Energy Visions 2035 for Syria

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Abstract. The Syria’s energy sector will face major challenges in the coming decades. Demand for primary energy is continuously increasing to 23 Mtoe in 2008 and then is decreasing to 8.9 Mtoe in 2017. The limited resources and supply uncertainty of especially oil and gas will lead to increasing price instability. Electricity consumption is changing similarly and amounted to 15 TWh in 2017. Syrian power plants generate electricity at 17.5 TWh using mostly traditional fuels. One of the important challenges for Syria is restricting access to the required amount of traditional fuels. The optimistic estimate of the gross and technical potential of wind energy over the territory of Syria is obtained. The paper estimates the technical potential at 490 TWh per year, which exceeds the maximum electricity consumption by almost 12 times. The gross and technical solar energy is determined. Scenarios of the growth of electricity consumption and its cover through the use of various energy sources are simulated. For each scenario, carbon dioxide emissions estimates for Syria were obtained. The most rational scenario for the development of Syria’s energy sector was found. The results show that Syria has huge potentials of renewable energies (solar and wind energy in the first place) and that the exploitation of these sources can solve energy problems in Syria.

1. Introduction

Syria is going through a difficult historical period and faces challenges in how to meet the demand for electricity. This is due to the war and the control of several parties on fossil fuel resources, lack of production, oil companies shutting down, destruction of the electricity grid, insufficient conversion capacities and financial weakness of energy entities, halting imports, and corruption. In addition, the demand for electricity will increase as an expected result of population growth and industrialization. The restoration of the national economy and its economic and social development, therefore, require a sustainable, safe and effective energy sector.

Syria is located within the sunbelt zone; it has about 300 sunny days with high solar radiation. There are many areas where the average annual wind speed exceeds 6 m/s. Highest average wind speeds detected in Sendiania, Barshin and other sites that are suitable for wind energy investment. On this basis, this work aims to assess the reality of electricity and discussing other possible sources of power generation and supporting the Syrian electrical system, especially the use of wind and solar energy. To achieve this objective, the environmental and economic aspects of the most rational scenarios are studied.
2. The reality of the Syrian electricity sector

2.1. The supply and consumption of energy

In Syria, in 2011 roughly 20.41 Mtoe of energy resources were consumed mainly from gas and oil [1]. The energy supply has increased between 1991 and 2008 and then decreased dramatically after the war in Syria began until it reached 8.937 Mtoe in 2017 (Figure 1) [2], which means a decrease of more than 55% compared to the pre-war period. In 2008, Syria became a net importer of natural gas, but the current state of conflict in the country and the sanctions affected Syria’s ability to receive natural gas. During the war, the Syrian primary energy provision was mainly made by oil from Iran due to a reduction in oil production by more than 95%. Maximum electricity consumption reached 39 TWh/a (Figure 2). The transport sector is the most consumer of primary energy, and agriculture is the lowest [2]. The largest consumers of electricity are industry and the residential sector of the economy (Figure 3).

![Figure 1. The primary energy supply by source, Syria 1991-2017.](image)

2.2. Electricity consumption

Electricity consumption increased from 17 TWh in 2000 to 39 TWh in 2010, an annual rate of about 2.2 TWh/a. Almost all regions of Syria are covered by the electrical grid.
2.3. Electricity generation

Syria's electricity production depends mainly on traditional fuels, whose share in the electricity structure over the past two decades has exceeded 80%. In 2017, Syria generated almost 17.474 TWh of electricity (using gas (10.56 TWh), fuel and diesel fuel (6.9 TWh)), of which 96% from traditional power plants (TPPs). The remaining 4% from hydropower plants. This means a decrease of 58% compared with 2011 (41.86 TWh at the beginning of the war). In 2010, Syria generated almost 44 TWh of electricity (Figure 4) [2].

