Assessing Efficiency of Solar Energy Applications as a Sustainable Energy Resource in Saudi Arabia

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الخلاصة :

تعتبر الاستدامة في مصادر الطاقة من المتطلبات الاساسية لبناء اقتصاد راسخ ومستقر على مستوى العالم. مصادر الطاقة المتجددة قد تم توظيفها على مستوى شاسع من التطبيقات المدنية وأثبتت قدرتها على توفير طاقة مستقبلية يعتمد عليها كبديل لطاقة البترول المتعارف عليها. تعتبر الطاقة الشمسية أحد أشكال الطاقات المتجددة التي شهدت تطوراً كبيراً في تقنياتها على مدى العقديين الماضيين. لدى المملكة العربية السعودية موقع إشعاع شمسي عالي التركيز وتمتلك الموارد الداعمة للمضي قدماً في مجال الطاقة الشمسية والتخطيط السليم سيقودها إلى نتائج راسخة في إنشاء هذه الصناعة الحيوية وتوطينها، وبالتالي تقليل الاعتماد الوطني على البترول وإيجاد البديل المستدام من الطاقة المتجددة والنظيفة لدعم الاقتصاد الوطني .

يعتبر التنوع في مصادر الدخل الوطني على قائمة اولويات خطط التنمية الخمسية ومع الدعم الموجه للأبحاث والتطوير في صناعة الطاقة الشمسية تبني المملكة العربية السعودية من خبراتها للسير قدما نحو تحقيق أهداف الخطط التنموية ولكن تحقيق الهدف الاكبر في ريادة هذه الصناعة على المستوى الدولي هدف لا يزال بعيد المنال. كما أن مدى فعالية التطبيقات في مجال الطاقة الشمسية على أرض الواقع مؤشر حيوي يحكمه عدة عوامل تشارك مجتمعة في رسم الصورة الإجمالية على المستوى الوطني وتحديد مواطن القوة والضعف لمواصلة التطوير. يلقي هذا البحث الضوء على التوجه الاستراتيجي في مجال الطاقة الشمسية في المملكة العربية السعودية و يتناول الممارسات و التطبيقات الخاصة بهذا المصدر تحت معيار الفعالية الشاملة. تم من خلال البحث تطوير مؤشر لتقييم الفعالية تحت مسمى "مقياس الأهمية النسبية للفعالية" والذي يمكن استخدامه كمؤشر لقياس مدى فعالية الممارسات في استخدام تطبيقات الطاقة الشمسية. خرجت الدراسة بأن التطبيقات في مجال الطاقة الشمسية في المملكة العربية السعودية تمارس حاليا بنسبة فعالية ٥٥,٨% ، حيث تدل هذه النسبة على مستقبل واعد لهذه التطبيقات على مستوى تقني متوسط بينما تشارك عوامل الجدوى الاقتصادية ودور المجتمع والدعم الحكومي في وضع بعض المحددات على المؤشر والتي تحتاج إلى تطوير في جوانبها لتحقيق فعالية أداء أعلى.

Abstract

Sustainable power resources have become a major demand for stable economy worldwide. Renewable energy resources have been implemented in a wide range of civil applications and proven to be a promising and reliable alternative for conventional hydrocarbon energy source. Solar power is one form of renewable energy that has witnessed a great technological improvement in the last two decades. Saudi Arabia has a very intensive solar location and strong funding capabilities to tackle this filed with confidence. Good planning will lead to firm establishment and localization for solar power industry. Consequently, it would lessen the reliance on oil and provide a sustainable, renewable, and clean alternative energy source for Saudi national economy.

Diversifying income resources has become one of the top priorities in the progressive national development plans. Unlimited Funding allocated to support solar power industry has enabled Saudi Arabia to build its national experience in this field, but the ultimate goals of being a leading edge in solar energy industry is still far beyond this stage. Current efficiency of solar power applications is a vital indicator that is usually used with many factors that shape the final result of efficiency on national level and determine strength and weakness for continuous development.

This paper sheds light on solar energy strategy and approach in Saudi Arabia. It introduces the recent practices and applications tested under total efficiency criteria. The paper has developed an assessment tool for total Efficiency. This tool is named “The Efficiency Relative Importance Scale” (ERIS) and can be used to indicate how efficient the practice is in employing solar applications. It has been found out that the current ERIS in Saudi Arabia, as a case study, is 55.8% in total. This leads to a conclusion that Solar Energy has a promising future with certain applications that required low-profile technology. Meanwhile, economic visibility, community role and government support have certain limitations that need some improvement in order to achieve a higher efficiency rate for this vital energy source.

Keywords: Renewable Energy, Solar Power, Power Efficiency, Solar Application, Sustainable Power Resource.

1- Introduction

The world's concerns about energy security are an everlasting issue. Worries are growing rapidly with continuous exhaustion of hydrocarbon energy resources to meet the expanding energy demands for different nations. Great efforts have been exerted worldwide to shift from a hydrocarbon energy source to a new form of renewable energy. Looking for renewable energy resources as a strategic alternative option is motivated by many important considerations such as the national security, environmental issue, and economic stability. Therefore, remarkable progress in renewable energy researches has been attained in form of technologies that enable the utilization of these natural resources to maximum and employ it as an effective power source that could make it a real support to national development and economy. Oil-producing countries, in general, have overlooked this issue as they represent economies that are entirely based on oil industry. Oil revenues sustain development in these countries to a great extent, but, on the other hand, delay research to diversify incomes and preserve natural energy from fast depletion.

Saudi Arabia is a world leading oil producer country with fast land area of 2.3 million km^2 of mainly desert type nature. It is a modern country that witnesses fast urban, industrial growth and energy demands are rising consequently. Saudi Arabia's energy consumption (6.7 toe per capita in 2010) is estimated at 3.6 above world's consumption average (1.9 toe per capita). The consumption rate shows a steady and rapid growth profile at an average rate of 5.5 percent/year since 1990. The rate is tripled between 1990 and 2009. Industry is considered to be the largest consuming sector. It consumed a 29% of the total energy consumption in 2010 against 24% in 1990 . The petrochemical sector accounts for about 19% of energy consumption in 2010. The energy consumption of the power sector in 2010 accounts for 27% (stable since 1990). Electricity consumption per capita has been growing fast. It stands at about 8,300 kWh/cap (2010), against of 2,700 kWh/cap that stands for world consumption average for electricity. The share of electricity in energy consumption increased from 13 % in 1990 to about 17% in 2010 [1].

Figure 1 shows electricity network over the wide areas of Saudi Arabia. The country's electricity consumption has been growing rapidly since 1990 (+6.2 percent/year). This growth was propelled by demand in the residential and service sectors, which reached 82% of total electricity consumption in 2010 against 73% in 1990.

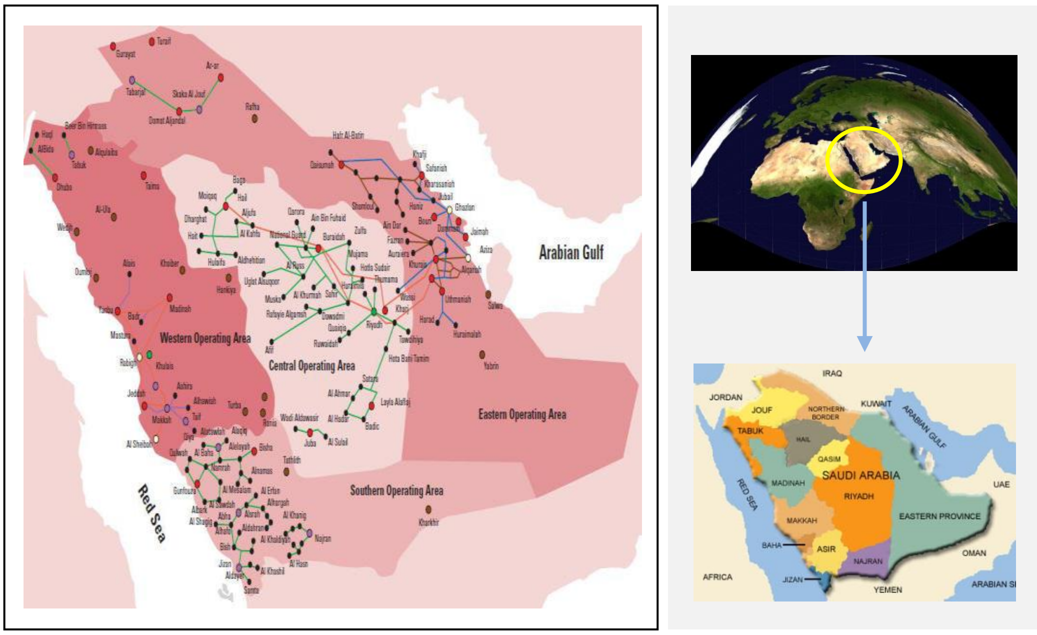


Figure 1. Saudi Arabia map and electricity network. (Source: S.Elec.Co.)

