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Investigating the Current State of Solar Energy Use in Countries with Strong Radiation Potential in Asia Using GIS Software, A Review

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Abstract

The adverse environmental effects of traditional ways for producing electricity necessitate accurate and extensive planning for renewable and sustainable energy generation systems. A review of the research in this field shows that no work has been conducted so far to study the condition of solar energies in Asia to find suitable places for installing large-scale solar power plants. Therefore, given lack the general modelling in this case, the purpose of analyzing solar data in Asia in the present work is to support the utilization of large-scale renewable power plants. Along with analyzing the current level of using renewable energies in Asian countries, the present work also identifies suitable places for using solar energy using GIS software and meteorological data taken from NASA website for 2892 stations in 49 Asian countries. Boolean Logic was used for managing and selection of data. Results indicated that, except for Russia, a small area in South of Mongolia, Eastern half and North-western of China, North of Vietnam, Northern half of Taiwan, North Korea, South Korea, Kazakhstan, Northern half of Kyrgyzstan, Northern half of Uzbekistan, North-west of Turkmenistan, North-west of Iran, Azerbaijan, Armenia, Georgia, and Northern one-third of Turkey, other areas in the Asian continent are totally suitable for using solar energy.

Keywords: GIS Software; Renewable Energies; Daily Radiation; Boolean Logic.

Introduction

Asia is the largest and most populated continent on Earth (Fig. 1) and about 60% of the world's population lives in this continent [1]. In 2013, global greenhouse gas (GHG) emissions raised by 2.2% compared with 2012, with an estimated growth rate of 4.5% for China and 3.5% for the Asia region (excluding China). A reason for this high growth rate is the ascending trend of energy consumption in Asian countries along with their economic boom in recent decades. So that, at present, such countries as China, India, Japan, and South Korea which have been experiencing a rapid economic growth, are among the top energy consumers in Asia and account for 72.5% of total energy consumption in this continent [2].

Given the rapid economic development, population changes, and current growth trends, it is expected that Asia's share of global energy consumption will escalate from around one-third in

2010 to more than half by 2035 [3]. Developing renewable energy technologies is now widely recognized as one of the crucial elements in finding a total solution for reducing GHG emissions [4-6]. By increasing their share in the energy mix, renewable energy technologies are progressively expanding in many countries [7]. Renewables play an important role in Asia's energy consumption since Asia produces 40% of the world's renewable energies and China takes a leading role in investment, development, and growth of renewable technologies [8, 9]. China also supports such countries as Laos, Bhutan, and Myanmar which are moving fast towards providing 70% of their electricity from renewable energies. For instance, as seen in Fig. 2, a country which is particularly joining this trend is Cambodia which has reached from 0% of renewable-based energies in 1990 to 67% of its total energy production at present primarily from biogas, biofuel, geothermal, and solar energies [10].

Figure 1. Asia’s location in the World

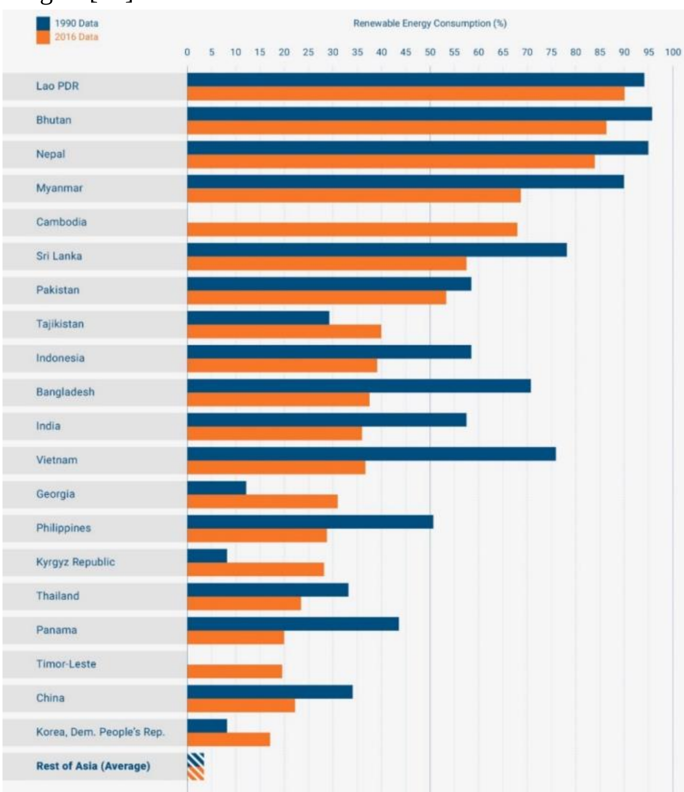

Figure 2. Percentage of renewable energy consumption in Asia as a function of total energy consumption [10]

