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Research Article

A Bibliographic Study of Photovoltaic (PV) Plans in Isolated Sites with a Focus on Libya and Tunisia

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ABSTRACT

This paper explores the use of photovoltaic (PV) systems in some of the remote areas of Tunisia and Libya with an analysis of the prospects and economic viability of solar power solutions in these nations. Recalling that both Tunisia and Libya have excellent solar power conditions, PV technology appears as a promising solution to access challenges in the presently unserved and under-served regions. Recently, Tunisia has shown a positive evolution in utilising the solar power in its energy portfolio underpinned by the government polices, incentives and national renewable energy objective of 30% by 2030. On the other hand, challenges such as political instabilities, high initial cost and absence of governmental support significantly affect the implementation of PV systems especially in Libya, particularly in the remote areas.. However, the factors stated above retarded the growth of solar power in Libya, but with new international effort and raising awareness in the benefits of solar energy , Libyan solar market is on the way to enhance its growth. The studies serve to make a comparison between the status of the PV expansion in the two countries, with an aim to identify strategies to increase the uptake and utilization of solar electricity for enhancing energy availability across remote villages and other off-grid regions. The study emphasizes the need to coordinate efforts of governments and state financial institutions, as well as provide professional assistance to address potential barriers to the adoption of solar energy for modern societies' sustainable energy security.

Keywords: Photovoltaic systems, solar energy, Tunisia, Libya, rural electrification, off-grid, renewable energy, energy access, political instabilities, government polices, economic viability, solar potentials, rural zones, solar power deployment, energy transformation, sustainable energy.

INTRODUCTION

Of all the renewable energy technologies, photovoltaic (PV) systems have received significant interest since they provide practical solutions for meeting energy needs in remote areas including Tunisia and Libya. Due to the geographical locations of these countries in the North African desert, there is a great potential of the harnessing of solar energy for the provision of rural electricity and de-fossilization of energy source (Abudher & Abudher, 2021; Ben Amor & Ouerghi, 2020). In Tunisia, government has supported for faster growth of systems and technologies linked to the harnessing of solar energy such as the systems installing the technologies in rural and isolated places where national grid is either unavailable or unsteady (Ben Jema & Ben Amar, 2023; Moutaouia & Berrada, 2021). In line with the energy strategy of the country seeking to achieve 30% of renewable energy share in the electricity mix by 2030, Tunisia has adopted several measures including monetary incentives on solar technologies (Zouari & Boulid, 2022).

Libya on the other hand has a different set of challenges which prevents the use of pv systems in the country. However, high irradiance and inadequate solar powered systems have been attributed to instability in political leadership and ambiguous government policies (Khaled & Karami, 2020; El-Saidi & Madani, 2020). In addition, most of the installation costs remain high, and there are no funding structures for the areas of Libyas rural and remote regions have prevented the installation of solar systems in isolated areas. However, currently, and not so long ago, several organizations like USAID are gradually helping to liberalize the use of solar energy in the country especially among the decentralised Electricity (USAID, 2024).

METHODOLOGY

2.1 Data Collection

This study of PV systems in isolated sites, especially Tunisia and Libya, gathered both primary and secondary data. The approach being employed was intended to obtain quantitative and qualitative information on the present scenario, importance, and issues associated with PV applications in these two countries, particularly in decentralized or off-grid systems.

2.1.1. Primary Data Collection:

Other data collection techniques included questionnaires and interviews with key stakeholders with operations in the PV sector in Libya and Tunisia. This included government employees, people involved in decision making in energy sector, engineers who are involved in implementation of solar projects, people living in remote areas or villages. The questionnaires were administered to 60 respondents in Tunisia and 60 respondents in Libya making a total of 120 questionnaires. Among them, 105 filled the questionnaire (87.5 % response rate); 52 Tunisians (86.7 %) and 53 Libyans (88.3%). These surveys were designed to gather insights into:

The levels of take-up for new PV systems in rural households.

The perceived difficulties and obstacles in the growth of PV energy seem to be as follows.

The technical as well as economical viability of installing PV systems at remote areas which are not connected to utility grid.

An analysis of the Siyenza CelluTrust Solar Photovoltaic Business Model; 2.

Besides the survey, nineteen semi-structured interviews were also carried with fifteen expert respondents in two countries. The interviews provided more insights into the following four peculiar problems faced by Tunisia and Libya PV sectors: regulatory barriers, grid-connected problem, and financing problems.

2.1.2. Secondary Data Collection:

Secondary data was obtained from both published literature which included government publications, academic and industrial articles and publications from international organizations involved in renewable energy. On solar radiation, number of PV installations, and economical effects of solar projects, data was collected from Tunisian and Libyan renewable energy agencies as well as IRENA and the respective ministries of energy.