Unbalance growth between energy consumption and the GDP has been noticed. The consumption growth rate exceeds fast the GDP rate which result in an intensifying demands on energy. This profile does not match with the general profiles noticed in most of other countries. Energy total intensity rose in average by 2.3 percent/year in the last decade [1].

This type of trend draws a picture of the ongoing development that demands high energy in their different aspects, i.e. industry, urban life style , transportation and building sectors, driven by low and subsidized prices for energy.

2- Saudi Vision for the Future of Solar Energy

Saudi Arabia aims to go far in the field of solar energy as an alternative strategic commodity beside oil. The international expectation considers Saudi Arabia to be a leading producer and the largest exporter for solar power worldwide and their future revenues from this source might exceed its income for oil. Therefore, by adopting this vision, policies have to be carefully made in order to support the establishment of a robust national market of solar power. Strong economic value chain, once created, will pave the way to overcome many challenging issues that are associated with social life patterns and environmental constraints. King Abdullah City for Atomic and Renewable Energy (KA-CARE) is a recent established governmental body that undertakes major accountability of managing national energy resources.

KA-CARE has set its ambitious national plan for the future of this industry. It planned that the kingdom would be able to secure 30% (or 41 Giga-Watts) of the peak-load demands from solar power by 2030. The cost for achieving this goal was estimated to exceed the line of $100 billion [2]. The economic base of the feasibility for such an ambitious plan is based on the following scenario: supporting advancement in solar technology would reduce initial costs and flourish the market, flourished industry will be positively reflected in terms of job opportunities for domestic qualifications, and eventually, great national saving would be released from conserving oil for coming generations and directing oil to serve as a valuable export rather than a burned resource.

Development of solar power market in Saudi Arabia is motivated by many competitive natural and social advantages that make it of a high potentiality. On top of these advantages is the merit of location. Saudi Arabia is geographically located within the equatorial hot zone where the amount of solar radiation received on this zone is at its maximum more than any other locations. On average, this location annually receives 2,200 kWh/m2 with an average daily irradiance estimated by 5.8 kWh/m2/day. Second reality is the wide land that Saudi Arabia is placed on.

Solar power generation systems usually need a large plot of land to be established on, and mostly this demand causes a problem that obstructs the industry due to the shortage of undeveloped lands, which will not be the case for Saudi area.

Thirdly, natural formation of Saudi land surface is considered as desert area. In solar industry, the major element for the manufacturing of photovoltaic cells (PV) is silicon that can be found in sand. As a base material for this industry, silicon will be locally and richly available with very low cost almost everywhere in Saudi Arabia and, hence, it represents great support for future industry. Lastly, manpower needed to launch the industry is a well-settled resource represented by an educated young generation that counts for 60% of total national population [2].

Many challenging issues have to be resolved to make out solar power a reliable and sustainable source that will be accepted in economical and technical terms. However, Saudi Arabia is seriously working to overcome the technical and financial hurdles connected to these issues.

3- Energy Profile for Saudi Arabia

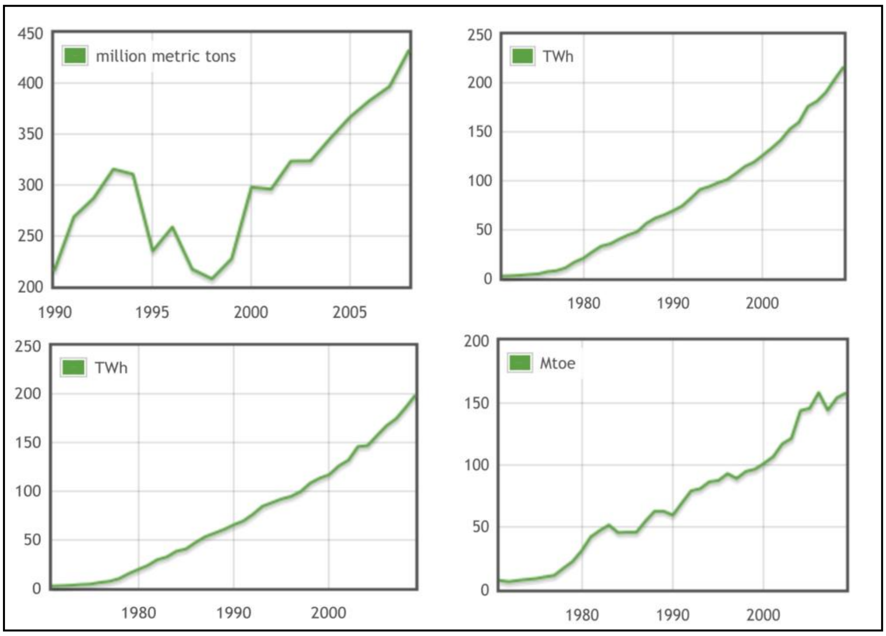
Saudi Arabia is considered to be the largest producer and consumer of conventional energy in the area that used to facilitate the undergoing large development to flourish. Energy demand is mainly directed to support power generation, transportation, industrial and constructional fields.

Oil markets have witnessed a substantial increase in prices in the last decade that made a great revenue for Saudi Arabia to spend on development plans. On other hand, domestic energy demands to meet the development boom also recorded a high rise in form of energy consumption. Though Saudi Arabia is still classified as a developing country, its consumption rank was 15th among the largest consumers represented by developed industrial countries. Energy used to support the development is generated by conventional burning of hydrocarbon natural resource in its two forms, oil and natural gas.

In order to lessen the intensive exhaustion of the national resource of oil, Saudi Arabia is targeting another clean and sustainable resources in form of nuclear and other promising renewable sources of energy. Nuclear reactors for energy generation is to be put in service by 2020. Plans to meet periodical peak power failure have also been in action. Power-grid links with Gulf cooperation Council’s (GCC) electricity network system has been established to support any shortage in power supply.

Saudi government is expected to invest 117 BDollar to improve the energy sector and enhance its future outlook. Current capacity for electrical generators is 25000 MW and it is expected to increase to 66400 MW by 2023 as demand for energy is increasing and total energy consumption is growing steadily and very rapidly (average rate of growth is estimated by 8.7 percent/year during 1982-2007). Continuous annual growth of 5% is expected [5] .

Figure 2 shows energy profile for Saudi Arabia that includes carbon dioxide (CO_2) emission footprint, electrical production , consumption and total energy use. All curves are going up with time and expected to keep rising for the next coming years [6].



1- Carbon Dioxide Emission (CO_2)
2- Electrical Production
3- Electrical Consumption
4- Energy Use

Figure 2. Energy Profile in Saudi Arabia. (Source: Worldbank Data)

4- Energy Management in Saudi Arabia

Official energy department does not exist in Saudi Arabia as a stand-alone organization who looks after energy issue in-total. The Ministry of Petroleum and Mineral Resources is the official body that controls oil industry field. Energy issues are mainly managed by the Ministry of Water and Electricity (MoWE) that is in charge of power generation and power supply.

Saudi Arabia has started researches in the field of solar energy in the mid-seventies with an active mutual collaboration programs with the United State of America and the Federal Republic of Germany. Many pilot projects have been launched to introduce technology of utilizing solar power in form of efficient applications for direct generation of electricity, water desalination, cooling systems, and agricultural applications. The national R&D scope of work in the solar energy has ever since been directed to explore the application arrays of solar technical systems that could be deployed with maximum efficiency and acceptable economical visibility. Research activities have partially taken place within the MoWE beside limited contributions from the research centers in Saudi Universities and large companies, but not on largely based projects.

The national research center ‘King Abdulaziz City for Science and Technology’ (KASCT) is the leading official organization with research-oriented base that concerns renewable energy and technology transfer knowledge in this field. It is aligned with the national strategy with regards to diversifying income sources and lessens dependence on oil and promotes research in other energy sources. King Abdullah City for Atomic and Renewable Energy (KA-CARE) is the recent addition in the Government organizational structure that will be looking after energy security in the Saudi Arabia. High expectations and great challenges will be facing KA-CARE in order to achieve its vision, goals, and objectives for the national service in the important field of such energy.

