POLITECHNIKA LUBELSKA

ROZPRAWA DOKTORSKA

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Unit Commitment in a dispersed power system involving renewable energy sources on the example of Kazakhstan

Promotor:
prof. dr hab. inż. Piotr Kacejko

Lublin 2017

Składam serdeczne podziękowania dla Promotora prof. dr hab. inż. Piotra Kacejko za cenne wskazówki, wyrozumiałość i poświęcony mi czas.

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Special thanks to my family, parents for their support and patience.

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Keywords: unit commitment, dispersed power system, renewable energy sources, electric power storage, Kazakhstan, global energy trends.

Abstract

This paper presents a common approach for the unit commitment problem solving in a dispersed power system involving renewable energy sources on the example of Kazakhstan. The proposed methodology will help all interested organizations and structures to see the possibility of covering the shortage of power generation capacities by increasing the share of renewable energy sources in generating electricity and their parallel work with the existing generation facilities instead of commissioning of traditional energy sources. Also, according to this methodology, there is a possibility to choose the optimal source of renewable energy and the possibility of testing the operation of a part of the dispersed power system, as autonomous. This methodology includes the analyzing of impact of the regional and global energy trends, legislation and the potential for renewable energy sources. The numerical results show the possibility of solving the problem of unit commitment with renewables with the least operating costs and with the most optimal renewable energy source type in the region. Also, the possibilities of autonomous operation of a part of the dispersed power system with a certain combination of renewable energy sources and electric power storage and covering the electricity deficit from the renewables instead of commissioning of traditional energy sources are shown.

Struktura generacji w rozległym systemie elektroenergetycznym z uwzględnieniem odnawialnych źródeł energii na przykładzie Kazachstanu

Słowa kluczowe: struktura generacji, rozległy systemy elektroenergetyczny, odnawialne źródła energii, magazynowanie energii elektrycznej, Kazachstan, globalne trendy energetyczne.

Streszczenie

W pracy przedstawiono wspólne podejście do rozwiązania problemu struktury generacji w rozległym systemie elektroenergetycznym wykorzystującym odnawialne źródła energii na przykładzie Kazachstanu. Proponowana metodologia pomoże wszystkim zainteresowanym organizacjom i strukturom dostrzec możliwość pokrycia niedoboru mocy wytwórczych poprzez zwiększanie udziału odnawialnych źródeł energii w wytwarzaniu energii elektrycznej i ich równoległą pracę z istniejącymi urządzeniami wytwórczymi, zamiast uruchamiać tradycyjne źródła energii. Ponadto, zgodnie z tą metodologią, istnieje możliwość wyboru optymalnego źródła energii odnawialnej i możliwości testowania działania części rozproszonego systemu elektroenergetycznego, jako autonomicznego. Ta metodologia obejmuje analizę wpływu regionalnych i globalnych trendów energetycznych, prawodawstwa i potencjału odnawialnych źródeł energii. Wyniki analityczne wskazują na możliwość rozwiązania problemu struktury generacji odnawialnych źródeł energii przy najniższych kosztach operacyjnych i najbardziej optymalnym źródle energii odnawialnej w regionie. Pokazano także możliwości autonomicznego działania części rozproszonego systemu energetycznego z pewną kombinacją odnawialnych źródeł energii i magazynowania energii elektrycznej oraz pokrycia deficytu energii elektrycznej z odnawialnych źródeł energii zamiast uruchamiania tradycyjnych źródeł energii.

Согласованная работа генерирующих мощностей в распределенной энергосистеме с использованием возобновляемых источников энергии на примере Казахстана

Ключевые слова: согласованная работа генерирующих мощностей, распределённая энергетическая система, возобновляемые источники энергии, аккумулирование электроэнергии, Казахстан, глобальные энергетические тенденции.

Аннотация

В настоящей работе представлен общий подход к решению проблемы согласованной работы генерирующих мощностей в распределенной энергосистеме с использованием возобновляемых источников энергии на примере Казахстана. Предлагаемая методика поможет всем заинтересованным организациям и структурам рассмотреть возможность покрытия дефицита мощностей по производству электроэнергии за счет увеличения доли возобновляемых источников энергии в производстве электроэнергии и их параллельной работы с существующими генерирующими мощностями вместо ввода в эксплуатацию традиционных источников энергии. Кроме того, в соответствии с этой методикой существует возможность выбора оптимального источника возобновляемой энергии и возможности тестирования работы части распределенной энергосистемы как автономной. Эта методика включает анализ влияния региональных и глобальных тенденций в области энергетики, законодательства и потенциала использования возобновляемых источников энергии. Числовые показатели показывают возможность решения проблемы согласованной работы источников электроэнергии с использованием возобновляемых источников энергии с наименьшими эксплуатационными расходами и с наиболее оптимальным типом источника возобновляемой энергии в регионе. Также показаны возможности автономной работы части распределенной энергосистемы с определенной комбинацией возобновляемых источников энергии и использованием устройств для аккумулирования электроэнергии и покрытия дефицита электроэнергии из возобновляемых источников энергии вместо ввода в эксплуатацию традиционных источников энергии.

List of major abbreviations

RES – renewable energy sources
UC – unit commitment
ED – economic dispatch
UN – United Nations
EAEU – Eurasian Economic Union
IEA – International Energy Agency
GDP – gross domestic product
EIA – U.S. Energy Information Administration
BP – British Petrol
OECD – Organization for Economic Co-operation and Development
TOE – tone of oil equivalent
KEGOC – Kazakhstan Electrical Grid Operating Company
DGC – distribution grid companies
CDA – Central Dispatch Administration
SDPP – state district power plant
HPP – hydro power plant
TPP – thermal power plant
OHL – overhead line
UNDP – United Nations Development Programme
PV – photovoltaic
GRG – Generalized Reduced Gradient Method
VG – variable generation

1. Introduction

The power sector is a strategic industry, which plays an important role in the economic and social sphere of the state. Kazakhstan is not an exception. Needs of economy growth within the country and its integration into the world economy determines the development of the country's energy sector. But the power sector of Kazakhstan has some unsolved problems that hinder emerging trends for a growth. The most important is the lack of the generation capacities and a high level of its depreciation. It raises the question of the introduction of new generation facilities. There are two ways of solving such problem: installing the traditional generation objects the more that Kazakhstan has considerable reserves of coal and hydrocarbons, or use renewable sources of energy, which have a number of undoubted advantages. The most significant are the zero cost of primary energy sources and the minimal impact on the environment.

At the same time, in practice the introduction of renewable energy sources (RES) is accompanied by the solution of a number of serious problems, connected primarily with the variability of most of the types of such energy used. One such task is to overcome technical barriers when integrating RES into the energy system in cases where their share in the total generation capacity becomes noticeable. In this case, you must decide on the coordinated operation of existing generation capacity with renewable energy sources or in other words to solve unit commitment (UC) problem with the renewables. There are many different methods and algorithms created for the UC problem solving. But there is a question of their applicability in modeling a real network, taking into account many different factors and not only technical ones. It is necessary to develop a common approach for solving such problems. On the other hand, the power system of each country has its own characteristics and Kazakhstan has some features because of its huge territory, history, population and industry distribution and the electrical power system of Kazakhstan can be characterized as dispersed. Therefore, the solution of the UC problem with the renewables must occur taking into account the features and characteristics of a particular power system.

2. Thesis and research target

In the presented dissertation the following thesis will be proved: *"By solving the UC problem in a dispersed power system with RES, it is possible to cover the shortage of power generation capacities by increasing the share of RES in generating electricity instead of building traditional power facilities".*

The target of this work is to develop a common approach for the UC problem solving in a dispersed power system involving RES on the example of Kazakhstan to fill the shortage of generating capacity and more fully use the potential of RES.

To achieve the goal, it is proposed that instead of building new traditional electric power sources, in order to cover the power deficit and dependence on the flow of electricity to the external network, in some regions of the country, the introduction of new RES of equivalent capacity. To test the possibility of this in the paper, the simulation of the joint operation of RES to solve the UC problem will be performed.

This work will consist of the following steps of the research:

1. Identification of the impact factors on the development and implementation of RES in Kazakhstan, namely:
    - world and regional energy trends; natural resources consumption, energy production structure forecast;
    - Kazakhstan's energy sector structure; it's future and problems;
    - perspectives and potential of the different RES usage in Kazakhstan;
    - Legal basement and governmental support of the RES.
2. Problem of the UC with the RES in Kazakhstan's electrical power network as a dispersed power system:
    - elaborating of the approach of the UC solution in such conditions;
    - chosen the most critical part (from the point of view of the electric power deficit and the potential for the RES) for the simulation;
    - elaborating and choosing the instruments for the RES different kinds power output forecast, their optimal combination for the power generation and UC simulation.
3. Analyzing the results of the simulation and providing propositions for the implementation of the elaborated approach of UC problem solving in a dispersed power networks and recommendations for the RES integration.

Currently, Kazakhstan is working on the introduction of RES in generation, but there are no studies that would cover the problem of UC with RES. The approach has not been worked out and studies of the effect of connecting large RES power plants on the existing generation. There are no specific examples of the use of modeling the work of different types of RES with the electric grid. Also, there is no general approach and analysis of the problem of UC with a RES in Kazakhstan, which would include a comprehensive analysis of the impact factors on the development of RES in Kazakhstan. In addition, there is a lack of research works that would solve the problem of UC, modeling the processes based on a real working dispersed networks. Proceeding from the foregoing, the proposed work is relevant and important from scientific and practical point of view.

3. Analysis of the current state and development trends of the world energy, natural resources consumption and energy production

3.1. Forecast of the energy consumption in the world

Process of globalization and international energy trends certainly affects on the development of the energy sector of Kazakhstan. Energy sector of Kazakhstan has been developed decades as a part of Soviet Union's energy sector. Nowadays as an independent state Kazakhstan is trying for follow international trends of energy sector development. To make the reliable forecast of the Kazakhstan energy sector's future structure it is important to take a look on the global processes in the world's energy sector development.

There are several players which provide such information and forecasts: International Energy Agency (IEA), UN, World Bank, huge international companies and etc. In the case of focusing on Kazakhstan as a part of Eurasian Economic Union (EAEU) it is important to take a look on the forecasts provided by the countries – members of EAEU. The materials of The Energy Research Institute of The Russian Academy of Science should be useful.

The key index for any energy forecast it's the energy demand which depends on the dynamic of the population level but not only. Economy situation, energy consumption per capita and the energy intensity also important factors. The increase in energy consumption per capita can be seen as a key indicator of the quality of life and the result of the economic development of the world. Energy intensity of GDP mostly characterized the progress of technological development. So, it seen that three key indicators should be taken into account. According the last UN forecast in the year 2040 the world population should be reached 9,1 billion people (Fig. 3.1.) [1]. By this time, the demographic transition from high to low birth rates will basically end.

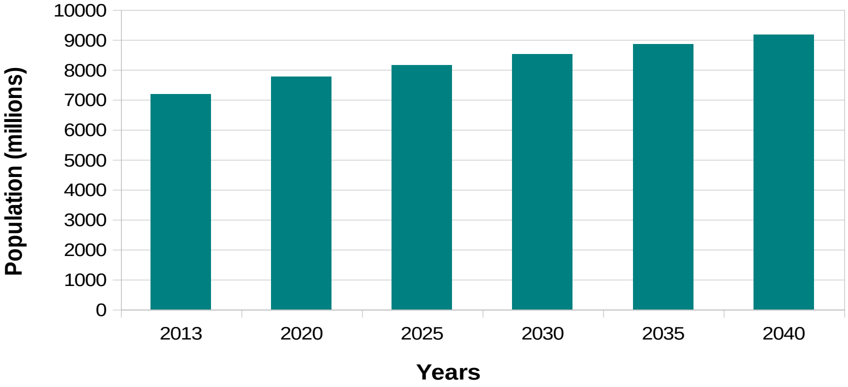


Fig. 3.1. The World population growth forecast [1]

As a result, the population growth speed will be reduced in comparison with the current double. This largely explains the decline in energy consumption growth. The values of forecasting from different sources are different but the tendency of the processes is mostly the same (Fig. 3.2.–Fig. 3.4.).

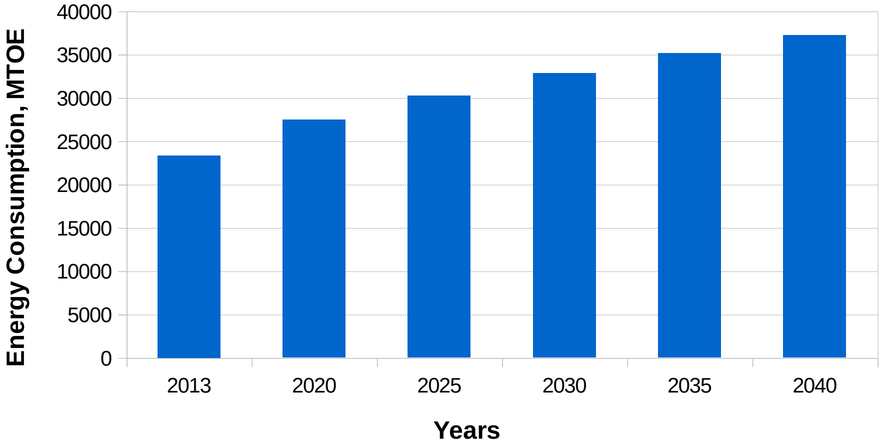


Fig. 3.2. Energy consumption growth in the world. U.S. Energy Information Administration (EIA) forecast [2]

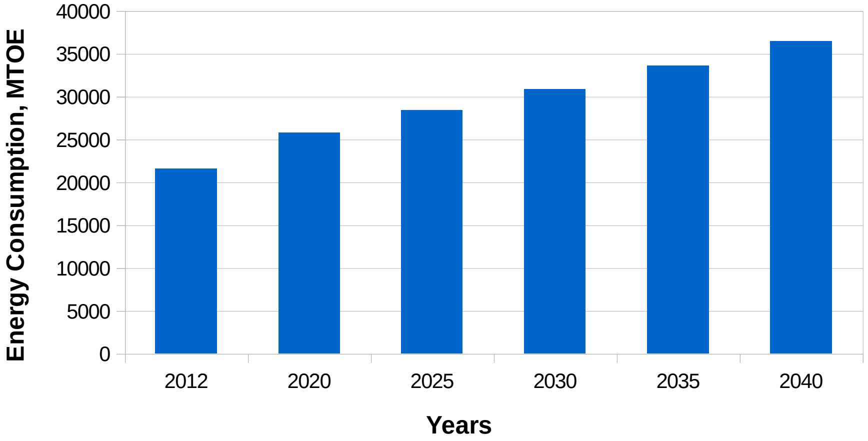


Fig. 3.3. Energy consumption growth in the world. Energy Research Institute of The Russian Academy of Science forecast [3]

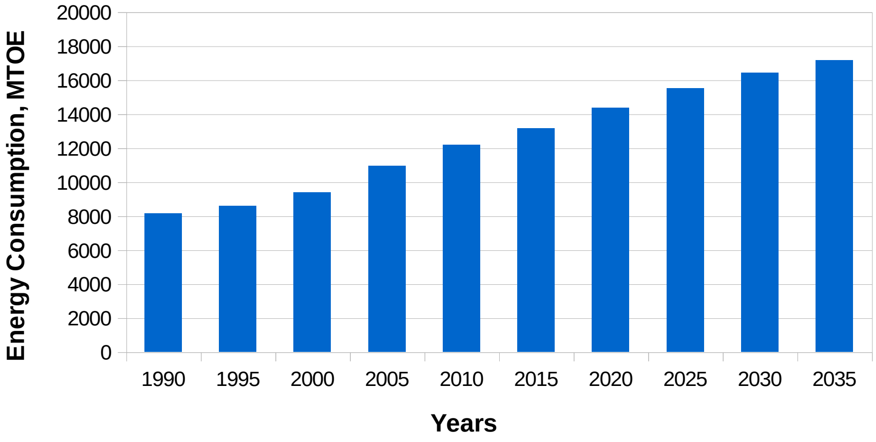


Fig. 3.4. Energy consumption growth in the world. BP Energy Outlook [4]

Africa, Asian countries and India will give the most significant growth (83% and 33%) but the population of China should be on the same level. So, Asian countries will be the most populated and have the biggest demand for the energy consumption (Fig. 3.5. Non–OECD countries).

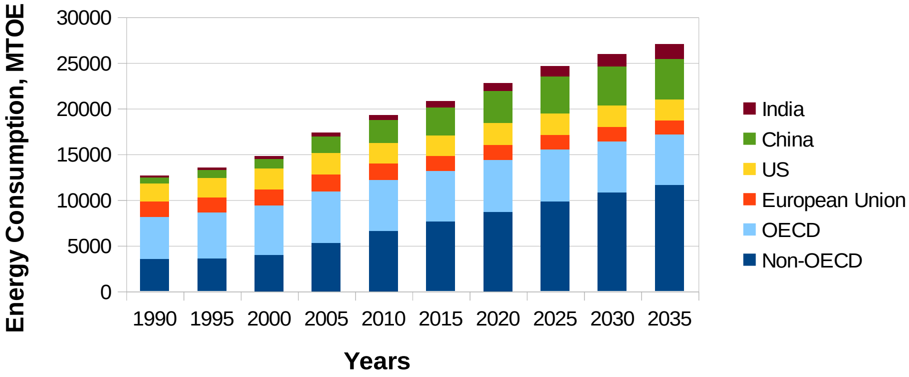


Fig. 3.5. Energy consumption by the regions [4]

Technology development will undoubtedly have an impact on the energy sector. The most actual problem of the actual energy sector is the energy saving problem. This problem has both economic and environmental components as a driver for the innovations. A lot of forecasts based on the assumption that in the nearest future there will be no technological revolution in the energy sector, but some technological breakthroughs are expected. Such scenario often called as a basic. It is expecting the decreasing in energy intensity of GDP almost 1.5 times by 2040 (Fig. 3.6.) [3].

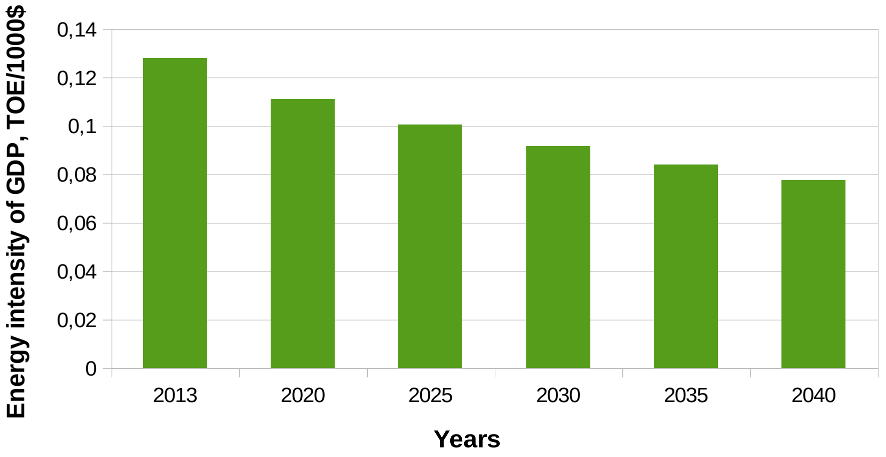


Fig. 3.6. Dynamic of the energy intensity of GDP [3]

This factor works to reduce energy consumption in the world but the population growth and the growth of energy consumption per capita (Fig. 3.7.) as a result will lead to an overall increase in energy consumption.