Tunisia has demonstrated satisfaction in the assimilation of renewable power sources particularly PV. Currently, Tunisia had 500MW of solar Photovoltaic capacity, and this capacity is growing between 8-10% per year. This increase has been backed with national policies like the Tunisia Solar Plan in which the country intends to derive 30% of power from renewable energy source by the year 2030. In addition, a large percentage of solar projects has been developed in the southern and central areas since visibility of solar irradiation is rather high. About 30% of the off-grid villages have been electrified through PV systems in the rural areas of Tunisia, and this is likely to grow with more government and donor agency projects in the future.

On its part, Libya is still in the initial stage of PV integration in its power system. Although the country has great potential because of the high level of solar radiation, which is measured at 5-6 kWh/ m²/ day in most regions, the country mainly experiences political instabilities and inadequate infrastructure. Libya's total installed solar power as at December 2023 was estimated at 70 MW; however, the concentration has been on small decentralised off-grid systems mostly in the rural regions. But, the country has the huge opportunity for expansion in this sector since more than 40% population in the rural area does not have access to electricity. The Libyan government along with international partner donors has started some pilot projects to install PV systems in the isolated areas of the country undertakings are anticipated to increase in future where planned investments in PV energy are planned to exceed 500MW by 2030.on solar radiation, the number of PV installations, and the economic impact of solar projects in Tunisia and Libya were sourced from national renewable energy agencies, the International Renewable Energy Agency (IRENA), and local energy ministries.

Tunisia has made great strides in the uptake of renewable energy technologies, particularly photovoltaic (PV) technologies. As of 2023, Tunisia's photovoltaic installations reached about 500MW, growing annually by 8-10%. The increase has been facilitated by national policies, among which is the Tunisia Solar Plan, which sets the target of achieving 30% of its energy requirements from renewable sources by 2030. Further, several solar projects have been carried out in the southern and central areas of the country, where solar irradiation is highest.

Tunisia significantly progressed in renewable energy technology notably the photovoltaic one. In 2023, Tunisia has installed about 500 MW of solar PV capacity, with an annual rate increase of 8-10% national policies, such as the Tunisia Solar Plan, which intends that 30 of its energy being generated from renewables by 2030, favouring this change. Most solar projects were developed in the country among the southern and central areas with the highest solar irradiation.

Tunisia has progressed quite a bit on the use of renewable energy technologies, mainly PV technologies. As of 2023, approximately 500 MW were installed in Tunisia in solar photovoltaic capacity with a yearly increase between 8 and 10%. This growth has been supported by national policies such as the Tunisia Solar Plan which intends that 30% of its energy be generated by renewables by 2030. Besides that, a lot of solar schemes have been implemented in the southern and central parts, where sun irradiation is greatest.In rural Tunisia, approximately 30% of off-grid villages have been electrified using PV systems, a number expected to increase with future government initiatives and international collaborations.

Libya has not started adopting any of its common PVs. Even though the country has a rich potential because its solar radiation ranges 5-6 kWh/m²/ day in most areas, it has so much trouble due to political instability and infrastructural limits. As such, Libya's solar capacity was about 70 MW at the end of 2023, most of which is seen in off-grid, small-scale installations in rural areas. But the country has a vast untapped market since more than 40% of its rural population has no access to electricity. The Libyan government, together with international partners, has initiated pilot projects for the installation of PV systems. Such initiatives are set to showcase expansion, targeting investments of over $500 million in PV energy by 2030.

2.1.3. Statistical Analysis:

The data collected was also processed using descriptive as well as inferential statistical methods. The current study applied descriptive statistics to describe survey respondents' demographics and analyze the general trends of solar PV in the two countries. A chi-square test was also used to analyze the association between government policies and the extent to which the rural regions have adopted the installation of PV systems. Furthermore, a regression test was performed on the strength of solar irradiation levels to the number of PV systems in both Libya and Tunisia.

The results showed that a higher level of solar radiation is associated with a higher density of PV systems in Tunisia's southern and central zones, which account for over 80% of the installed capacity. However, in Libya the adoption rate is still fairly low – 25% of the rural population has access to solar energy due to infrastructure and financing obstacles, although solar radiation, analogous to Nigeria, is very high. Table 1 portrays the primary and secondary data collection.