![Figure 2. Electricity consumption, Syria 1991-2017.](image)

![Figure 3. Electricity consumption by sector, Syria 1991-2017.](image)
Syria's electric capacity in 2012 was 8.9 GW. In 2007-2008 Syria’s total installed capacity was 7.9 GW. For comparison, in 2001 it amounted to 8.2 GW, that is, during that time, the total capacity has not increased, but even slightly decreased. At the same time, the production of electricity in Syria in 2000-2009 \[1\] increased by more than 75%. Damage to the electrical network and Syria's electrical infrastructure, including power plants, substations, and power lines, was often the target of sabotage. The cost of direct losses since the start of the war is around 830 billion SP. By the beginning of 2013, more than 30 Syrian power plants were inactive and losses in the distribution of electricity, already accounting for 17% of total generation in 2012 \[1\]. Syria planned to switch all its heat generators to natural gas as soon as possible, although this is unlikely until the end of hostilities. The lack of domestic refining capacities in Syria, ongoing sanctions on the country's energy sector and a decrease in natural gas processing volumes all together limit the availability of necessary fuel for Syria's power plants and contribute to blackouts in many parts of the country.

3. Assessment of the gross and technical potential of wind and solar energy in Syria

The use of renewable energy sources is limited to hydropower. As for the rest of the renewable sources, their installed electric capacity is negligible \[3\].

3.1. Wind energy

3.1.1. The gross potential of wind energy in Syria. The gross potential of the region’s wind energy is the average long-term total wind energy of air mass movements over a given territory. The region is represented as a set of zones, areas in which the specific power of wind energy, geographical, climatic and weather conditions are uniform throughout the area. As a rule, the zones should correspond to the location of the weather stations. In this work, we used the data of measuring wind speeds from 2 weather stations from the site www.rp5.ru and the data of measuring wind speeds for a certain period at 7 weather stations conducted by the Main Department of Meteorology as initial data. In addition, 15 ready-made velocity distribution functions obtained from the measurement results were used. Measurements were taken by the National Energy Research Center in Syria. By installing wind monitoring stations, each of which has a height of 40 m. The gross potential of the region is calculated as wind energy, which can be used by a wind turbine system of height h. It is assumed that the perturbed flow is completely restored at a distance of 20h from each installation \[4\]. Therefore, the full
use of wind energy is carried out by a wind turbine system, in which the rows of installations are separated from each other at a distance of 20h.

Specific power and specific energy of a wind flow:

\[ \langle P \rangle = \sum_{i} P(v_i) \cdot t_i = \frac{1}{2} \cdot \rho \cdot \sum_{i} v_i^3 \cdot t_i, \quad (1) \]

where \( \rho \) - air density, kg/m\(^3\), T - hours per year, \( t_i \) - probability of wind speed, o.e. When using the Weibull distribution:

\[ M[P] = \frac{1}{2} \cdot \rho \cdot \int_{0}^{\infty} v^3 \cdot f(v)dv = \frac{1}{2} \cdot \rho \cdot c^3 \cdot \Gamma(1 + \frac{3}{k}). \]

Specific wind energy \( E_W \) equal to:

\[ E_W = \langle P \rangle \cdot T. \quad (2) \]

The calculation results according to formulas (1) and (2) are shown in Table 1.

The total wind energy captured by installations on an area of \( S_i \) m\(^2\) per year represents the gross potential of the territory \( W_{GR,j} \) in kWh/a with a specific wind energy \( E_{wi} \) in kWh/(m\(^2\). a) equal to:

\[ W_{GR,j} = \frac{E_{wi} \cdot S_i}{20} = \frac{1}{40} \cdot \rho \cdot T \cdot S_i \cdot \sum_{j=1}^{n} v_j^3 \cdot t_j, \]

\[ W_{GR,j} = \frac{1}{40} \cdot \rho \cdot T \cdot S_i \cdot \int_{0}^{\infty} v^3 f_i(v)dv. \]

For the Weibull distribution, this gives the expression:

\[ W_{GR,j} = \frac{1}{40} \cdot \rho \cdot T \cdot S_i \cdot c_i^3 \cdot \Gamma(1 + \frac{3}{k_i}). \quad (3) \]

where \( c_i, k_i \) - distribution parameters, \( \Gamma \) - gamma function. The gross potential of a region is the sum of the gross potentials of its constituent zones.

\[ W_{GR,REGION} = \sum_{i=1}^{n} W_{GR,j}, \quad (4) \]

where \( n \) - number of zones.