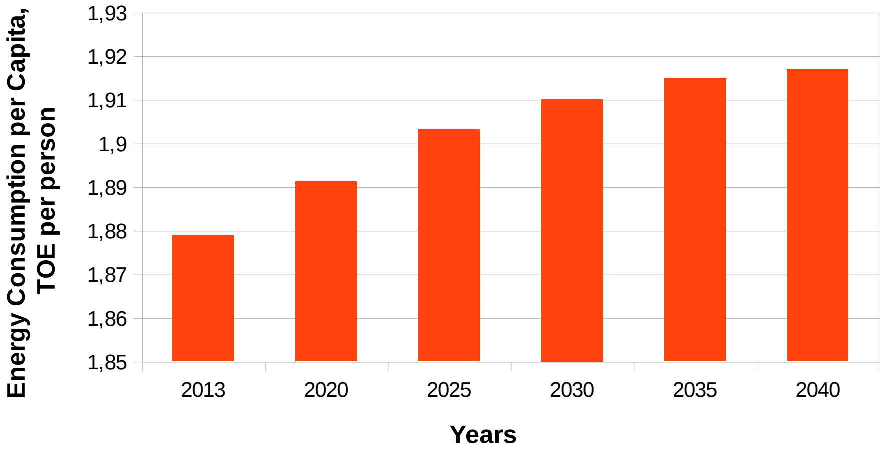


Fig. 3.7. Dynamic of the energy consumption per Capita [3]

Energy consumption per capita is a key factor of the life quality and it is expecting the growth of the index from 1.88 TOE per person till 1.92.

3.2. Forecast of the energy consumption structure in the world

Ecological, economy problems and luck of some resources in the future will change the structure of the energy consumption in the few decades. The share of the hydrocarbons will be less, and it is expecting the great growth of the renewable energy sources and nuclear energy. Different forecasts show mostly the same picture (Fig. 3.8.–3.10.).

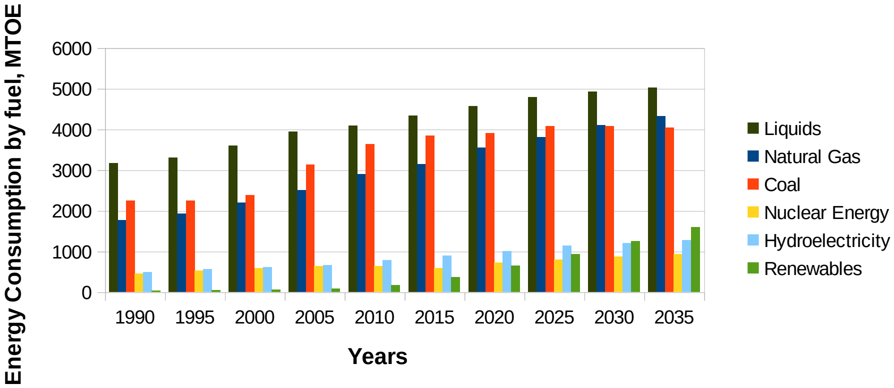


Fig. 3.8. Energy sector consumption structure by fuel. BP forecast [4]

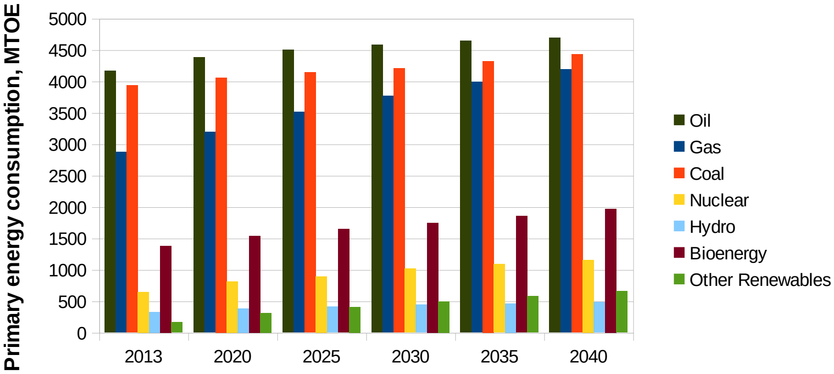


Fig. 3.9. Energy sector consumption structure by fuel. Energy Research Institute of The Russian Academy of Science forecast [3]

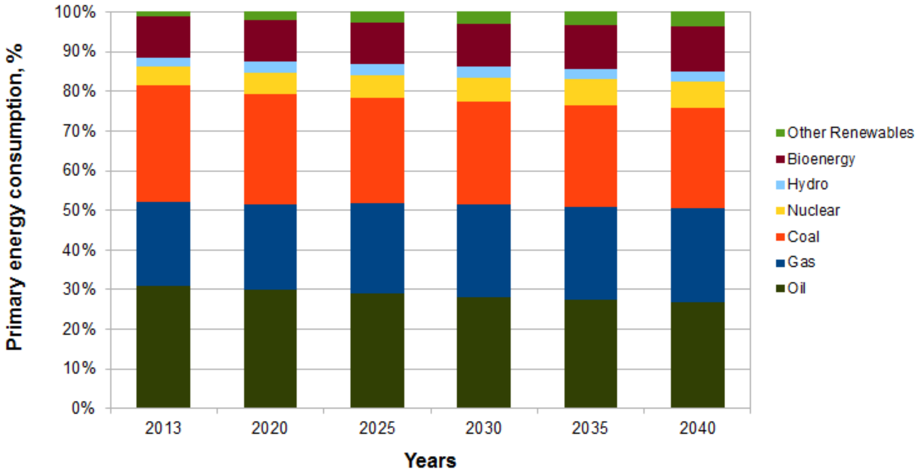


Fig. 3.10. Energy sector consumption percentage ratio distribution structure by fuel. Energy Research Institute of The Russian Academy of Science forecast [3]

3.3. Forecast of the energy generation structure in the world

To supply the increasing demand for the energy consumption accordingly should be installed additional generating capacities. The structure of the power generation also should be changed (Fig. 3.11–3.13.).

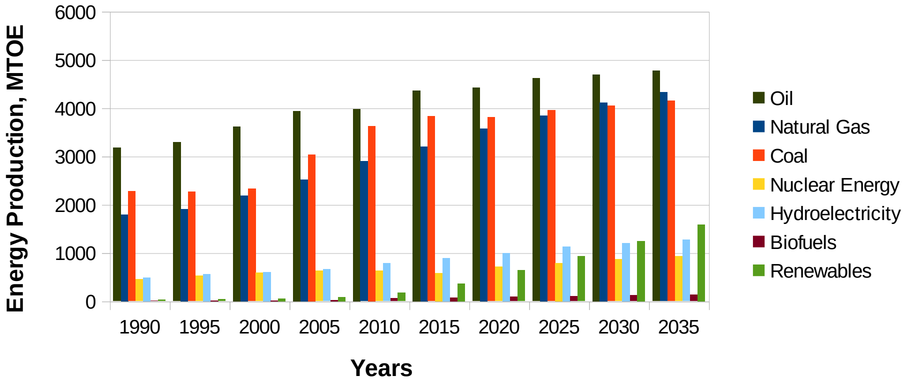


Fig. 3.11. Energy sector production structure. BP forecast [4]

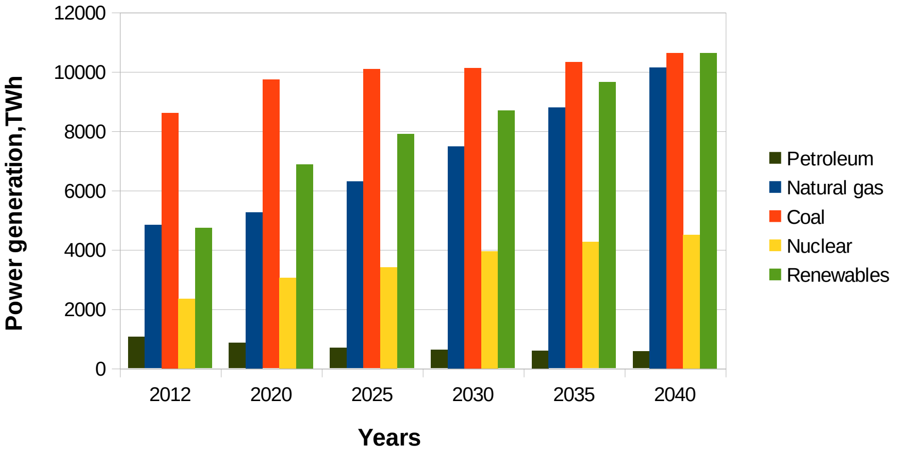


Fig. 3.12. Energy sector production structure. U.S. Energy Information Administration (EIA) [2]

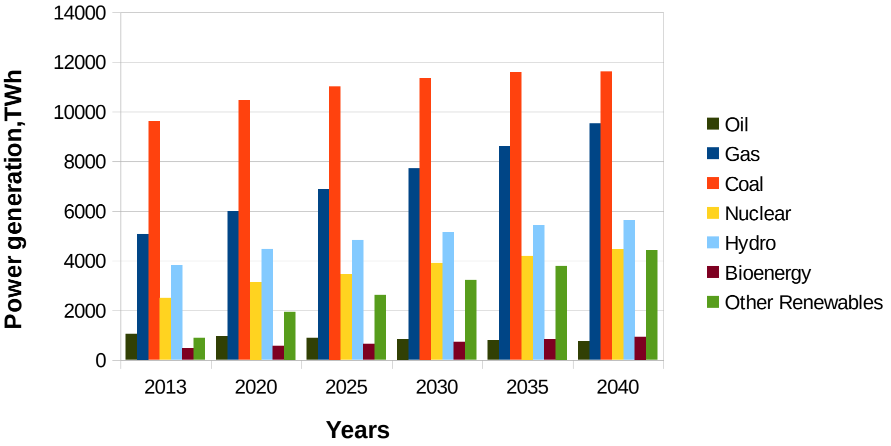


Fig. 3.13. Energy sector production structure. Energy Research Institute of The Russian Academy of Science forecast [3]

The share of the renewable energy sources will be increasing for sure (Fig. 3.14–3.15.).

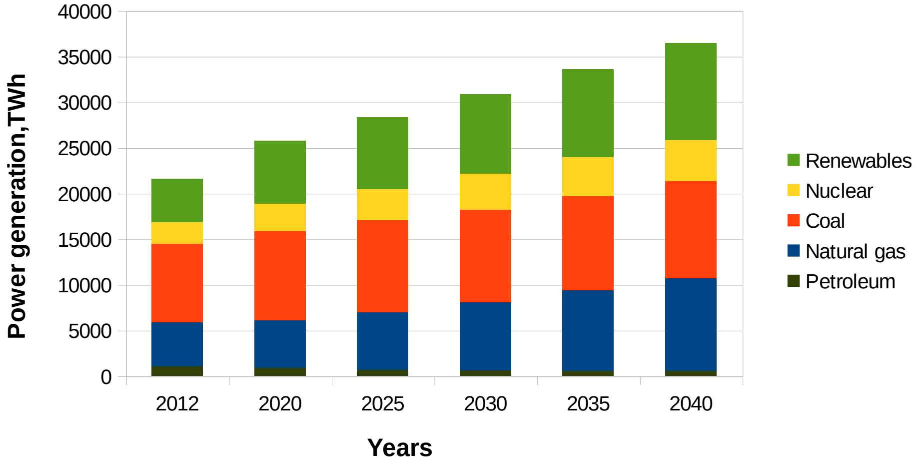


Fig. 3.14. Energy sector production structure. U.S. Energy Information Administration (EIA) [2]

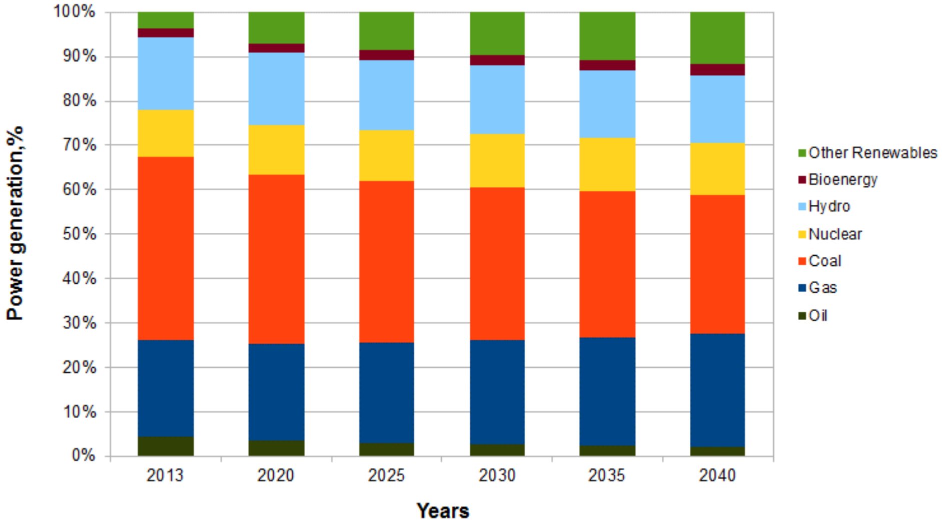


Fig. 3.15. Energy sector production percentage ratio distribution structure. Energy Research Institute of The Russian Academy of Science forecast [3]

3.4. Forecast of the energy generation and consumption structure in the EAEU countries

Kazakhstan was one of the founder of the Eurasian Economic Union (EAEU) which was started in 2014 [5]. EAEU provides for free movement of goods, services, capital and labor. The common electricity market will be created by 2019 in EAEU [6].

Unlike global demographic tendencies it's expected the stagnation and decreasing of the human population growth in the years of 2030–2040 (Fig. 3.16.).

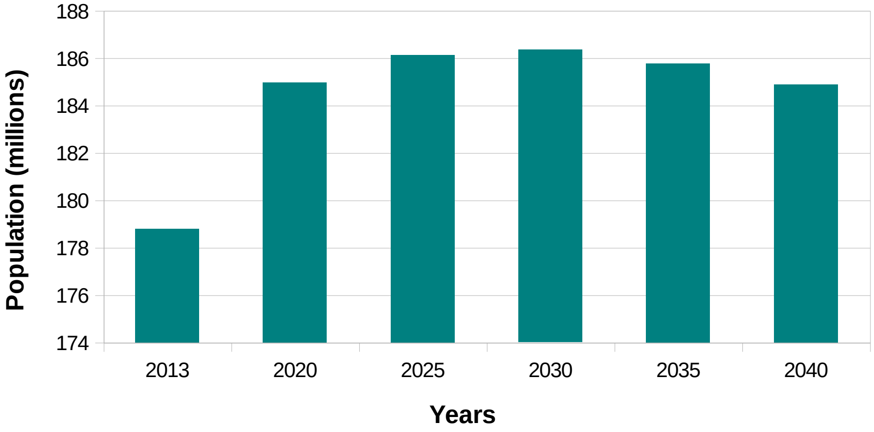


Fig. 3.16. The EAEU population growth forecast. Energy Research Institute of The Russian Academy of Science forecast [3]

However, the energy consumption growth will not show the stagnation in the EAEU countries (Fig. 3.17.).

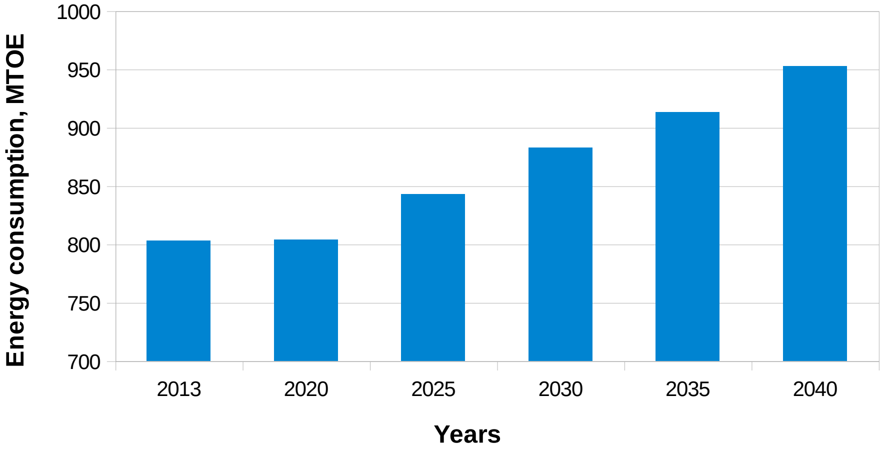


Fig. 3.17. Energy consumption growth in the EAEU. Energy Research Institute of The Russian Academy of Science forecast [3]

As a result, energy consumption per capita will growth and will be reached about 5,15 TOE per person (Fig. 3.18.). Which is much higher than the World's factor (1,92). So, the life quality growth is expected in the region.

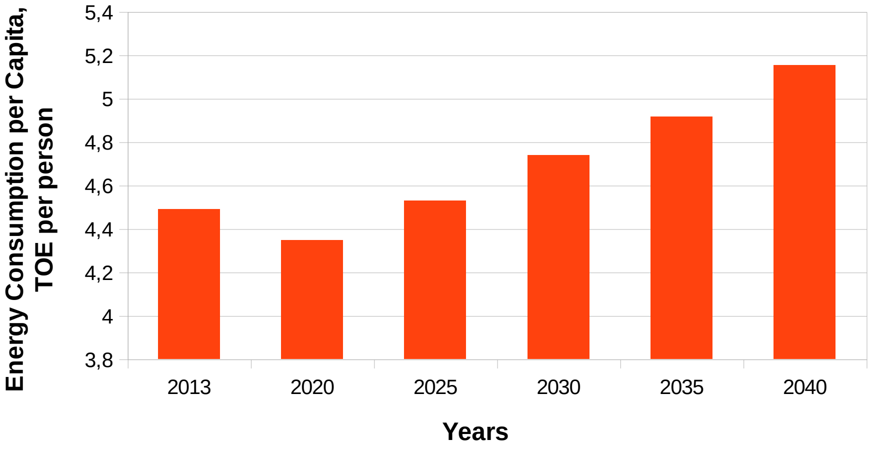


Fig. 3.18. Dynamic of the energy consumption per Capita in EAEU [3]

Using modern technologies and conduct the energy efficient programs countries of EAEU will show the energy intensity of GDP decreasing (Fig. 3.19.).