4.1 King Abdul-Aziz City for Science and Technology (KASCT)

KACST has been the major official national body engaged in this line of research since 1977. The Energy Research Institute (ERI), a research division from (KACST), has taken the lead as it represents energy center like organization on the national level [7]. As a national research center, and for the last two decade, ERI has executed many national projects that have dealt with solar energy technology and applications and undertaken knowledge in this field. History of projects that have been established is listed below.

Table 1 lists all the projects that have been launched since 1981 to make use of solar energy in Saudi Arabia [8]. These projects were designed and operated on experimental level as they did not aim to provide total solutions. The projects helped in gathering information from a real context of solar application systems in operation and assessing efficiency and deficiency for different systems which are in turn used to upgrade and further develop these systems. Applications were made to serve the remote areas as the Kingdom enjoys fast land and urban settlements are scattered over a large area that make the basic services like electricity difficult to secure over the entire country.

	Project	Duration	Application
1.	350 kW PV System (2155 MWh)	1981-87	DC/AC Electricity for Remote Area
2.	350 kW PV Hydrogen Production Plant (1.6 MWh)	1987-93	Demonstration Plant for Solar Hydrogen Production
3.	Solar Cooling	1981-87	Developing of Solar Cooling Laboratory
4.	1 kW Solar Hydrogen Generator (20-30 kWh)	1989-93	Hydrogen Production, Testing & Measurement Laboratory Scale
5.	2 kW Solar Hydrogen (50 kWh)	1986-91	Testing Different Electrode Materials - Solar Hydrogen Plant
6.	3 kW PV Test System	1987-90	Demonstration of Climatic Effects
7.	4 kW photovoltaic System	1996	DC/AC Electricity Remote Areas
8.	6 kW PV System	1996-97	Grid connection
9.	PV Water Desalination (0.6 m^3/hour)	1994-96	PV/RO Interface
10.	Photovoltaic in Agriculture (4 kWp)	1996	DC/AC Grid Connected
11.	Long-term Performance of PV(3kW)	Since1990	Performance Evaluation
12.	Fuel Cell Development (100 -1000 W)	1993-95	Hydrogen Utilization
13.	Internal Combustion Engine (ICE)	1993-95	Hydrogen Utilization
14.	Solar Radiation Measurement	1994-95	Saudi Solar Atlas
15.	Wind Energy Measurement	1994-95	Saudi Solar Atlas
16.	Geothermal Power Assessment	1995-96	Establishment of Accurate Data
17.	Solar Dryers	1988-93	Food Dryers (dates, vegetables)
18.	Solar Thermal Dishes (2x50 kW)	1986-94	Advanced Solar Sterling Engine
19.	Energy Management in Buildings	1988-93	Energy Conservation
20.	Solar Collectors Development	1993-97	Domestic, Industrial, Agricultural

Table 1. Solar Energy Projects History in Saudi Arabia

KACST research came to enhance the experience in collective knowledge about solar energy application benefited from the advanced technologies of the industrial countries that share the same interest in this power source.

4.2 King Abdullah City for Atomic and Renewable Energy KA-CARE

KA-CARE was established by a Royal decree on 2010 and it is meant to be the official authority that regulates the contribution of sustainable development in Saudi Arabia by developing an alternative energy power resource efficient in size and enhanced by a World-class national industry. Reliable and well-established solar power industry is crucial for achieving KA-CARE national targets that aims to release the pressure of consuming more of the national reserve form oil [9].

KACARE is determined to achieve an integrated energy supply system that incorporates energy from conventional resource and renewable resources energy as a future strategic target that Saudi Arabia is heading to accomplish in order to secure prosperity for its nation, strength and stability for its economy, and to maintain its global strategic position as a leading country in energy market.

Atomic energy and energy from renewable resources will be considered as a major power supply introduced for energy future in Saudi Arabia. KA-CARE is committed to present these two sectors to their best updated technology and practices recognized internationally and comply with conventional rules and regulations. Full power capacity from this mix, when realized, will be reflected on conservation plans of the depletable resource of oil and will save substantial amount used to burn to provide local energy to redirect it to export purposes.

KA-CARE has a road map for Saudi Arabia's energy sector to be able to secure efficient capacity to meet peak-load power demand from the new energy sources. KA-CARE plan to invest as much as a $ 100 billion to achieve its goals in two decades time. The announced target from energy is 41 Giga-Watt to be secured from solar energy alone[9].

The targeted 41 GW will be generated through many solar plants that will be put to implementation according to a preset time frame. KA-CARE has started tendering for two large projects for solar plants that will produce an estimated electrical power of 3 GW at their initial stage but reach to 25 GW at their advanced stage.

The two plants will be executed with two different technologies; the largest plant will be generating power through the use of Concentrated Solar system and the other plant will be using Photovoltaic solar arrays plant to complement the targeted power capacity. These technology types have been researched for their properness for Saudi Arabia’s given environment, economic, and social nature and proved to be encouragingly acceptable [8].

4.3 King Abdullah University for Science and Technology (KAUST)

A new innovative model for Saudi universities has been presented by KAUST. KAUST has been designed to enhance the postgraduate research in multinational base mode. It aims to transfer and localize technologies through unconventional fast track system and make research advancement tangible for the benefit of national products. Facilities were provided to make KAUST a distinguished research location with regards to state-of-the art laboratories fostered by a well design and LEED certified campus. The campus has been established in 2009 and chosen by the Environment Committee in the American Institute of Architect (AIA) as one among 10 best green projects worldwide. The university attracts and recruits the elite researchers from all over the world and focuses on advanced science to be a major research line that matches the goals of the National Science, Technology and Innovation Plan.

Special research emphases were directed towards energy issues as a part of the KAUST mission in driving world class research for providing innovative solutions for national interest. As a result, a 2MW solar plant were established to serve as a solar lab that is considered to be among the largest labs worldwide [10] .

Being a green campus, KAUST aims to be partially energy self-sufficient in their urban setting by providing clean energy for ongoing use and maintain low carbon emission on site. The campus estimated CO2 reduction is approximately 33,320 tons and the annual generated power through solar system is estimated at 3,332 MW/h. It is believed that KAUST will lead energy researches and take them up to a higher level that may satisfy its stockholders represented by the giant oil company, Saudi ARAMCO, one of the leading energy companies in the world [10].

5- Solar Energy Profile in Saudi Arabia

Geographically, Saudi Arabia is situated over most of the Arabian Peninsula on the tropic of cancer at 23.5 degrees north to the equator. This location is considered to be as one of the highest intensity of solar regions worldwide. Desert nature prevails and high temperature profile is usually recorded. Surface water does not exist anywhere and climate is classified as a hot and dry region.

Incidental monthly average insulation that falls on horizontal surface approximately counts between 5-6 KWh/m2/day far above the global average which counts as 1.3 KWh/m2/day [3].

Figures 3&4 show the country's solar profile by geographical regions. Different altitudes are recording high solar insolation intensity. It concentrates mainly on high elevation lands on the west coast region and on the south (the Empty quarter desert) [4].

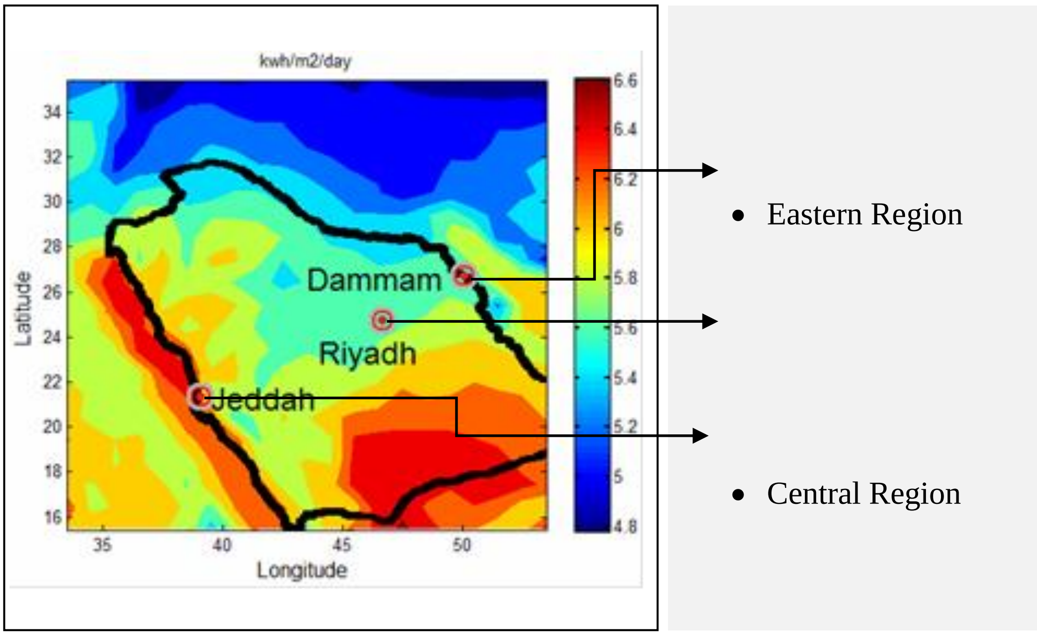


Figure 3. Solar Insolation Profile by Regions in Saudi Arabia. (Source TSI)