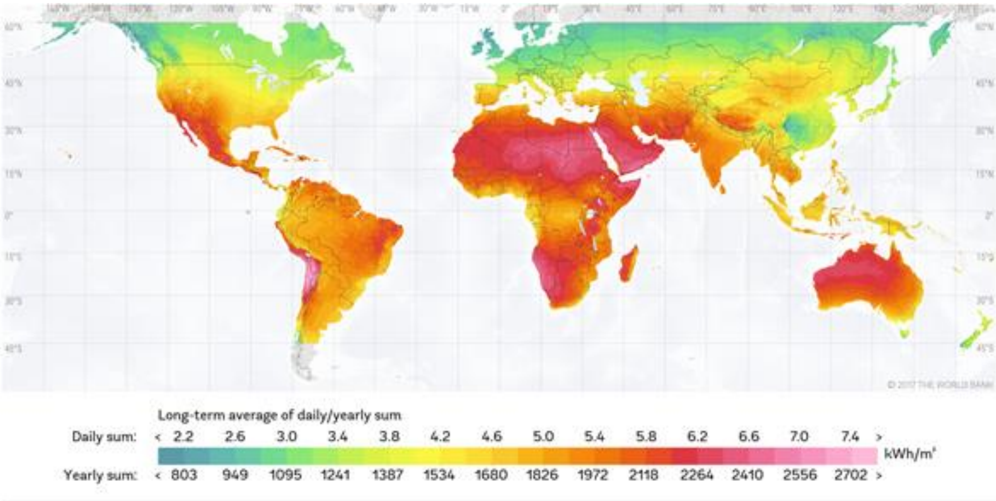

Figure 3. Map of global radiation on a horizontal surface [11]

In the solar energy sector, as can be seen in Fig. 3, South Asian countries are blessed with the highest potential for receiving solar radiation compared with other Asian countries as well as the high duration of sunshine [11].

In the present work, a graph analysis of solar energy potential is performed using ArcGIS to find suitable areas with solar power of more than 4.5 kWh/m^2-day [12]. Following a comparison of various countries' potential in terms of using solar power, Boolean logic and IDW method are used to locate areas appropriate for construction and operation of solar power plants. The merit of strict Boolean method is that the areas identified as desirable are suitable and economic analyses need to be done for the construction of hybrid power plants in these areas [12].

2. Solar potential of Asia and the world

Fig. 4 shows the global capacity of solar power [13]. From this figure, the year 2017 has hit the highest increase in solar power capacity so far (98 GW) with the total global installed capacity of 402 GW for photovoltaics. Another point which can be drawn from this figure is that, during the last 10 years, solar energy using has increased up to 26.8 times which indicates the rapid growth of solar energy usage.

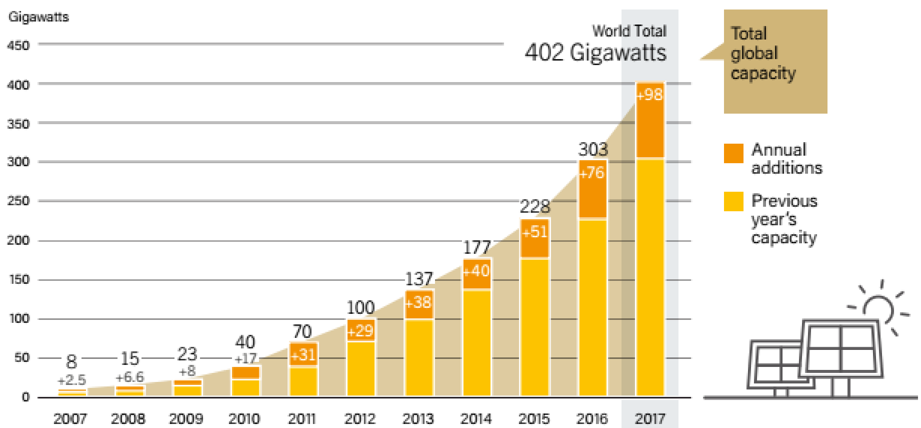

Figure 4. The annual capacity of solar energy and its annual increase for the period 2007-2017 [13]

For the fifth consecutive year, Asia has pioneered in the development of solar energy installed capacity, so that, the added solar capacity in Asia alone accounted for 75% of total added globally [13]. In the following, a review of the recent works on renewable energies in Asia will be presented.

The growth of energy consumption in the last few years signifies a rapid increase in energy demand for Middle-Eastern countries. In their research, Nematollahi et al. (2016) studied the energy consumption and demand for Middle-Eastern countries [14]. To this end, the potential for solar and wind renewable energies of the region were investigated using GIS maps and RETScreen software. Results suggested that the Middle-East region possessed great potential for using renewable energies. Also, according to GIS maps, Yemen, Saudi Arabia, and Egypt were most efficient for solar installations while Iran, Turkey, Iraq, Egypt, Yemen, and Oman are identified as having great wind power potential.

Halabi et al. (2017) investigated the installation of two decentralized power plants in Sabah, Malaysia each consisting of various arrangements of photovoltaics, Diesel generator, converters and battery storage [15]. HOMER was used for modeling. Results indicated that the PV/diesel/battery hybrid system outperformed other scenarios in terms of technical issues and 24-hour availability of energy while the independent diesel generator system was the best economic scenario and the system consisting totally of renewable energies showed the best environmental characteristics and, of course, the highest costs.