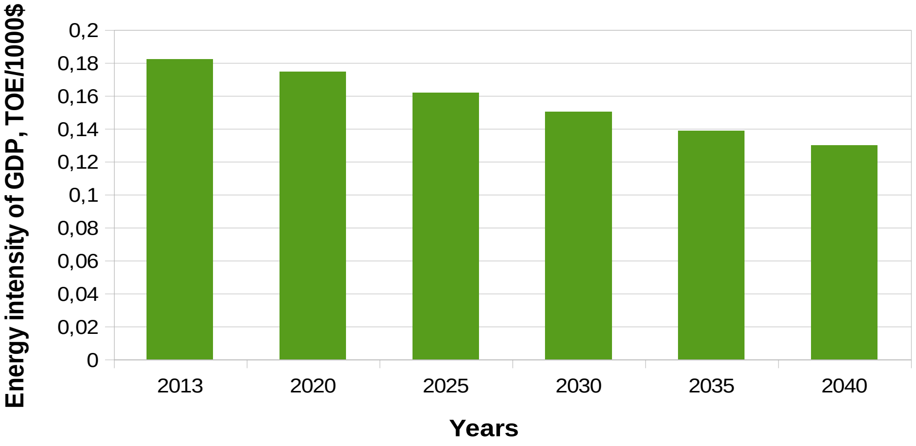


Fig. 3.19. Dynamic of the energy intensity of GDP in EAEU [3]

Availability of the natural resources in the region will be reflected in the structure of the primary energy consumption. Natural gas looks like the most demanded source in the region (Fig. 3.20–3.21.).

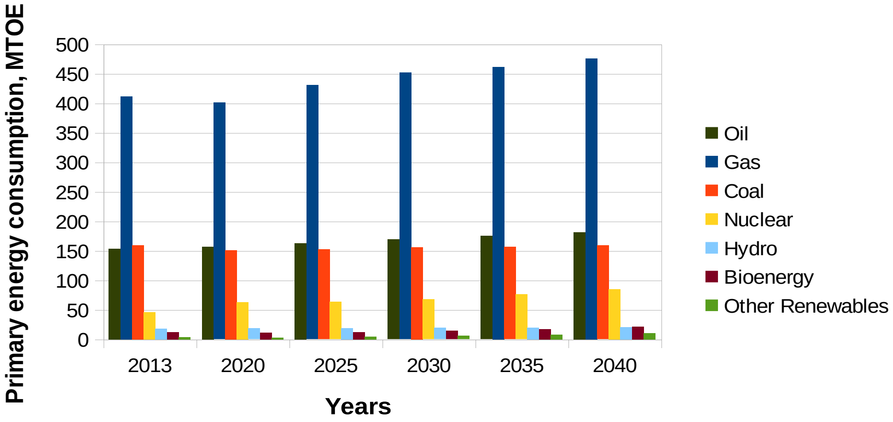


Fig. 3.20. Energy sector consumption structure by fuel in EAEU. Energy Research Institute of The Russian Academy of Science forecast [3]

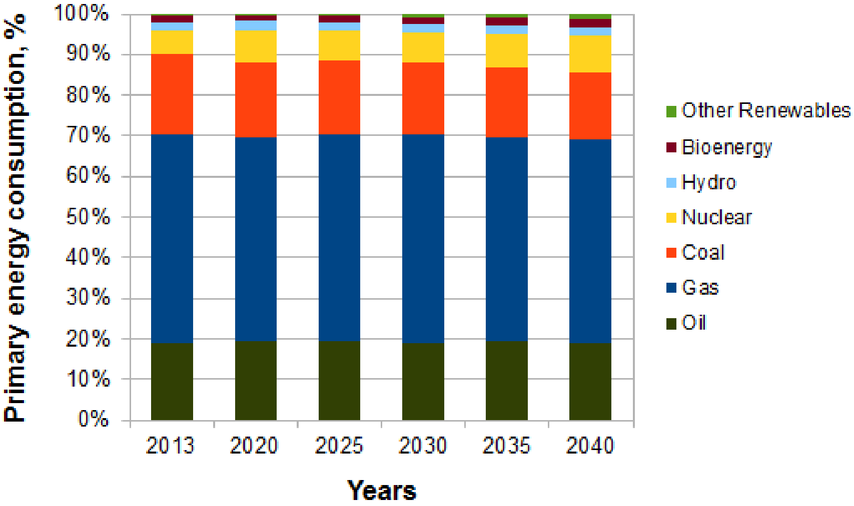


Fig. 3.21. Energy sector consumption percentage ratio distribution structure by fuel in EAEU. Energy Research Institute of The Russian Academy of Science forecast [3]

Power generation structure forecast reflects the global tendencies. The share of the renewable energy sources will be significantly increased by 2040 (Fig. 3.22–3.23.).

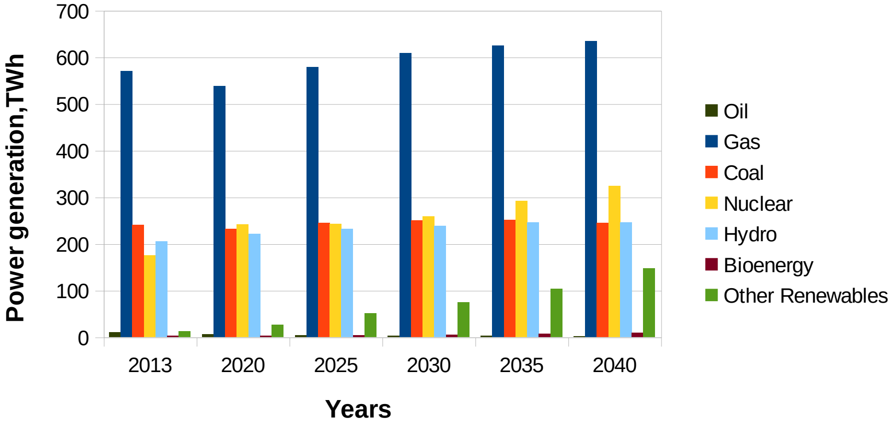


Fig. 3.22. Energy sector production structure in EAEU. Energy Research Institute of The Russian Academy of Science forecast [3]

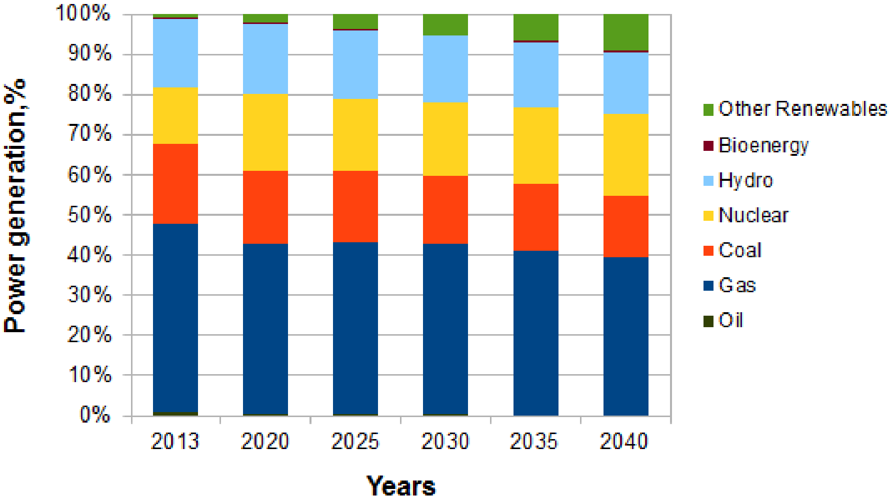


Fig. 3.23. Energy sector production percentage ratio distribution structure in EAEU. Energy Research Institute of The Russian Academy of Science forecast [3]

3.5. Conclusion

Two main opposite processes: population growth and energy intensity of GDP will affect on the future energy consumption and production in the world and EAEU region, which includes Kazakhstan. No doubt energy demand will grow constantly. The task of energy sector is to ensure the production of electricity in accordance with demand.

According to majority forecasts significant part of the future energy sector will be based on hydrocarbons. However, the unstable prices for hydrocarbons and not clear political situation in the world [7] as well as worsening ecological situation forcing the involving other energy sources into the generation process. Developing of the nuclear and renewable energy sources will be the priority for the upcoming decades.

4. Kazakhstan's energy sector current structure and future development forecast

4.1. History and reforms of energy sector of the Republic of Kazakhstan

Energy sector of the Republic Kazakhstan was formed as a part of the common energy sector of the Soviet Union, of which Kazakhstan was until 1991. After Kazakhstan gained independence, the country's economy was based on the development of energy-intensive industries enough, although their share fell slightly. Meanwhile, the power supply of the national economy faced a number of new problems. The state monopoly, which is stored in the power industry, in the new economy does not provide efficient industry. Funding from the state was reduced, electricity prices rose, and investment industry is increasingly lacking. As a result, it slowed the renewal of fixed assets of electric power, and increased wear to the mid-1990s (the time of the reforms) reached 50%.

The state monopoly has failed to update the industry, power industry turned into a deterrent for the economic development of the country, which resulted in the need for reform.

Thus, the state has ceased to cope with the task of maintaining, let alone the development of the industry. For modernization of electric power were needed private investment. However, independent investors do not want to invest in is not controlled by them, inert state monopoly, inefficient resource consumption.

This situation is not in keeping with the plans of the leadership of Kazakhstan: policy priority was and still is "the integration of the economy" into the global economy, while the absolute monopoly in the power sector has become a brake on investment. Foreign investors and international financial institutions recommended to Kazakhstan to reform the energy sector. As a result, in the mid-1990s the government started to take practical steps to liberalize the sector. In the first half of the 1990s, the electric power industry of Kazakhstan was represented by a single state vertically integrated monopoly. This industry structure has not changed in principle until 1996, despite a number of organizational changes and privatization of certain assets.

Radical reform of the structure and property relations in the power sector, as shown above, started in 1996 by the adoption of the "Program of privatization and restructuring in the electricity industry", the implementation of the provisions of which have been further legal development, led to the formation two spheres: the natural monopoly and competitive.

The legislation of Kazakhstan belongs to the sphere of natural monopolies: transmission of electricity, including:

- pass through the main electrical networks, which together with substations and other infrastructure, are combined in a specially formed JSC «KEGOC» (Kazakhstan Electrical Grid Operating Company);

- distribution of electricity on the low voltage network (110 kV and below), which transferred to the control of distribution grid companies (DGC).

The operational control of United Electrical System (UES) of Kazakhstan executed Central Dispatch Administration (CDA) of UES Kazakhstan as a part of «KEGOC». In addition, the State retains monopoly control in some areas of the industry, which are not affected by the legislation the scope of natural monopolies. Thus, the state-owned market operator JSC "KOREM" and the largest hydroelectric power plant load control function as the national grid.

Distribution networks within individual areas are local natural monopolies. In contrast to the main networks, united under a single government structure, decentralized control over them: they belong to the rack-that deal and other activities (sale of electricity on the retail market and buying it wholesale). In addition, some DGC affiliated generating enterprises.

The characteristics of a competitive electricity sector in Kazakhstan (production and sale of electricity, mainly in the wholesale market) consists in the fact that there is a strong state intervention in the competitive field of activity.

The analysis the dynamics of the production of electricity in Kazakhstan for the period from 2000 to 2015 leads to the conclusion that there is positive dynamics in the industry, the production and consumption of electricity is increasing (Fig. 4.1.) [8].

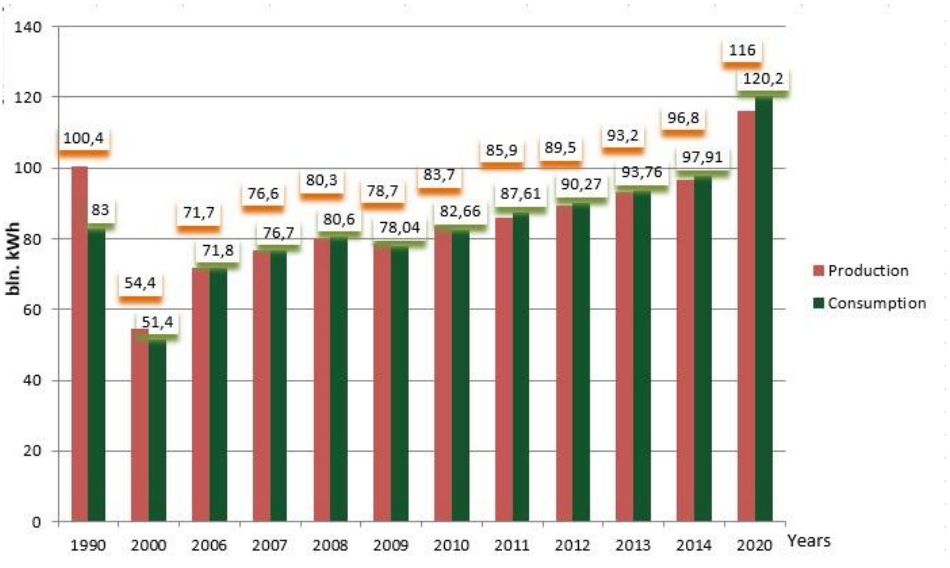


Fig. 4.1. Dynamics of production and consumption of electricity in the Republic of Kazakhstan during 1990–2020 [8]

In 2009 compared to the previous 2008 there was a slight decline in electricity production (-2%), which was due primarily to the negative impact of the global financial and economic crisis on the economic development of Kazakhstan – a decline in industrial production and, consequently, power consumption, which once again proves the relationship between the level of energy production and industrial production.

The analysis of the structure of energy consumption in Kazakhstan for the period from 1990 to 2010 shows that a large proportion of consumption of energy is still owned by the industry. However, compared with 1990, decreased the level of power consumption in agriculture. This was due to a decrease in the number of large farms, a significant reduction in the share of industry in GDP and reduction in power consumption in small agricultural enterprises, which was typical in the '90s and 2000s.

A considerable part in electricity consumption (over 17%) took the domestic sector, which is associated with the development of housing and communal services, the growth of real incomes and higher levels of well-being. Positive trends in per capita GDP and nominal per capita income in Kazakhstan is an important factor in maintaining a sufficiently high level of power consumption in the domestic sector of Kazakhstan.

4.2. Installed facilities of the power sector of Kazakhstan

Today, the installed capacity of power plants in Kazakhstan is 18.992 GW [9], which is comparable with those of countries such as Switzerland (17,600 thousand MW [10]), the Netherlands (15,000 thousand MW [11]), Turkey (21,000 thousand MW [12]). Annual electricity production 86200 GWh [9]. Around 40% of the installed capacity of power units is about of 500 and 300 MW and thermal power capacity reaches 4,000 MW. The overwhelming part (85%) of electricity produced by burning Kazakhstan relatively cheap local coal, about 11% provide hydroelectric power (Fig. 4.2.).

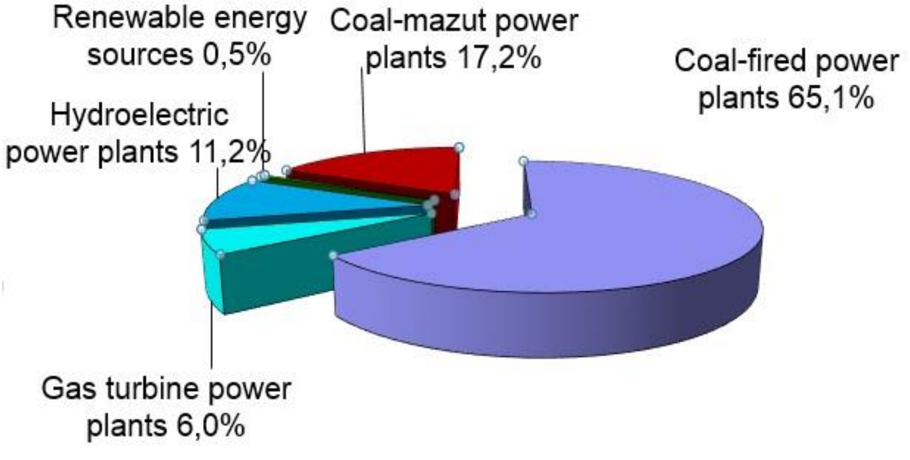


Fig. 4.2. Structure of the installed capacity of power plants in Kazakhstan. Source: author’s calculations

Totally, in operation are 63 power plants.

The basis of the electric power industry of Kazakhstan are large coal-fired power stations:

- Ekibastuz State District Power Plant (SDPP) 1 – 4 mln kW.
- Aksu SDPP – 2,1 mln. kW;
- Zhambyl SDPP – 1,2 mln. kW;
- Ekibastuz SDPP-2 – 1 mln. kW.

On the river Irtysh was built Bukhtarma Hydro Power Plant (HPP – 0,7 million kW, Ust-Kamenogorskaya HPP – 0,3 million kW and Shulbinskaya HPP – 0,7 million kW. On the river Ili was build Kapchagay HPP – 0,4 million kW.

In group of the largest thermal power station, carrying heat and power supply of large industrial enterprises and nearby settlements included: Pavlodar Thermal Power Plant (TPP), Shymkent TPP, Balkhash TPP, Rudny TPP and others.

The largest new projects that are planned to introduce in the near future are: Moinak hydropower plant on the river Charyn (now working one unit 150 MW and future capacity will be 300 MW) Balkhash thermal power plant (capacity of the first stage – 1,3 million kW in 2016 – 2,6 million kW).

From 1973 to 1999 was functioned Mangistau Atomic Energy Complex (formerly Shevchenko nuclear power plant) with a capacity of 350 MW. The produced electricity is used to desalinate seawater. The country has a technically integrated national grid, including the two largest combined power systems: North Kazakhstan and South Kazakhstan (Fig. 4.3.) [74].

These systems connected to backbone transmission lines (OHL) 500 kV.

The total capacity of the existing interstate electrical networks of the Northern, Southern and Western Kazakhstan is about 30 billion. kWh / year, of which the connecting with Russia overhead lines has to 1214 billion. kWh.

In Kazakhstan system, high voltage lines have 1150, 500 and 220 kV. For distribution networks of regional importance attributed 35–110 kV lines, to the local network 0,4, 6-10 kV lines. 30% of the length of main transmission lines has voltage level of 500 kV and 1150 (the last is one of the most powerful in the world). High in compartment, for example, the majority of European countries, indicators of voltage networks are explained by historical reasons (OHL 1150 kV created as a transit route for the transport of electricity between Siberia and the European part of the USSR), and the need to transfer large amounts of electricity over long distances between regional power grids of Kazakhstan. To date, on Kazakhstan section of the line wires on five of the eight intervals are removed; on the Russian part of the line wires has been saved. The unique 1150 kV substation equipment manufactured in 1981–1986 now is unsuitable for usage. The line operates at a voltage of 500 kV. OHL was involved in the accident at the Sayano-Shushenskaya hydroelectric power plant in 2009 to compensate for the loss of the Siberian power [13].

Management of high-voltage electricity grids of Kazakhstan provides the state company KEGOC. At the beginning of 2010 at the company's balance sheet were 310 power lines 0,4–1150 kV.