3.1.2. The technical potential of wind energy in Syria. The technical potential of the region’s wind energy is the total electric energy that can be obtained in the region from the use of gross potential with the current level of development of technical equipment and compliance with environmental restrictions \[4\]. The technical potential of the region consists of the technical potentials of its constituent zones. An important parameter of the technical potential of the zone is the area of \( S_t \) which is suitable for the use of wind energy. It is equal to part \( q \) of the total area \( S \) remaining after subtracting the areas of agricultural land, industrial and water management territories, parks, residential, medical buildings, etc. \( S_t = q \cdot S \). To calculate the technical potential, it is required to determine the area \( S_t \) for each zone. But first you need to determine the regions with an average annual wind speed of at least 5 m/s. Thus, it turns out that out of 24 zones only in 15 (In green) it is advisable to use wind energy (Figure 5). The order of placement of wind turbines for maximum use of the wind flow depends on the
wind rose on the ground. The optimal arrangement of the wind turbine in the form of rows oriented perpendicular to the wind and spaced from each other at a distance of 20 diameters of the wind wheel D. Moreover, on the area \( S_t \), it is possible to place \( \frac{S_t}{20 \cdot D^2} \) installations. If we introduce the installed capacity utilization factor \( K \), then the technical potential can be represented as:

\[
W_T = K \cdot N_{IC}^{WPU} \cdot T \cdot \frac{S_t}{20 \cdot D^2}, \quad K = \left( \frac{N}{N_{IC}^{WPU}} \right),
\]

where \( K \) is calculated by the following formula [4]:

\[
K = \sum_{v_i \beta \in V} \left( \frac{v_i \beta - v_B}{v_B} \right) + \sum_{v_i \beta \in V} I_i.
\]

To assess the technical potential will be used wind turbines of high power - GAMESA G80-2MW with the following characteristics [5]: - Rated power \( N_{IC}^{WPU} = 2 \text{ MW} \), Hub height 80 m, Diameter \( D = 80 \text{ m} \), Cut-in wind speed \( v_0 = 4 \text{ m/s} \), Rated wind speed \( v_p = 13 \text{ m/s} \), Cut-out wind speed \( v_o = 25 \text{ m/s} \). To recalculate the wind speed at the tower height, we use the following equation:

\[
v(h_2) = v(h_1) \cdot \beta, \quad \beta = \left( \frac{h_2}{h_1} \right)^m = \left( \frac{80}{40} \right)^{0.2} = 1.15,
\]

where \( v(h_1) \) is the wind speed at the height of the regular observation data; \( h_2 \) - estimated height of the axis of the wind wheel; \( m \) - is the Helman power coefficient, taking into account the influence of orography (roughness) of the underlying surface on the wind speed.

Table 2 shows the amount of electricity that can be produced annually from each region, where it is clear that the largest share can be obtained from the region Palmyra (11 zone) which has an average wind speed 6.15 m/s where it gives 157.2 TWh/a. This is due to the expansion of its area while the area. According to our estimates, the gross Syria’s wind energy potential is about 15.9 PWh/a. The technical potential of Syria’s wind energy is about 490 TWh/a or 3.1% of the gross wind energy potential.