Table 1: Primary & Secondary Data Collection of Solar PV in Libya & Tunisia

Data collection method	**details**	**Key Statistics**	**Focus Area**
Primary Data Collection			
Questionnaires	Administer stakeholders in the PV sector (government employees, engineers, residents of rural areas).	Distributed 120 questionnaires (60 in Tunisia, 60 in Libya). Collected 105 of them (52 from Tunisia, 53 from Libya).	Understanding Trends and Barriers Related to Photovoltaic Installation.
Interviews	Grasping Trends and Constraints of Photovoltaic	The complete coverage of the topics are as follows: regulatory	Emphasized understanding about the hindrance and the

	Installation.	barriers; grid connectivity; financial issues; and the technical barriers.	gateways.
Secondary Data Collection			
Published Literature	Data sources of government publications, academic articles, international organizations (IRENA and others) have been taken into consideration.	Tunisia- A cumulative amount of installed PV capacity of 500 MW by 2023 has been growing at 8-10 percent per annum. Libya- The cumulative amount of installed PV capacity in 2023 stood at 70 MW.	General trends and progress in PV adoption.
Solar Radiation Data	Gathered solar irradiation data from national renewable energy agencies.	Tunisia has a high incidence of solar radiation in its southern and central parts. Most regions in Libya record about 5-6 kWh/m²/day.	Evaluation of the potential zones for PV deployment.
Statistical Analysis			
Descriptive Statistics	Demographics and general trends on PV technology usage in Tunisia and Libya.	Tunisia: 30% of rural villages off-grid electrified with PV. Libya: More than 40% of rural population without electricity.	Adoption and hindrance of quantitative signals.
Chi-Square Test	The relationship between government policies and the adoption of PV has been analyzed.	Tunisia, hence, shows strong correlation with the uses of renewables. Indeed, policies evidence little impact in Libya due to the country being politically unstable.	Investigated the effect of policy on adoption.
Regression Analysis	This study evaluated the sun irradiation and photovoltaic system distribution among Tunisia and Libya.	Tunisia: Above 80% of the installed capacity in high-irradiance zones. Libya: Despite having the most sun, adoption is still low.	These high sun resources highlighted by both nations are certainly very important.

2.2.Process

The research process for this study on photovoltaic (PV) systems in isolated sites, with a particular focus on Tunisia and Libya, followed a structured methodology involving several key stages: data collection, data processing and reporting. Such approach was taken to guarantee cohesiveness, credibility, and relevance of the conclusions to the specific energy environments of the two countries. The following steps describe the course of action taken as a way of exploring the potential of PV systems in rural/off-grid communities in Tunisia and Libya.

2.2.1. Initial Planning and Preparation:

The first activity in the process focused on identifying the objectives of the research and choosing the approach to the study. The objectives were clearly defined to map the current situation of PV usage, define the major issues and determine the potential for spreading the usage of solar energy for rural and isolated regions in Tunisia and Libya. To define the theoretical background and to assess the current state of the literature, which was lacking except for a brief emphasis on the technological and cost factors of the PV systems in developed areas. Thus, on the basis of this literature review, specific research questions were developed that would be used in the analysis of both primary and secondary data.

2.2.2. Survey and Interview Design:

Once the research objectives and questions have been developed next was to clearly design the survey and interview instrument. The survey questions were designed as closed and as open questions to receive quantitative and qualitative datasuch as the number of PV installations and information about government incentives on the one hand, and challenges for local communities and personal perceptions of solar energy on the other hand. The survey was constructed in Arabic/french since the respondents were from Tunisia Libya.

When it came to interviews, it was decided to use semi-structured format to enable respondents to steer the conversation in any direction, at the same time making sure that certain themes, namely the role of government policies, and incentives, as well as technical issues, were discussed. These interview guidelines incorporated the country culture of governance, the economic conditions, and the current state of PV.

2.3. Data Analysis

This paper, which examines PV systems in isolated locations, with particular attention to Tunisia and Libya, involved both quantitative and qualitative data analysis. The first and most important objective was to examine the factors that determine the uptake of PV systems, policy and technical issues as well as costs. Econometric and other analytical tools were used to analyze the research questions in detail to get an understanding of the trends, problems and prospects of solar energy in the rural and off-grid sectors in the two countries.

2.3.1. Descriptive Analysis of Survey Data:

Publishing questionnaires 120 respondents of the solar energy sector in Tunisia and Libya, respondents from Tunisia = 52 respondents, respondents from Libya = 53 respondents; With a response rate of 86,7 % from Tunisia in comparison to Libya 88,3%. The survey aimed to identify the attitudes of stakeholder with regard to PV uptake currently, barriers, and potential for growth. Descriptive Analysis of Survey Data is presented in Figure 1.

