Geospatial analysis for assessing the potentials of large-scale generation of solar energy in Syria

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Absztrakt: Szíria a természetes energiaforrások széles skálájával rendelkezik. Az ország a mai napig nem aknázta ki a nagyüzemi napenergia-termelésben rejlő lehetőségeket villamosenergia-termelésre különböző okok miatt, például a tiszta energiába való beruházások hiánya, az elektromos átviteli hálózatok rossz szerkezete és kapacitása, valamint a jelenlegi politikai válsághelyzet miatt. A kutatás térinformatikai elemzési technikákkal felméri és több térképpel bemutatja azokat a területeket, amelyek országon belül nagyüzemi termelésre alkalmasnak minősülnének, és becslést ad ezeknek a területeknek a teljes maximális villamosenergia-termelési kapacitására. A regionális elemzések eredményei azt mutatják, hogy Szíria területének 72%-a a felszínformák és a napsugárzás intenzitása szempontjából nagyon jó, nagyszabású napenergia-beruházások műszakilag potenciális területe. Az alkalmasnak minősített teljes terület 84%-a főként 5 körzetben található: Homsz, Deir ez-Zor, Damaszkusz vidéki, Ar-Rakka és Al-Haszakeh kormányzóságban. Az eredmények azt is mutatják, hogy az ország keleti és déli részein növekszik a napenergiával kapcsolatos alkalmassági index. A kutatás rávilágított a jelenlegi szíriai energiaátviteli hálózatra és a megújuló energiatechnológiákkal való integráció kihívásaira is a szíriai konfliktust követő szakaszban.

Abstract: Syria has a wide range of natural energy resources. Up to the present moment, Syria has not exploited its potential of large-scale solar energy production for electricity generation due to various reasons such as the lack of investments in clean energy, poor structure and capacity of the electric transmission grids as well as the current political crises. Using geospatial analysis techniques, this research assesses and presents with several maps the areas which would be defined as suitable for large-scale generation within the country and provides an estimation of the total maximum capacity of these lands for electric power production. The results of regional analysis show that 72% of the Syrian territory is considered as technically potential areas for very good large-scale solar power investment with regard to the landforms and the solar radiation intensity; 84% of the total area defined as suitable is mainly located in 5 districts: the governorates of Homs, Deir ez-Zor, Rural Damascus, Ar-Raqqa, and Al-Hasakeh. The results also show that the suitability index regarding solar energy is increasing in the eastern and southern parts of the country. The research also shed light on the current power transmission network in Syria and on the challenges of integration with renewable energy technologies in the post-Syrian conflict phase.

Kulcsszavak: térinformatikai elemzés, megújuló energia, napsugárzás, napenergia-potenciál, Szíria
Keywords: spatial analysis, renewable energy, area-solar radiation, solar energy potential, Syria

Introduction

Syria, with an area of 185,180 km², is located in southwest Asia, at the eastern end of the Mediterranean Sea. The country is formally divided into 14 governorates (muhafazat) (Fig. 1). This paper assesses and uses maps to visualize the suitability potential of large solar energy production and its distribution within the governorates of Syria.

Up until the outbreak of war in 2011, the country had enough fuel resources to cover most of its oil and gas needs for electricity generation (Hatahet et al., 2021). Since then, the country has suffered a massive power blackout across the country leaving the people predominantly reliant on heavily polluting and expensive diesel generators to keep the lights on. According to https://www.worldometers.info/electricity/syria-electricity/, 95% of electritcy production comes from fossil power plants and 5% from hydro sources. On the other hand, Syria has rich solar energy resources like other countries in the Middle East and on the Mediterranean coast.

To help in finding a solution for the power shortage problem and to solve one of the environment-related challenges in producing clean power, sustainable energy supplies such as solar energy power stations would be the ideal solution once the conflict has moved to a recovery phase. Syria is ideally placed to include large-scale solar power as a major part of its energy sources.