**Table 1.** Distribution parameters, wind power and energy.

| Zone number | Zone           | V at 40 m height [m/s] | Distribution parameters c and k | \( \langle P \rangle \) w/m²a year | \( E_W \), kWh/m²a year | Zone number | Zone           | V at 40 m height [m/s] | Distribution parameters c and k | \( \langle P \rangle \) w/m²a year | \( E_W \), kWh/m²a year |
|-------------|----------------|------------------------|---------------------------------|-----------------------------------|-------------------------|-------------|----------------|------------------------|---------------------------------|----------------------------------|-------------------------|
| 1           | Al-Qamishli     | 4.1                    | c=3.7                           | 123                              | 1077.48                 | 13          | Latakia       | 2.5                    | c=3.7                           | 75.4                              | 660.50                  |
|             |                 |                        | k=2.3                           |                                   |                         |             |                |                        | k=1.3                           |                                   |                        |
| 2           | Al-Hasakah      | 1.5                    | -                               | 52.7                              | 461.652                 | 14          | Alsindian     | 7.94                   | c=8.9                           | 484                               | 4239.8                  |
|             |                 |                        |                                 |                                   |                         |             |                |                        | k=2.4                           |                                   |                        |
| 3           | Tal Abiad       | 3.8                    | c=3.3                           | 101                               | 887.388                 | 15          | Tartus        | 1.4                    | -                               | 38.1                              | 333.75                 |
Table 2. Calculation of gross and technical potential of wind energy in Syria.

| Zone number | S [km²] | W<sub>GR</sub> [TWh/a] | Usable zones for using wind energy | q [%] | S<sub>f</sub> [km²] | W<sub>f</sub> [TWh/a] | Zone number | S [km²] | W<sub>GR</sub> [TWh/a] | Usable zones for using wind energy | q [%] | S<sub>f</sub> [km²] | W<sub>f</sub> [TWh/a] |
|-------------|--------|----------------|----------------------------------|-------|----------------|----------------|-------------|--------|----------------|----------------------------------|-------|----------------|----------------|
| 1           | 6728.5 | 362.49          | ✗                                 | -     | -              | -              | 13          | 3172.38 | 104.77          | ✗                                 | -     | -              | -              |
| 2           | 14626.6 | 337.62          | ✗                                 | -     | -              | -              | 14          | 1462.29 | 309.99          | ✓                                 | 3     | 43.87          | 3.053           |
| 3           | 6572.15 | 291.60          | ✗                                 | -     | -              | -              | 15          | 1439.63 | 24.02           | ✗                                 | -     | -              | -              |
| 4           | 18457.5 | 1828.67         | ✓                                 | 1     | 2030.32        | 85.38          | 16          | 1088.39 | 255.04          | ✓                                 | 2     | 21.77          | 1.426           |
| 5           | 31358.9 | 814.49          | ✗                                 | -     | -              | -              | 17          | 1335.2 | 375.86          | ✓                                 | 3     | 40.05          | 6.243           |
| 6           | 10009.7 | 501.12          | ✗                                 | -     | -              | -              | 18          | 1474.89 | 152.78          | ✓                                 | 6     | 88.49          | 3.118           |
| 7           | 5167.68 | 808.95          | ✓                                 | 6     | 310.0         | 14.11          | 19          | 4768.19 | 586.86          | ✓                                 | 5     | 238.4          | 8.446           |
| 8           | 6886.79 | 793.0           | ✓                                 | 1     | 1033.46       | 2691.0         | 20          | 15334.2691 | 10533.8 | ✓                                 | 10    | 1533.8         | 83.85           |
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3.2. Solar energy

The assessment of the gross potential of solar energy in Syria based on four different sources. The assessment of the total potential of solar energy in Syria on the basis of daily global horizontal solar radiation for the year 2012 is an average of 6.5 kW/(m²d) \[3\].

The technical potential of solar energy is the average long-term total energy that can be obtained from solar radiation during the year with the current level of development of science and technology and environmental standards \[6\]. The technical potential of solar energy is the sum of the technical potentials of thermal (\( S_{TH} \)) and electric energy (\( S_{EL} \)) obtained by converting solar radiation. The technical potential is equal to the gross part, because not the entire area of the country can be allocated for the use of solar energy. From this area, the areas of forests, parks, agricultural lands and other territories where installation is difficult or prohibited are deducted \[4\]. If for \( S \) we take the area of the whole country, and for \( q \) the fraction of the area available for use, then the area \( S_C \) available for calculating the technical potential is defined as follows:

\[ S_C = q \cdot S \]  \hspace{1cm} (8)

for installing solar photovoltaic batteries, then

\[ S_C = S_{TH} + S_{FOTO} \cdot S_{HT} = k_{th} \cdot S_C \cdot S_{FOTO} = k_{foto} \cdot S_C \]  \hspace{1cm} (9)

and the amount is naturally equal

\[ k_{th} + k_{foto} = 1 \]  \hspace{1cm} (10)

The \( q \), \( k_{th} \), and \( k_{foto} \) values are different for each zone.