The length of the whole network is 24,5 thousand km, including:

- 1150 kV OHL – 1,4 thousand km;
- 500 kV OHL – 6,4 thousand km;
- 220 kV OHL – 16 thousand km;
- 110 kV OHL – 0,6 thousand. Km;
- Transmission lines with voltage of 0,4 – 35 kV – 0,1 thousand km. [9]

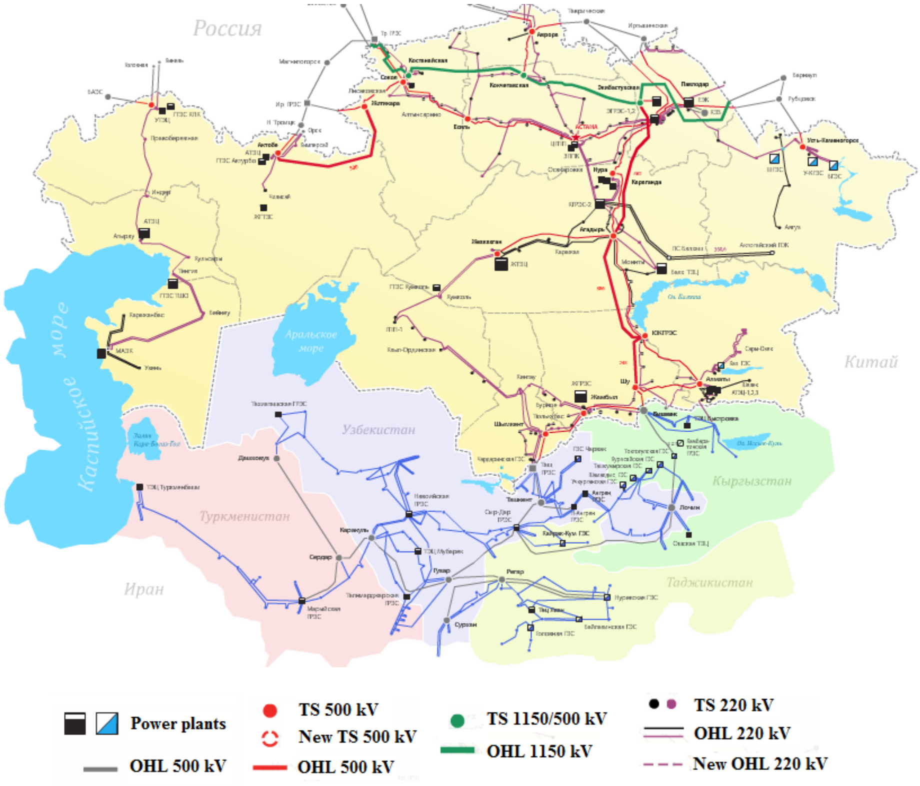


Fig. 4.3. Power grid of Kazakhstan [74]

Very powerful energy system (relative to the current size of the economy) was created during the Soviet era, based on the maintenance of energy-intensive industry, extraction and primary processing of raw materials (in particular, the production of aluminum, ferroalloys, copper). Despite the fact that consumption in the 1990s dropped twice before the beginning of the decade of Kazakhstan's electricity balance remained in deficit: the volume of imports was 37% of total consumption. Only since 2002, electricity imports for the first time no longer exceed its exports.

For example, in 2010, Kazakhstan imported 6,2 billion kWh of electricity (Tab. 4.1.), including 4,6 billion kWh from Russia and 1,6 billion kWh – from Kyrgyzstan. Russian electricity supplied to consumers in Western Kazakhstan, Kyrgyz Republic – consumers of the southern regions of the country. [14]

Tab. 4.1. Export and import of electricity, bln. kWh

	2005	2006	2007	2008	2009	2010
Import of electricity	3,5	4,0	3,4	2,8	1,7	6,2
Export of electricity	3,6	3,7	3,3	2,5	2,4	4,7

4.3. Reforms and governmental support

In order to create favorable conditions for attracting investments in the rehabilitation and development of power capacity at the end of 2008 on the 2016 law introduced fixed by groups of energy producing organizations maximum tariffs for electric energy to enforce the principle – "tariff in exchange for investments." Adopted in order to attract investments in the sector limited tariffs on groups of energy producing organizations for electricity, improve the investment climate, have significantly reduced competition and restricted the rights of consumers. It should also be noted that the introduction of tariff increases in 2009, the prices of electricity from energy sources were increased by 30–50%. The annual increase in the maximum tariffs laid down in the Government Decision “On approval of maximum tariffs” is 7%, which can be equated to the level of inflation in the country, with annual growth in electricity tariffs for end consumers is around 20% a year. The mechanism of the so-called “limited tariffs” allow power plants to plan their financial resources. In 2009, for activities on the reconstruction and modernization of existing power plants were involved more than 65 bln. KZT, in 2010 – more than 85 bln. KZT. It was made without the funds provided in the republican and local budgets. According to the forecasts for 7 years will be attracted more than 700 bln. KZT, and the replacement of installed power of 3700 MW. In 2009, we introduced 135.2 MW of new generating capacity, including:

- in Aktobe region introduced Zhanazhol GTPP "CNPC – Aktobe", power of 33.8 MW.
- in Karaganda region in the TPP "Kazakhmys Corporation" introduced steam turbine K-55-90 of 55 MW.
- in Karaganda region increased power turbines №1, 2 of the Balkhash TPP (increased by 30 MW).
- in Almaty region was put into operation Karatal GPP-3 with a capacity of 4.4 MW.
- in Pavlodar region Ekibastuz TPP introduced steam turbine K-12-3,4/ 05 of 12 MW.

In the long term, with the introduction of new generating capacity and development of national power grid Kazakhstan power system of the country is projected to excess. Electrical industry in Kazakhstan does not provide the current level of the needs of the economy and population of the country (Tab. 4.2.). [9]

Tab. 4.2. Balance of the electrical power in Kazakhstan, bln. kWh

	2009	**2010**	**2015**	**2020**
electricity consumption	78,04	82,66	97,91	116,00
electricity production	78,7	83,7	96,8	120,2
Deficit (-), surplus (+)	0,66	1,04	-1,11	4,2

4.4. Unsolved problems

In the recent years, the electric power industry of Kazakhstan has undergone radical transformation: forming a new legal and regulatory framework, changing the structure of the industry, gradually forming a competitive electricity market. Thus, Kazakhstan is becoming the way of the majority of developed countries, who are currently undertaking or have already carried out reforms in the power sector, seeking to adapt it to today's economy.

As a result, the power sector reform could solve some economic problems of the country, in particular, refuse to subsidize the sector from the state budget, to generate market prices that reflect the real cost of electricity, which contributed to the establishment of parity prices for goods and services to other industries. In addition, it is possible to equalize the disparity in prices between the domestic market of Kazakhstan and foreign export, thus facilitating the integration of Kazakhstan's economy into the world economy [15].

At the same time, many of the problems of electric power sector is not resolved, in particular:

The increase in depreciation of fixed assets is not stopped, and therefore, given the growing consumption and increased stress on the equipment, the risk of failures in the power grid;

The infrastructure sector is technically behind the modern requirements (40–50% of the equipment over 20 years old), which hinders the development of the energy sector, it prevents the further optimization of the energy system.

Limited tariffs are not enough to fully meet the needs of projects PFIID (program of forced industrial-innovative development of the country), the necessary amount of electricity. Emphasis is placed on key energy facilities of the country, such as:

- Balkhash thermal power plant, with a capacity of 1320 MW with the prospect of a further increase
- Large-scale project aimed at electricity consumers scarce Southern region of Kazakhstan and ensuring energy independence and security;
- Moynak HPP, 300 MW – maneuverable source of electricity for delivery to the deficient power grid South Kazakhstan area of electric power and energy, cover peak loads South zone;

- Will restore power unit of 875 MW at the largest coal fired power plants in Northern Kazakhstan, Ekibastuz SDPP-1 and SDPP Aksu. On the Ekibastuz SDPP-2 will be built third unit of 500 MW. Associated gas oil fields will be used in the gas turbine power plant in western Kazakhstan and Kyzylorda region. The absence of guarantees for the implementation of power leads to the fact that the current competitive electricity market in Kazakhstan does not create the necessary incentives for investments.
- There are significant territorial differences in the availability of energy sources. Coal deposits are concentrated mainly in northern and central Kazakhstan, placed here and the largest generating capacity. Accordingly, these regions are fully secured sources of electricity and potentially energy surplus.

The South Kazakhstan does not have enough primary energy and electricity based on imported fuel: coal and gas. Part of the electricity needs covered by its imports from Kyrgyzstan.

West Kazakhstan does not have sufficient generating capacity and imports electricity from Russia. However, there are huge reserves of fuel resources (oil and gas fields), which, in the case of their development, will in the shortest possible time to increase the local production of electricity and make the region energy surplus.

4.5. Conclusion

Thereby, Kazakhstan's energy sector has some problems which create difficulties in carrying out further reforms: the lack of sufficient reserve, maneuvering capacity in the power brakes start in the normal operation of the balancing market of electric energy, for the introduction of which had to be for a limited period established by law, to implement the automatic system for commercial accounting of power consumption on the market. This work was delayed for several years, and to date the question of equipment metering devices to be resolved.

An urgent task is to engage in the country's electricity market of RES. In Kazakhstan, there is a real possibility of using wind energy, solar energy, geothermal energy, energy of small rivers (small hydro). The increasing demand for energy resources and environmental constraints, lead to the need to take measures to develop renewable energy sources, in particular, the construction of small hydro power plants, wind power plants.

However, the question of the introduction of renewable energy requires a careful analysis of both the position of the technical capabilities of the implementation of the energy system and the parallel operation of existing energy sources, and consideration of economic aspects.

5. Renewable energy sources and their perspectives in Kazakhstan

5.1. Classification of renewable energy sources and their general characteristics

RES are energy resources of constantly heterogeneous processes on the planet, as well as energy resources of living products of biocenoses of vegetable and animal origin. A characteristic feature of RES is their inexhaustibility, or the ability to recover their full potential in a short time – within the lifetime of one generation.

Almost 40 years ago, the UN General Assembly, in accordance with resolution 33/148 (1978), introduced the concept of "new and renewable sources of energy" [16]. According the resolution the scope of new and renewable sources of energy includes: solar, geothermal and wind power, tidal power, wave power and thermal gradient of the sea, biomass conversion, fuel-wood, charcoal, peat, energy from draught animals, oil shale, tar sands and hydropower.

According the evaluation and the estimation of the potential of renewable energy sources usage let's assume that to create comfortable living conditions an average of 2 kW per person is needed. From each square meter of the earth's surface, it is possible to obtain, on average, 500 watts of power using different RES. If it is assumed that the conversion efficiency of this energy into a form convenient for consumption is only 4%, then for a power of 2 kW an area of 100 m^2 is required. The average population density in cities, considering the suburban area, is about 500 people per 1 km^2. To ensure their energy at a rate of 2 kW per person, it is necessary to remove 1,000 kW from 1 km^2, that is, it is enough to occupy only 5% of the area. Thus, renewable energy sources can provide a satisfactory standard of living, whether there will be found acceptable in cost methods of its transformation, taking into account the resource potential (Tab. 5.1.) [17].

Tab. 5.1. World RES resources energy potential

Type of energy source	Theoretical resources, million toe	Technical resources, million toe
Solar energy	$1{,}3 \cdot 10^8$	$5{,}3 \cdot 10^4$
Wind energy	$2{,}0 \cdot 10^5$	$2{,}2 \cdot 10^4$
Geothermal energy (To a depth of 10 km)	$4{,}8 \cdot 10^9$	$1{,}7 \cdot 10^5$
Energy of the World Ocean	$2{,}5 \cdot 10^5$	–
Energy of biomass	$9{,}9 \cdot 10^4$	$9{,}5 \cdot 10^3$
Hygroenergy	$5{,}0 \cdot 10^3$	$1{,}7 \cdot 10^3$

5.1.1. Solar power

Maximum solar radiation at the Earth's surface can reach about 10 kWm^{-2} in a wavelength band range 0,3–2,5 μm [18].

Solar energy resources of the territory are directly influenced by geographical and climatic characteristics: the duration of a light day; Average monthly and annual duration of sunshine; average monthly and annual characteristics of the transparency of the atmosphere, and many others. The estimation of the potential of solar energy is based on long-term data of actinometric observations on as many stations as possible, distributed fairly evenly across the territory. Potential opportunities for the arrival of solar radiation are determined by the geographical breadth of space. Climatic characteristics of the area, indirectly characterized by the duration of sunshine, make significant adjustments to the possibility of efficient use of solar energy.

Solar energy comes in three basic forms: low temperature solar thermal; high-temperature solar thermal energy and solar electric or photovoltaic (PV) [19]. Low temperature solar energy sources imply water heating. The technology looks very simple and reliable: the sun's rays heat up some dark surface (usually black) for maximum energy absorption, which in heats water or sometimes air. The main problem here is to organize the heat storage. Usually stones or water are used. High temperature solar energy is used usually to generate electricity or heat for industrial applications. Construction of typical installation consists of mirrored collector which concentrate the sun’s rays to the point where energy can be absorbed and transferred to the turbine and electrical generator by high-temperature liquid. Such systems are very complicated and nowadays not widely used. Solar energy can be also converted to the electricity directly by using photovoltaic cells with semiconductor materials (Fig. 5.1.). Solar cells generate fixed output voltage of about 0.5 to 0.6 volts depending upon the type.

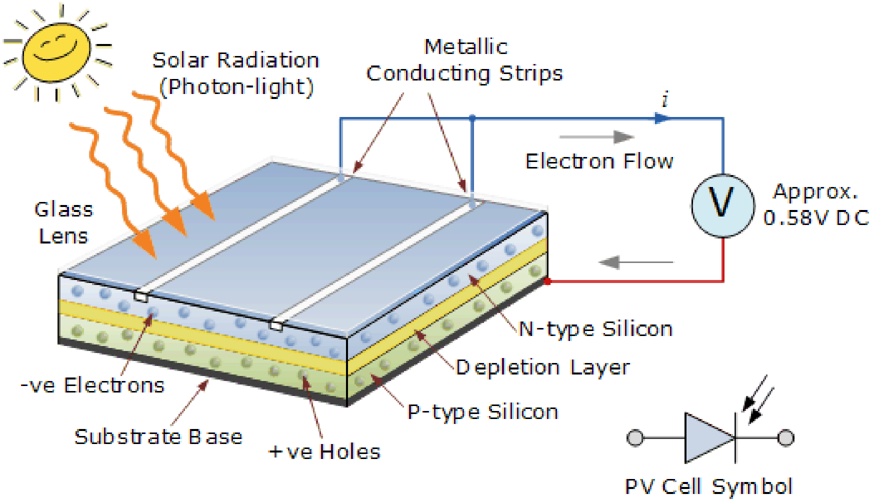


Fig. 5.1. Example of the photovoltaic solar cell construction [20]

In a full irradiance (1000 W/m^2) at the equator typical solar cell has the volts-ampere characteristic shown on Fig. 5.2. If we have less sun energy in will reduce power output by a proportional amount (Fig. 5.2.) [20].

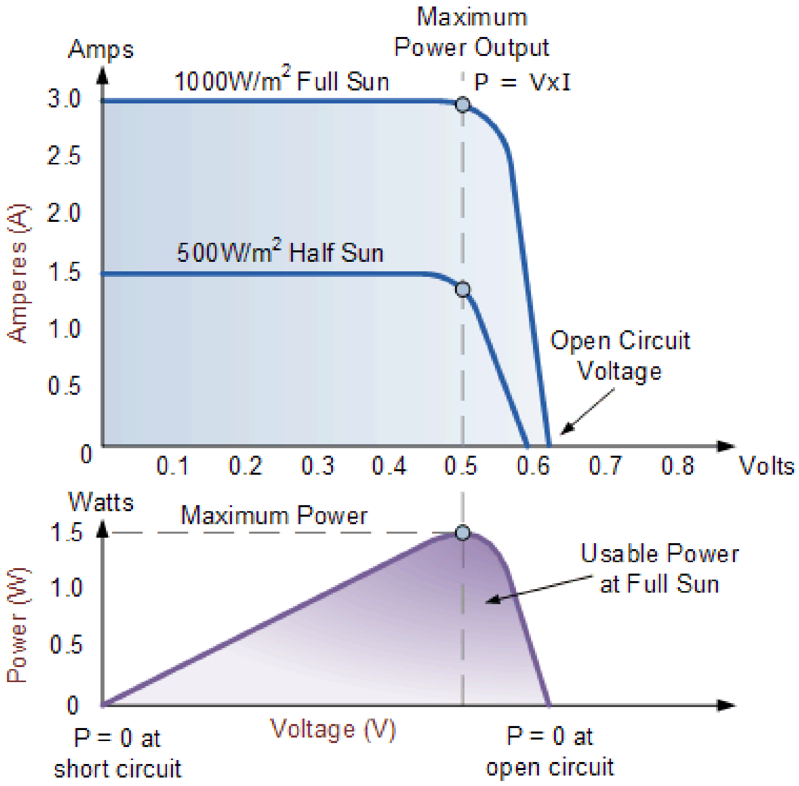


Fig. 5.2. Example of the photovoltaic solar cell volts-ampere characteristic [20]

Nowdays photovoltaic technology is the fast-developing technology which can provide acceptable energy efficiency and longtime life cycle. For example, when first time Bells Labs invented first sun sell at 1954 it's energy efficiency was only 6 percent. Today energy efficiency of SunPower's sells achieved 24,1 percent [21].

But the overwhelming majority of the manufactures offers the panels with the efficiency range between 14 and 17% (Tab. 5.2.) [22].

Tab. 5.2. Efficiency Rating of PV Models by Solar Panel Manufacturer

Solar Panel Manufacturer	Minimum Efficiency (%)	Maximum Efficiency (%)	Average Efficiency (%)
Amerisolar	14.75	17.01	15.97
Axitec	15.37	16.9	16.1
Canadian Solar	15.88	17.72	16.58
CentroSolar	15.3	17.8	16.21
China Sunergy	14.98	16.53	15.78
ET Solar	15.37	17.52	16.51
Grape Solar	16.21	17.64	16.75
Green Brilliance	14.24	15.58	15.03
Hanwha Q CELLS	15.9	18.3	16.97
Hanwha SolarOne	14.7	16.2	15.45
Heliene Inc.	15.6	19.3	17.31
Hyundai	14.2	16.5	15.37
Itek Energy	16.49	18.94	17.71
JinkoSolar	15.57	18.57	16.95
Kyocera	14.75	16.11	15.42
LG	16.8	19.5	18.28
Mission Solar	15.98	18.36	17.18
Mitsubishi Electric	16.3	16.9	16.6
Panasonic	19	21.6	20.3
REC Solar	14.5	17	15.62
ReneSola	14.9	16.9	15.91
Renogy Solar	15.3	18.5	17.3
Seraphim	15.67	17.52	16.55
Silevo	16.9	18.5	17.7
Silfab	15.3	18.4	16.75
Solaria	18.7	19.3	19
SolarWorld	14.91	17.59	16.64
Stion	12.4	14	13.2
SunEdison	15.5	16.8	16.12
Suniva Inc	16.66	17.65	17.14
SunPower	19.1	22.2	20.58
SunSpark Technology	15.2	16.1	15.65
Trina Solar Energy	15.2	17.8	16.3

The advantages of photovoltaic cells are:

- simple construction, without moving parts and as a result low costs for service;
- long life cycle of the installations and the availability of the solar energy.

The most critical disadvantage of the solar energy is based on its nature:

- the energy from the Sun can be produced only at the day time;
- generation depends on the season, geographical and weather conditions.

The disadvantages also include high prices per kW of the installations, space required for the big capacities and low energy efficiency.

5.1.2. Wind energy

By now, wind power has become a significant branch of energy sector which makes a tangible contribution to the production of electricity in some countries. The main reason for the occurrence of wind is the uneven heating of the earth by the sun. The terrestrial surface is not homogeneous: land, oceans, mountains, forests cause non-uniform heating even on the same latitude. The rotation of the earth also causes a deflection of the air currents. All these causes cause a heterogeneous circulation of air masses.

The wind speed usually increases with altitude, and their horizontal component is much larger than the vertical one.