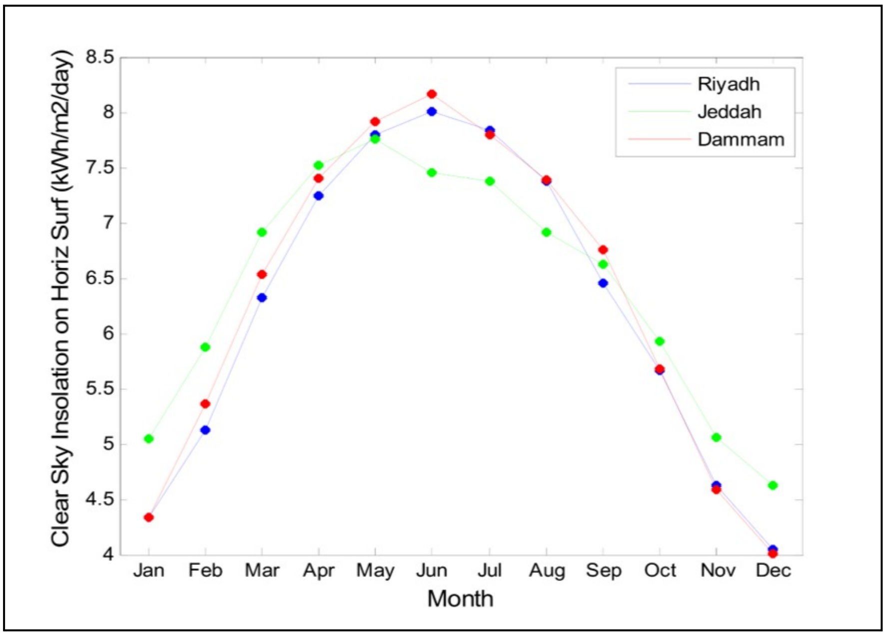


Figure 4. Solar Insolation Intensities in Saudi Arabia's major cities.
(Source: TSI)

6- Solar Energy Applications in Saudi Arabia

The Kingdom of Saudi Arabia is a large country that occupies most of the area of the Arabian Peninsula. Community settlements spread wide on the Kingdom's land that national power grid system only covers about 80% of the populated area those living in the big cities and major villages. The rest of the remote settlements in the Kingdom is not covered by the grid network service due to economical issues that make the connections for these areas of high cost. Therefore, Independent source of electricity is more practical, economical and flexible. The remote locations increase the potentiality for employing renewable energy applications as an alternative, stand-alone power supply source.

Current applications to solar energy are driven by certain strategies aligned with the progressive five-year national development plans [11]. The most important objectives are:-

- To diversify energy resources and save oil for coming generations.
- To increase the exporting capacity of oil in international markets as it can be replaced by alternative power sources to generate local electricity.
- To transfer the Kingdom to a major exporter of solar energy.
- To fulfill the international commitments for clean environment and reduction of CO_2 emissions.
- To support national economy by new industry in energy sector that has high potential elements for success.
- To take an active part in international scientific communities in renewable energy research and development.

Initial experience in solar technologies in Saudi Arabia has been supported by pilot projects, good research, development and demonstration (RD&D) facilities. It directed research and applications towards practical uses that have important community demands. Some of the projects were based on limited capabilities as experimental and lab testing environment. The national Initiatives led by the ERI in this regard are more sophisticated and productive-based projects that focus on the following applications:

6.1Electricity Generation.

This is a direct use for solar radiation to produce electricity as stand-alone system that serve the remote locations or as a supportive part of national grid to offset peck-loads demands during summer time. The technologies available for this purpose are through either photovoltaic (PV) system or through thermal boilers and steam turbine engines.

PV system was initially employed in two national projects connected to the KSA – USA joint program in solar energy research SOLARES. Solar village is a PV solar field established in 1980 over an area of approximately 67,180 m2 to partially supply two local villages with electricity as stand-alone system and as a co-generation mode of operation. It also introduced the first unit in solar energy research in the Kingdom. This project has provided fundamental knowledge of real application in process and allowed gathering information about performance and efficiency for this application.

Solar thermal dish is an application for electricity generation to produce 50kW using thermal engine concentrator. The project has been launched in 1982 under the mutual cooperation joined KACST and the German Federal Ministry of Research and Technology. Most recent solar project was added in 2009 and represented by KAUST solar labs.

6.2Water Desalination

Another important issue of concerns on national level is the scarcity of water. There is no surface water of any type, running on land and the only resource is underground water and desalinated sea water. Solar-powered water desalination project is another application under SOLARES agreement to serve industry with different power forms driven by solar technologies.

Pilot project of a desalination plant was completed in 1984 at the west coast (Yanbu City) to produce 200m2/day of potable water using indirect contact heat-transfer freeze process. The main serving purpose of this project was to simulate a test field environment in order to monitor the desalination process at its different stages that incorporates operation side, maintenance requirements and performance levels. Utilizing renewable energy in water desalination is an extremely demanding and promising field for securing scarce water resources over the Kingdom land and to save the natural resources of oil used to operate the current conventional oil-based desalination plants [12].

6.3 Underground Water extraction

In remote sites, water was secured for people use and irrigation purposes from underground sources. Diesel-operated pumps are usually used to elevate deep subsurface water to the surface level. Supplying fuel to maintain regular operation of these engines is costly. Solar energy has another practical application appropriate for remote and undeveloped sites in the Kingdom. Solar-operated pumps are a well established technology that uses PV solar plant to generate power for these pumps. The first project of this kind was installed in a small village close to the capital in 1994 served by two separate fields of PV arrays , one power a 0.55kW submersible pump. The other field is used to operate a mechanical unit work by a reverse osmosis for desalination purposes.

6.4Other Applications

Other Solar power applications were running in parallel projects at a small scale that powered domestic water heating, highways/tunnels light and safety device systems, crops/fruits drying, operation of metrological stations. These applications are proven to work efficiently as they serve limited operations especially in remote locations.

1- Sustainability and Efficiency of Solar Energy Applications

Solar radiation is a great sustainable natural source of energy that can provide endless power to operate every machine on the planet. Fossil Fuels demands for energy markets will accelerate the exhaustion of all available resources and would threaten development plans everywhere. Though solar energy is valued by multi-billion dollars growing industry worldwide, but actual share for this resource in the international energy market remains insignificant at 1% or less contribution against 85% of total consumption coming from oil resource [13].

The practical sustainability of this vital resource is strongly attached to how successful the deployment and policies are in achieving efficient optimization to meet national target plans. In this field of new technology, there are many issues that have to be tackled in order to control solar energy industry and to make it acceptable and practical competitive source in front of the fossil energy sources.

In theory, the use of solar energy is a process to collect solar radiation, convert it by proper technology to one of regular energy forms, and store excess power and harnessing means of transmission and distribution. In practice, this process is a challenging and interdisciplinary advanced field of knowledge that requires engineering innovations in different areas.