Divide the territory of Syria as one zone. To determine \( q \), we summarize the area of forests, agricultural land, and mountains. Forest area: 2.7% of the total area [https://knoema.ru/atlas/Syria/Forest_Area]. Water surface area: 0.6% of the total area [https://en.wikipedia.org/wiki/Geography_of_Syria]. Area of agricultural land: 139,120 sq. M. km [http://data.trendeconomy.ru/dataviewer/wb/wbd/wdi?ref_area=SYR&series=AG_LND_AGRI_K2], which is 75% of the total area. Of the remaining 25 percent, about 10% are mountains - an analysis of the geographic map of Syria. We calculate the \( q \) value:

\[ q = 1 - \frac{S_{FOREST} + S_{WATER} + S_{HOMES} + S_{AGRICU} + S_{MOUNTAINS}}{S_{TOTAL}} \]  \hspace{1cm} (11)

For the values of \( k_{th} \) and \( k_{foto} \), we take the values of 0.5 and 0.5, respectively.
### Table 3. Calculation of gross and technical potential of solar energy in Syria.

| Region | GHI [kWh/(m² d)] | Total area [km²] | The gross potential [TWh/a] | q [%] | Usable area for solar thermal and PV systems [km²] | Usable area for PV systems [km²] | PV surface area [km²] | $w_i$ [TWh/a] |
|--------|-----------------|------------------|-----------------------------|-------|-----------------------------------------------|---------------------------------|----------------------|------------------|
| 1      | 4.9             | 5703.4           | 27947.6                     | 1     | 57.03                                         | 28.5                            | 25.08                | 6.73             |
| 2      | 5.1             | 45428.26         | 231939.1                    | 4     | 1817.13                                      | 908.5                           | 799.48               | 223.23           |
| 3      | 5.2             | 42003.49         | 218678.1                    | 9     | 3780.31                                      | 1890.1                          | 1663.28              | 473.53           |
| 4      | 5.3             | 23033.74         | 122343.8                    | 15    | 3455.06                                      | 1727.5                          | 1520.2               | 441.12           |
| 5      | 5.4             | 17501.98         | 94780.7                     | 14    | 2450.27                                      | 1225.1                          | 1078.08              | 318.73           |
| 6      | 5.5             | 915              | 5307.6                      | 1     | 9.15                                         | 4.5                             | 3.96                 | 1.19             |
| 7      | 5.6             | 20725.4          | 116342.4                    | 15    | 3108.8                                       | 1554.4                          | 1367.87              | 419.39           |
| 8      | 5.5             | 14875            | 81816.35                    | 14    | 2082.5                                       | 1041.2                          | 916.25               | 275.9            |
| 9      | 5.8             | 14290.26         | 81233                       | 11    | 1571.92                                      | 785.9                           | 691.6                | 219.61           |
| 10     | 6               | 703.48           | 4122                        | 30    | 211.04                                       | 105.5                           | 92.8                 | 30.48            |
| **Total** | **185 180**     | **984510.7**     | **Total** 18543.21          | **9271.2** | **Total** 8158.6                          | **2409.9**                     |

The table shows the third and fourth regions are the highest technical potential (473 and 441 TWh/a) respectively.