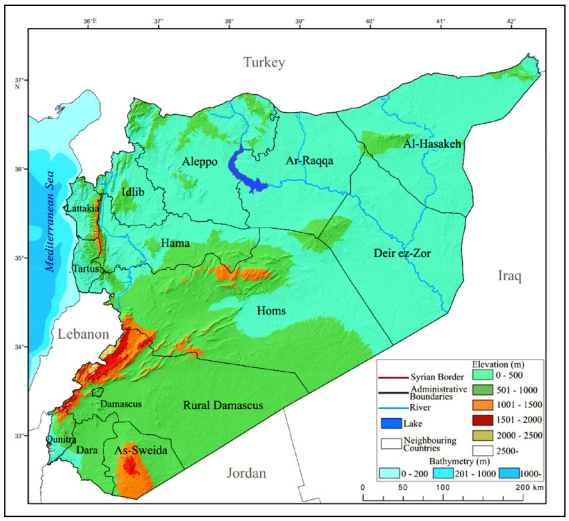

Figure 1. Governorates of Syria
(Prepared by the author based on Open Street Maps, USGS data)

Methodology

To assess the overall potential lands for large-scale solar power usage, layout is needed in a way that suits the specific topography and current land use of the site, as identifying the optimal solution in these areas is also a key part of achieving a cost-effective design. Multiple criteria were applied including solar radiation, landforms, and land use. The output is a restriction map that eliminates those areas from the territory where it is not possible to install large-scale solar power plants according to the defined conditions that were selected.

Solar Radiation

SRTM 1 arc-second (~30 metres) product was used to calculate different parameters including solar irradiation (area solar radiation tool), which calculates radiation based on a sophisticated model that takes into account the position of the sun throughout the year and at different times of the day, obstacles that may block sunlight such as nearby trees or buildings, and the slope and orientation of the surface as well as the units of the output radiation rasters in watt-hours per square metre (Wh/m²) (ArcGIS Pro Documentation, 2021) and the computed solar radiation over the entire year of 2020. The majority of the country enjoys a huge amount of solar radiation, but there are very small areas receiving a little amount of solar radiation due to various factors. These areas were removed from the model as the suitable areas should receive at least 800 kWh/m² of solar radiation if solar panels are to be installed (Bujarkiewicz et al., 2018).

Slope

Slopes are one of the important factors when selecting a site for launching a solar power plant project. The steep slopes having a value of more than 45 degrees, i.e., they receive less sun light, were removed from the model.

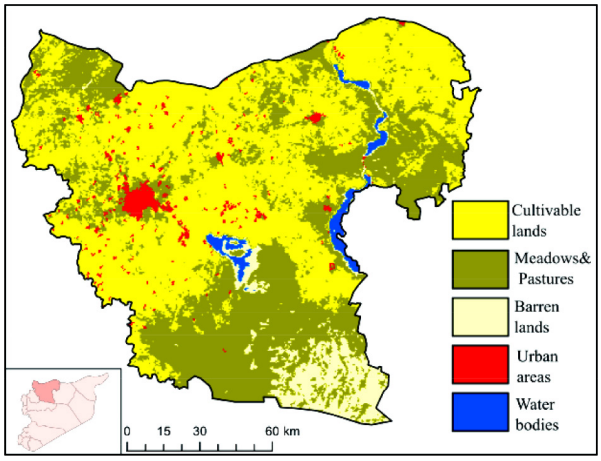

Figure 3. Land use classification in the governorate of Aleppo (Prepared by the author based on MODIS data)

Aspect

The aspects (direction of slope) should also be taken into consideration as the study area is located in the Northern Hemisphere. The areas facing north lack direct sunlight throughout the day, so these areas were removed and joined to the unsuitable areas for solar energy investment (Fig. 2).

Elevation

High elevation areas are not desirable for our model due to technical reasons. All regions above 1,500 metres were excluded (M. Haidar et al., 2017). One example of high elevation areas removal is shown in Damascus and Rural Damascus governorates (Fig. 2).

Land use

Land use is a very important factor. To assess the potential areas that are suitable for any future project , major land use categories in the region are needed to be considered and to think according to the priorities they hold. Accordingly, major cultivable and urban lands as well as the water bodies should be excluded. Our main focus is on the barren lands and the lands covered by meadow and pastures.