The future of solar energy industry is based on an integral system that incorporates many essential elements that effect efficiency. Key factors in this system are:

1. Technology
   - RD & D
   - Reliability
   - Effectiveness
   - Availability
2. Economics
   - Value Chain Economy
   - Capital Investment
   - Running Cost
   - Energy Cost Saving
   - Increasing Assets Value
3. Community
   - Enhance Public Image
   - Increasing Energy Security
   - Awareness
   - Certainty of Saving
4. The Government
   - Government Utility Incentives
   - Mandatory Renewable Energy Use
   - Price on Carbon Emission
   - Tax Incentives
   - Building Codes

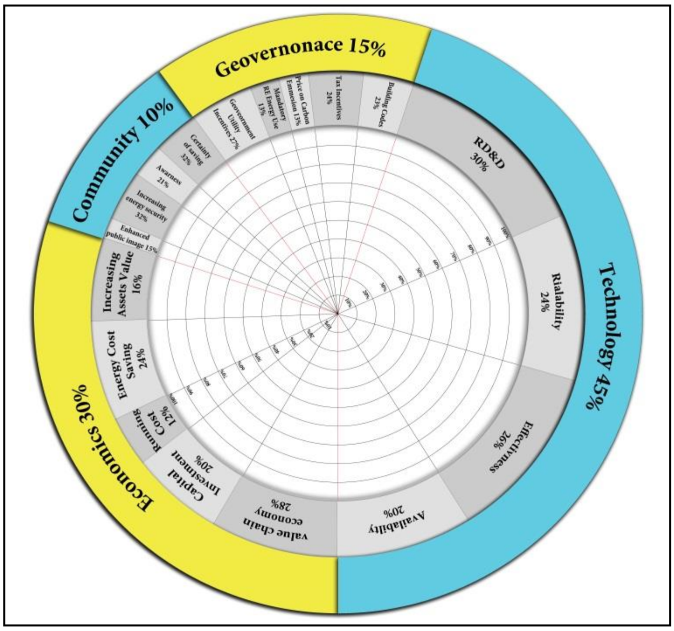
These elements work together to produce an overall image for how efficient the efforts would be at investing in RE according to local circumstance for these elements in different country.

2- The Efficiency Relative Importance Scale (ERIS)

In order to build an integrated system that brings all the above mentioned elements in one order, Efficiency Relative Importance Scale (ERIS) has been developed by the author to be used as an Efficiency indicator. Table 2 lists the elements that influence efficiency (mentioned above) according to their relative importance in this perspective and their proposed influence values . The relative importance percentage has been proposed on the bases of personal interviews and observations with energy experts. Technology has given the maximum relative importance on the scale with a value of 45% followed by economics with 30%, then governess with 15% and community with 10% relative importance. The diagram in figure 5 shows a markable background for elements weight in order to draw an overall image for the Efficiency.

Efficiency Relative Importance Scale (ERIS) 100%							
Technology 45%		**Economics 30%**		**Community 10%**		**Governess 15%**	
• RD & D	30%	• Value Chain Economy	28%	• Certainty of Saving	23%	• Government Utility Incentives	27%
• Reliability	24%	• Capital Investment	20%	• Awareness	21%	• Mandatory Renewable Energy Use	13%
• Effectiveness	26%	• Running Cost	12%	• Increasing Energy Security	32%		
• Availability	20%	• Energy Cost Saving	24%	• Enhance Public Image	15%	• Price on Carbon Emission	13%
		• Increasing Assets Value	16%			• Tax Incentives	24%
						• Building Codes	23%

Table 2. Efficiency Relative Importance Scale (ERIS) – List of Elements and Weights



ERIS

- **Technology 45%**
- **Economics 30%**
- **Community 10%**
- **Governess 15%**

Figure 5. *Efficiency Relative Importance Scale (ERIS) – the Chart*

8.1 Technology

Sustainable development needs to be equipped with resources that can provide the country with a long and unobstructed sustainable energy other than oil. Therefore, solar power acts as an appropriate source that merges cleanness , reliability, and affordability .

Dramatic advancement has been witnessed in the last decade on technologies attached to solar power. Extensive R&D work was carried out in order to improve technologies that make it more practical and economically competitive in such a way that would make the deployment fast all over the world.

The use of technology in community is a very significant factor that enables a successful deployment of any potential program for utilizing solar resource. Figure 6 shows the conversion technologies known in this field which are as follows [14]:

I. Solar Photovoltaic (PV) Solar Cells

Solar energy converted into electrical energy by PV's solar cells arrays.

II. Solar Thermal

Solar energy is converted into thermal energy by solar collectors and use of energy to operate power turbines to produce electricity.

III. Solar Collectors:

Photons generate atomic vibrations (phonons) producing thermal energy, which is collected by cooling using a heat transfer fluid (air, water, thermal oil, etc.). System types are various and include the following base types:

- Based on Heat Transfer Fluid
- Based on Glazing
- Based on Absorber Surfaces
- Based on Storage
- Based on Collector Filling
- Based on Methods of Concentration
- Based on Solar Tracking

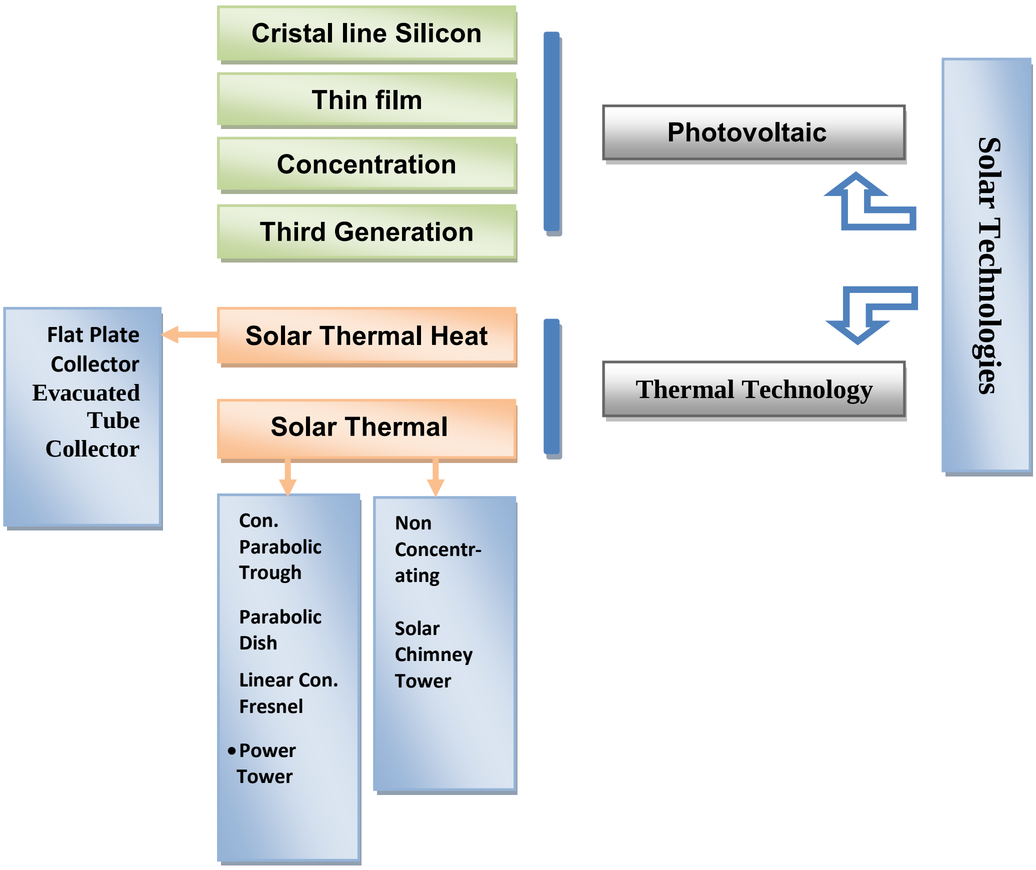


Figure 6 Solar to power conversion technologies

- **Conversion Technologies**

The technology available for converting solar power to electrical power can be either by solar thermal power or by direct conversion using PV cells. The contribution of generated power from solar to the general power demand on site can be through the following themes :

1- Central power generation field using the above mentioned technologies (see *Figure 7*).
2- Non-central / distributed thermal or PV power production units.
3- Stand-alone electrical applications integrated within the mechanical and electronic units.

Figure 7. Central solar power plants - conversion technologies. (Source KACST)

The aforementioned systems have gone through long R&D process that made them currently available in the international markets on a large scale and various manufacturers. Though cost is another issue to be discussed later, these systems have proven that they are a mature technology that utilizes the accumulated experience for solar power source.

Solar PV system seems to be encouraging technology for power production in Saudi Arabia according to all initiative projects that have been launched on site so far. PV technology is growing fast and efficient among other renewable energy systems. Strong indications that PV-based systems will take a substantial role in future of electricity generation mix. This technology also offers a number of vital practical answers to some related power issues due to its following specifications:

- PV system is highly modular which makes it easy to apply anywhere.
- PV system has a relatively low operation and maintenance cost.
- PV system can be synchronized well with peak load demands occurring during summer seasons.

There are three generations of PV technology classified according to manufacturing base material and how mature the product level is for commercial markets. The technical potential generation types are as follows:

1. First PV systems usually use wafer technology that are based on a single and multiple crystalline silicon. This production fully commercialized in solar power markets.
2. Second generation is an early deployed version of this PV technology in the markets. The system uses a thin film as a base material.