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**Figure 5.** Map of annual average of daily Global Horizontal Irradiation (GHI) over Syria [7].
4. Demand for electrical energy and the expected deficit (energy gap) to 2035

Local sources of petroleum fuels are limited and the demand for electrical energy in Syria will increase, the available petroleum fuel quantities will not be enough for the needs of generation power plants [1]. As a result of these challenges in the energy and electricity sector, we have developed two scenarios to estimate the final energy requirements for each scenario, thus determining the electrical gap and assess the use of renewable energy sources outlined above within the electricity system in Syria in addition to environmental and social assessments of energy development scenarios. Since Syria has been in an abnormal situation since 2011 as a result of the war, the expected demand for electrical energy and electrical capacity were studied in light of a number of assumptions as it was considered a recovery phase until 2025 as oil and gas resources will be restored and the activity of all sectors as it was before the current war (i.e. annual electricity production was 39 TWh and the installed capacity in that period reached 8 GW (1.5 hydro and 6.5 thermal)) [3].

1) Scenario A: assumes that the demand will grow continuously according to the average increase during the decade before the war (2000-2010) (i.e. growth by about 2.2 TWh/a for the consumption of electrical energy). Based on this, the demand will be 50 TWh in 2030 and 61 TWh in 2035. That is, the electrical gap (deficit) will be 11 and 22 TWh in 2030 and 2035, respectively.

2) Scenario B: assumes double the average increase (2.2 * 2 = 4.4) within the period 2000 till 2010 for the years 2025 till 2035 (the electrical gap 22 TWh/a in 2030 for energy and 44 TWh/a in 2035 for peak power) (Figure 6).

5. Transmission

The existing electric grid is able to handle future electric power and there is no need for new lines until 2035

6. Electricity generation cases to cover the deficit (electric gap)

To close the gap, the technical potentials are numerous. However the gap is growing over time, if new power plants are not built. Four different generation cases are defined to cover possible developments (Table 4). Assuming that the reference year is 2025 and 20% is the assumed share of renewable energy sources by 2035. This means an annual growth rate of 2% for wind turbines and PV systems.

To achieve the assumed wind energy participation rate in the Syrian electrical system to bridge the gap, areas with wind speeds greater than 5 m/s will be used, in particular, region 7. Thus, the full load hours are 2920 hours. The consequence is 1506.85MW and 753.42 MW to be constructed by 2035
(Case II and case IV in Scenario A) 3013.7 MW and 1506.85 MW (Case II and case I in Scenario B).

For solar energy: the ninth region will be exploited, where the population density and the demand for electricity are high. Thus, electrical power of 2113 MW and 1056.5 MW to be erected in PV systems by 2035 (Case III and case I in Scenario A) 4226 MW and 2113 MW (Case III and case IV in Scenario B) as the full-load hours is 2082 h in year.

7. Economic assessment of both scenarios in all generation cases

Approximately 75% of the total energy cost for a wind turbine and PV systems is related to upfront costs. Thus a wind turbine and PV systems are capital-intensive compared to conventional fossils fuel-fired technologies such as a natural gas power plant, whereas as much as 40-70% of costs are related to fuel and O&M. The cost of installed capacity of renewable energy sources for a specific region including wind energy turbines, including the cost of equipment, the cost of transporting it to places of installation and the cost of construction. Investment and O&M costs of generation technologies accepted according to research [8-15] (Table 5).

The issue of cost-effectiveness of power generation technologies is solved by the optimization parameters of power plant and find option that provides the minimum price of producing the electricity.

We further believe that during the economical lifetime $T_L$, the real interest rate $r$ is constant and $U_{WPU}=U_{EPU}=$ const and $E_{WPP}=E_{GPP}=$ const. Under these assumptions, the cost of electricity produced by wind power plant can be written as [9, 10]:

$$z = \frac{K_{WPP} \cdot CRF(r, T_L) + U_{E_{WPP}}}{E_{WPP}},$$

where $CRF$ are the capital recovery factor, $U_{E_{WPP}}$ are the WPP operation and maintenance cost, $E_{WPP}$ are the annual average of WPP electricity generated, $K_{WPP}$ the capital cost of wind power plant. The factor of using installed capacity of wind power plant is defined by the formula:

$$\theta = \frac{N_{AC_{WPP}}}{N_{IC_{WPP}}},$$

where $N_{IC_{WPP}}$ are the annual average of capacity of wind power plant, $N_{IC_{WPU}}$ are the installed capacity of WPU. The annual average of electricity generated can be written as:

$$E_{G_{WPP}} = N_{AC_{WPP}} \cdot T = N_{IC_{WPP}} \cdot T_U = \theta \cdot N_{IC_{WPP}} \cdot T,$$

where $T = 8760 \text{ hr}$, $T_U$ are the number of hours of using the installed capacity.