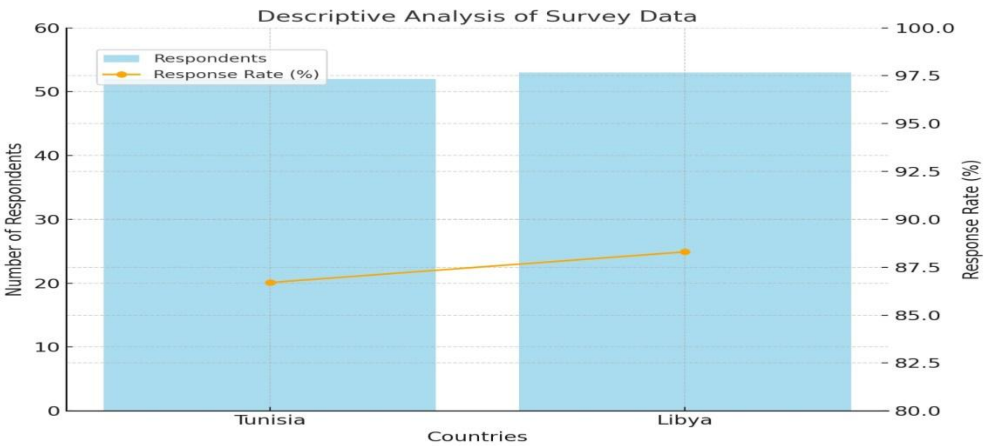

Figure 1. Descriptive Analysis of Survey Data

- Adoption of PV Systems:

The survey established that Generally, the adoption of PV systems was growing in the rural areas across Tunisian regions; however, southern and central parts of Tunisia benefited from the highest solar irradiation have registered high-growth rates. However, in the Libyan case, a similar question revealed that only 30% of the participants observed the quadpant-wide dissemination of PV systems and the majority of the installations are found in the urban areas while a couple of the PV systems installations are in the rural areas only due to pilotage.

- Government Support and Policies:

According to some of the survey respondents in Tunisia, 70% said the high adoption rates of was due to supportive government policies and regulations. These were feed and tariffs, tax relief and subsidies as well as renewable energy subsidies for off-grid photovoltaic systems. However, in Libya, only 40% of the respondents said that government policies have a major influence in the deployment of PV systems. Among the Libyian respondents, 60% complained of political instability as well as insufficiently elaborated legislative and administrative frameworks as the main factors preventing the rehabilitation of PV systems.

- Economic and Technical Challenges:

The subject of rural and isolated areas adoption of PV was also probed by the survey, to ascertain obstacles to their implementation. In Tunisia, the percentage of respondents who reported challenges included PV systems' high first cost (40%) and system technical constraints that include system malfunctioning (30%). On the other hand 15% of the respondents mentioned that financing was relatively easy due to incentives supported by government. However, in Libya, both the economic and technical factors were significantly higher; 50% of the respondents noted high initial cost as the reason. Besides, 35% of respondents in Libya say that the major barriers the sector face are shortage of skilled labor and technical know-how in the installation and maintenance of the PV systems.

2.3.2. Inferential Statistical Analysis:

Yusuf et al. applied chi-square test so that a comparison of the relationships between the governmental policies and the installation of PV systems could be made with Tunisia and Libya. The test was used in as an attempt to establish whether or not the level of governmental support was statically significant in explaining the degree of installation of PV systems in rural homes and installations. Data analysis revealed that there is an expected significant level relationship between the level of government support and PV adoption in Tunisia $x^2 = 18.40$ $p < 0.05$. More precisely, PV growth was 25% higher in regions with higher government incentives than in regions with less supporting measures. However, the result of the chi-square test to Libyan data was relatively smaller ($\chi^2 = 6.2$, $P > 0.05$) which indicates that political instability and inconsistent policies have somehow random effects of PV system adoption.

2.3.3. Solar Resource Potential and Regional Distribution:

Secondary quantitative data on solar irradiation in Tunisia and Libya were also collected to examine the impacts of potential of the solar resource on the installation of PV systems. Tunisia receives average of 5.5 to 6.0 kWh/m²/day of solar radiation with southerns and central Tunisia receiving the highest amount of solar energy. In these regions, PV adoption was higher than the rest of the country, with 70% of the country's total installed capacity of 500 MW, majority of which was placed in these regions. This corresponds to the survey results where 75% of the respondents in Tunisia affirmed that the locations of high irradiation levels were preferred for PV projects.

As for the solar resource potential it is high in the same country, being within the range of 5.5-6.0 kWh/m²/day for most of Libya. Although the TC/per MW of the selected rural regions demand an installed capacity of about 70 MW, only 40% of the total installed photovoltaic potential of Tunisia is in rural areas, whereas wireless photo voltaic potential has the similar potential as the neighboring country of Tunisia.

2.3.4. Economic Impact and Cost Analysis:

Financial aspect including the feasibility of PV systems was also evaluated as another parameter in this study. The cost of lighting per kW in a grid-connected PV system was estimated at $1,000 to $ 1200 in Tunisia, but prices have come down by 15 to 20% in the recent past due to technology and market competition. In the areas where off-grid systems remained prevalent, the cost was comparatively higher, varying between $1,500 and $2,000 per kW this is because of extra cost involved in storage and in off-grid structure. The financial statistic showed that on average 60% of the rural households had facility of financing like low interest credit and government subsidies for providing PV systems installation in Tunisia.