3. PV systems in the third generation use Concentrating PV (CPV) and another technology that is still under development known as the organic PV technology.

Technologies' role in efficiency as a solar power resource has four primary issues to be considered in any hosted community; these issues are described as follows:

8.1.1- Research, Development and Demonstration (RD&D)

RD&D is an essential integrity for any industry. It is a genuine part for continuous improvement and innovative solutions that work in compatibility with all other associated issues of systems efficiency. This section needs to be well established to play its part. Without being there, systems will be disabled.

Solar R&D activities will:

- Provide the data base for a domestic solar industry,
- Enable the design of locally applicable solar products,
- Help attract solar companies and experts from abroad,
- Create jobs and contribute to the GDP

8.1.2- Reliability

Reliable technologies usually have a long proven history of accumulative success and continuous improvement in their systems. Reliability depends on full control on the products that make the performance even better time after time. It also takes into consideration various aspects of design and operating conditions that have to deal within the various fields.

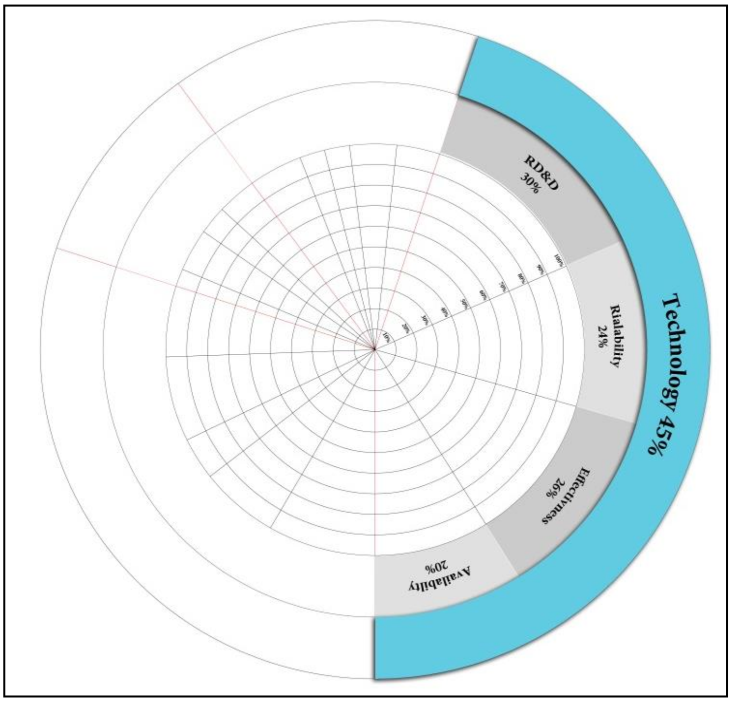
8.1.3- Effectiveness

Effectiveness can be described as doing the right thing in order to achieve your targeted goals. Effective technology is how to choose the best technology that enhances your overall efficiency. It counts as a driving force for successful implementation to any system. In solar filed markets, there is no doubt that research is advancing rapidly in order to produce highly efficient technologies for this industry. Choosing the wrong technologies could put the system at jeopardy of degrading its efficiency.

8.1.4- Availability

Efficiency of technology relies on the availability of this technology in local markets. For long term plans to develop solar energy industry, technology transfer and localization for these technologies are essential for successful outcomes. It is concerned with industry containment and self-sufficient technology markets.

These four dimensions impose a proportional effect on the technology with regards to its impact on overall system efficiency. The effect may vary from country to country according to the history of solar power generation in these countries. The chart in Figure 8 shows the relative importance for these elements on the ERIS.



Technology (45% ERIS)

- RD&D – 30%
- Reliability – 24%
- Effectiveness – 26%
- Availability – 20%

Figure 8. Technology – (ERIS)

8.2- Economics

Despite this impressive growing interest and the actual projects of solar power systems, solar energy only makes up an extremely small portion of the world's energy consumption right now. Only 7.5% of total energy demands in China (leading renewable energy producer) comes from renewable sources [15]. Economic issues associated with this energy source are still controversial as short term economic feasibility has not yet reached a satisfactory level because of the high cost of production, low storage/transporting capabilities, high maintenance demands, and low energy efficiency.

Economics impact on overall efficiency can be discussed through five major perspectives and can be seen graphically in Figure 9 :

8.2.1 Value Chain Economy

Economy is the backbone of any development worldwide, and the more industries there are in the communities the more opportunities for strongest economy to be recognized. Introduction of new industry could boost economic situation further and create a new chain value economy in the community. Solar power is promising and vital industry that witnesses a high and rapid growth in the world markets. It enhances the national economies with more stable resource that brings new jobs and technology for communities.

8.2.2 Capital Investment

Solar industry needs significant governmental and private investments in order to create a sound base for its existence in national economy. The investments should be planned in a careful manner that improves efficiency and develop a cost–effective structure for this industry. Short term saving to capital cost often misleads the real medium and long term vision for total economic gain in such a way that leads to do the job with low quality equipment following poor work practices [5].

8.2.3 Running Cost

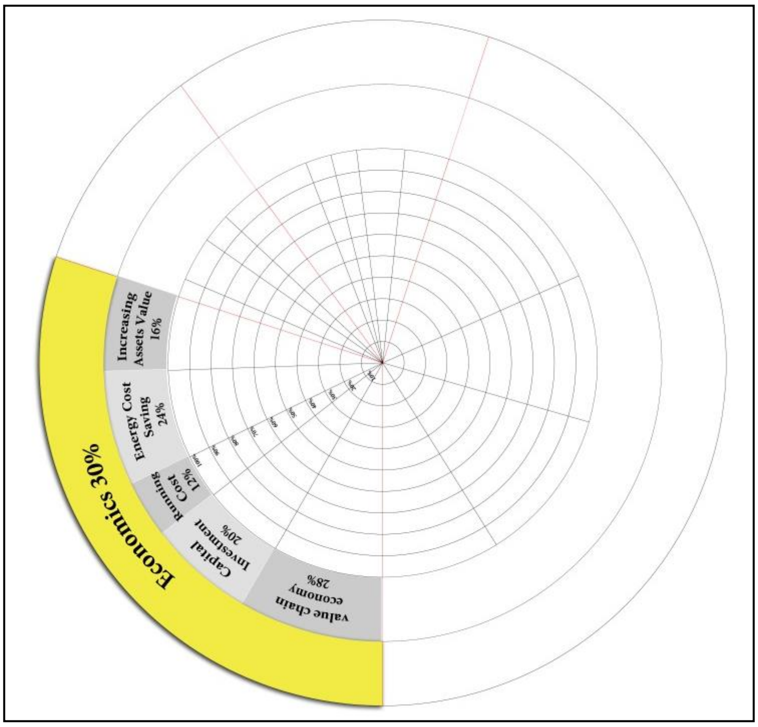
The primary costs for solar power are those associated with costs and installation . Running cost is considered to be minimal in comparison with initial costs. This cost usually goes for maintaining the systems in order to keep it running in efficient order.

8.2.4 Energy Cost Saving

Solar energy production remains more expensive than its fossil fuel counterparts worldwide. World electricity demands forecast counts for 2.5% annual growth rate in 2030 [16]. The actual cost of electricity produced by this technology is difficult to be universally generalized because of different subsidies, taxes, and duties that power sources receive. However, energy cost saving can be relatively calculated within particular country according to their system and signs can be marked on the ERIS to draw a picture of the impact ratio for this factor on efficiency issue.

8.2.5 Increasing Assets Value

Value assets are a resource with an economic value that it will provide future benefit the owners and increase their valuable strength. Solar energy projects usually add this kind of value and compensate for initial cost on the long run. In countries with well-established market in solar industry, this factor would count positive on the ERIS and, hence, will improve system efficiency. On the contrary, in countries with limited experience in this field, the value of the assets would remain limited according to the footprint of the implementation of solar energy projects in their locations.



Economics (30% ERIS)

- Value Chain Economy – 28%
- Capital Investment – 20%
- Running Cost – 12%
- Energy Cost Saving -24%
- Increasing Assists Value – 16%

Figure 9. Economic – (ERIS)

8.3 Community

Community issue that interrelates to solar power is controlled by the level of comprehensiveness of the scale of utilization for this power in the community. A part of this situation has to do with having a well-established solar power industry where technology would be available to the society at an affordable level in such a way that improves economy. It is also necessary to point out in this context other social aspects such as general income, standard of living, educational level, and differences between an urbanized and industrialized society. Solar power benefits for the community are improving health, consuming choice, greater self-reliance, work opportunities and technological advances. Societies recognize economic behavior not by nature but by practicing ideas as cultural norms that eventually translated as economic behaviors [17]. Four dimensions were used to indicate efficiency for community factor on ERIS according to their direct impact role (Figure 10).