In Southern Asia, some developing countries like India, Pakistan, Sri Lanka, Bhutan, Nepal, Afghanistan, and Maldives are paying more attention to renewable sources like solar, wind, hydropower, and biomass. Shukla et al. (2017) conducted a comprehensive update and review on the status of renewable energies in South Asian countries including the potential for and capacity of renewable energies in these regions [16]. Results indicated that Afghanistan, in solar and wind energies sector, and India, in the hydropower sector, hold the highest capacity among South Asian countries. Afghanistan enjoys adequate sources of renewable and non-renewable energies. While renewable resources are underutilized, a heavy reliance exists on the exploitation of scarce traditional energies. For example, only 10 to 15% of Afghani residents have access to electricity and energy supply is considered as a major priority of this country. Rostami et al. (2017) studied the potential of available renewable energy sources to be used as a substitute for current energy sources (coal, natural gas, oil) in Afghanistan [17]. According to their results, given the natural endowments and geographical location of Afghanistan, there are good opportunities for renewable energies like solar, wind, geothermal, and micro-hydro power and renewables can be the final solution for energy supply in this country.

3. GIS data

To specify the quality and quantity of the solar energy and wind speed of a region, identification of its geographical location is a necessity. Due to limitations like lack of facilities, field measurements are very costly in many areas. Therefore, remote sensing techniques can be a good alternative to old an dexperimental methods due to their high accuracy and speed [18]. Today, the Geographical Information System (GIS) technology plays an important role in the analysis and management of potentials. This technology is used for locating the most optimal places for various applications like waste landfills [19, 20], urban planning [21, 22], and renewable energy sites [23, 24].

GIS has been reported as the best tool for locating renewable power plants [25]. Wind and solar maps are plotted using ArcGIS and the potentials of wind turbine and solar array for electricity generation can be calculated.

Although it has been reported that one-year data are adequate for long-term seasonal predictions with a 10% precision and a 90% confidence level [26], the current work uses 20-year average data of solar radiation taken from NASA Website [27]. In the present work, the conversion of point data to Raster layers has been conducted using Inverse Distance Weighting (IDW) which is the most precise method. In this method the value of the cell is specified using a linear weighted combination of a set of sample points. The weight of any point is set inversely proportional to the distance and the interpolated surface is a locational dependent variable [28]. By overlaying 2 or more polygon maps in GIS a new map can be created [29] and the output map will include all the features of the input files [30]. The relation used in GIS for calculation of IDW method is as follows [31]:

$$z_j = \frac{\sum_{i=1}^{n}\left(\frac{z_i}{d_{ij}^{n}}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_{ij}^{n}}\right)} \tag{1}$$

where z_i is the value of the known point, d_{ij} is the distance to the known point, z_j is the value of unknown point, and n is the power coefficient selected by user which is 2 in the present work [12].

2892 stations were studied that included: 46 stations in Afghanistan, 14 stations in Azerbaijan, 1 station in Bahrain, 4 stations in Armenia, 14 stations in Bangladesh, 1 station in Bhutan, 1 station in Brunei, 9 stations in Jordan, 34 stations in Uzbekistan, 109 stations in Indonesia, 102 stations in Iran, 28 stations in Myanmar, 62 stations in Pakistan, 7 stations in UAE, 10 stations in Tajikistan, 72 stations in Thailand, 36 stations in Taiwan, 24 stations in Turkmenistan, 107 stations in Turkey, 4 stations in Timor-Leste, 198 stations in Japan, 1 station in Singapore, 11 stations in Sri Lanka, 15 stations in Syria, 27 stations in Iraq, 45 stations in Saudi Arabia, 14 stations in Oman, 93 stations in Philippines, 7 stations in Cyprus, 15 stations in Kyrgyzstan, 124 station in Kazakhstan, 5 stations in Qatar, 2 stations in Kuwait, 11 stations in Georgia, 32 stations in North Korea, 51 stations in South Korea, 12 stations in Laos, 2 stations in Lebanon, 15 stations in Maldives, 31 stations in Malaysia, 43 stations in Mongolia, 11 stations in Nepal, 15 stations in Yemen, 38 stations in Vietnam, 453 stations in China, 679 stations in Russia, 235 stations in India, 13 stations in Cambodia, and 9 stations in Israel.

4. Boolean Method

The capabilities and potentials of an area vary depending on the application required for that area. Therefore, depending on the desired application, the parameters have to be integrated with some criteria to assess the potential of that area accordingly. For using parameters, accurate and thorough information about the area is required [32].

Weighing each unit in each layer of the Boolean model is based on 0 & 1 logic. In other words, in basic maps, data units are specified as 0 or 1 according to whether they are appropriate or not appropriate, respectively and there is no halfway value for adequacy. In the final integrated map, each pixel is identified as appropriate or not appropriate. This model is equipped with two operators, And/Or, which are used to extract the intersection and union of sets, respectively [12]. Fig. 5 shows the operation of "and" which is also used in the present work. It is noteworthy that the input format for the Boolean model should be Raster [33]. A schematic representation of the Boolean model's functioning is shown in Fig. 5.