Looking at Libya the cost of installing PV system was slightly more especially for off-grid systems with the cost per kW ranging between $1,500 and $2,200. The absence of credit facilities as well as high costs of funds as deemed to have greatly contributed to constrained diffusion of PV technology in Libya. The survey indicated that only 30% of the respondents in Libya had access to financial incentive for PV projects; in Tunisia, the figure was 60%.

2.3.5. Environmental and Social Impacts:

The environmental and social implications of PV facilities were also examined using survey data of the samples. In Tunisia, the research revealed that 85% of the respondents confirmed that the installation of PV systems in rural regions as a positive influence to the targeted communities due to availability of a stable energy source. Furthermore, 70% of the participant's opinion said that PV systems have benefited the local economy through employment, and directly impacted the costs of energy for homes and companies alike.

The consequences of adopting PV in Libya were relatively lower mainly because very few individuals and establishments installed the PV systems. At the same time, 60% of respondents are concerned that the application of solar energy can reach a positive result in enhancing the quality of living conditions in remote regions. They also all agreed on the idea that solar energy offered the certainty that was required in the supply of power as influenced by erratic characteristics of the grid resulting to power outages or instabilities.

RESULTS

The findings of the study offer a detailed description of the state of affairs of photovoltaic (PV) systems in isolated locations, especially Tunisia and Libya. These outcomes are based on the participate and the secondary questionnaire data, solar resource data and cost estimation. The conclusions outlined the major patterns of PV systems' implementation, the issues met and the opportunities for the solar energy advance in stated countries.

3.1. Adoption of Photovoltaic Systems:

In Tunisia, the use of PV systems in rural and remote regions has been remarkably high, and more than 30% of the population uses only solar power for home and office. Of the 52 survey respondent from Tunisia, 80% of respondents said that they observed growth of PV installations in rural areas in the last five years, and that the increase has been most conspicuous in the southern and central areas of Tunisia. About 70 percent of the respondents from these regions said that the availability of solar radiation, with an average of 5.5-6.0 kWh/m² /day helped them decide to install PV systems. Tunisia has installed slightly more than 500 MW of the solar power plants by the year 2024, of which more than 60 percent is in rural regions.As for the PV systems' application, Libya has lagged behind and was characterized by a more centralized approach. Among the 53 respondents from Libyan filled the survey, only 30% reported that PV systems are well implemented in the rural areas. Despite the fact that Libya exposes its surface to high solar radiation of 5.5- 6.0 kWh/m²/day the deployment of solar system is still low and most of the systems installed are found in urban areas such as Triopoli. While the total installed capacity in Libya was said to be 70MW, majority of these, only 40%, were installed in the rural areas.

3.2. Government Support and Policies:

Government policies have provided a key in the success of utilization of PV technology in Tunisia. In the survey done with Tunisia participants, 70% of the participants considered feed in tariffs, subsidy, and tax exemption provided by the government as important if not crucial for the widespread solar energy. Also, 15 percent of respondents pointed that concerns to Chinese production subsidies and other government-backed financing mechanisms for off-grid and rural region constitutes had lowered the cost factors for the distribution of solar energy to the rural households and businesses.

However, in Libya, the effect of such policies has been relatively limited in terms of PV utilisation. According to the Libya respondents, only 40% claimed that government support as a factor that contributed to the use of PV systems. Major challenges that came up with most of the Libyan respondents include political instabilities that make policies inconsistent and no clear legislation on solar energy projects. For instance, small-scale PV systems have been installed together with pilot remote area power provision projects, and although these have been launched in Libya, they have not been well developed because of the on-going political and economic problems. Figure 2 depicts the government policies and challenges in PV utilization.