To obtain data suitable for the very large territory of Syria, MODIS Land Cover Type Product (MCD12Q1) was used at a 500-metre spatial resolution, which took the annual time step for the classification. This was created of spectro-temporal features derived from data from the Moderate Resolution Imaging Spectroradiometer (Mark Friedl et al, 2015). A sample of the land use classification in Aleppo Governorate is presented in Fig. 3. The land use data were classified into five main categories (cultivable lands, meadows and pastures, barren lands, urban areas, and water bodies).

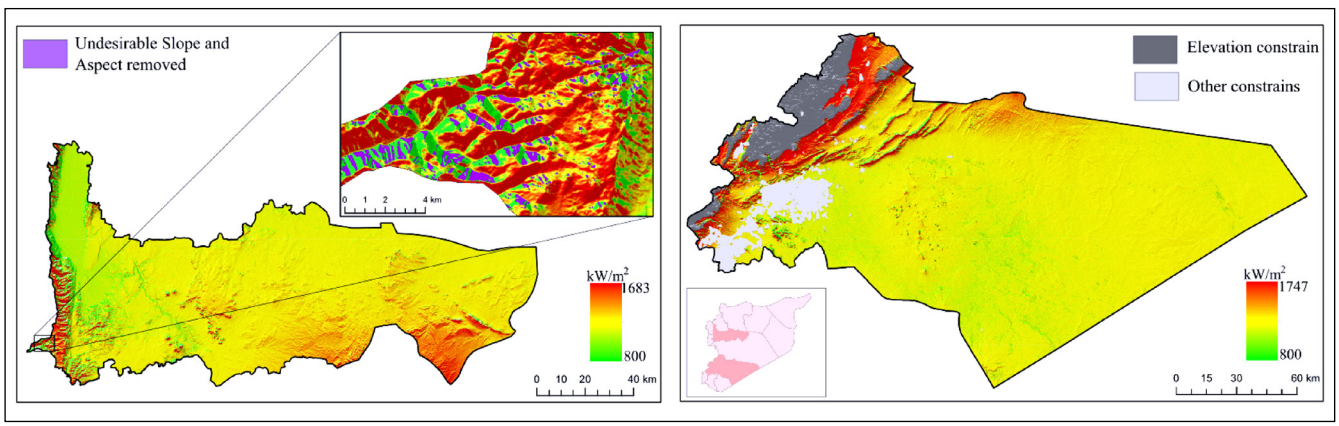

Figure 2. Undesirable slope and aspect removal in Hama Governorate (to the left); area above 1,500 m elevation removed in Damascus and Rural Damascus governorates (to the right) (Prepared by the author using spatial analysis tools, ArcGIS)

The results after applying the above criteria give us a general overview of the total capacity of the country regarding the natural conditions discussed in the methodology (Table 1).

Table 1. Evaluation criteria used in this study

Evaluation criteria	Condition
Solar radiation	> 800 kWh/m²
Slope	< 45
Aspect	North direction
Elevation	< 1,500 m
Land use	Avoid Cultivable lands, Water bodies and Urban areas

After obtaining the overall results, as well as to go further with assessing the national capacity for launching renewable energy projects. For this, several technical conditions are needed to be considered such as the distance from the main road network and electricity grids (Table 2). The impacts of these constraints is determined in the discussion section.

Table 2. Road network and electricity grid constrains

Evaluation criteria	Condition
Distance from road network	< 2,500 m
Distance from electricity grid	< 2,000 m

Results

According to the above conditions, 72% of the Syrian territory is considered technically as potential areas for very good large-scale solar power investment as these areas receive sufficient solar power energy with suitable landforms and land use conditions (Fig. 4). After excluding areas that receive very low solar radiation (less than 800 kWh/m²-year), the country can be divided into three regions: low radiation regions with radiations below the annual average of solar radiation of 1,396 kWh/m²-year, medium radiation regions with radiations between the annual average and the solar radiation of 1,470 kWh/m²-year, and higher radiation regions with radiation above 1,470 (with the maximum of 1,757 kWh/m²-year).