At velocity v_0 and air density ρ the wind-driven sweeping area A develops power (5.1):

$$\boldsymbol{P = C_P A \frac{\rho v_0^3}{2}}, \tag{5.1}$$

where C_P– is the parameter, characterizing the efficiency of wind flow energy using by the wind wheel and is called power factor (coefficient depends on the design of the wind wheel and a wind speed) [23].

Since the wind speed is variable, and the power is very much dependent on the wind speed, the choice of the optimal design of the wind wheel is largely dependent on the requirements of electricity consumers.

According to the standards of different countries, the power of wind turbines is determined by wind speed 10.4, 11 or 11.2 meters per second, depending on the country. This is considered the nominal capacity, which is reported by the manufacturer of the installation to the buyer.

That is, if the wind speed is below the specified value, the wind turbine gives out less power. For example, a 3 kW wind turbine at different wind speeds produces the following power according to the cubic dependence (Tab. 5.3.) [24]:

Tab. 5.3. Dependence of the power of wind turbines on wind speed

Wind speed, m/s	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Rotor speed, rpm	46	61	76	91	106	121	137	152	176	191
Instantaneous power, kW	0,06	0,2	0,4	0,7	1,1	1,7	2,5	2,9	4,4	5,7
Daily energy, kWh	1,4	4,8	9,6	16,8	26,4	40,8	60	69,6	105,6	136,8
Monthly energy, kWh	43	144	288	504	792	1224	1800	2088	3168	4104
Annual energy, kWh	518	1728	3456	6048	9504	14688	21600	25056	38016	49248

There are different types of wind turbine construction. In general, they differ in the design of the blades and the location of the axis of rotation of the windmill. Wind turbines, in which the axis of rotation is horizontal and parallel to the wind flow nowadays are the most widely used. Wind generators in this case usually have two (a), three (b) or more (c) blades (Fig. 5.3.) [25].

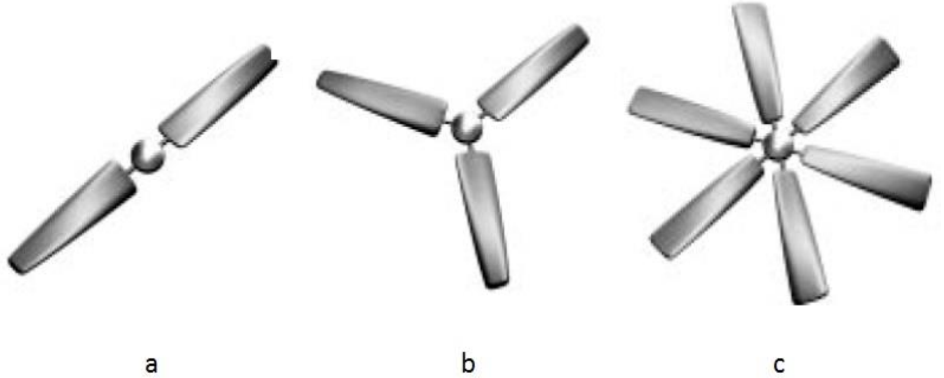


Fig. 5.3. Wind rotor different types [25]

Another type of wind turbines is the concept with vertical axes. A lot of different types and construction are available now: Savonius (a), Darrier (b), H (c) rotors and some other constructions (Fig. 5.4.) [26].

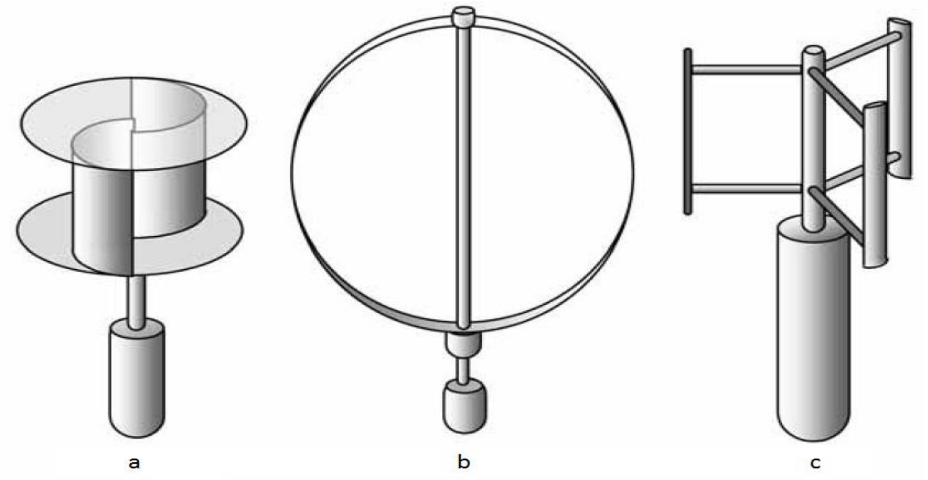


Fig. 5.4. Wind rotors with vertical axes [26]

A significant advantage of vertical axis installations is that they do not need a rotation mechanism in the direction of the wind and in the complex design of the rotor. Another advantage is that the main components, such as gearbox and generator, are located near the ground and are easily accessible. Thus, it does not require expensive mast constructions and greatly facilitates maintenance, operational maintenance and repairs, which leads to lower operating costs.

The main disadvantages of vertical axis units derived from the principle of the arrangement of the working surfaces of the propeller in the flow of the wind, namely:

- Since the working blades of the wheel move in the direction of the air flow, the wind load acts not simultaneously on all the blades, but alternately. As a result, each blade experiences a discontinuous load, the wind energy utilization factor is very low and does not exceed 30%;
- The motion of the surfaces of the wind wheel in the direction of the wind does not allow to develop great speed, because the surface can not move faster than the wind;
- The dimensions of the part of the air flow used (swept surface) are small in comparison with the dimensions of the wheel itself, which significantly increases its weight, referred to the unit of installed capacity of the windmill.

In rotor windmills of the Savonius system, the maximum coefficient of wind energy use is 25%, for carousel engines – 30% [25].

The main disadvantage of the horizontal oriented axis turbines is the need for orientation according to the direction of the wind flow for maximum power. This significantly complicates and increases the cost of construction. Also, wind turbine usually can’t operate at the whole wind speed range and the manufactures gives the power curves in the data shits for their products (Fig. 5.5.).

Fig. 5.5. ENERCON E-44 900 kW wind turbine calculated power curve [27]

There are big advantages of wind energy source for producing electricity:

- absence of environmental pollution – the production of energy from the wind does not lead to emissions of harmful substances into the atmosphere or the formation of waste.
- use of a renewable, inexhaustible source of energy, saving on fuel, in the process of its extraction and transportation.
- the area in the immediate vicinity can be fully used for agricultural purposes.

But there are some disadvantages also:

- high investment costs;
- variability of power in time;
- noise;
- threat to birds;
- changes in the landscape.

5.1.3. Geothermal energy

Geothermal heat is the biggest constant in time (its capacity is not dependent on the daily, annual and other periods) and relatively evenly distributed over the surface of the Earth's source of energy available to the humanity.

And this energy in its pure form, since it already exists as heat, and therefore it does not need to burn fuel or create reactors to produce it. Geothermal deposits are divided into three types:

- deposits of dry steam;
- hot water deposits;
- deposits of heated rocks.

Unfortunately, there are few deposits of natural steam or superheated water boiling in the atmosphere with sufficient steam formation.

In connection with the change in the intensity of solar radiation, the thermal regime of the first 1.5–40 m of the earth's crust is characterized by daily and annual fluctuations. The temperature of the rocks at a depth Hcan be approximately determined by the formula (5.2).

$$\boldsymbol{T = T_0 + \frac{(H-h)}{\sigma}}, \tag{5.2}$$

where T_0– is the average temperature of the earth's crust at a depth h of constant temperature zone (1.5–40 m); σ – geothermal step [25].

When using ground heat energy, the following problems occur:

- creation of a sufficiently deep well, allowing to reach high temperatures;
- providing high power of heat recovery from the well.

The operating principle of the geothermal power plant is as follows: two wells must be drilled. In one well, cold water is pumped under high pressure, and hot water or steam comes from the other well due to excessive pressure and low density (Fig. 5.6.) [28].

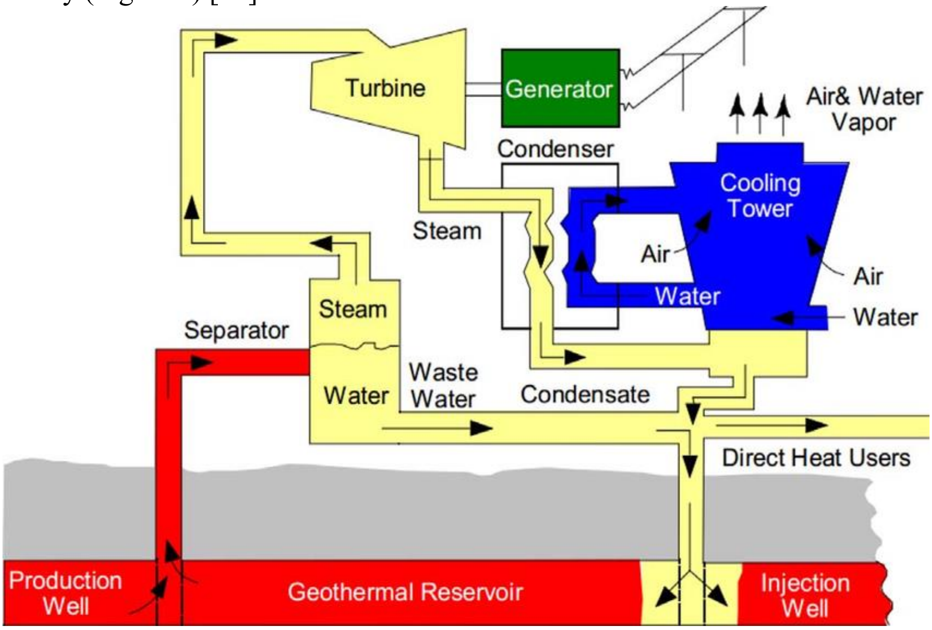


Fig. 5.6. Flash steam geothermal power plant [28]

There are a lot of advantages of geothermal power plants:

- Large reserves of geothermal energy;
- The geothermal power plant does not require the supply of fuel from external sources;
- The work of geothermal power plants is not accompanied by harmful or toxic emissions;
- The operation of the geothermal power plant does not require additional costs, except for the costs of preventive maintenance or repair;
- Geothermal power plants do not spoil the landscape and do not require significant land acquisition.

But there are some significant disadvantages which are limiting the usage of the geothermal energy:

- It is difficult to find a suitable place for the construction of a geothermal power plant;
- Sometimes an operating geothermal power plant can stop as a result of natural changes in the earth's crust. In addition, the reason for its stop may be poor site selection or excessive water injection into the rock through the injection well;
- Through the production well, combustible or toxic gases or minerals contained in rocks of the earth's crust may be released. It's difficult to get rid of them.

Also, it should also be taken into account that, due to low rock temperatures, the efficiency of processing their thermal energy into electric energy will not exceed 15% [25].

5.1.4. Energy of the World Ocean

The World Ocean contains huge reserves of energy: the energy of solar radiation absorbed by ocean water, which manifests itself in the energy of sea currents, waves, surf, the difference in temperatures of different layers of water, the energy of attraction of the Moon and the Sun, which causes sea tides. This energy source is still not widely used.

The main types of ocean renewable energy are [29]:

- Wave energy. According to experts from the European Association of Ocean Energy, a meter wave section "carries" from 40 to 100 kW of energy, suitable for practical use [30];
- Energy of sea currents. The current level of technology development allows you to extract energy from currents at a flow rate of more than 1 m/s. The use of such powerful currents as the Gulf Stream and Kuroshio, which bear respectively 83 and 55 million cubic meters of water at a speed of 2 m/s and flow Florida – 30 million cubic meters at a speed of up to 1.8 m/s is promising;

- Energy of tides. The total power of the tides on Earth is about one billion kilowatts, that is almost equal to the energy potential of all the rivers of the planet. Use this energy can be by cutting the dam of the bay or bay from the sea. The passage of sea water through the dam is carried out through special channels, in which horizontal submerged capsular hydroelectric generators are installed (the turbine together with the generator), which convert the kinetic energy of water into electric water during its flow in direct (at high tide) and in reverse (at low tide) directions;
- Energy obtained due to temperature differences at different ocean depths. The difference in temperature between the sea surface and the depths can be used to convert the thermal energy of the ocean into electricity – OTEC (Ocean Thermal Energy Conversion). The basis of such units is the use of the principle of the operation of heat pumps and light boiling liquids (propane, freon or ammonium) for the organization of the turbine operation process and a number of others (Fig. 5.7.);
- Energy obtained due to differences in salt content in salt and fresh water (osmotic energy). The technology uses the osmotic pressure that occurs between salt and fresh water when they are pumped into a double chamber and separated by a special semipermeable membrane. Technology is still at the very beginning of its development. This technology can be applied in the mouths of rivers, where fresh water is mixed with salt water.

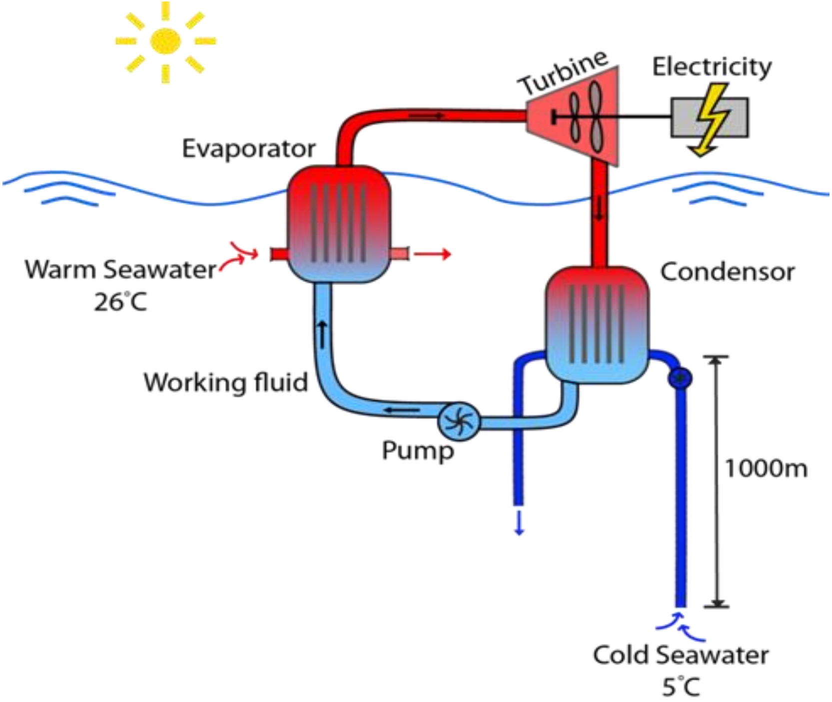


Fig. 5.7. OTEC power plant work scheme [31]

Nowadays the most widely used power plans are power plants which are using the energy of tides.

The main advantages of such power plants are [32]:

- lack of land flooding;
- a positive impact on mitigating the ice regime;
- Can produce huge amount of electricity.

But there are some disadvantages of such type of power plants also [32]:

- work with interruptions;
- can only be built on the shores of the oceans and seas. And if the tidal station is far from the nearest large center of energy use, long and expensive transmission lines will be required;
- changing the height of the tide with a period of two weeks, resulting in power fluctuations;
- large water flows at relatively low headers lead to the need to use a large number of turbines operating at a relatively low efficiency.

5.1.5. Energy of biomass

One of the most common and universal life-supporting resources of mankind is biomass. Biomass is formed in the process of photosynthesis – a chemical reaction that occurs in plants under the influence of solar radiation. As a result, organic substances are formed, which are used as food to obtain building materials, tissues and many other things. One of the promising areas of application of biomass is the production of electricity.

Depending on the variety of biomass, various technologies for its energy use are possible (Fig. 5.8.). There are the following groups of biomass sources [33]:

- wood, wood waste, peat, leaves, etc.;
- wastes of human life, including production activities;
- agricultural waste;
- specially grown high-yielding agricultural crops.

To use dry biomass for energy purposes, thermochemical technologies (direct combustion, gasification, pyrolysis, etc.) are most effective.

For wet biomass, biochemical processing technologies are used to produce biogas (anaerobic decomposition of organic raw materials) or liquid fuels (fermentation processes) [17].

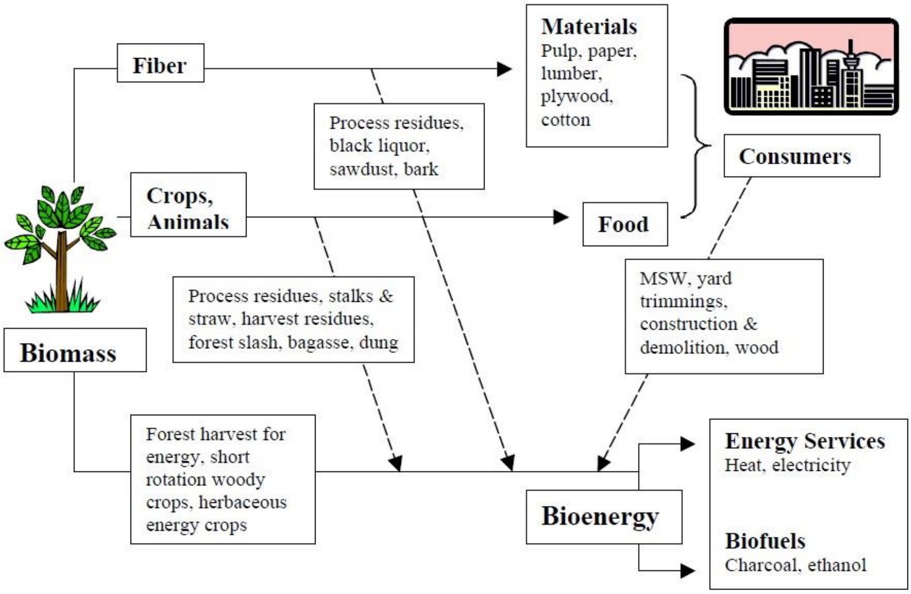


Fig. 5.8. Biomass and bioenergy flow scheme [34]

The most ancient technology of energy production is direct burning of wood. The use of an open flame is characterized by low energy conversion efficiency. It is much more effective to burn biomass in special boilers. Good boilers are characterized by an efficiency factor of 80–90%. Widely used low-temperature fluidized bed furnace, allowing burning biomass humidity of 60 percent or more. Vortex furnaces are effective for the combustion of comminuted wood and vegetable waste. One of the most promising technologies for processing wood waste today is the production of fuel pellets – pellets. Pellets are a normalized cylindrical pressed product of dried and crushed wood. Due to the high pressure during pressing, the pellets do not contain chemical fixers. This energy carrier is very efficient and meets all environmental requirements [17].

The direction of combined generation of electricity from biomass and traditional sources of energy, for example coal, seems promising. It is also possible to gradually replace fuel with biomass (Fig. 5.9). Thus, the process of generating and outputting electric power mode to the network will not differ substantially from the conventional thermal power plants.