8.3.1 Certainty of Saving

Based on economical ground, saving on energy costs is an essential demand in every community. Solar power is a promising, low cost source of power that could make the difference against the conventional energy sources. Certainty of saving with solar power is continuously improving with the advancement of technologies in this field and many communities have benefited from this source.

8.3.2 Awareness

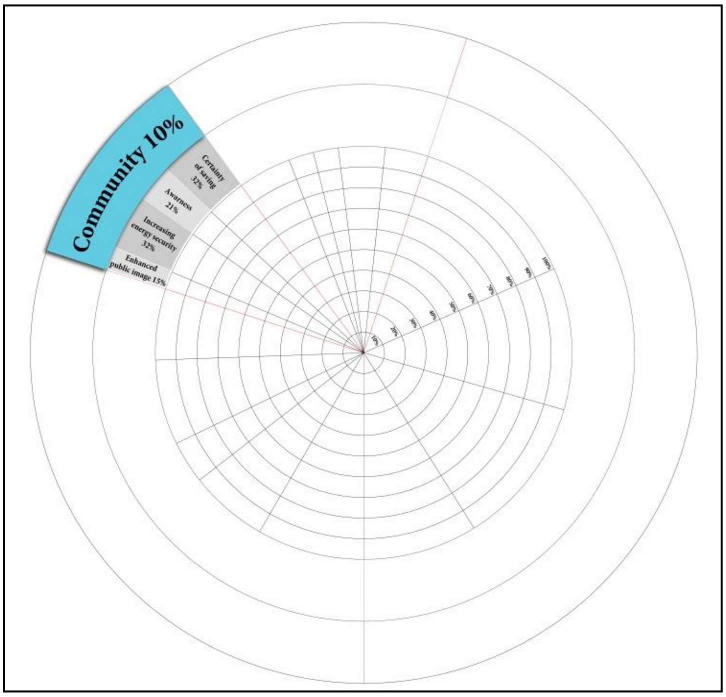
Public awareness with the privileges of solar power could enhance community acceptance, and, therefore, spread the industry wide to cover more applications and gain more users. Educated community appreciates the merits of trying a new source of energy meant to help them in reducing the cost and keeping the environment clean and healthy.

8.3.3 Increasing Energy Security

Energy has always been a very important issue that drives economic and development movements in any community. In fact, the entire economy state is totally effected by securing energy on stable and affordable cost. Securing power in communities with low resources could be a problematic issue if imported energy is declined. The introduction for a local, independent and free source of power to the community is an increasing in energy security that would never be threatened. The decision to go solar enables the community to stabilize budgets, decrease risks, and attain energy independence.

8.3.4 Enhanced Public Image

Solar power as an advanced technology is a smart way of thinking if introduced and efficiently utilized in community institutions. Institutions with sustainable energy systems enhance their public image and increase eco-conscious in the community and create a brilliant example for implementing new energy source that improves their overall performance.



<u>Community - 10% ERIS</u>

- Certainty of Saving – 32%
- Awareness – 21%
- Increasing Energy Security – 32%
- Enhance Public Image – 15%

Figure 10. Community – (ERIS)

8.4 The Government:

Governmental role in promoting efficiency of solar power can be seen through supporting growth and speeding up renewable energy (RE) projects deployment. Also, substantial saving could be achieved through well-design energy policies and programs. A reduced cut estimated by 11% in energy use was observed in the USA after applying sets of energy policies and programs [18]. There are many of the best practices attached to policies and legal instruments in the field of community utilization of renewable power that governments can adapt to improve this issue.

The Government is the top authority in charge of successful implementations and carries out development for renewable energy industry. Active national strategic plans that includes well–developed policy and implementation instruments are essential in leading to the best practical results.

The Government's part on efficiency can be discussed under five dimensions that are strongly associated with this context. These dimensions are charted in Figure 11 and explained as follows :

8.4.1 Building Code

Building code represents an important key factor in regulating and enhancing solar energy policy in the built-up environment. The value of energy efficiency requirements in building code or standard extends beyond their role in new buildings and often serves as the efficiency target for refurbishment or other improvements of existing buildings [19]. The presence of such dimension indicates a certain level of advanced urbanization and governmental orientation towards this filed. Countries without power section in their building code are many steps behind those with a well-established one.

8.4.2 Tax Incentives

Incentive taxation is a major asset in promoting solar power industry. In practice, heavy taxes are imposed on energy prices in order to rationalize the usage and meet limited supply from imported conventional fuel. Reduced tax plans are aimed at supporting solar power transfer and enhance its applications for more community coverage. The incentives play positive role on efficiency scale when the government gives it priority over other incentives.

8.4.3 Prices of Carbon Emission

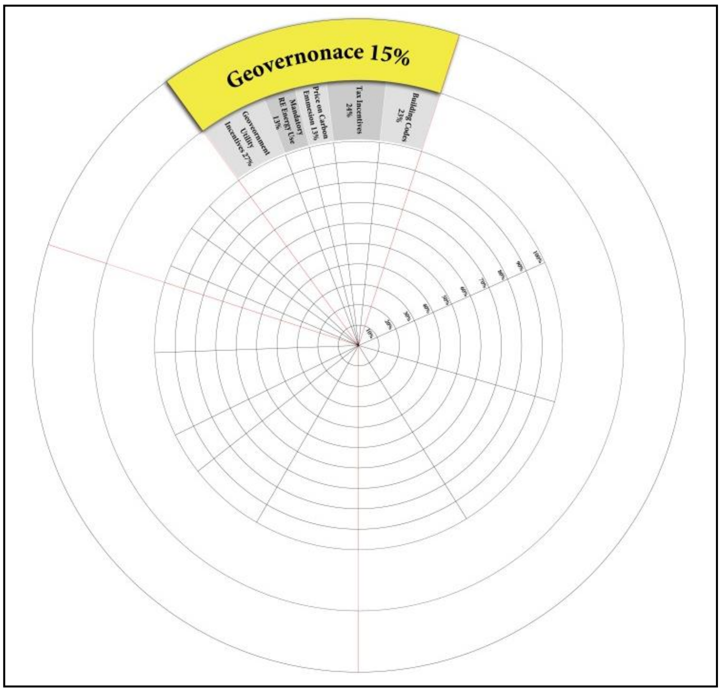
Carbon emission foot print acts according to international protocols that regulate and control the share of this emission specially over the industrialized countries. Imposing penalties for not complying with targeted carbon emission ratio would enhance the transfer of carbon free source of power generation in order to avoid fine prices.

8.4.4 Mandatory RE Energy Use

Governmental policy can broadly be classified to two major categories, mandatory and optional one. In terms of applying and use of renewable energy, mandatory rules are more effective in expanding RE applications inside the community. These sets of mandatory rules are usually designed according to countries vision and long strategic plans. The more mandatory rules the better usage of solar power applications and the good impact on overall efficiency scale.

8.4.5 Government Utility Incentives

Utilities and infrastructure that support the spread of solar power industry and enhance market are presumably the responsibility of the government to be fulfilled in the first place. Any sets of incentives towards encouraging utilities to adopt RE applications are a positive move that



Government - 15% ERIS

- Building Code
- Tax Incentives
- Prices of Carbon Emission
- Mandatory RE Energy Use
- Government Utility Incentives

Figure 11. Governance – (ERIS)

elevates efficiency rate and makes it practically and economically feasible.

3- Efficiency of Solar Applications in Saudi Arabia

Saudi Arabia has begun initiatives in the field of solar power since the early sixties with small research-based projects on a large scale energy production-based projects. For a country that possesses enormous oil resources, tangible outcome for these initiatives on energy economic is a trifle so far. But in what way would Saudi Arabia reach its national target of being the largest solar power exporter in the world?

In order to draw a picture about how efficient the current situation is in Saudi Arabia with regards to solar applications, practical values were superimposed on the ERIS diagram. Table 3 lists these values according to what has been concluded through the interviews with professional bodies in the field. Total efficiency is estimated by 55.8%. This value is a promising performance for an oil-based energy country in its early stage of getting to solar industry market. The Resources to establish a strong and efficient solar power industry is available. Moreover, there are robust governmental plans to make this objective a reality in the near future.

