) examined cost-effective wind farm in different locations in Egypt; Ramadan (2017) carried out a feasibility analysis for harnessing wind power in Sinai; Abdelhady (2017) evaluated the levelized cost of wind energy located along the Mediterranean Sea in Egypt; and Abd El-Sattar (2020) conducted levelized cost of wind energy in multiple locations in Egypt. In term of economic viability of bioenergy technologies, there is a few studies that pointed out to those technologies, El-Halwagi (1986) conduced a cost analysis for biogas programs and systems in rural Egypt; Arafa and El-Shimi (1995) investigated the economic return of biogas technology “biogas digester” adoption in rural Egypt for the farmer household; Ehab Abd El-Aziz (2016) carried out a comparative study of the technical and financial efficiency of biogas technology in adopter and non-adopter farms in Fayoum governance via a cost analysis and stochastic frontier model; and Tawfik and Abd Allah (2019) highlighted the potential of biogas production using biogas units “anaerobic digester” in both Lower and Upper Egypt by using Benefit-Cost (B/C) analysis.

Moreover, a recent study showed the economic viability of renewable energy technologies under the different climate change scenarios. Mahmoud Adel Hassaan (2024) investigated the negative impacts of climate change on both solar and wind energy in Egypt by 2065. Other studies focused on the potentials of renewable energy in Egypt, including solar, wind, hydro, and biogas energy, such as Nour (Brief review on Egypt's renewable energy current status and future vision, 2022); Mostafa (Solar Energy in Africa—An Overview, with a Focus on Egypt, 2024), and Salah (Towards a sustainable energy future for Egypt: A systematic review of renewable energy sources, technologies, challenges, and recommendations, 2024).

In summary, based on the previous studies mentioned, Egypt has high potential for renewable energy as well as the presence of the economic viability of renewable energy in rural Egypt, but on the other hand, there are many barriers restricting the

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development of the renewable energy sector in Egypt. So, the paper attempted to investigate the most suitable renewable energy technologies for rural and remote areas in Egypt that can supply those areas with affordable and reliable energy services in their houses and farms.

3. Data and methods

The data was collected from four main sources, such as SolarReviews, IRENA, IEA, and the Bioenergy for Sustainable Rural Development project (BSRD). Data used for studying the economic viability of RE technology adoption in the agriculture sector in rural Egypt in this research are as follows: (1) Annual power generation; (2) Average cost per watt or Levelized cost of energy (LCOE); (3) Financial Incentives for photovoltaics; (4) Construction costs; (5) Operational costs; (6) Net benefit; (7) Net saving; (8) Payback period; and (9) Interest rate of return.

3.1 The Time Value of Money

Money has a value associated with time. The discount rate is essential for analyzing a renewable energy project. The equation for calculating the discount factor is as follows:

$$\text{Discount Factor} = \frac{PV}{(1+i)^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where
PV = present value
i = the interest rate or cost of capital
n = years from project implementation

3.2 The Benefit-Cost Ratio (BCR)

The benefit-cost ratio (BCR) is an indicator and use for showing the relationship between the relative benefits and costs of a suggested project. The equation for calculating the BCR is as follows:

$$\text{BCR} = \frac{\Sigma \text{ Present Value (PV) of Future Benefits}}{\Sigma \text{ Present Value (PV) of Future Costs}} \quad \ldots\ldots\ldots\ldots \quad (2)$$

3.3 The Internal Rate of Return (IRR)

The internal rate of return (IRR) is an indicator used in financial analysis to assess the potential profitability of investments or the annual rate of growth that an investment is expected to generate. The equation for calculating the IRR is as follows:

$$\mathrm{IRR} = r_a + \frac{\mathrm{NPV_a}}{\mathrm{NPV_a} - \mathrm{NPV_b}} (r_b - r_a) \quad \ldots\ldots\ldots\ldots \quad (3)$$

Where

r_a = lower discount rate chosen
r_b= higher discount rate chosen
NPV_a = net present value at r_a
NPV_b = net present value at r_b

3.4 Payback Period

The payback period is the amount of time required to recover the initial investment cost, or the number of years it would take an investment to return its original cost. The equation for calculating the payback period is as follows:

$$\text{Payback period (stable cash flow)} = \frac{\text{Investmet cost}}{\text{Annual Net Cash Flow}} \quad \ldots\ldots\ldots \quad (4)$$

$$\text{Payback period (differences in cash flow)} = \frac{\text{Investmet cost}}{\text{Average Annual Profit}} \quad \ldots\ldots \quad (5)$$