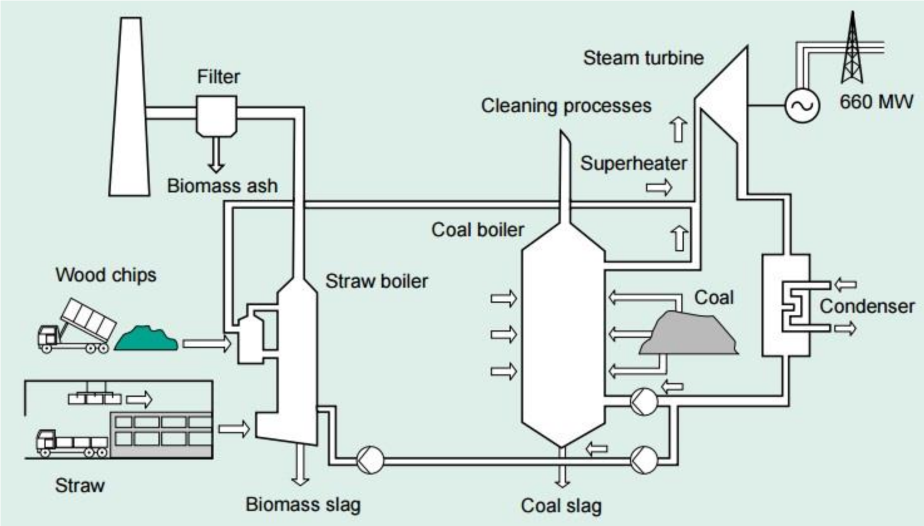


Fig. 5.9. Process diagram of the plant with biomass energy sources [35]

The main advantages of bioenergy are:

- biofuels can be produced in any region with a wide variety of climates;
- use of biofuels partially solves the problem of garbage disposal;
- available and low-cost resource.

But there are some disadvantages of such type of power source:

- mass cultivation of crops destined for biofuels can provoke depletion of fertile land;
- not 100% emission free source of electricity.

5.1.6. Hygroenergy

Hydropower resources are part of the water resources of a territory that can be used for energy production. Hydropower is the biggest renewable resource used for producing electricity in more than 160 countries. Hydroenergy continues to be the most efficient way to generate electricity. Hydro turbines have the efficiency more than 90 percent. The best fossil fuel plants can convert only about 50 percent of the fuel potential into electricity. [36]. The hydraulic energy of rivers caused by the projection of gravity along the direction of water flow, which is determined by the difference of water levels at the beginning and end of the portion of the river. When the level difference H (m) on the part length l (m) and an average water consumption of Q (m^3/s), the power of the watercourse P (W) is:

$$\boldsymbol{P = \rho g Q H = 9810 Q H,} \tag{5.3}$$

where ρ – is the density of water, kg/m^3; g – acceleration due to gravity in m/s^2 [17].

Consequently, water power installation is carried energy conversion or water pressure, or the water content at a certain minimum flow velocity.

To determine the useful power produced by the hydroelectric station, the resulting efficiency of the plant, consisting of a hydro turbine, a generator, and a voltage stabilization system, should be taken into account.

The possibility of using water power is largely determined feasible water pressure, which primarily depends on the terrain, defining longitudinal gradients of the rivers at different sites. Hydro power plants (HPP) installations use different schemes for high water pressure creation:

- the dam scheme – creates a dam for the pressure of water masses;
- derivation scheme – creates a channel, pipeline or tunnel for the pressure of water masses;
- dam-derivational scheme – dams and derivations are created (Fig. 5.10).

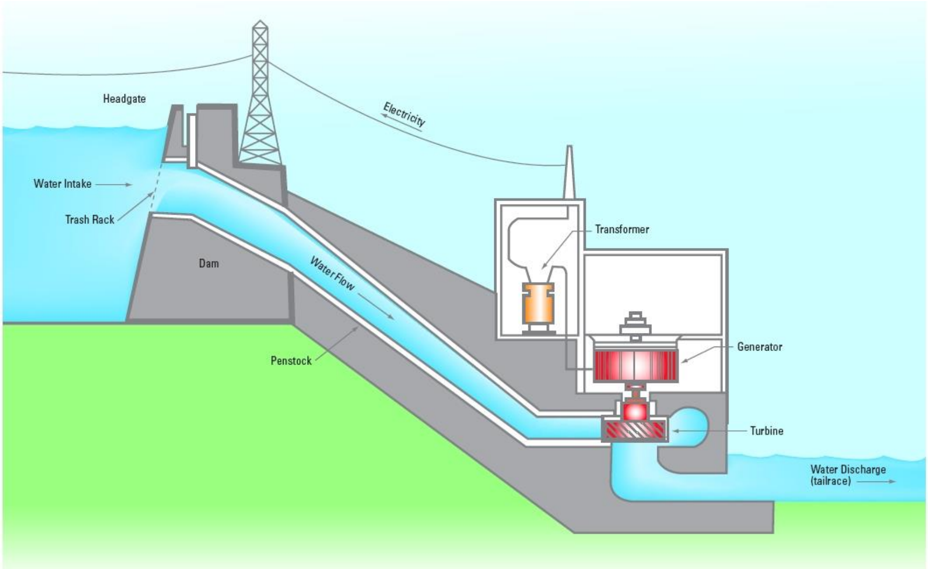


Fig. 5.10. Dam-derivational scheme of the power plant [37]

In addition to dam hydropower plants there are in small scale hydropower plants which use derivational and channel hydroelectric installations (Fig. 5.11).

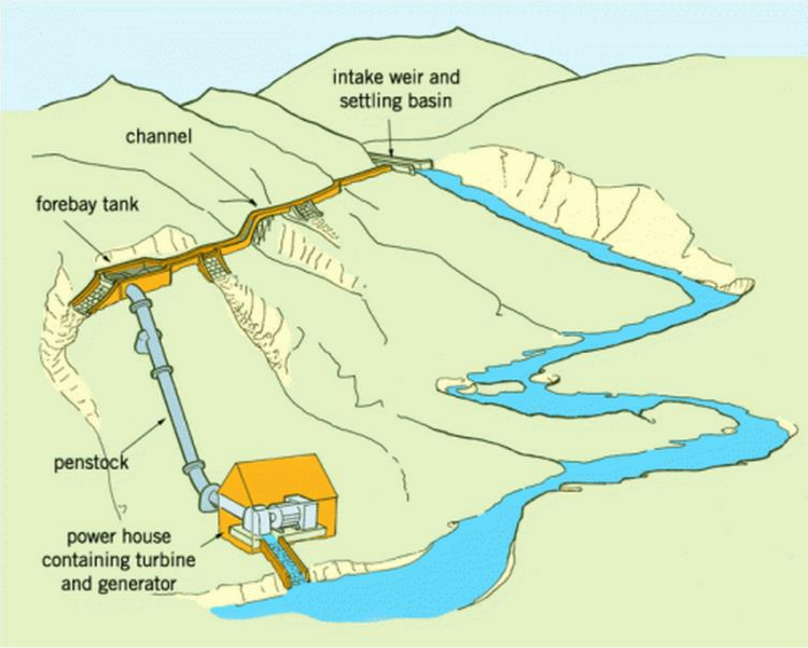


Fig. 5.11. Run-of-river small hydro power plant scheme [38]

The main disadvantages of dam power plants are:

- the large interference to the environment;
- the flooding of large areas;
- the changing in the temperature regime of the discharged water;
- the obstacle to migration of aquatic organisms and the threat of man-made disasters.

When comparing small HPPs with other traditional sources of decentralized power supply, they are currently distinguished as follows:

- availability and renewability of a cheap energy source;
- a well-known and not difficult technology for the production of equipment and construction work;
- simple operation, including the possibility of full automation of the service;
- minimal negative impact on the environment;
- improvement of water exchange and aeration of water and, as a result, improvement of oxygen regime and increase of biological activity of the river;
- the possibility of building hydroelectric power stations on the basis of existing specialized water management systems (navigable, irrigation water supply, refining, fish farming, waterbird breeding, etc.).

At the same time, the use of the energy of watercourses by small HPPs can be restrained by the following negative circumstances: the dependence of HPP generation on hydrological and meteorological conditions. Creation of hydroelectric power plants is associated with large specific initial costs (capital investments), which are 1 and 2 times higher than those in thermal power plants [25].

5.2. Perspectives and potential for renewable energy sources development in Kazakhstan

Kazakhstan occupies the territory of 2 million 724.9 thousand square kilometers, the country is the ninth largest country in the world. In the north and west the republic has common borders with Russia – 7,591 km (the longest continuous land border in the world), in the east with China – 1,783 km, in the south with Kyrgyzstan – 1,242 km, Uzbekistan – 2,351 km and Turkmenistan – 426 km (Fig. 5.12.). The total length of land borders is 13,200 km.

Kazakhstan is the largest country in the world, which has no direct access to the World Ocean. Most of the country's territory consists of deserts – 44% and semideserts – 14%. Steppes occupy 26% of Kazakhstan's area, forests – 5.5%. There are 8,500 rivers in the country. The north-eastern part of the water area of the Caspian Sea is part of the republic [39].

Fig. 5.12. Kazakhstan on the map [40]

The economy of Kazakhstan is largely based on the extraction of natural resources, the leading role of which is played by energy resources. This is due to both the relative provision of the country with resources, given the presence of significant reserves of oil, gas, coal and uranium, and the country's role in the world system of the division of labor that emerged after the collapse of the USSR [41].

At the same time, Kazakhstan has great potential for the renewable energy sources development.

5.2.1. Solar energy potential

For evaluating the solar energy potential, it is important to take into account not only geographical location but the weather conditions also (Fig. 5.13.). Within Kazakhstan the maximum value of the cloudy number was noted at the meteorological station of Astana city and amounted to 241.65 per year. The minimum value was noted at Kazalinsk station and amounted to 120.98 days a year. According the Kazakhstan's Solar energy potential atlas the territory of Kazakhstan was divided in to 5 zones on the efficiency of solar panels with standard nominal capacities (Fig. 5.14.) [42].

Fig. 5.13. The number of cloudy days a year in Kazakhstan [42]

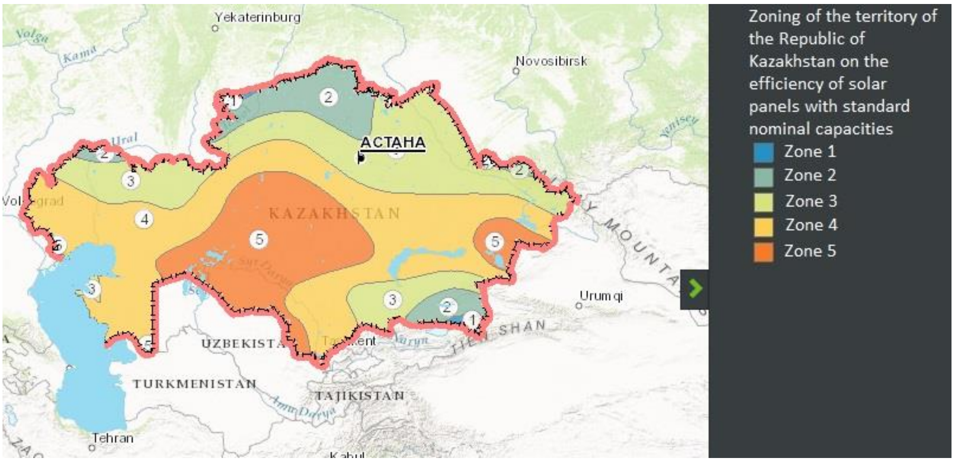


Fig. 5.14. Zoning of the territory of Republic of Kazakhstan on the efficiency of solar panels with standard nominal capacities [42]

According the Global Solar Atlas which was founded by the World Bank photovoltaic energy potential distribution is shown on the Fig. 5.15. Where PVOUT (PV Electricity output) it is the amount of energy, converted by a PV system into electricity [kWh/kWp] that is expected to be generated according to the geographical conditions of a site and a configuration of the PV system. Three configurations of a PV system are considered: (i) Small residential; (ii) Medium-size commercial; and (iii) Ground-mounted large scale [43].

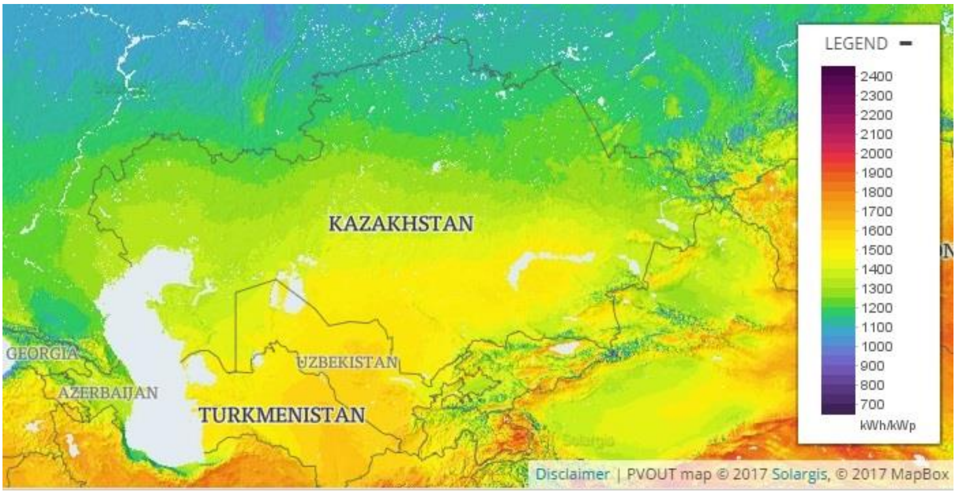


Fig. 5.15. Zoning of the territory of Republic of Kazakhstan on the photovoltaic electricity output [42]

5.2.2. Wind energy potential

For the best wind generators placement is required to use information about wind speeds in places where wind farms should be created. Obtaining information on wind conditions is performed by the analysis and evaluation of the wind velocities at certain altitudes. The installation of wind generators in regions with sufficient wind energy potential allows to generate electricity according the planned capacity.

The first wind energy atlas of Kazakhstan was created according the Wind Energy Market Development Initiative under UNDP Kazakhstan [44]. On the interactive web page, you can see the wind energy potential (Fig. 5.16.).

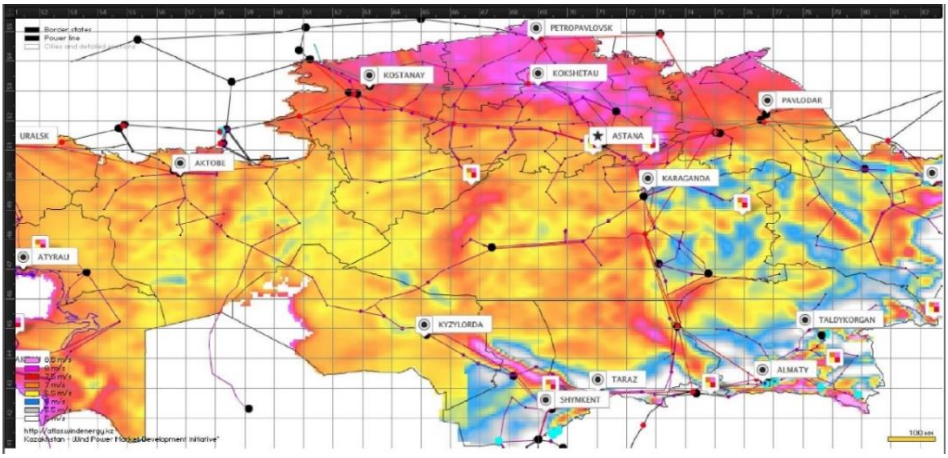


Fig. 5.16. – Wind atlas of Kazakhstan at a height of 80 m above ground level and a resolution of 9 km [45]

It was the pilot project and gave just general overview of wind energy potential in Kazakhstan. The next step was done in the frame of program # 0071 / PCF "Development of Clean Energy Sources, Republic of Kazakhstan for 2013–2017, as part of EXPO-2017 [42].

The web-atlas of the energy potential of wind energy lists the distribution of wind speeds for the seasons of the year at altitudes of 10, 50 and 100 m above the surface of the earth through the territory of the Republic of Kazakhstan (Fig. 5.17.–5.19.). This study will allow to start the practical implementation of the construction of wind power plants.

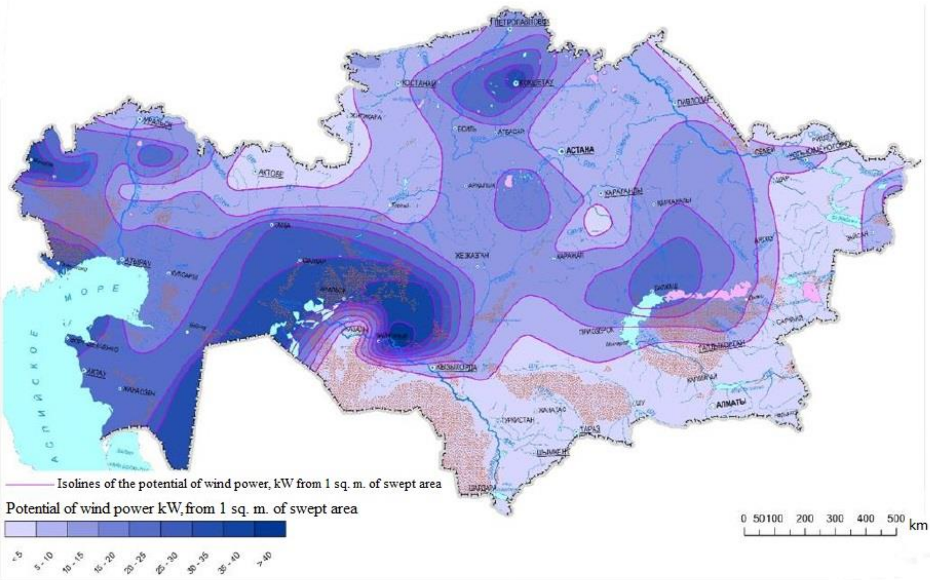


Fig. 5.17. Wind energy potential from 1m^2 of sweeping area, at an altitude of 10 m from the earth's surface. kW*m^2 / year [46]

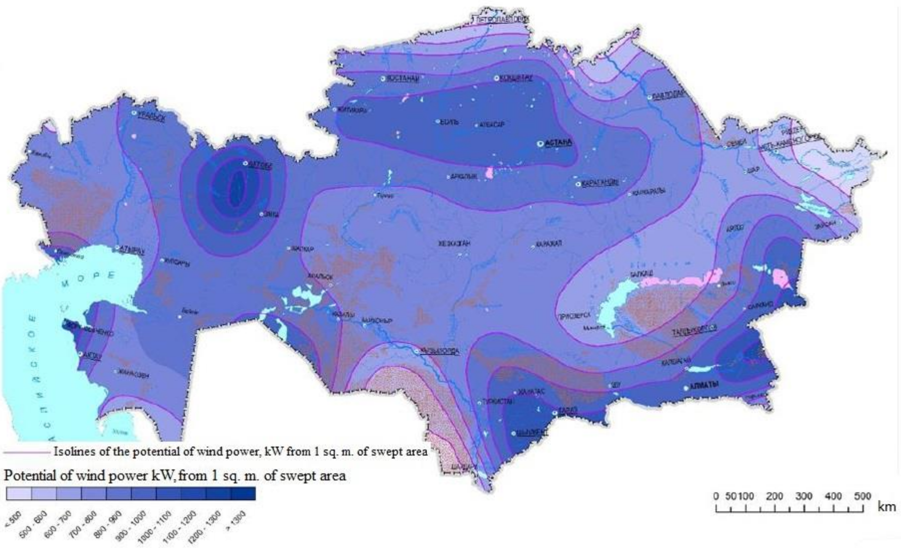


Fig. 5.18. Wind energy potential from 1m^2 of sweeping area, at an altitude of 50 m from the earth's surface. kW*m^2 / year [46]

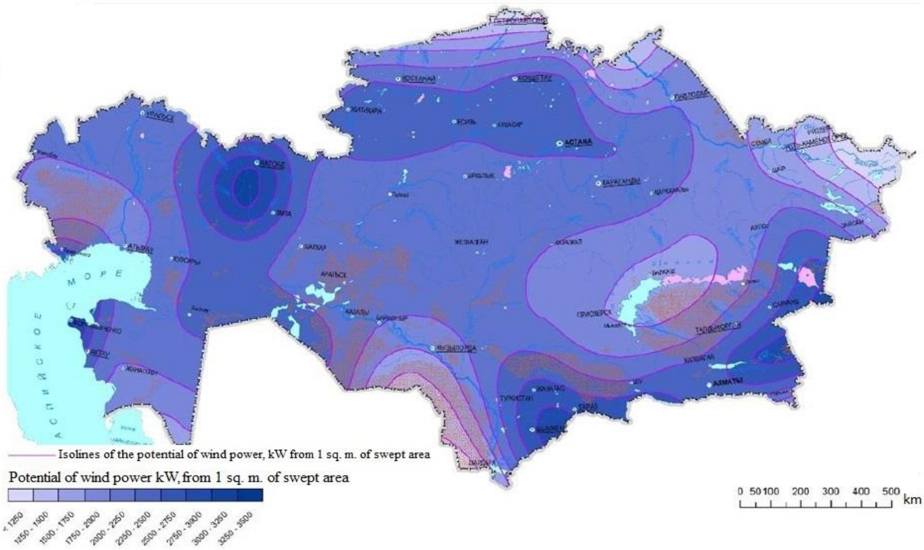


Fig. 5.19. Wind energy potential from 1m^2 of sweeping area, at an altitude of 100 m from the earth's surface. kW*m^2 / year [46]

Additional information about the potential of wind energy in Kazakhstan can be obtained from Global Wind Atlas coordinated by International Renewable Agency (IRENA) [47]. The data for the aggregated mean power density is provided at 50, 100, 200 m (Fig. 5.20.–5.22.).