| Table 4. Generation cases to cover the electrical gap till 2035. |
|---------------------------------------------------------------|
| Deman scene | Generation Case | Contribution of sources in % by 2035 | The electrical gap [TWh] | $N_{IC_{WPU}}$ [MW] | The electrical gap [TWh] | $N_{IC_{WPU}}$ [MW] |
|-------------|----------------|--------------------------------------|--------------------------|------------------------|--------------------------|------------------------|
| Scenario B | Case I          | 100% fossil fuel                     | 22                       | 3201.86                | 44                       | 6403.72                |
|             | Case II         | 80% fossil fuel plus 20% wind      | 17.6                     | 2561.5                 | 35.2                     | 5123                   |
|             | Case III        | 80% fossil fuel plus 20% PV         | 17.6                     | 2561.5                 | 35.2                     | 5123                   |
|             | Case IV         | 70% fossil fuel plus 10% wind       | 15.4                     | 2241.3                 | 30.8                     | 4482.6                 |
|             |                 |                                      |                          |                        |                          |                        |
The operation cost is defined by the formula:

$$U_{E, \text{WPU}} = b \cdot k_{\text{WPU}} = b \cdot k_{\text{IC}} \cdot N_{\text{IC, WPU}} = i \cdot N_{\text{IC, WPU}},$$  \hspace{1cm} (15)$$

where $i = b \cdot k_{\text{WPU}}$ - fixed operation costs, $/ \text{kW per year}$.

The costs of different generation technologies are assumed to be stable until 2035 for all technologies (current and new). In addition, an annual interest rate of 4 % and a lifetime of 20 years for all technologies. Assuming that over time, investment costs are stable and that potential cost reductions and efficiency gains are offset by increased safety and compliance with environmental standards.

Fuel consumption rate using IGCC energy technology is 0.211m$^3$/kWh and it is the most efficient technology of the steam with 0.285m$^3$/kWh and gas turbine with 0.315m$^3$/kWh.

Above data make possible to estimate the amount of fuel needed from these stations to provide the amount of electricity needed to bridge the electrical gap, and this, in turn, allows the calculation of the cost of the fuel needed. It is assumed that the fuel cost in 2025 will constant until 2030 (0.33 $/m^3$) and rise till 2035 to the level of 2012 (0.45 $/m^3$). Necessary fuel costs are calculated accordingly.

**Table 5.** Investment and O &M costs of generation technologies in 2015 [8].

| Power generation technology | Investment cost [US$/kW] | O &M cost [US$/kW per year] |
|-----------------------------|---------------------------|-----------------------------|
| Steam Turbines              | 825                       | 7                           |
| Power Plants IGCC           | 1125                      | 10                          |
| Gas Turbines                | 825                       | 9                           |
| Diesel Turbines             | 825                       | 9                           |
| Wind Turbines               | 1400                      | 30                          |
| PV Systems                  | 1500                      | 25                          |
Figure 7. Total costs (billion) for all generation cases 2026-2035.

Figure 7 shows the total costs (investment, fuel, operation and maintenance) for all generation cases mentioned above. As shown, for scenario A, the total cost of closing the electrical gap is up to 1.895 billion dollars in the fourth case by 2030, which is the least expensive of all cases. As for scenario B, it would score 3.79 billion. Figure 8 shows the costs of generating electricity.

| Generation Case | 2030     | 2035     |
|-----------------|----------|----------|
| Case I          | 0.082547 | 0.1078   |
| Case II         | 0.074804 | 0.09506  |
| Case III        | 0.078523 | 0.098779 |
| Case IV         | 0.068409 | 0.086133 |