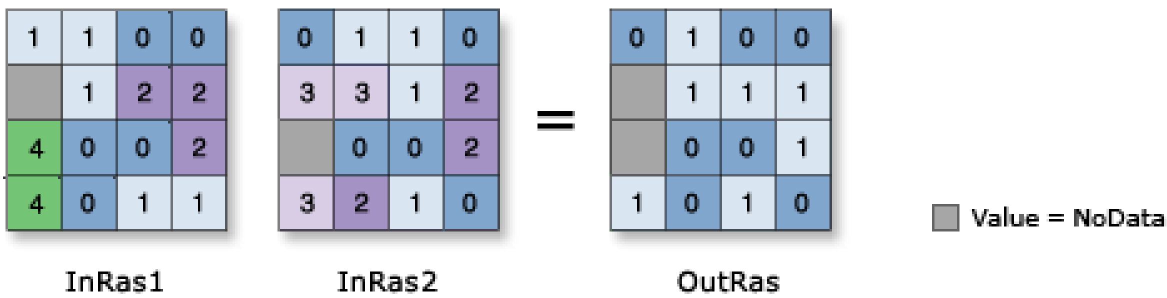

Figure 5. Schematic representation of Boolean Logic [33]

Advantages of the Boolean method are its simplicity and straightforwardness. Another merit of this method is that the regions specified in the final solution as appropriate regions are 100% suitable from all aspects. Following are some of the disadvantages of this method: units from a layer which are slightly inappropriate will have no chance of being selected and model is not capable of classifying the areas into first, second, etc. priorities [12, 34].

5. Results

5.1. Solar Potential in Asia

Solar photovoltaic technology is the fastest-growing renewable form of energy in the world [32]. PV prices have recently dropped by about 80%. This continuous drop in prices and the effect of enhancing markets on further reduction of prices [35, 36] have led to the rapid growth of this technology. Compared to other forms of renewable energy, solar energy requires vast areas for installation and operation. Also, such issues as the variation of solar radiation from one point to another highlight the importance of selecting an appropriate place for the construction of a solar power plant [37]. A comprehensive analysis for locating the solar power plant will be the first step to ensure its efficiency and cost-effectiveness [38]. GIS is a powerful tool for the analysis of data, maps, and spatial information which has been used as a means of studying the optimal location for the construction of a solar power plant in recent years [37]. The necessity of finding the optimal construction location can be justified by helping to minimize project costs, maximize the power output of solar plant and planning for infrastructure projects. Fig. 6 shows the research done on locating the optimal installation place for solar power plants by country [37]. As can be seen, China, Spain, and India are ranked as first to third.

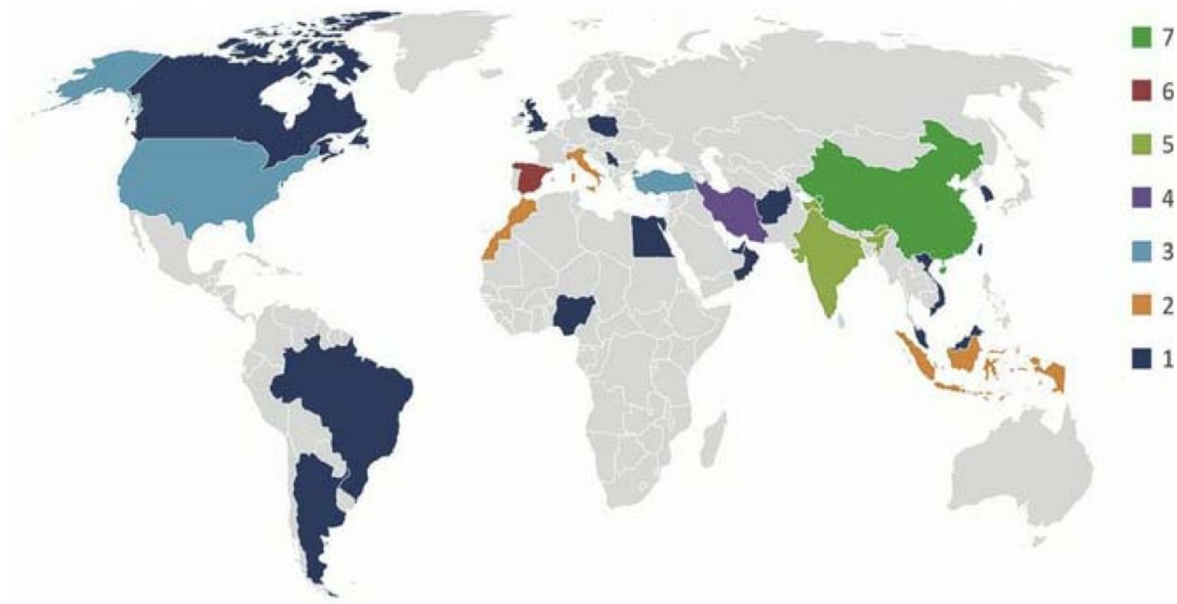

Figure 6. Amount of research conducted globally on locating the optimal place for photovoltaics [37]

Since solar radiation is a crucial criterion in large-scale solar projects which results in higher electricity generation [32, 37], it has been studied by many researchers [39-44]. It should be mentioned that reasonable solar projects are large-scale power plants with a capacity of at least 5 MW [45, 46]. The amount of solar radiation on a horizontal surface for Asian countries is shown in Fig. 7.