The results show that 84% of the total suitable areas is located in five districts: Homs, Deir ez-Zor, Rural Damascus (as Damascus Governorate is considered totally as urban land), Ar-Raqqa and Al-Hasakeh (Table 3). Most of the suitable areas are located in the eastern and southern parts of the country and it can be clearly seen that the intensity of the solar irradiance increases southwards. It is also noted that 92% of the highly suitable areas are located mainly within three governorates (Rural Damascus, Homs, and As-Sweida) (Fig. 5). They – with an area of 10,804, 6,699 and 4,520 sq km, respectively – receive a higher yearly average of solar radiation with a maximum of 1,757 kWh/m² (Table 3).

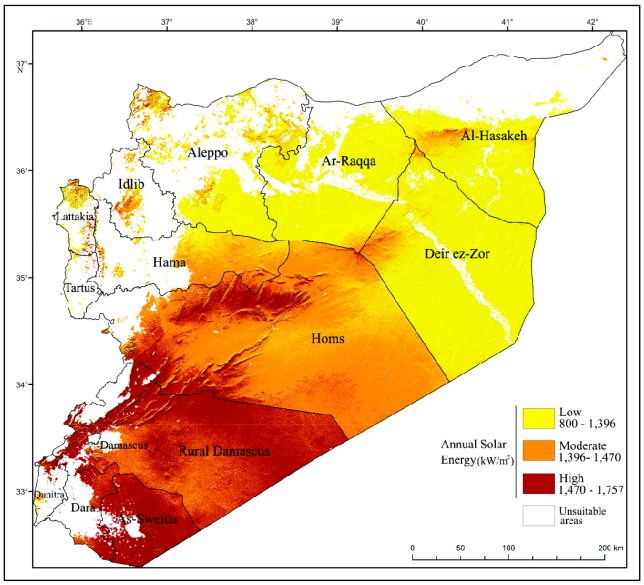

Figure 4. Solar radiation intensity distribution on areas defined as suitable (Prepared by the author using spatial analysis tools, ArcGIS)

Table 3. Total estimation of the suitable lands in governorates

Governorate	Area (sq km)	Mean solar radiation (kW/m²)	Suitable area (sq km)			
			Low	Moderate	High	Total
Homs	40,922	1,438	4,709	26,833	6,699	38,241
Deir ez-Zor	33,060	1,361	29,487	1,713	67	31,267
Damascus & Rural	18,137	1,485	117	5,281	10,804	16,202
Ar-Raqqa	19,616	1,360	14,049	446	5	14,500
Al-Hasakeh	23,334	1,358	10,451	692	21	11,164
Aleppo	18,500	1,366	6,716	847	74	7,637
Hama	10,181	1,406	2,065	2,949	207	5,221
As-Sweida	5,550	1,523	10	344	4,520	4,874
Dar'a	3,730	1,483	6	416	1,199	1,621
Idleb	6,097	1,398	463	455	47	965
Lattakia	2,297	1,351	463	160	99	722
Quneitra	1,861	1,499	56	64	216	336
Tartous	1,896	1,352	89	21	16	126