Technology has scored 60.6% out of 45 points and is considered to be the leading factor in the system. Great efforts in transforming technologies are recognized through many national research centers and in the universities' laboratories. King Abdullah City for Atomic and Renewable Energy KA-CARE is looking strongly forward to implementing their action plans according to a considered time frame. Huge governmental funding support has been allocated to this task.

Economic factor has a moderate effect on ERIS as it is a reflection of a wealthy country in terms of available energy resource at subsidized cheap price. This situation has effected economy associated issues on ERIS negatively by delaying the deployment of a comprehensive solar industry base in local markets. Conventional power generated with burning fossil fuel with heavily subsidy plans still represents an economically privileged issue that does not have severe impact on community. Should any change in governmental subsidy plans may come to sight, economical factor will be changed dramatically in favor of solar power applications.

Saudi community acts low on this ERIS factor. Saving, awareness, security…etc, are not common notions in the community background with regards to energy issues. The main reason for this conception is due to the low and affordable energy prices make of thinking alternative energy is totally not featured specially with delicate high technologies associated with this type of resource. Community still need to appreciate the real situation out there where energy issues represent a crucial impact of every field of life.

Governance role on the ERIS is above the average in applying the set regulatory rules with regards to solar power. Although the strategically vision and the fanatical support for heading ER are very strong, Saudi Arabia still has a long way to go in this clockwise direction . Effective governmental bodies in this organization are building their system to be solid, updated, and fit to community localization as a rule.

Table 3 shows the current situation of solar applications efficiency as a result of the discussion above and the related factors have been given a practical percentage from the ERIS system.

The ERIS diagram for Saudi Arabia can visually indicate where improvement should take place in order to enhance the current efficiency situation for better places. By the same token, the ERIS can be working for any country by superimposing the factors' information on the diagram. Moreover, the ERIS diagram allows a multi-layered presentation for situations in different countries for comparison purposes. Figure 12 charts efficiency pattern for Saudi Arabia.

Efficiency of Solar Applications in Saudi Arabia							
Technology 45		**Economics 30**		**Community 10**		**Governess 15**	
• RD & D	**80** / 30 %	• Value Chain Economy	**50** / 28 %	• Certainty of Saving	**50** / 32 %	• Government Utility Incentives	**80** / 27 %
• Reliability	**60** / 24 %	• Capital Investment	**70** / 20 %	• Awareness	**30** / 21 %	• Mandatory Renewable Energy Use	**40** / 13 %
• Effectiveness	**70** / 26 %	• Running Cost	**40** / 12 %	• Increasing Energy Security	**20** / 32 %		
• Availability	**20** / 20 %	• Energy Cost Saving	**20** / 24 %	• Enhance Public Image	**60** / 15 %	• Price on Carbon Emission	**40** / 13 %
		• Increasing Assets Value	**70** / 16 %			• Tax Incentives	**70** / 24 %
						• Building Codes	**50** / 23 %
27.27 / (45)		**14.64 / (30)**		**4.89 / (10)**		**9 / (15)**	
Total Efficiency = 55.8 / 100 %							

Table 3. Total Efficiency of Solar Applications in Saudi Arabia

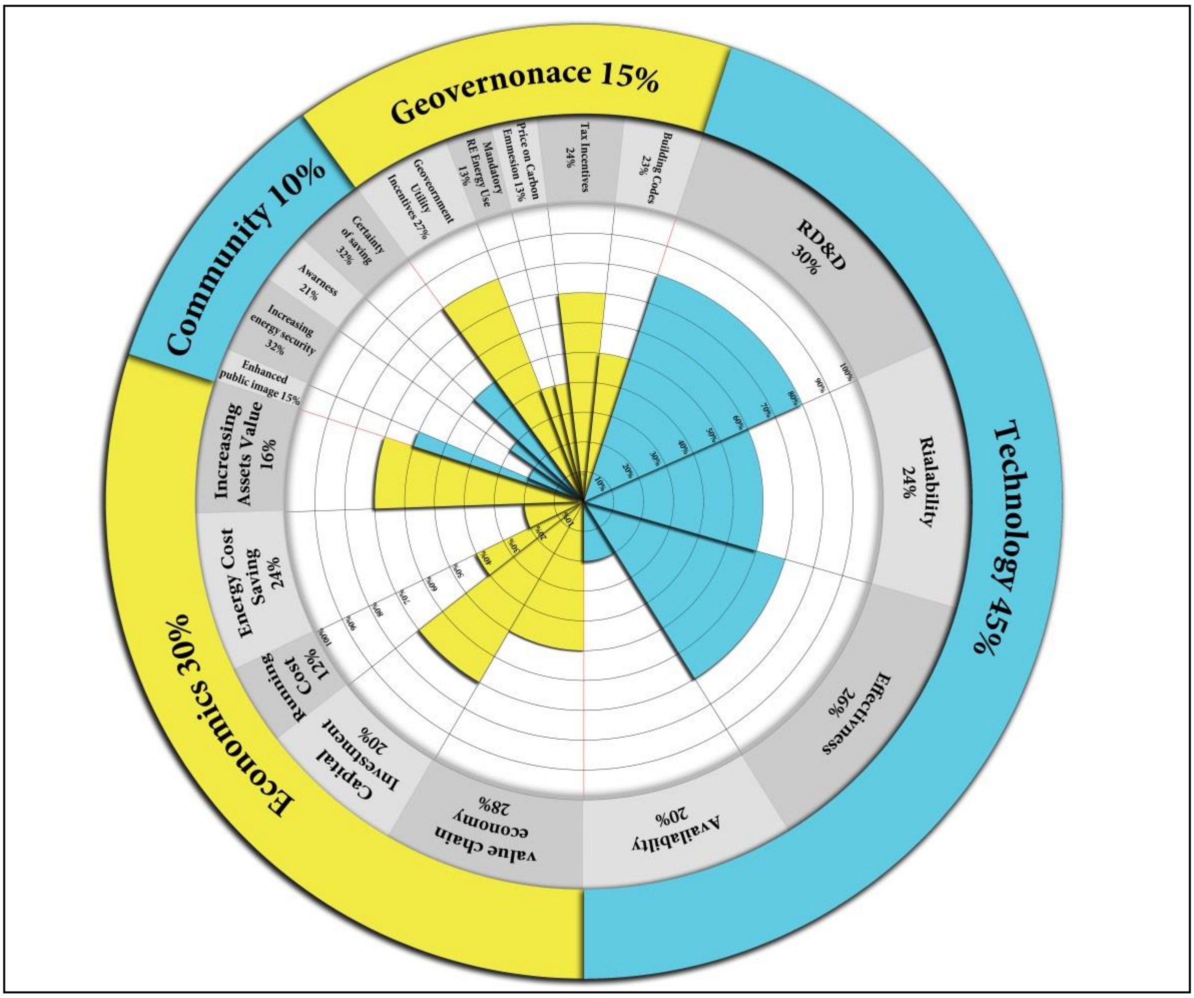


Figure 12. Efficiency pattern for solar applications in Saudi Arabia

4- Conclusion

Solar Energy is a promising renewable, clean, and free power source that made a tremendous technology advancement in its usage and applications worldwide. However, the footprint broadened for these applications still covers a very limited percentage from total power global demands. The efficiency of dealing with this power sources is also in focus . It is quite recognizable that solar power industry is advanced and well established in many countries and still to be established in some other countries. Saudi Arabia has a solid and ambitious plans to be in the front rows among leading countries in the field of exporting solar power. Plans of utilizing solar power in Saudi Arabia have started since the early seventies with several piloting small projects spread over some parts of the country for electricity generation and water desalination. The challenge is how to go solar in one of the biggest oil-based economic countries such as Saudi Arabia and how efficient the current situation is in dealing with solar power?

Efficiency Relative Importance Scale (ERIS) has been developed by the author to be used as an indicative tool to assess efficiency of solar power applications. The ERIS shows that the efficiency of solar energy applications in Saudi Arabia is 55.8%. The efficiency could be improved further by improving certain arrays in Technology, Economic, Community and governmental aspects. It is concluded that the decision of diversifying energy sources in the country and going toward RE industry is feasible. The current situation has indicated a positive sign for successful deployment of solar applications in the Kingdom of Saudi Arabia. More attention should be given to community in order to promote their RE awareness that helps in making this source more popular and comprehensive.

ERIS is an assessment tool for overall efficiency that can be used in different countries according to their local circumstances. Further research topic is to validate the ERIS with more customized detailed information that fills in any gaps that might come up in this version.

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