4. Results and Discussions

4.1. Renewable Energy Potentials in Egypt

Egypt has high renewable energy potential that can be used to boost sustainability and energy diversification and deployed in the agriculture sector to improve the living standards in rural areas and the productivity of farms. Solar and biogas energy are the most stable and suitable renewable energy resources to be used in rural Egypt over the other RE resources like wind energy which is not stable all the year except in specific areas in Egypt and hydropower is a limited resource. Renewable energy resources in Egypt represented about 4% of global energy consumption in 2010, with an expectation to reach 8% by the end of 2024 and 14% in 2035. The total RE installed capacity equaled 3.3 GW in 2010, and it is expected to reach 19.2 GW by the end of 2022 and 62.6 GW in 2035. The solar atlas for Egypt stated that Egypt counted as a "sun-belt" country with total radiation intensities ranging from 2400 to 3300 kWh/m2/year. The sun shines from 2900 to 3400 hours annually, with normal direct radiation intensity ranging from 1980 to 3200 kWh/m2/year. The total

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installed capacity of PV systems is expected to reach 3451 MW in 2023, with total electricity generated expected to reach 4720 GWh by 2023 (compared to 4453 GWh in 2020).

In Egypt, the most common form of solar technology is solar photovoltaic (PV). This technology generates electricity by converting the sun's energy directly into electricity through cells made from silicon, known as photovoltaic cells. PV relies on the technology of a semi-conductor to convert solar radiation directly from the sun into an electric current that is used immediately to power appliances (e.g., lighthouses, microwave repeater stations, traffic lights, calculators, street lighting, watches, water pumping for irrigation, and satellites) or stored for later use in a battery. Solar PV technology is used for various commercial applications in Egypt, particularly in remote areas. Table (1) shows the planned PV projects for small and large scales units in Egypt up to 2023.

The wind atlas for Egypt stated that Egypt is blessed with numerous wind energy resources, especially in the Gulf of Suez area. This area is considered one of the most suitable locations in the world for using wind energy due to the stability of wind speeds (8–10 m/s) at a height of 100 meters. The total installed capacity of wind systems is expected to reach 4610 MW in 2023, with total electricity generated from wind systems expected to reach 4499 GWh by 2023 (compared to 4245 GWh in 2020). Table (2) shows the planned wind projects for both small and large-scale plants in Egypt up to 2023. The Nile River is the primary hydroelectric resource in Egypt; hydropower represented about 9% of the nation’s electricity (amounting to 2,832 megawatts in 2021).

Hydropower has the highest share among other renewable energy technologies in Egypt, with about 45.5% of the total renewable energy capacity. Table (3) shows the stations and capacities of hydroelectric stations in Egypt (Aswan), where the total annual generated electricity from hydroelectric stations amounted to 13,545 GWh.

Egypt is endowed with abundant biomass energy resources from agricultural waste, animal dung, and solid waste. Annually, approximately 35 million metric tonnes of agricultural waste are generated. Biomass technologies are used for various applications in Egypt, particularly in rural areas (for electricity and high-value fertilizers). Biogas is a gas composed of methane and carbon dioxide, with 60 percent methane and 40 percent carbon dioxide. Biogas production results from the process of “anaerobic bacteria” that convert organic waste into methane, which is the main component of natural gas. Because biogas is mainly composed of methane, it can be used for energy, and a by-product of this process is organic fertilizer.

Table 1: Planned PV projects in Egypt (2023).

Location	Size (MW)
Kom Ombo	200
West Nile	600
West Nile	200
West Nile	600
FIT	50
FIT	1,415
Hurghada	20
Zaafarana	50
Kom Ombo	76

Source: IRENA (2018)

Table 2: Planned wind projects (2023).

Location	Size (MW)
Gulf of Suez	500
Gulf of Suez	400
Gulf of Suez	2,000
Gabal El Zayt	220
Gabal El Zayt	690
West Nile	200
West Nile	600

Source: IRENA (2018)

Table 3: Current Capacity of hydroelectric stations in Egypt.

Location	Annual generated electricity (GWh)
High dam	9,484
Aswan	3,101
Esna	507
Naga Hamady	453
Total	13,545

Source: IRENA (2018)

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4.2 Data Description

Descriptive statistics were carried out to describe or summarize the characteristics of the data for all variables mentioned earlier in table (4). It includes three main categories of measures: (i) Measures of central tendency, (ii) Measures of frequency distribution, and (iii) Measures of variability.