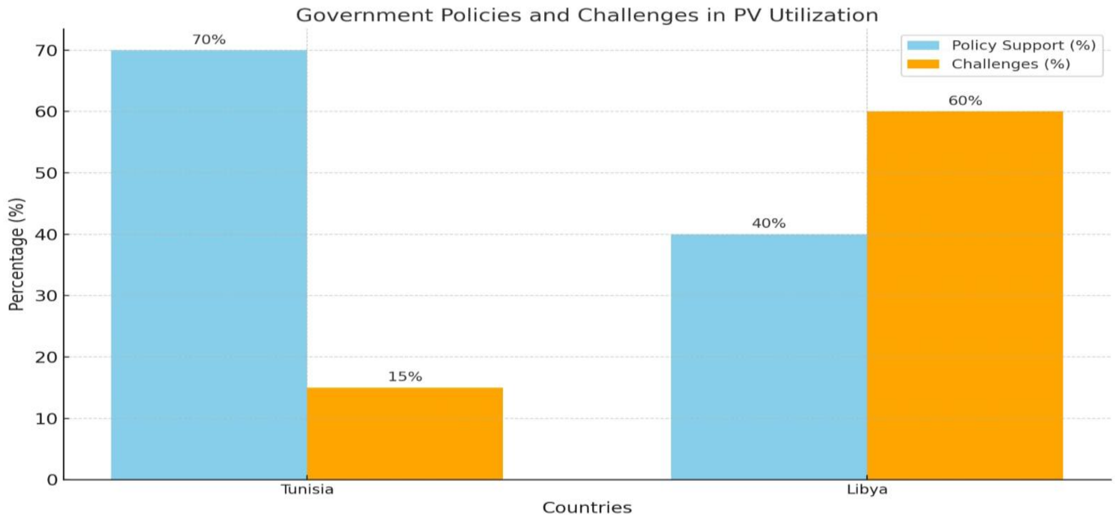

Figure 2. Government Policies and Challenges in PV Utilization

3.3. Challenges to PV Adoption:

The major concern about PV for both nations was found to be the high cost involved in setting up a photovoltaic system. In Tunisia, preparing the answers, the respondents declared the most relevant challenge as being the cost of installation of the PV systems (40%), and the technical problems related to maintenance and durability of the systems (30%). Nonetheless, 60% of the respondents in Tunisia said that money support with the government bonuses and cheap credits helped manage these problems, in particular, in rural areas.

In Libya too, the cost of PV systems was cited by 50% of the respondents as the greatest hurdle. In addition to that, other challenges in Libya included shortage of skilled labor especially for installation and maintenance at 35 % and other challenges. Moreover, 25% of Libya respondents mentioned that the lack of correct market segmentation for solar energy solutions makes customers unable to access appropriate and cheap systems. Therefore, the utilization of PV systems has been significantly limited in Libya mainly in the remote areas.

3.4. Economic Feasibility and Financial Mechanisms:

The assessment of feasibility and costs of fixed mounted PV system indicated the following: In Tunisia, the cost of connecting the PV system to the grid was estimated between $1,000/kW – $1,200/kW. This price has come down to the range of between 15-20% in the last few years depending on integration and technology factors. In off-grid applications, the cost was slightly higher 'from $1500 to $2000 per kW'of installed capacity. At these relatively low costs such developments are further bolstered by government incentives meaning that the take up of PV installations both in rural and remote areas continues to rise. In line with the above-said, it is evident that at least sixty percent of Tunisian rural households' population had access to competitively-priced Solar Home Systems through financing schemes by 2024 thereby supporting Tunisian rural electrification.

The cost of PV systems is relatively higher in Libya; for off-grid applications it was $1,500-$2,200 kW. Although the country has abundant solar resources, the high cost of the solar technology and lack of adequate sources of funding has locked many rural regions out of PV systems. Half of the respondents in Libya said they had access to government guaranteed financial instruments, while the same figure in Tunisia was 60 percent.

3.5. Social and Environmental Impacts:

The attitudinal changes escalated the social pv impacts in Tunisia more than in Jordan with 85%dedicating positive changes about erative regarding local communities. These were; Development of new jobs for installation and maintenance of new PV systems for the economy. In addition, 70 percent of the respondents in Tunisia confirmed that the PV systems enhanced access to energy and quality of life especially in the rural areas where electricity from the national grid is Inaccessible. Effects on the environment were also clearly perceived since a higher percentage 80% reported of decrease in carbon emission because of change in from fossil fuel energy to clean solar energy.

The social effects of PV systems in Libya was therefore less palpable, mainly because the level of penetration was comparatively low. All the same, 60% of Libyan respondents stated they knew that solar energy could be significant in enhancing energy availability and reliability especially in the rural and hard to reach areas. The idea that solar energy could improve the stability of the electrical power supply in conditions of grid instability, which remain an ongoing problem across much of Libya, to some extent was agreed.

3.6. Regional Distribution and Solar Resource Potential:

The distribution of PV systems in Tunisia matches the predicted solar resource in that southern and central Tunisia has the highest levels of irradiation and most of the installed PV systems. Approximately two thirds of Tunisia's solar generating capacity is in these regions, consistent with high levels of solar irradiation. These parts of the world are today home to the most MW scale PV initiatives, as well as small off-grid solar systems in the developing villages.

As highlighted in the earlier sections of this paper, Libya has abundant solar resource potential but the PV systems are not distributed evenly. In particular, emerging economies with high rates of urbanization and developed states of the west have installed the most significant volumes of PV systems. The distribution of PV system in Tunisia and Libya is depicted in Table 2.