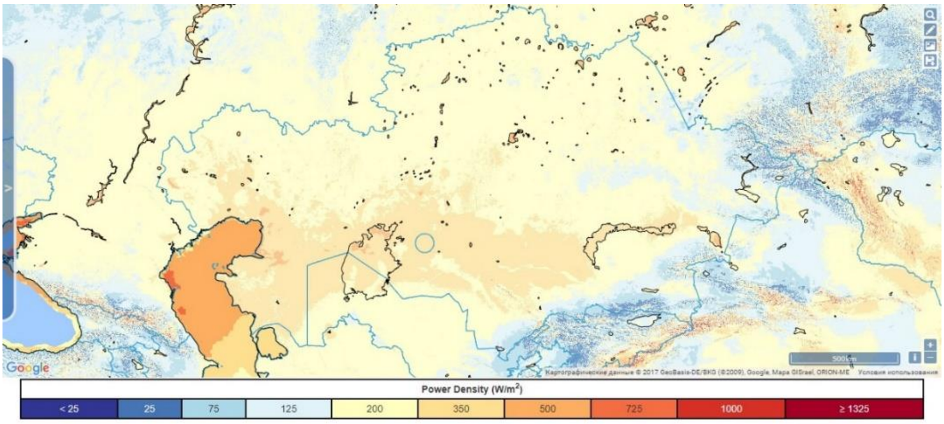


Fig. 5.20. Wind energy potential, aggregated mean power density at an altitude of 50 m from the earth's surface. W/m^2 [47]

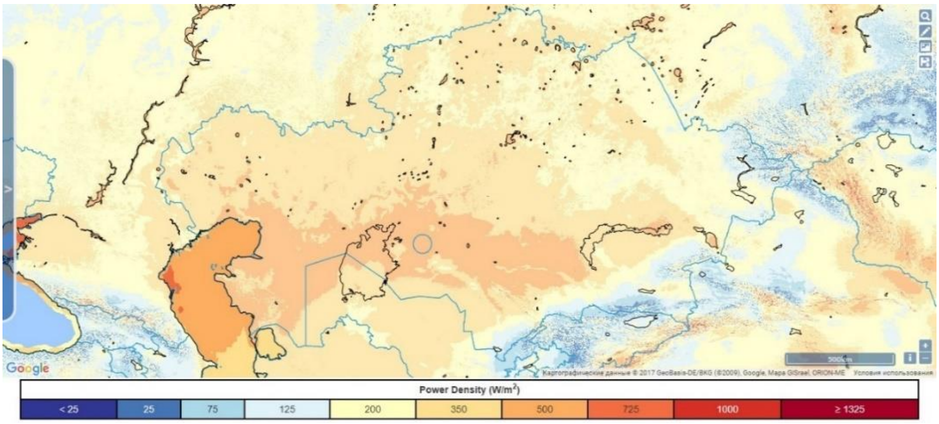


Fig. 5.21. Wind energy potential, aggregated mean power density at an altitude of 100 m from the earth's surface. W/m2 [47]

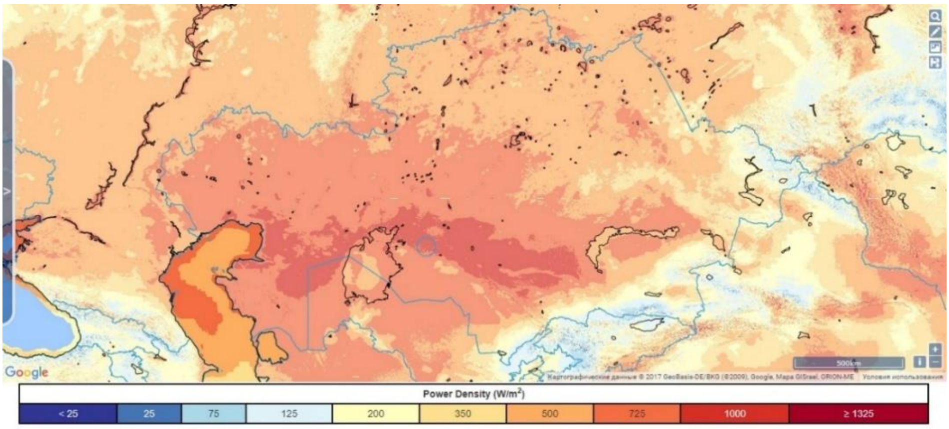


Fig. 5.22. Wind energy potential, aggregated mean power density at an altitude of 200 m from the earth's surface. W/m^2 [47]

5.2.3. Geothermal energy potential

The suitability of geothermal energy source as a source of heat and energy is determined primarily by the energy potential, the total reserves and flow rates of boreholes, the chemical composition, mineralization and aggressiveness of the waters, the presence and distance of the consumer, the temperature and hydraulic conditions of the boreholes, the filtration capacity of the reservoir rocks, the depths of the aquifers and their characteristics, the possibility of utilizing wastewater and etc.

The main criteria for assessing the suitability of geothermal sources as energy resources are: water temperature at the spout – not less than 75°C; pressure, low mineralization – not more than 20 g/l; and profitable reserves – not less than 22 years [42].

Geothermal resources are mainly located in Western Kazakhstan – 75.9%, in South Kazakhstan of 15.6% and in Central Kazakhstan – 5.3% (Fig. 5.23.) [42].

Fig. 5.23. Map of the thermoanomalies and energy potential of hydrogeothermal resources in perspective areas of Kazakhstan [42]

5.2.4. Ocean energy potential

Although Kazakhstan has no access to the world's oceans, it is nevertheless possible to use the energy of the Caspian Sea. According results of the measurements and mathematical modeling the most promising from the point of view of the wave energy is the central part of Caspian Sea.

The maximum values in the sea around 3 m for Hs and 20 kW/m for the wave power in the case of the average energy conditions are at the central part of the Caspian Sea.

The wave energy analysis in the Caspian Sea is shown on the Fig.5.24. The background shows normalized wave power (ETR/ETRmax) and the foreground shows energy transport vectors (represented withered arrows in kilowatts per meter of wave front). The locations in the computational domain of the maximum values for the wave power are marked with circles. a) CS1 average energy conditions (time frame 2009/10/02/h18); b) CS2 high energy conditions (time frame 2009/11/27/h03) [48].

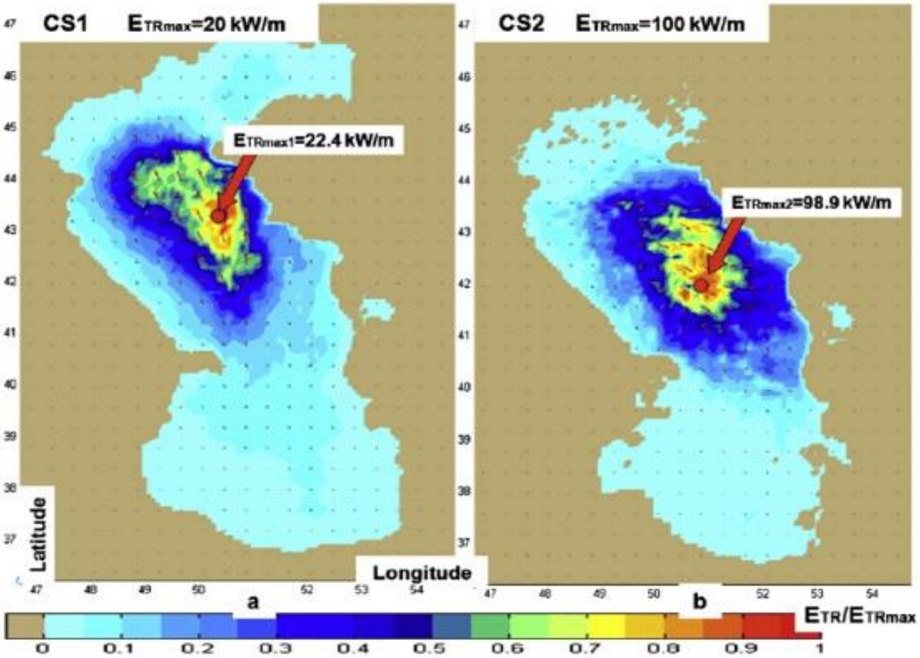


Fig. 5.24. Wave energy analysis in the Caspian Sea [48]

5.1.5. Energy potential of biomass

Kazakhstan has huge territory and agriculture potential as well (Tab. 5.4.) [49].

Tab. 5.4. Basic agriculture statistics

Physical areas	Year	Value	Unit
Area of the country	2009	272 490 000	ha
Cultivated area (arable land and area under permanent crops)	2009	23 480 000	ha
as % of the total area of the country	2009	9	%
arable land (annual crops + temp fallow + temp meadows)	2009	23 400 000	ha
area under permanent crops	2009	80 000	ha

In Kazakhstan, forests occupy an area of more than 10 million hectares, which is 4% of the total territory of the country, of which 4,700 thousand ha are covered with saxaul. The volume of the waste timber for felling and wood on wood plants, and wood is used as firewood is nearly 1.3 million m^3 or 1 mill. tones. Thus, the energy potential of wood waste is more than 200,000 TOE.

Straw of cereals is the most important renewable energy resource in the Republic of Kazakhstan. In 1990, the production of straw amounted to almost 37 million tons. If we assume that 20% of this volume can be used for energy purposes, then the energy production will be more than 87 GW. The most promising projects on the use of biomass for energy purposes associated with a straw. Another potential direction is the use of biogas. Kazakhstan has a significant number of livestock and poultry. The potential for methane production from cattle wastes is more than 85 thousand tons, or more than 52 thousand TOE. Due to the processing of agricultural waste, the country can annually receive up to 35 billion kW/h of electric and 44 million gigacalories of thermal energy. The potential for methane production from municipal waste water treatment is about 3 thousand tons or almost 1 800 thousand TOE [50].

5.1.6. Small hydro power plants potential

Creation of hydroelectric power stations on small rivers requires taking into account the relief, the water regime of the river, the landscape features of the territory and the calculated values of the average annual expenditures using data from the flow module maps.

Hydropower potential – a current supply of energy flows and river water reservoirs located above sea level.

A characteristic of the river network of Kazakhstan is its uneven distribution of runoff both within the year and in the multi-year section, total low water availability, lack of constant surface runoff, the presence of a large number of shallow river network, etc. The specific features of the river network of the mountainous part of Kazakhstan are marked by continental and arid climate. In addition, the density and nature of the river network depend on the relief, geological structure and lithological composition of the rocks, etc. The greatest number of rivers in Kazakhstan (about 50%) falls on the highland basins of the Irtysh and Ili rivers. The main number of tributaries also falls on the same high-mountainous basins of the Irtysh and Ili rivers, as well as the basin of Lake Balkhash. These three basins comprise about 70% of all tributaries. [42].

According the analysis based on the criteria mentioned above was created the map on the hydropower potential and the places for the small hydropower plans possible placement (Fig.5.25.).

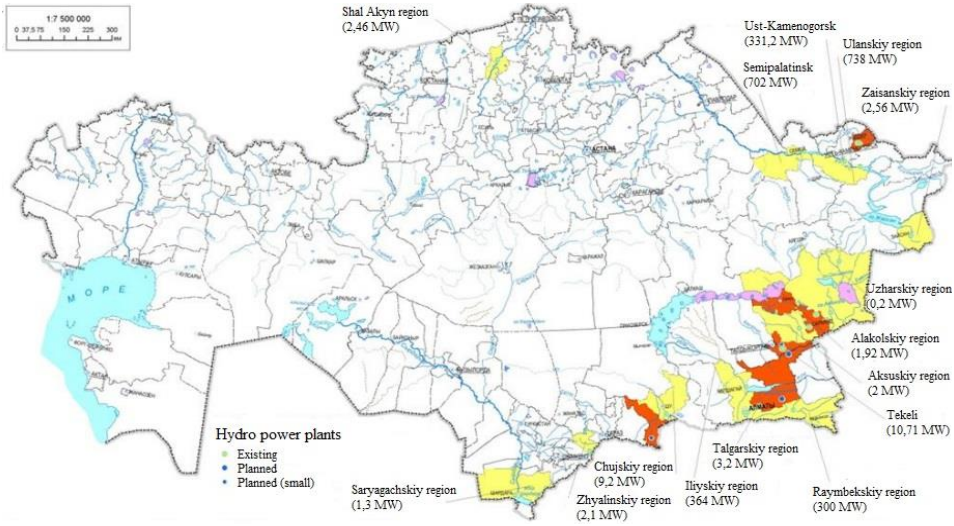


Fig. 5.25. Coverage area and the planned construction of hydroelectric power plants and small hydropower plants of the Republic of Kazakhstan [42]

5.1.7. Kazakhstan's renewable energy sources potential summary

Different experts and researches gives different values but undoubtedly the potential of renewable energy resources (wind, solar, hydropower and biomass energy) in Kazakhstan is significant (Tab. 5.5.) [51]. For example, only the potential of wind power can cover the present demand in electricity by 10–20 times! However, unfortunately, except the part of hydropower, these resources have not been widely used up to the present time. If we will talk about the using of the Caspian Sea energy and geothermal energy, the assessment of the potential now quite conditional and does not cite any specific assessment of the potential.

Tab. 5.5. Potential of renewable energy resources in Kazakhstan

Type	Value	Unit
Wind	929–1820	billion kWh per year
Solar	2,5	billion kWh per year
Biomass energy	35	billion kWh per year
Small hydro	7,5	billion kWh per year

Analyzing the share of the potential of renewable energy sources (Fig. 5.26.), it can be concluded that the most promising are wind and biomass energy.

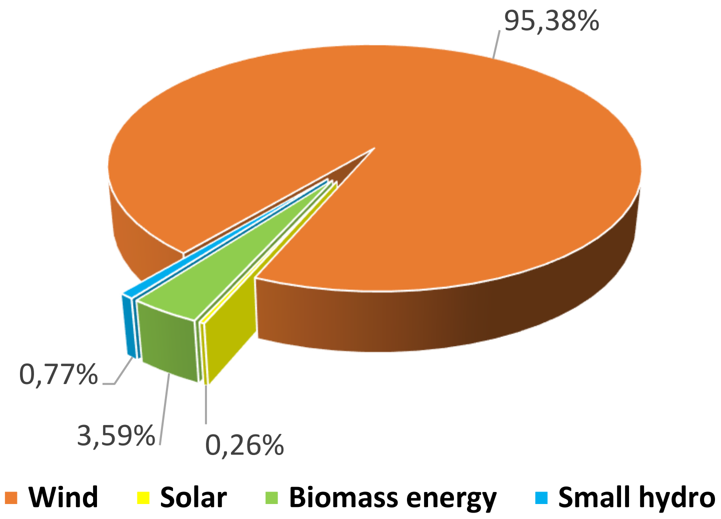


Fig. 5.26. Shares of renewable energy sources potential in Kazakhstan [51]

However, the widespread use of bioenergy is still limited to the inability to involve big territory of the land for special crops, as well as underdeveloped infrastructure and complicated process of the biofuel production. But undoubtedly in the future, the use of this type of energy will solve both the problems of power generation, and some environmental problems, primarily related to waste disposal. Using the energy of small rivers is also not possible on the entire territory of Kazakhstan mainly due to uneven distribution of water resources.

Accessibility in most parts of Kazakhstan and the relative simplicity of installations for generating electricity allows us to consider the sun and wind the most promising renewable sources of electricity at the current moment.

5.3. Legal basement, current situation and programs of the renewable energy generation sources development in Kazakhstan

In general, the issues related to the transmission and consumption of electricity and heat are governed by the Law of the Republic of Kazakhstan from July 9, 2004 No. 588-II “About the Electric Power Industry” [52].

In 2009, renewable energy sources began to be regulated by a separate law – the Law of the Republic of Kazakhstan "On Support for the Use of Renewable Energy Sources" from July 4, 2009 No. 165-IV [53].

Some questions related to the use of RES are regulated by other legislative acts such as the Land Code of the Republic of Kazakhstan [54], the Water Code of the Republic of Kazakhstan [55], Code of the Republic of Kazakhstan on Administrative Offenses [56], and Law on Natural Monopolies and Regulated

Markets [57]. Issues that arise in the production and turnover of biofuels are regulated by a separate law – Law of the Republic of Kazakhstan "On state regulation of production and turnover of biofuels" [58]. For the further development of renewable energy and the exchange of international experience in Kazakhstan acceded to the International Renewable Energy Agency which was started in Bonn 26 January 2009 and ratified its statute [59]. In August 2014, the functions of the authorized body in the field of public policy in the sphere of the use of RES were transferred from the Ministry of Industry and New Technologies to the Ministry of Energy [60]. For the development of renewable energy, the state provides some preferences, the most important of which are [60]:

- No license is required for renewable energy production;
- Guaranteed access to points of connection to electrical networks;
- Priority of electricity transmission from RES through electric networks;
- It is guaranteed to purchase the entire amount of RES energy at a fixed tariff for 15 years (Tab. 5.6.);
- Predictable and long-term tariffs;
- Investment preferences;
- Exemption from customs duties;
- State natural grants;
- Tax preferences;
- Investment grants.