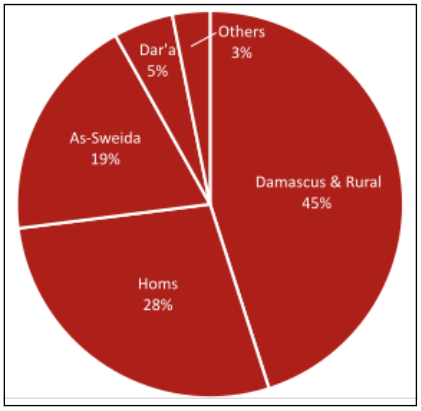

Figure 5. Percentage of higher radiation regions

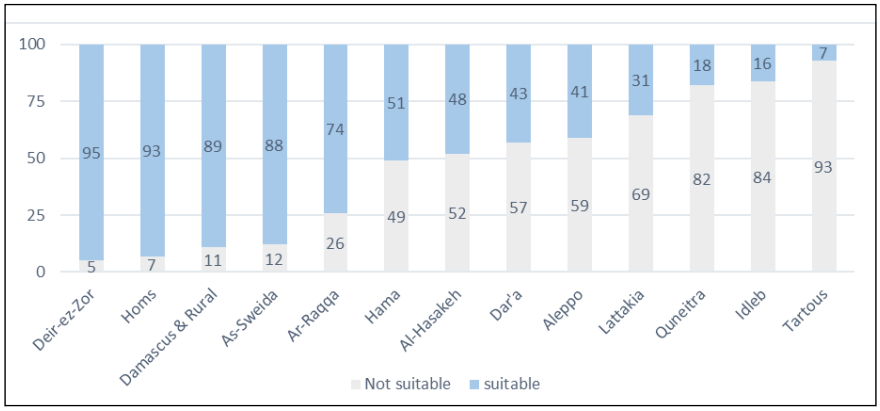

Figure 6. Percentage of total suitable area in governorates

According to the percentage of total suitable areas per governorate, the total of suitable areas in the governorates of Deir ez-Zor, Homs, Rural Damascus, and As-Sweida is higher than in the rest of the Syrian governorates (more than 80% of their territories defined as suitable) (Fig. 6). Thus, opportunities for large-scale solar energy investment in these areas are very high. Total areas and the total suitable areas for each governorate are given in square km in Table 3.

Electrical power output estimation

To convert solar radiation to power (the usable solar radiation), total suitable area as well as mean solar radiation were used for each governorate (received per year for the suitable areas). This was achieved by multiplying the suitable areas by their average of solar radiation per square metre, these values (the usable solar radiation) were converted then to electric power using the efficiency and performance ratio values (the amount of power that solar panels can produce depends not only on solar radiation but also on the solar panels' efficiency and the installation's performance ratio) (Khanna, 2021) (U.S. Environmental Protection Agency, 2021). The annual average performance ratio of the photovoltaic (PV) system in Syria is estimated at 0.799 (Ramadan et al., 2019) and at 0.8 in the neighbouring Lebanon and Jordan (M. Haidar et al., 2017).

As a result, an estimation the potentials of electric power production for each governorate were generated (Fig. 7). This indicates the maximum production of suitable areas in each governorate. If these suitable areas were covered by solar power plants, these areas could produce more than 2000 GWh/year in only four governorates (Homs, Deir ez-Zor, Rural Damascus and Ar-Raqqa). The maximum estimated production is identified in Homs Governorate with a total production of over 7 million GWh/year. Following the same method, the less productive governorate in terms of the electric estimation would be Tartous. As for the electric production in only highly suitable areas, these numbers reflect the previous finding regarding the number of areas defined as highly suitable. Damascus and Rural Damascus, Homs, and As-Sweda are the top three governorates with regard to estimated electricity production (Table 4).

These huge numbers indicate how important is the role that future solar energy projects could play for offering solutions to the power generation shortage problem within the country as well as for having a sustainable future in Syria.

Discussion

At any large-scale renewable energy project, the investors have to take every opportunity of reducing costs in addition to the constraints analysed above. Therefore, they also have to consider two main technical criteria: the distance from main electric grids and the road network.

Table 4. Total estimated electric power production potential in Syrian governorates

	All suitable areas		High annual solar energy areas	
Governorate	Usable solar radiation (GWh/year)	Electric power production (GWh/year)	Usable solar radiation (GWh/year)	Electric power production (GWh/year)
Homs	54,990,558	7,093,782	9,633,162	1,242,678
Deir ez-Zor	42,554,387	5,489,516	91,187	11,763
Damascus & Rural	24,059,970	3,103,736	16,043,940	2,069,668
Ar-Raqqa	19,720,000	2,543,880	6,800	877
Al-Hasakeh	15,160,712	1,955,732	28,518	3,679
Aleppo	10,432,142	1,345,746	101,084	13,040
As-Sweida	7,423,102	957,581	6,883,960	888,031
Hama	7,340,726	946,953	291,042	37,544
Dar'a	2,403,943	310,109	1,778,117	229,377
Idleb	1,349,070	174,030	65,706	8,476
Lattakia	975,422	125,830	133,749	17,254
Quneitra	503,664	64,973	323,784	41,768
Tartous	170,352	21,976	21,632	2,791