Figure 8. The cost of electricity generated for both scenarios and for all cases.
8. Environmental assessment of both scenarios and all generation cases
The CO₂ emissions factor can be calculated by multiplying 0.055 kg CO₂/MJ with the amount of energy that the power plants need to produce one kWh of electricity and given the difference in the amount of energy needed in different generation plants (8.08 MJ/kWh, 10.98 MJ/kWh and 12 MJ/kWh) for the combined cycle plant, steam power station and for gas turbine, respectively. The CO₂ emissions factors were calculated to be, 0.444 kg CO₂/kWh, 0.604 kg CO₂/kWh and 0.66 kg CO₂/kWh of previous techniques respectively [8, 16-21].

\[\text{Scenario A}\]

![Scenario A Graph](image)

\[\text{Scenario B}\]

![Scenario B Graph](image)

**Figure 9.** Emitted amount of CO₂ for all cases till 2035.

It is evident, that the amount of emissions is the same in the second and third cases due to the same share of energy sources. The area between the three lines in Figure 9 (Scenario A) indicates the CO₂ emissions that can be saved in scenario A by 2035 through the IV generation case compared to the I case. This value will be 3.93 million tons of CO₂.

9. Conclusions
The results demonstrate that the realization of a strategy for the wider use of renewable energy sources (primarily solar and wind) can solve energy problems in Syria. The growing role of renewable energy in Syria should lead to greater stability and efficiency of energy supply. Such changes will have a positive impact on the environment and help economic development of the region. Syria is a promising region for the development of solar and wind energy. To obtain these goals Syria has the necessary resources and support both from Government and public.
References

[1] Annual Statistical Report 2017 (Ministry of Electricity, General Directorate for Electric Power Transmission) http://www.pete.gov.sy/
[2] International Energy Agency (IEA), Key world energy statistics https://www.iea.org/regions/middle-east
[3] Ministry of Electricity (National Energy Research Center) http://www.nerc.gov.sy/
[4] Arbuzov J, Bezrukikh P, Borisov G and others 2002 Resources and efficiency of using renewable energy sources in Russia (St. Petersburg) p 314
[5] Technical Specifications http://www.gamesacorp.com/en/products-and-services/
[6] Ackermann T 2005 Wind Power in Power Systems (UK: Wiley, Chichester)
[7] Solar Atlas for the Mediterranean https://solargis.com/maps-and-gis-data/download/syrian-arab-republic
[8] Al-Omary M, Kaltschmitte M, Becker C 2018 Electricity system in Jordan: Status & prospects (German Jordanian University)
[9] Sidorenko G, AL Jamil A 2018 IOP Publishing, IOP Conf. Series: Journal of Physics: Conf. Series 1087 022016
[10] WindPower Program http://www.wind-power-program.com
[11] 2003 Energy Vision 2030 for Finland (Helsinki: VTT Energy, Edita Prima Ltd) p 237
[12] Kopylov A 2015 Renewable Energy Economics (Moscow: Grifon) p 364
[13] 2002 The Future for Renewable Energy. Prospects and Directions (EUREC Agency) p 250
[14] Burton T, Sharpe D, Jenkius N and Bossanyi E 2001 Wind Energy Handbook (Chichester, UK: Wiley)
[15] Dicaroto M, Forte G, Pisani M, Trovato M 2011 Renew. Energy 36 2043
[16] Snyder B, Kaiser M 2009 Renew. Energy 34 1567
[17] Wang S, Wang S 2015 Renew. Sustain. Energy Rev. 49 437
[18] Saidur R, Rahim N, Islam M, Solami K 2011 Renew. Sustain. Energy Rev. 15 2423
[19] Abeliotis K, Pactiti D 2014 Int. J. Renew. Energy Res. 4 580
[20] Gibon T, Hertwich E, Arvesen A, Singh B, Verones F 2017 Environ. Res. Lett. 12 034023
[21] Luderer G, Pehl M, Arversen A, Gibon T, Bodirsky B, de Boer H, Fricko O, Hejazi M, Humpenoder F, Iyer G et al. 2019 Nat. Commun. 10 1