Table 4: Descriptive statistics of the variables.

Descriptive	Investment ($)	Operation ($)	Saving ($)	Benefit ($)	DF (5%)	DF (8%)	NPV (1)	NPV (2)
Mean	12.5	1034	288	1615	601	0.542	0.410	58
Stand. Error	1.5	472	11	64	380	0.044	0.048	388
Median	12.5	0	300	1680	1379	0.517	0.354	616
Stand. Dev.	7.65	2409	58	329	1942	0.224	0.244	1983
Sample Var.	58.5	5804634	3469	108553	377231	0.050	0.059	39324
Kurtosis	-1.2	3.04	26	26	4.60	-0.041	-0.549	11
Skewness	0	2.13	-5.09	-5.0990	-2.47	-	0.569	-
Range	25	8050	300	1680	6000	0.952	0.925	9363
Minimum	0	0	0	0	- 4620	0	0	-8050
Maximum	25	8050	300	1680	1379	0.952	0.925	1313
Sum	325	26900	7508	42000	15641	14.09	10.674	1512
Count	26	26	26	26	26	26	26	26

Source: Author

4.3 Economics of SHS and Biogas Plant in Egypt

The average solar panel installation cost in Egypt is between US$ 7,758 and US$ 17,026 (based on the size of a solar panel system), with the average cost per watt between US$ 2.28 and US$ 2.79. Details of the initial cost of solar home systems (SHS) in Egypt (based on different system sizes) have been calculated and summarized in table (5) and based on data collected from Solar Reviews. In order to figure out whether the installation of solar home systems is an economically viable option in Egypt, the table (6) shows the cost, savings, payback period, and internal rate of return on investment for a solar home system in Egypt (based on different system sizes). The results showed that the average payback period for a solar system home in Egypt is 5.8 years (a short period of repayment) and the average internal rate of return on investment is 4.1% (a more viable option compared to investing in shares or property based on their historical returns). Therefore, SHS are economically viable options for both urban and rural electrification. With the falling prices of solar panels in the future, it will be a more economically viable option. Biogas units in rural Egypt are built in livestock farms from 4 to 7 cattle in average, which produce about 12 kg of dung/day/head. These units consist of a gas holder, biogas digester, a moisture unit, and a retrofit with production capacities of biogas units (2, 3, 5, or 6 m^3 per day). The average biogas plant installation cost in rural Egypt is between US$ 134 and US$ 403 (based on the capacity of the biogas plant). Once the digester unit is constructed, it has a long life of 25 to 30 years with a low operational cost of around US$ 25 per year. The initial cost, operational cost, savings, net benefits, and pay-back period of a biogas units in rural Egypt have been calculated and summarized in table (7). The results concluded that the it is an economically viable option for rural households. The average payback period of these biogas units is 3.1 years (a short repayment period), and the IRR on investment is 40%, which is greater than the commercial interest rate (27%) in Egypt.

Table 5: Initial cost of solar home systems in Egypt (2024).

System size (KW)*	Annual power generation (kWh)*	Average cost per watt ($)*	System cost after tax ($)
4 KW	5,434	2.77	7,758
5 KW	6,793	2.66	9,303
6 KW	8,151	2.54	10,653
7 KW	9,510	2.51	12,301
8 KW	10,869	2.55	14,258
9 KW	12,227	2.46	15,487
10 KW	13,585	2.43	17,026

Source: Data collected from Solar Reviews

Table 6: Cost, pay-back period, and IRR for solar home system in Egypt (2024).

System Size (KW)*	System cost ($)*	Incentives & rebates ($)*	Net cost ($)*	Saving /Year ($)*	Pay-back (Years)**	IRR (%)**
4	7,758	2,429	5,329	960	3.3	2.3
5	9,303	3,036	6,267	1.200	4.2	2.9
6	10,653	3,643	7,010	1,440	5.0	3.5
7	12,301	4,250	8,051	1,680	6.0	4.1
8	14,258	4,857	9,401	1,920	6.6	4.6
9	15,487	5,464	10,023	2,160	7.5	5.2
10	17,026	6,072	10,954	2,400	8.3	5.8

* Data collected from Solar Reviews
** Source: Author

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Table 7: Payback period and IRR of biogas plant in rural Egypt (2023).