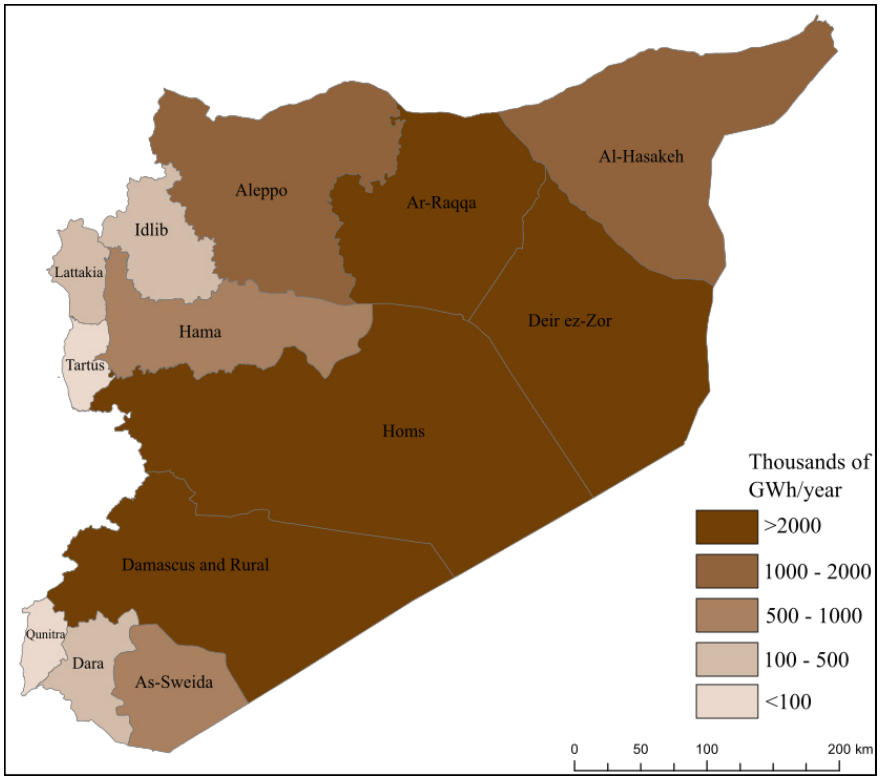

Figure 7. Total estimated electric power production potential (GWh/year) for total suitable areas of governorates (Prepared by the author using spatial analysis tools, ArcGIS)

Syria has poor structural and performance indicators of electricity infrastructure, which was barely functional even before the Syrian crises (Hatahet et al, 2021). In 2010, the primary transmission grid consisted of 5,719 km of 230 kilovolt (kV) lines and 1,594 km of 400 kV high voltage lines (Husam Beides et al, 2010) (Fig. 8).