Table 2: Distribution of PV System in Tunisia & Libya

Category	Tunisia	Libya
Adoption of PV Systems	About 30% of the rural population resorts to using PV systems; currently 500 MW has been installed (60% in rural areas); and there is an annual growth of about 8-10%.	70 MW installed (rural areas grasp about 40% of this); very little adoption; oriented mostly towards urban Tripoli.
Government Support	70% stated that they consider policies such as subsidies, tax exemptions and feed-in tariffs as really important.	Supposed 40% public support; political instability and vague policy disallows anything from being done.
Challenges to PV Adoption	40% stated that cost is the major challenge, while government incentives have reduced barriers for 60%.	Cost accounts for 50%; in addition, about one-third said that such additional challenges include lack of skilled labor and inadequate access to market.
Economic Feasibility	Grid-connected expenditure: $1,000-$1,200/kW; for off-grid systems: $1,500-$2,000/kW; and rural adoption financed by borrowings.	The price of going off-grid ranges from $1500 to $2200 per kilowatt; high costs and financing constraints limit adoption.
Social and Environmental Impact	81% reported improvements in jobs and quality of life; 73% reported a reduction in carbon emissions.	The majority, at 60%, realized that energy reliability and rural electrification have the potential to bring more benefits, but little actual impact has been seen.
Regional Distribution	Majority of PV installation capacity (66%, mostly in southern and central parts) is in line with high solar irradiation.	Very unevenly distributed, with a bias towards the urban domain while there is great solar potential in the rural areas.

DISCUSSION

The focus of the conversation regarding this research is based on the results regarding the implementation, barriers, and opportunities of photovoltaic (PV) systems in remote areas of Tunisia and Libya. This section discusses the findings with the specific country analysis along with the information about the utilization analysis based on the solar energy resources and provides guidelines for further development of the two countries.

4.1. Photovoltaic System Take up

The analysis of data showed that the two countries Tunisia and Libya use photovoltaic systems in different way, which depends on factors of political and economical nature. PV technology adoption, however, has been more popular in Tunisia than in Mexico. Close to respondents 80% of the respondents from rural areas said that there was a rapid rise in PV installations in the last five years. This is in line with the national drive to promote renewable energy especially in rural and remote areas where access to the national grid is frequently another challenge. This growth has been led by government many incentives including subsidies and low-interest loans, while 70% of the respondents have identified that such polices have indeed been of great help.

Nonetheless in Libya, the integration of PV system has been very limited despite the fact that the country has been widely endowed with solar resources. In Libya, out of 100 respondents only 30 stated that PV systems were widely used in rural areas. These laggardly developments can be attributed to political uncertainty that has stagnated energy infrastructure progress in the country. In addition, 50 percent of respondents stated that the installation cost of PV systems was very expensive at the onset. Even though Libya exposure to solar radiation is slightly similar to Tunisian at 5.5-6.0 kWh/m²/day, the major constraints in the uptake of solar energy include the ineffective and unstructured market of solar technologies and inadequate government support.

4.2. Government

Policies are the most important determinant for the advancement of utility scale solar energy industry in Tunisia and Libya. In Tunisia, also, government incentives have shown to be effusive; 60% of the rural participants admitted that of the financial inclinations including feed-tariffs and direct subsidies had reduced the impediment to investing on solar systems. Tunisia has consistent and effective regulation supporting solar PV and has ambitious for renewables, targeting 30% of electricity from renewables, including solar by 2030. This is further supported by the evidence that about to 60% of the installed capacity are in the rural areas where PV systems were critical.

In Libya, however, the role of parties is not the same as in other countries of the continent and plays a different role. This had slowed down the pace of adoption due to ambiguity in the policies and incentives that would support this kind of technology. Compared to Tunisia, the percentage of Libyan respondents who thought that government support had encouraged PV adoption was low at 40%. Lack of adequate policies together with political instabilities that have characterized the country since 2011 has seen many areas without the requisite statutes to support large-scale PV. Thus, Libya's solar energy is still dominated by a few large-scale projects mainly in urban areas, especially around the capital city, Tripoli, with very limited occurrence of systems in remote rural areas.

Barriers to the Use of Photovoltaics

The two countries share similar key obstacles in the deployment of PV systems; this is the high initial costs of the systems. However, costs were mentioned as a constraint present to a high level of 40% in Tunisia, while 60% of the participants believed that financial support was sufficient to counter this problem. This emphasizes the need to subsidize and avail government-funded loans on systems that have assisted people in the rural places make use of solar energy. Tunisia has relatively cheaper installation cost of about \$1000- \$1200 kW for the grid-connected systems; this perhaps has enhanced the installation of solar systems chiefly in places with high solar intensity.

In Libya, however, the cost of PV systems is slightly higher compared to those costs exemplified above, ranging between \$1,500–\$2,200/kW, for off-grid systems, thus remaining a challenge. While Libya has excellent solar irradiation, 30% of the rural areas install PV system since the costs are still prohibitive plus available financing options are also limited. Apart from cost, the greatest difficulty such as shortage of skilled labor in installation of solar panels and maintenance as posted by 35% of the respondents applies to Libya. The absence of technology knowledge prevents correct installation, adequate system care, and stable output of the PV systems.