Capacity (m^3/day)	2	3	5	6
Construction cost ($) *	134	202	336	403
Operational cost ($/Year)	13	19	31	37
Total costs ($/Year)	147	221	367	440
Savings on LPG ($/Year)	37	37	37	37
Sold of Manure ($/Year)	36	53	89	106
Total benefit ($/Year)	73	90	126	143
Net benefit ($/Year)	60	71	95	106
Pay-back Period (Years)	2.2 – 3.8 Years			
Internal rate of return (%)	35 - 40 %			

Source: Author. (*) The construction cost was estimated according to the real prices of the developed biogas plant construction (Tawfik and Abd-Allah, 2019).

Moreover, in order to do more deep economic analysis for biogas plant in rural Egypt, the paper will rely on partial budgeting to show if the biogas plant is more viable option than LPG or not. Partial budgeting is a planning and decision-making framework used to compare the costs and benefits of alternatives faced by a farm business. It focuses only on the changes in income and expenses that would result from implementing a specific alternative. The results of partial budgeting of biogas plant in rural Egypt is summarized in Table (8).

Table 8: Partial budgeting of a biogas units in rural Egypt (2023).

(1) Added income	($/year)	(2) Added cost	($/year)
Savings of time	177	Labor	192
Bio-slurry	206	Maintenance cost (5%)	20
		Depreciation cost (3%)	13
(3) Reduced cost	**($/year)**	**(4) Reduced income**	**($/year)**
Alternative fuels	37	None	
Alternative fertilizers	40		
Disease	8		
Sub-total (5) = (1) + (3)	468	Sub-total (6) = (2) + (4)	225
Net Change ($/year)	Sub-total (5) - Sub-total (6) = 468 – 225 = 243		

Source: Author

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A benefit-cost ratio, payback period, IRR, and partial budgeting were used to get the results in this paper; these results are compatible with Maisha Islam (2010), Ehab Abd El-Aziz (2016), Tawfik (2019), and Dilruba Bedana (2022) results. For future research, studies can do more in-depth analysis by using net present value (NPV) and adding more sensitivity analyses under different scenarios. Moreover, surveying governorates can also strengthen such a study by gathering primary, accurate, and reliable data.

5. Conclusions and Recommendations

This paper demonstrated the potential of adopting renewable energy technologies in rural Egypt. The economic viability of adopting renewable energy technologies in was evaluated via a different economic analysis like BCR, payback period, and IRR. The obtained results of the residential solar panel system showed that it is a marginally viable option for rural households in Egypt in terms of the payback period of 5.8 years and an internal rate of return (IRR) of 4.1%. However, with the price of energy rising due to Egypt's removal of subsidies on most energy products and, on the other hand, the falling price of solar panels, the residential solar panel system will be a more economically viable option for rural electrification in Egypt.

Additionally, the economic evaluation of biogas plants in rural Egypt was carried out, and it was found that anaerobic digester units have a short repayment period of 3.1 years and a high internal rate of return (IRR) of 35% compared to the commercial interest rate of 27%. So, biogas plants are an economically viable option for rural households in Egypt. With the falling prices of RE “Solar” technologies, the viability of their adoption in the agriculture sector as an emerging option for Egyptian farmers is expected to increase. Therefore, establishing the foundation for renewable energy applications in Egypt, particularly in rural areas, would be a great investment in view of Egypt's need to boost its agriculture sector and rural development, create job opportunities, and meet the nation's energy requirements. Moreover, among the various renewable energy technologies, solar energy and biogas energy uniquely provide a synergy of solutions and benefits that can be adopted in the agriculture sector in Egypt.

Despite the abundance of renewable energy resources, there are many barriers that limit the adoption of renewable energy technologies like solar and biogas energies in rural Egypt. Therefore, the study recommends the following: (1) The Egyptian government has to adopt new policies that aim to discourage reliance on the conventional energy system and decrease energy subsidies; (2) The Egyptian government has to adopt new policies that aim to encourage reliance on renewable energy systems and increase awareness of using those technologies; (3) Overcoming the awareness and information barriers can be done by relying on the effective media campaigns to explain the negative impacts of the conventional energy system and energy subsidies on the Egyptian economy and, on the other hand, showing the positive impacts of using renewable energy in terms of socio-economic aspects; (4) Institutional and policy barriers can be overcome by creating and adopting a SMART national roadmap for the renewable energy sector to figure out the targets of renewable energy capacity and achieve it within a certain timeframe; (5) Overcoming the economic and financial barriers can be accomplished by exemptions of licensing procedures and reduction in taxes and customs duties for all equipment associated with renewable energy projects; and (6) Technical and market barriers can be removed by providing local education and training in the renewable energy field to set national standards for renewable energy systems in Egypt.

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