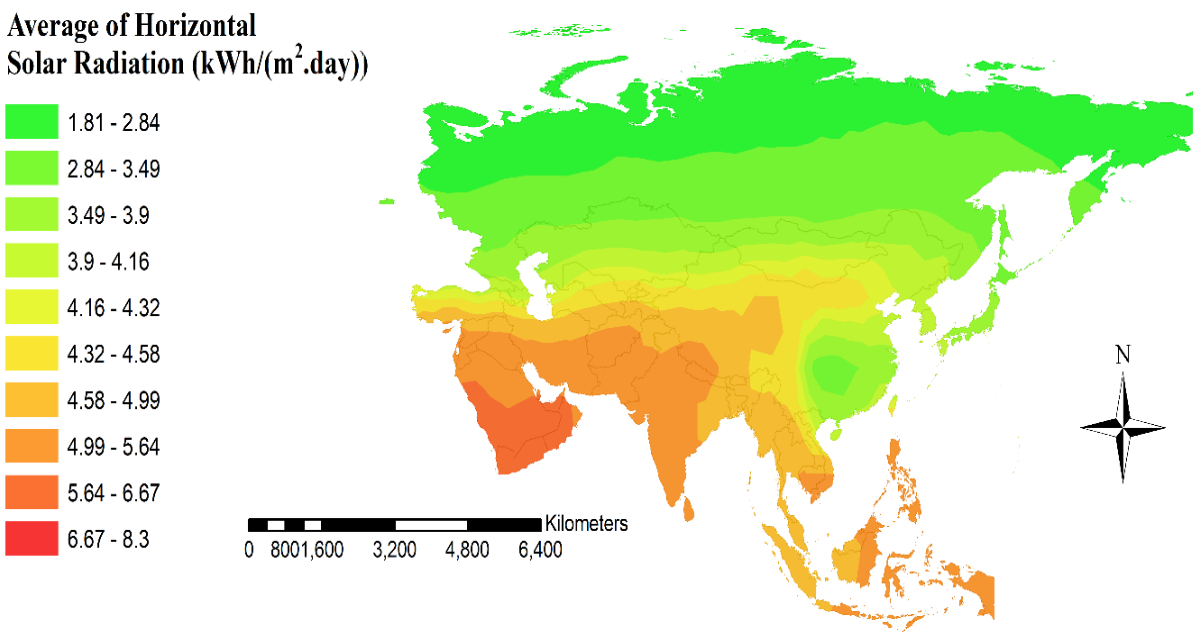

Figure 7. Average radiation on a horizontal surface for Asian countries

From the results in Fig. 7, the most appropriate countries in terms of high potential for using solar energy with average solar radiation of 5.64 to 6.67 kWh/m^2-day are Yemen and UAE. This is a very decisive result for countries like Yemen where most of the population lacks access to electric utilities [47] since field studies have also suggested that solar renewable energy, with an average daily sunny hours of 7.3 to 9.1 [48, 49], is one of the most significant solutions for this problem [50]. Regarding UAE, given its great potential, more serious decisions are recommended to be taken about such factors as the connection to the grid, environmental, economic, social issues, etc. [51]. Although it has been reported that Abu Dhabi aims at meeting 7% of its required electricity through renewable sources by 2020 [52].

From the results in Fig. 7, it is also seen that, except for the eastern part of Oman which accounts for about 20% of country's area, other parts are categorized as having excellent potential for using solar energy in Asia. The southern half of Saudi Arabia also fall in this category.

Due to long sunny hours [53] and for reducing the reliance on oil and gas [54], much research has been conducted on solar energy in Oman to help the decision-makers, maximize the country's revenues, and solve environmental issues [53, 55, 56]. Although such factors as high temperature of the solar array and dust shall be considered as inhibitory factors [53], since the energy consumption in the residential sector of Oman accounts for 13.2-48% of total energy consumption in this country and given the 28.5% growth in the residential sector of Oman, the necessity of using solar energy is felt more than ever [57].

Having the fastest-growing population and a very fast-paced trend of industrialization, Saudi Arabia ranks top in the world in terms of energy consumption [58]. Therefore, to reduce reliance on fossil fuels, Saudi Arabia plans to approach using renewable energies [59], especially solar energy [60], and install some solar power plants with a capacity of 41 GW by 2032 [58]. Today, the share of renewables in the primary consumption of this country is less than 0.1% [61] while, having excellent radiation, only 0.1% of its lands will suffice for achieving 2050 development goals [62].

From Fig. 7, it can be seen that countries like Lebanon, Palestine, Jordan, Israel, Kuwait, Bahrain, Philippine, Sri Lanka, Cyprus, Maldives, Timor-Leste, and Brunei, having a radiation ranging from 4.99 to 5.64 kWh/m^2-day, are ranked as the second priority for using solar energy in Asia. A brief overview of the current status and development plans of these countries in terms of generation and consumption of energy, with an emphasis on solar energy, is given in the following.

Lebanon faces plenty of difficulties in the electricity sector due to lack of maintenance and funds. For this reason, people have turned to the private sector and solar energy for meeting their electricity demands [63]. Also, it has been reported that having more than 3000 sunny hours during the year, Palestine considers solar energy as a very significant part of its strategies aimed at enhancing the energy security, reducing environmental concerns, and, also, wading out of electricity crisis [64].

In a collaborative effort, Jordan and Israel, which currently supply 4% of their energy demand through renewables, aim to use renewable energies to meet 10% of their demands up to 2020 [65]. The policies adopted in this regard include higher investments in the grid connection sector, feed-in tariffs for renewables, etc. [65]. All these, as well as the fact that 97% [66] and 78% [67] of Jordan and Israel’s energy is imported, justify the use of solar energy in these two countries.

Regarding Kuwait, despite being an oil- and gas-rich country, it has good plans for developing its solar projects (e.g. 200 MW solar project [68]) and it has adopted many measures for reducing GHG emissions and fossil fuel consumption, as also for accelerating these projects [69-71].