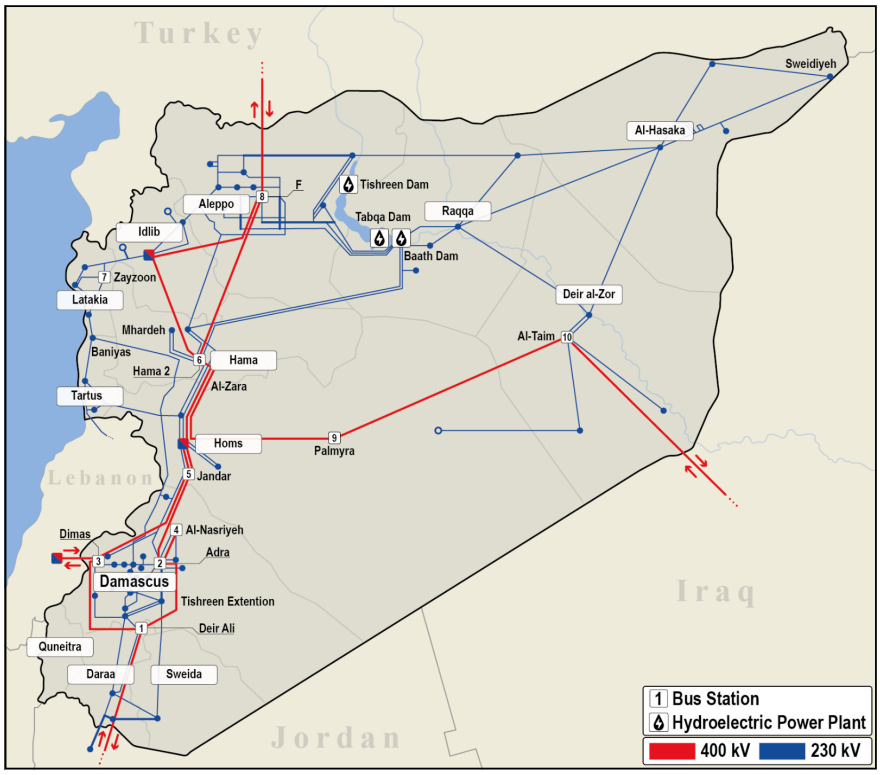

Figure 8. Transmission grid map of Syria (Source: Hatahet et al, 2021)

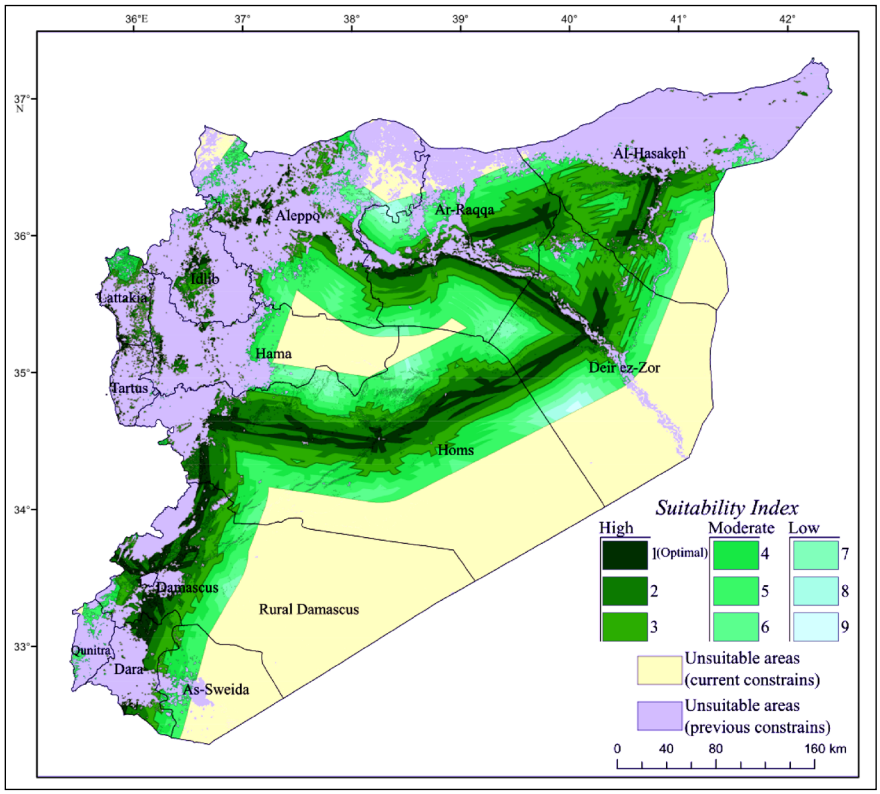

Figure 9. Suitability within the previously selected areas after considering the roads and electric grids network (Prepared by the author using spatial analysis tools, ArcGIS)

The weighted overlay technique helps to locate sites as close as possible to both roads and electric grid networks within the suitable areas to arrive at further selection based on these two inputs (the equal approach was used, 50% for roads and 50% for grids). The result is shown in the map below (Fig. 9). The optimal areas, highlighted in dark green, are within the most productive technical zone (closer than 2,500 m from main roads network and 2,000 m from the closest grid line).