Tools Used to Determine Economic Factors and Financial Structures

Technological feasibility involves the advancement in technology that has made economic feasibility major goal in the expansion of PV systems, and there was a significant difference between the two countries. In Tunisia also affordable prices have been realized in subsidization of electric power by technology created solar energy. Currently, the cost per kW in grid connected systems is slightly lower than in stand alone systems, having been reduced by 15-20 % in recent past and this coupled with the fact that even the rural families can afford to install solar systems. About 60% of the rural participants in Tunisia said that they had received government financing options which have an effect to alleviate the financial factor. Moreover, Tunisia has, for instance, declared its intention to achieve her target of generating 30% of her electricity from renewables by 2030, which has made the cost of solar energy even cheaper and attracted more foreign investment, especially into solar projects.

However, in Libya the feasibility of the PV systems is still high due to high costs of the systems, absence of financial mechanisms and political instabilities. Despite this, Libyan off-grid PV system costs are about $1,500/$2,200 per kW, and there are few, if any, mechanisms for financing them. While 30% of those who responded said they had benefited from financial assistance for the installation of PVs in Libya. Hence, the viability of organizing significant solar installations still evokes doubt since the cost of putting up the structures is expensive especially in the rural or isolated areas.

4.3. Social and Environmental Impact

The awareness of the social and environmental effects of solar energy adoption is evident through respondents who demonstrate positive change in their communities, with 85% of the rural respondents expressing such views considering the numerous PV systems in Tunisia. Some of these are creation of employment opportunities as installers and maintainers of the systems, provision of electricity to the rural poor. In addition, an agreement was reached that the transition to solar energy has made people’s quality of life better – 70% of the respondents pointed to this. The second advantage is environmental as 80% of respondents noted that carbon emissions have decreased because of the increasing use of renewable energy.

In Libya, this has not been as central an issue as in Germany since there has not been as great an emphasis put on the use of PV systems. However, 60 % of the respondents recommended that if implemented, solar energy could be beneficial in increasing energy access as seen from the り rural areas where there is minimal grid power infrastructure. That is why, despite the prospect of listing positive effects of solar energy on rural communities, the social and economical effects do not define the immediate development of solar energy in the points mentioned above, as the situation is quite opposite in Tunisia where by now, solar energy is realized as a certain part of the overall energy resources supply.

4.4. Regional Distribution and Access to Solar Energy

Tunisia and Libya contain immense solar potential, however, the installation of PV systems has been influenced by the regional politics, economy and infrastructure. Concentrated in the operation and planning section, approved solar capacity of Tunisia is mainly distributed in the southern and central provinces, which are characterized by high solar irradiation. Such areas are today host to massive solar installations occasioned by government policy and private investment. As I established, positive regulations, and policies have been effective in Tunisia’s solar energy investment attraction.

PV system is distributed densely in urban areas and densely populated areas especially in Libya around Tripoli. Although, receiving similar amount of solar radiation as Tunisia its PV facilities are largely confined to these city due to insecurity in Libya and the general absence of electric infrastructure in the rural areas. While 40% of total installed capacity of solar energy Libya is in rural parts of the country most of the cities are well lit at night.

CONCLUSION

Therefore, this study demonstrates the potential of photovoltaic (PV) systems to satisfy energy access demands of Isolated areas of Tunisia and Libya. Both the countries have immense solar potential however, the path to PV technology in each country is different owing to the different political, economical and infrastructural features. For instance, Tunisia has seen remarkable progress in the deployment of solar, especially in rural and off-grid territories; government backing has spurred lending to relieve some of the volatility typically found in this space, and the country’s strategic plan is centered on renewable energy. These have greatly facilitated systematic expansions in the installation of PV systems and the contribution in the realization of the 30% renewable power in the country's electric sector by 2030.

On the other hand, Libya has the following challenges which slows the use of solar energy, political instability, high initial costs, inadequate government policies and financial support. Some of these challenges have hindered the installation of PV systems in remote areas of high Solar Resource potential in the country. Nonetheless, the recent development of international support, as well as increased awareness and appreciation of the effectiveness of solar energy may be the key to future Libyan solar market development.

This research also suggests that in order to overcome the barriers for the GRs adoption of PV in both countries, further policy-making, sound financial instruments, and technical assistance must be encouraged. These lessons are beneficial for Libya especially in aspects of establishing conducive regulatory environment for solar power, coming up with measures to lower the cost of these equipments and methods of extending the provision of solar power to the areas of the least human inhabited in the country. By overcoming these challenges, both Tunisia and Libya shall be fully capable to realize maximize the potential of solar energy to effectively deliver power to the isolated and unserved populations.

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