In 2017, the government of Bahrain endorsed the first National Renewable Energy Action Plan (NREAP) of the country which included installation of solar arrays for government-built housing units [72]. Despite the sharp rise in energy consumption over past few years[73], challenges associated with solar energy, such as purchasing and installation problems as well as inadequate maintenance and repair facilities, have deterred Bahrainis from using solar energy and Bahrain possesses the lowest share of solar energy in its energy mix compared to other GCC countries [74]. It should be mentioned, however, that some research has been conducted on the use of solar energy due to 9-10 hours of sunshine per day in Bahrain [75, 76]. Results indicated lower prices for solar electricity compared to the grid electricity as much as 43%.

It's been a decade since Philippine has legalized some policies in support of renewable energies which have resulted in remarkable advances [77] and can serve as a good model for other developing countries. As from June 2016, the country’s installed capacity has been 20055 MWh, of which 33.99% is renewable energy [78]. Solar energy ranks second to wind for having the lowest price compared to natural gas and coal [79]. It has also been reported that, by taking incentive policies, solar energy will be a better option than importing fossil fuels for electricity generation purposes [80].

Despite the lack of fossil resources, Sri Lanka enjoys ideal conditions for using solar energy. Through government's support for the promotion of renewable technologies, around 10.5% of country's power is now generated by renewables [81], of which solar energy accounts for only 1% [82] and need more attention from the government. Some research has been conducted on using solar-based renewable energy micro grids [81, 83-85] which have enticed the government to use these systems for rural electrification [86, 87].

Since solar energy research plays a vital role in its development and investors, policymakers, and other people interested in developing power plants benefit from research results [88], some relevant research has been conducted in Cyprus recently [89-91]. It has been reported that, despite excellent radiation, solar energy is underutilized in this country [90]. This is very important when considering Cyprus’s recent financial crisis which has caused a sharp rise in electricity prices. Thus, to decrease dependence on fossil fuel imports, the country aims to meet 25% of its energy demands through renewables by 2030 for providing further energy security [91].

Conventional large-scale power generation systems based on fossil fuels are not sustainable options for small countries like Maldives and research has shown that a solar energy-based hybrid system is cheaper than grid power in Maldives [92]. Also, it has been stated that, due to heavy reliance on diesel [93] and fuel transportation problems [94], Maldives has the highest power costs in South Asia [95]. Therefore, considering its excellent solar radiation and wind speed, in 2009, in a very ambitious initiative, Maldives government endorsed a plan for meeting all of its electricity demand from non-fossil energy sources by 2020 [95, 96]. To this end, given the space constraints and great solar potential [97], PV systems have been recently installed on the rooftops of government-built houses [98] as a realistic and practical solution for meeting energy demands.

Timor-Leste has been reported to be blessed with excellent solar energy potential [99] which is of more importance for rural areas since a large proportion of people live in rural areas (70%) and do not have access to electricity [100]. Currently, electricity is generated by fossil fuels in Timor-Leste and is priced at around $0.27-0.4 per kWh [100]. It has been pointed out that Timor-Leste government plans to lift the electrification rate for households from 20% to 80% by 2025 which is achievable only by using solar arrays [101, 102] since, due to rough and mountainous lands, development of the national power grid is not possible [103].

Despite high potentials for solar energy development in Brunei, it is still underused and the generation of electricity is mostly reliant on oil and gas [104]. Results of a study showed that solar energy could be an adequate and reliable source for meeting electricity and heating demands in Brunei [104]. Therefore, solar technologies can be made more attractive and less subsidy-dependent by revising electricity tariffs [105]. It has been reported that the government plants to supply 10% of its generated electricity through renewables by 2035 [105]. These facts along with results of the present work regarding excellent solar potentials highlight the necessity of developing solar systems in Brunei.

The countries ranked as second priority for using solar radiation include Southern parts of Iran, Southern Iraq, Northern Saudi Arabia, Eastern Oman, Southern Syria, Central and Sothern parts of Pakistan and Afghanistan, more than 90% of India's lands (except its Northern area), more than 60% of Nepal (its Western area), Sothern half of Vietnam and Cambodia, and Eastern half of Indonesia and Malaysia. In the following, an overview of the solar potential, energy consumption rates, and plans of these countries, if present, will be presented.

Concerning Iran, as the results of the present work also suggest, it is reported that provinces in the Southern half of the country have adequate potential for using solar energy [106]. Having 280 sunny days per year [107-109] in more than 90% of the country's areas [110], much research is conducted on solar energy in Iran [111-114]. It is reported that solar energy is the most available and cleanest type of energy in Iran. However, being rich in oil and gas resources and the availability of cheap national grid power, solar energy is not used to its full potential in Iran [110].

Considering rapid population growth, higher demands for electricity and fluctuations of oil prices, as well as plans for reducing GHG emissions, renewable energies, particularly solar sources, have attracted much attention in Iraq [115]. However, the accumulation of dust on the solar panel surface reduces the system's efficiency up to 22% in two weeks [116]. It is stated that solar energy is currently underused in Iraq and since it can serve as a vital element in power generation of the country, the government's assistance can be effective in this regard [117].

The need for renewable energies, especially solar energy, is more felt in Syria which is because of main power grid impairment due to war damages, scarcity of fossil fuels, and the insufficient number of portable generators [118]. This can also be justified considering the high potential of solar energy in Syria [119, 120]. Recently there has been some efforts to provide the emergency power of hospitals and 30-40% of their total demand by solar arrays. However, this is very challenging because of the country's instabilities and its inexperience in using solar technologies [121].