If the main focus is only on the optimal zone and this territory is compared to the previous results (overall suitability), the total suitable surface area will be strictly limited to 8,125 km² (Table 5) and that the number of suitable areas highly decrease in every Syrian governorate (in Homs Governorate alone, the suitable areas decrease from 38,241 km² to 2,697 km² only). Generally, 83% of these optimal areas are located within four governorates (Homs, Deir ez-Zor, Ar-Raqqa and Damascus/Rural) (Fig. 10).

This indicates the important role that electric transmission network planning could play to integrate with renewable power technologies and the need for improving electric utilities structure in Syria to overcome the challenges of integrating solar and other renewable technologies into the main power systems as these projects will be an essential part of our energy future.

Conclusion

The study presented an overview of the potentials of solar energy and its distribution in Syria. The study has shown that the country has a high technical potential for large-scale solar energy production and various applications. The paper also presented an overall assessment of the annual average solar radiation in Syria as well as an estimation of the overall capacity of solar energy production within the country. The results show that 72% of the Syrian territory is considered technically as potential areas for very good large-scale solar power investment and these suitable areas include the majority of the territory of Deir ez-Zor, Homs, Rural Damascus,

Table 5. Electric power production potential (optimal sites) in Syrian governorates

Governorate	Optimal areas (sq km)	Usable solar radiation (GWh/year)	Electric power production (GWh/year)
Homs	2,697	3,684,292	475,274
Deir ez-Zor	1,656	2,248,661	290,077
Ar-Raqqa	1,370	1,863,299	240,366
Damascus & Rural	997	1,518,456	195,881
Al-Hasakeh	487	723,560	93,339
Dar'a	344	510,415	65,844
Aleppo	226	307,692	39,692
Idleb	136	191,035	24,644
Hama	81	116,211	14,991
Tartous	80	111,888	14,434
Lattakia	51	69,551	8,972
As-Sweida	—	—	—
Quneitra	—	—	—
Total	8,125	11,345,060	1,463,514

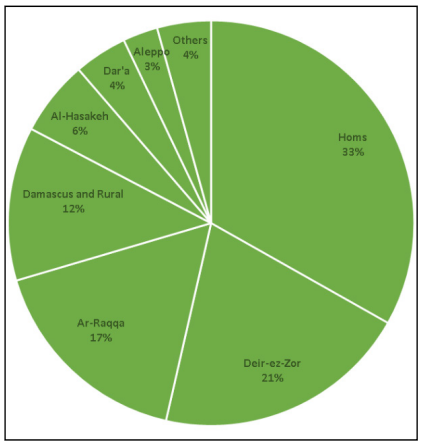

Figure 10. The percentage of optimal areas in governorates

and As-Sweida governorates. Almost all the governorates in Syria have good sites which receive annual solar energy varying from 800 kWh/m²-year and experience a good solar radiation range, the maximum of which is 1,757 kWh/m²-year. The analysis further indicates that eastern and southern governorates have the highest suitability index regarding the intensity of solar radiation within the defined areas. 92% of the areas which receive solar radiation between 1,470 and 1,757 kWh/m²-year are located in three governorates (Rural Damascus, Homs, and As-Sweida). Meanwhile, the electrical power output estimation reflects these facts and after assessing the maximum electrical power output of these suitable areas (supposing they are covered with solar power plants), it has been found that eight Syrian governorates could produce more than one million gigawatts/year each. As the production of electricity in Syria has decreased 56% from what it was before the outbreak of the conflict (Alwatan, 2015), this research indicates how important this kind of investment is to help in solving the electricity shortage within the country,. The research also discussed the current transmission of electric and road networks within the country and how the poor infrastructure can affect the available lands to be used for future renewable energy projects.

Syria has high estimated technical potential due to the high solar radiation received annually and the availability of large suitable areas related to geographical conditions for large-scale PV technology development. Therefore, with an ever-increasing of energy demand and natural challenges represented by climate change and the power shortage due to the ongoing Syrian crisis, solar energy appears to be one of the best effective solutions for production of sustainable and clean energy in Syria.

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