Power generation in Pakistan is heavily reliant on fossil fuels [122, 123] and the massive population along with industrial developments have made the problem of energy consumption more acute [124, 125]. Research has shown that solar energy outperforms other forms of energy in terms of price, solar panels lifetime, operation and maintenance costs [124, 126]. Currently, renewable resources provide less than 4% of the country's energy requirements [127]. The electrification rate in Pakistan is less than 74% [128] and this further underlines the necessity of using solar energy. To this end, the government has exempted solar energy products from import duties [123].

Afghanistan is among the lowest in access to electricity globally [129]. With damaged infrastructure due to war, 80% of the required electricity is imported and 20% of domestic generation is by hydro and diesel [130]. Afghanistan’s ambitious plan is to supply 95% of its energy mix through renewable energies by 2032 [131]. Though Afghanistan is very inexperienced at this, it should tap into others' experience and its disappointing results in the last few years to overcome the problems regarding the use of solar energy to achieve economic growth as well as more welfare for people [18].

India has seen an increase in energy demand in the last decade which, in addition to being the third-highest contributor to emissions globally [132], has persuaded the government to add the capacity of its solar power plants up to 100 GW till 2022 [133, 134]. Solar energy potential in India has been estimated to be 1300-5200 GW which is the highest among all forms of renewables [135]. However, land acquisition issues have to be taken into account [136, 137]. India accounts for the highest number of people with no access to the power grid which further intensifies the need for solar energy [138].

Wood and other forms of biomass are the primary and traditional energy sources used by most of the people in Nepal for meeting their energy demands [139] and only 44% of people have access to the main power grid [140]. Considering the rough and mountainous topography of the country, high costs of developing the grid, and the sparsity of population have rendered the construction of large-scale power plants impossible [140]. Consequently, solar technologies may be a potential solution to this problem [141, 142]. It is suggested that, under such conditions, not only the financial obstacles but also social aspects should be taken into account [143, 144]. Large-scale investments and technology transfer are necessary for less-developed countries like Nepal [145].

Given its high vulnerability to climate changes, the Vietnam government has declared its intention for developing renewable energies through the endorsement of regulations and taxation [146, 147]. In this regard, some research has also been conducted in Vietnam [148] to help planners in making better decisions. These along with the fact that currently 0.4% of Vietnam's electricity is supplied through renewables call for the use of renewable energies, particularly solar, in Vietnam [149].

In Cambodia, hydropower and coal are the sources from which electricity is generated and the country suffers from a low rate of electrification [150]. Thus, the government seeks to develop renewable energies [151, 152]. Cambodia enjoys a very high radiation level and 134500 km^2 of its lands are suitable for using solar energy [151] with a potential of 12000 GWh/y which has been left unused as of 2015 [151]. Solar-powered electricity in Cambodia is priced at $0.166-0.175 per kWh [151]. More research and improvement of government programs for meeting the electricity demand through solar arrays or a hybrid solar system seems to be a plausible solution [153, 154].

Economic development in Indonesia depends on the availability of energy and government's assistance to infrastructure sector can improve the development [155, 156]. Such assistance includes reduction of fossil fuel usage and more utilization of renewable energies [157, 158], particularly solar energy [159], through reducing investment costs and renewable energy tariffs [155, 160]. In Indonesia, around 86% of energy is produced using fossil fuels while, despite their excellent potential [155], renewable energies share is only 3% [138]. Also, the installed capacity of solar energy in Indonesia is more than 5270 kW [161].

As an oil-producing country, Malaysia is heavily dependent on fossil fuels [162, 163]. In the last two decades, however, it has taken some steps towards using renewable energies aimed at reducing environmental pollution and raising economic growth and welfare [164, 165]. It is reported that, among ASEAN countries, Malaysia ranks first in renewable energies potential [166] with solar energy being particularly suitable for residential-scale [167, 168]. Results indicate that, given Malaysia's adequate radiation potential, the government shall adopt policies for higher investments in this area [169, 170].

Due to population growth, the primary energy demand in the Middle East has almost tripled [171]. Without a targeted program, the Middle East region will not be able to adequately meet the energy demands of all its citizens [65]. Since it is predicted that as of 2050 around 68% of people in the Middle East will be living in cities, there will be an excessive demand for electricity [65]. Considering the results of the studies on the need for higher energy security and the results of the present work which indicate the excellent potential of radiation in the Middle East, more investment in the region is recommended.

5.2. Places Suitable for Using Solar Energy in Asia

Some advantages of implementing solar energy systems include a contribution to the economic growth by creating new jobs, mediating climate change impacts, and availability of electricity for rural communities, to name a few [172]. As of 1970, GIS has been recognized as a research and application tool which encompasses many scientific fields including solar technologies. This software is used for locating potential places for producing energy from solar renewable sources [173, 174].

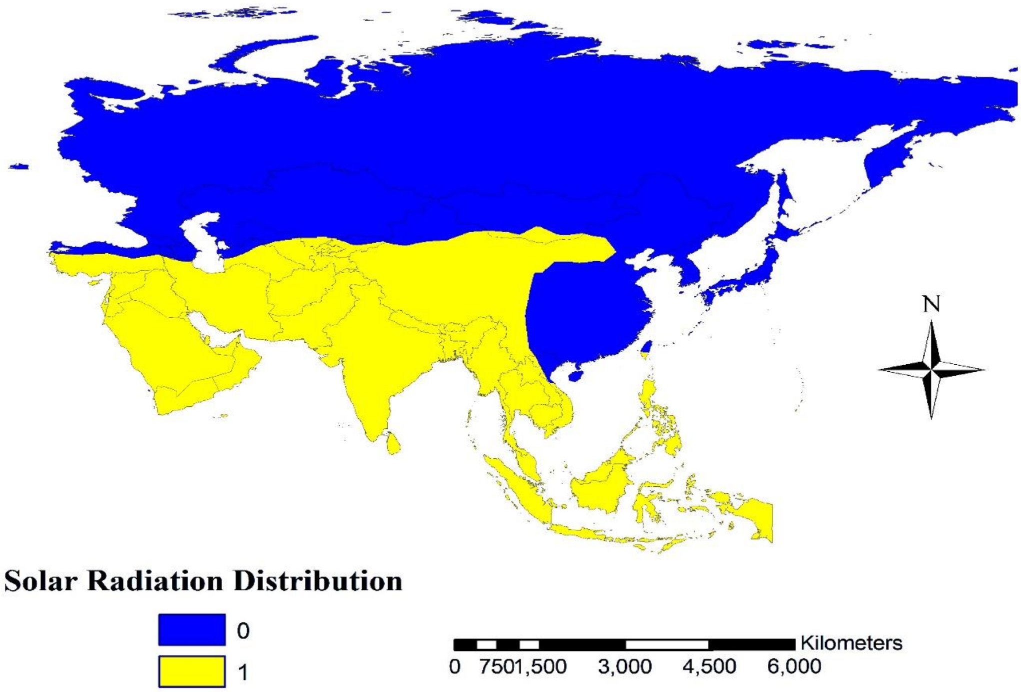

Figure 8. Places suitable for large-scale utilization of solar energy in Asia

Identification of plausible sites for solar projects is an initial strategic process which has been presented in many studies and also by strategic organizations like NREL [46, 175-177]. Reduced costs of solar systems, higher costs of fossil fuels, and the high price of grid electricity has created a tendency for using solar systems not only in remote but also in the urban area in Asia [178].

Fig. 8 shows the places suitable for utilization of solar energy (both thermal and PV) for Asian countries obtained by Boolean Logic. In this figure, suitable places are identified by number 1 (yellow) and unsuitable places by number 0 (blue). The criterion for being a suitable place is having a radiation level of more than 4.5 kWh/m^2-day.

From the results in Fig. 8, except Russia, a small area in Southern Mongolia, Eastern and North-Western China, Northern Vietnam, Northern half of Taiwan, North Korea, South Korea, Kazakhstan, Northern half of Kyrgyzstan, Northern half of Uzbekistan, North-Western Turkmenistan, North-Western Iran, Azerbaijan, Armenia, Georgia, and Northern one-third of Turkey, other areas in Asia are totally suitable for using solar energy. In other words, the potential of annual radiation on a horizontal surface is more than the studied criterion in other areas. These results are in agreement with the results of previous research [12] which suggested that Northern areas of the Middle East are not suitable for using solar energy.

It is noteworthy that inadequate radiation in the aforementioned countries does not mean that, at some points, small-scale solar power plants cannot be used. However, these results imply that large-scale solar projects are not justifiable or they have lower potential compared to other countries predicted as suitable.

The fact that South Asia is blessed with the ideal conditions for using solar energy, as well as a higher concentration of population in the southern part of Asia, provide an excellent opportunity for paying more attention to the development and improving the welfare of people living in South Asia. However, this calls for appropriate measures to be adopted by policymakers in the energy sector including the endorsement of protectionist policies, financing, provision of infrastructure, and, eventually, attracting private investors. Another way to support is the guaranteed purchase of electricity and heat generated by solar energy.

Since solar energy is growing quicker in Asia than anywhere [179] and the only challenge in this area is availability of capital, the authors of the present work recommend utilization of solar energy in South Asia in the off-grid mode (distributed generation) in order to avoid expensive installations of the main grid and electricity losses in cables. For other areas lacking suitable solar potential, solar energy can be used for other applications like irrigation and water supply pumps, solar water heaters, street lights, etc. to name a few.

6. Conclusion

GIS is a versatile tool for studying and evaluating massive volumes of data and data processing using a computer. It also enhances the speed and accuracy of calculations and permits the prediction of suitable areas. The principles of appropriate management and planning for renewable energies are based on the identification of potentials and evaluating the strengths of each renewable form of energy. Knowledge of the capacities and potentials of these resources can help in the development and implementation of practical and feasible schemes aimed at achieving economic and supportive goals. The optimal location of using solar arrays may strongly affect energy production costs. It is reported that the selection of the site is the solely most important parameter for development and one of the main technical challenges in the development of solar sources. Therefore, the present work is the first one that identifies the optimum locations for constructing large-scale solar power plants in Asia using GIS, Boolean method, and the proposed criterion (solar radiation of more than 4.5 kWh/m^2-day). Results indicated that generally speaking, almost the southern half of Asia (except for east of China) is suitable for installation of large-scale solar power plants and the results are in good agreement with data in the previous work of the author [12].

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