Tab. 5.6. Fixed tariffs for the renewable energy resources in Kazakhstan [61]

Type	**Tariff value, KZT / kWh**	**Tariff value, EUR / kWh, 1 EURO=367,52 KZT, 01.01.2017 [62]**
Wind power stations, except for a fixed tariff for the project of the Astana power plant "Astana EXPO-2017" with a capacity of 100 MW, for converting wind energy	22,68	0,062
Wind power plant, “Astana EXPO-2017”, with a capacity of 100 MW, to convert wind energy	59,7	0,162
Photovoltaic solar energy converters, with the exception of a fixed tariff for solar power plant projects using photovoltaic modules based on Kazakhstani silicon (Kaz PV), to convert the energy of solar radiation	34,61	0,09
Small hydro power plants	16,71	0,045
Biogas installations	32,23	0,088

For comparison, according to the trades on the site of the Kazakhstan's Operator of the Market of Electric Energy and Power [63], on July 12, 2013 the maximum price for 1 kWh was 6,5 KZT (0,018 EUR).

On March 19, 2010, the President of the Republic of Kazakhstan adopted the State Program on Forced Industrial–Innovative Development in the Republic of Kazakhstan for 2010–2014 [64]. Further, in August 2014, the State Program of Industrial and Innovative Development of the Republic of Kazakhstan for 2015–2019 [65] was approved. Both programs confirm the significant potential of RES, such as water, wind and solar energy in Kazakhstan in the short and long term. In particular, the program on Forced Industrial–Innovative Development in the Republic of Kazakhstan for 2010–2014 provided that by 2015 the share of RES in the total energy production should exceed 1%.

On 30 of May 2013 the President of Kazakhstan approved the Concept for the transition of the Republic of Kazakhstan to the "green economy" [66]. According the concept it is planned to establish a share of renewable energy in the country's total energy balance of about 3% by 2020, which is in the amount of installed capacity of 1850–1900 MW in the country.

At the same time, the total share of alternative energy sources, including renewable sources, nuclear power plants and hydroelectric power plants, will grow to 30% by 2030 and to 50% by 2050.

The later adopted Concept for the Development of the Fuel and Energy Complex of the Republic of Kazakhstan until 2030 [67] confirms the previously accepted announcements and the terms for the introduction of renewable energy sources.

Kazakhstan President Nazarbayev's initiative "Strategy Kazakhstan–2050" [68], involves the creation of pan-Eurasian energy system and the inclusion of Kazakhstan in the initiative united under the Green Euro-Asian Bridge initiative.

To date, there are 50 existing renewable energy facilities in the Republic of Kazakhstan with a total capacity of 288.3 MW (hydroelectric power plants – 139,8, wind power plants – 90,8, solar power stations – 57.3, biogas plant – 0,35) [69].

The locations of the realized objects up to the year 2015 (included) are shown in Fig. 5.27.

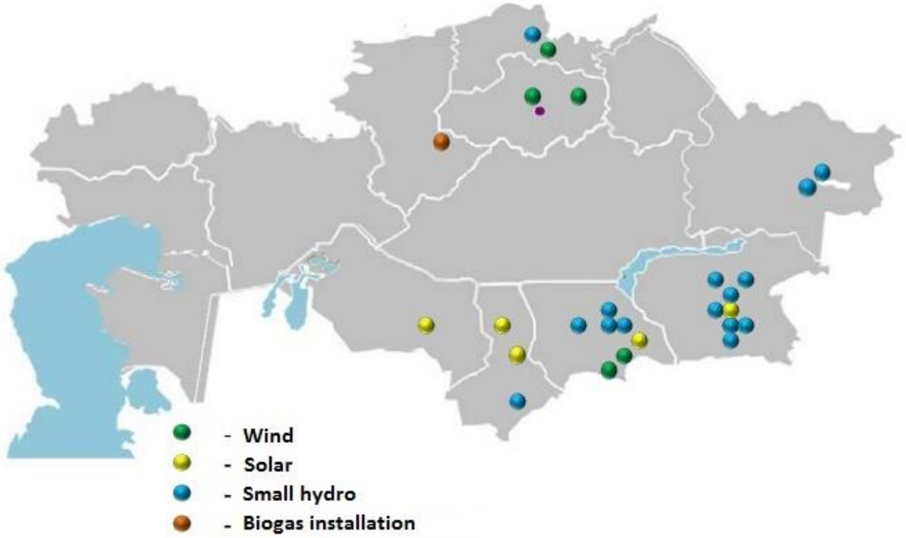


Fig. 5.27. Realized objects of the renewable energy sources in Kazakhstan up to the year 2015 (included) with a total capacity of 255 MW [69]

By 2020 it is planned to put into operation about 106 renewable energy facilities with a total installed capacity of 3054,55 MW (41 hydroelectric power plants – 539; 34 wind power plants – 1787; 28 solar power stations – 713,5; 3 biogas plants – 15,05) [69].

Prospective locations of the future RES are shown in Fig. 5.28.

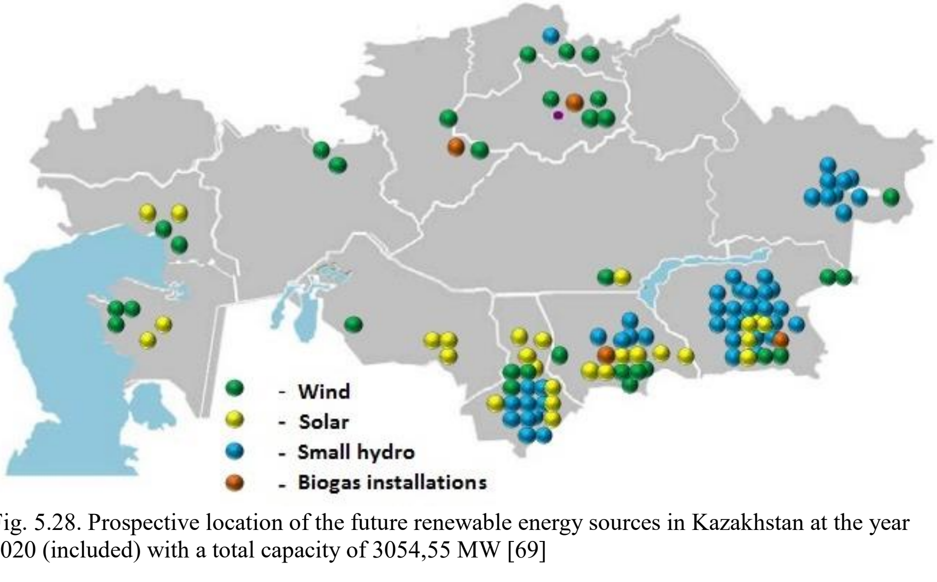


Fig. 5.28. Prospective location of the future renewable energy sources in Kazakhstan at the year 2020 (included) with a total capacity of 3054,55 MW [69]

5.4. Conclusion

Undoubtedly Kazakhstan has a significant potential for the RES development. According the analysis of the characteristics of RES, their potential, Kazakhstan's location, territory, industrial facilities distribution, landscape and climate conditions and the current level of the electrical infrastructure in Kazakhstan can be concluded that the most prospective energy sources now are wind and solar power. Nevertheless, the energy of small river and biomass should be taken in to account also.

The plenty of programs and legislation acts which are going to support and force the development of the renewables were adopted in Kazakhstan. They provide some instruments and mechanisms for supporting the renewables. The most important can be identified such as: guaranteed access to points of connection to electrical networks; priority of electricity transmission from RES through electric networks; purchase the entire amount of RES energy at a fixed tariff for 15 years. However, unfortunately, not all the announced plans for the implementation of renewable energy sources are being carried out in full. For this there are reasons for both organizational and technical nature.

One of the important technical reasons is the inclusion of RES in the electric grid and the provision of their operation in conjunction with traditional energy sources. In other words, the problem of unit commitment of the renewables should be solved in Kazakhstan. Solving this problem, it is also necessary to consider the peculiarities of Kazakhstan's electric network, such as long power transmission lines and uneven distribution of generation and consumption of electricity.

Also, it is necessary to take into account that the power system in the west of Kazakhstan works isolated from the whole power system of the republic and carries out the import of electricity to cover the deficit.

In this region, the problem of involvement in the generation of RES is most acute.

6. Problem of unit commitment with the renewable energy sources in Kazakhstan

6.1. Unit commitment problem overview

Nowadays, the main feature of the process of the electricity production and consumption according it's nature is that the produced electrical energy should be used immediately. As a result, to ensure the stable operation of the power system with the specified parameters, it is necessary to build inter-system power lines and observe certain operating modes of electric power generators. This problem can be considered as a special case of the unit commitment problem.

UC problem can be defined as an optimization problem used to determine the operation schedule of the generating units at every hour interval with varying loads under different constraints and environments [70].

There are plenty of methods and algorithms for the UC problem solution which have been created by different authors and organizations: Priority List (PL), Dynamic Programming (DP), Branch-Bound, Mixed Integer Programming (MIP), Lagrangian Relaxation (LR) [71] and many others.

But it is still actual to find new models and approaches for solving such problem. New conditions and demands of the modern power sector highlight the UC problem as one of the most significant.

By solving UC optimization problem, it is possible to reach such targets like power supply with the minimum fuel consumption or minimum loses. In addition, many constraints can be set: the order of starting-up and shutting-down of generating units, minimum up time, minimum down time, capacity limits, generation limit for the first and last hour, limited ramp rate, group constraint, power balance constraint, spinning reserve constraint, etc.

Mathematically, the UC problem is formulated as a non-linear, large scale, mixed integer combinatorial optimization problem with several constraints [71]. Because of the many preset parameters and the complexity of the UC problem, it is necessary to use modern software products and computing power to solve it. For example, 5 units, 24 hours UC solution can have $6{,}2 \cdot 10^{35}$ combinations. Processing 109 combinations per second, this would take $1{,}9 \cdot 10^{19}$ years to solve [72].

Nowadays created different programs and solvers for the UC problem calculation. In addition to the UC problem the Economic Dispatch (ED) problem should be considered in some cases as one of the most important optimization issues in power systems. The target of the Economic Dispatch problem solution is to allocate the power demand among committed generators in the most economical manner while all physical constraints are satisfied [73].

6.2. Unit commitment problem with renewable energy sources in a dispersed power system

Unit commitment problem with the renewables has some features. The most significant is that the produced energy from the renewables is not stable and cannot be regulated in a wide range. Also, usually by the governmental lows the "green" energy from the renewables has the priority of the connecting to the electrical grid. As was mentioned above, Kazakhstan adopted such low.

Dispersed power system also imposes some features on the UC problem. Sometimes, the parts of such system can be considered as a microgrid. The main differences between microgrid and large power grid are the following [73]:

- usually the penetration of the renewables to the microgrid is higher. That's why it is creates the problem of precise forecasting of energy production and consumption;
- it is the possibility of energy storage;
- small generators have shorter up and down time of the unit than the big ones.

However, in the reality such assumptions which can be done in microgrid in a dispersed power system cannot be fully applied which will be tested further in the work. Dispersed power system can be characterized as a power network with a distributed power generation with no or wear link to the united power system. Such system can include microgrids and the facilities of the traditional power system as well.

Complex of such constrains forces to develop new approaches and new methods to solve the unit commitment problem with the renewable energy sources in a dispersed power system.

6.3. Unit commitment problem solution with the renewable energy sources in a dispersed power system in Kazakhstan's energy sector conditions

6.3.1. The proposed approach of the unit commitment problem solution

The proposed approach of the unit commitment problem solution in such conditions consist of the following steps:

- identification of the impact factors on the development and implementation of RES;
- initial data analyzing and selection of the network part for modeling;
- setting the goal of the commissioning of the new renewable energy capacities and analyzing its availability and the profile of the electrical power output from RES;
- mathematical methods and software selection;

- getting all required information and the input data for the performing modeling and solving the UC problem;
- optimal combination of the RES search and storage facilities capacity selection;
- performing the UC simulation with different constraints and getting the results;
- return to the previous steps and re-execute them with new data, if necessary;
- conclusions and recommendations.

6.3.2. Initial data analyzing and selection of the network part for simulation

For the modeling of the unit commitment problem solution with the renewable energy sources in a dispersed power system the western part of the Kazakhstan's power system has been chosen (Fig. 6.1) [74].

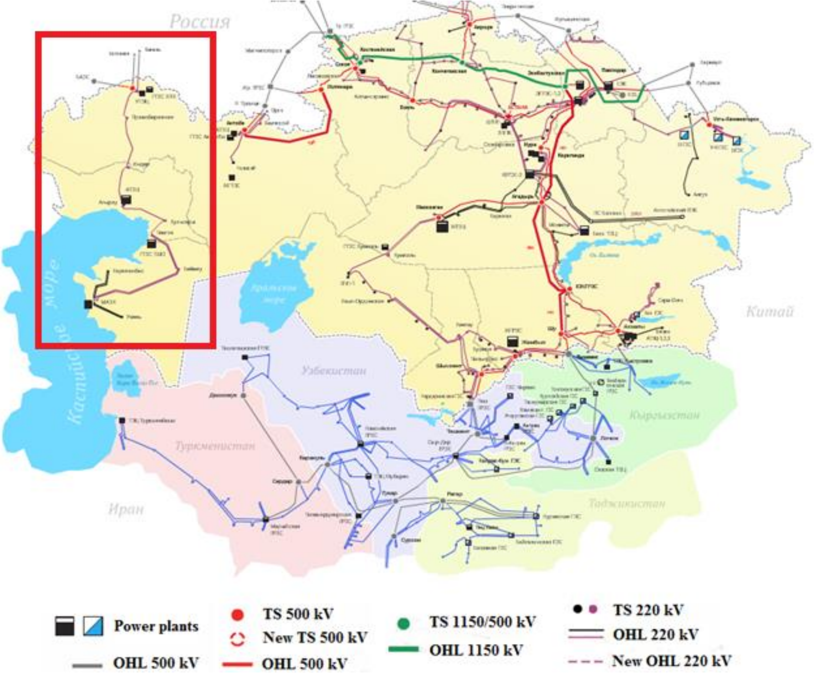


Fig. 6.1. Western part of the power grid of Kazakhstan [74]

Such part of the Kazakhstan's electrical power system has no direct connection to the main network of the country. It has only link to the Russian's power system and works separately form the Kazakhstan's power system. For the simplifying modeling process and realizing the modeling of the connection of the renewable energy sources the part near the Aktau city will be modeled (Mangistau region) (Fig. 6.2) [74].

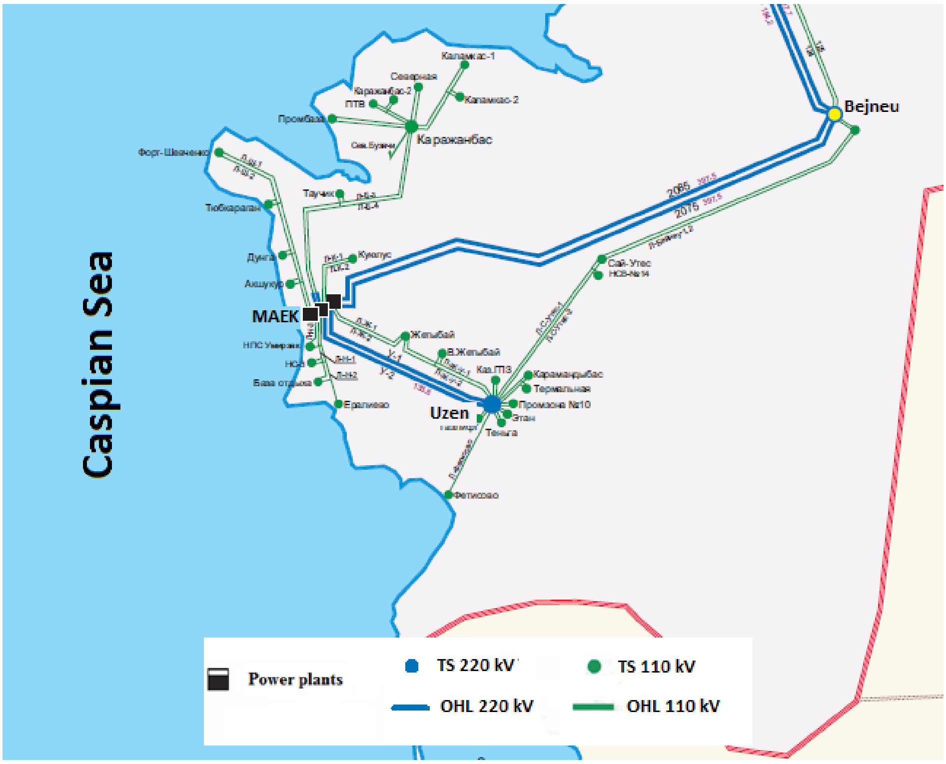


Fig. 6.2. – Simulation area of the western part of the power grid of Kazakhstan (Mangistau region) [74]

Generation capacities of MAEK power stations consists of the 3 generation units with the installed capacity of 630, 625 and 75 MW. Two buses connected to the load by three double-circuit lines (Fig. 6.3) [75]. Maxim load can reach 681 MW and the excess of the electrical power generation can reach 355 MW (Tab. 6.1.) [75].

Tab. 6.1. The power balance in the Mangistau region

Years	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Power balance, (-)excess/ (+)deficit, MW	-355	- 332	-322	-312	-242	-242	-242	-232	-162

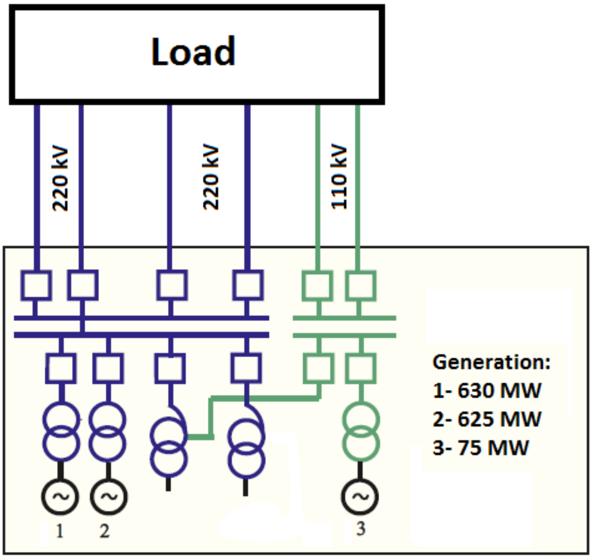


Fig. 6.3. Electrical scheme of the modeling part of the electrical grid [75]

However, if we look at the entire western region as a whole, then the problem of the deficit of power generation is acute, which will reach 297 MW by 2022 (Tab. 6.2.) [75].

Tab. 6.2. The power shortage in the western zone of the Kazakhstan's electrical network

Years	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Power balance, (-)excess/ (+)deficit, MW	-355	- 250	-197	-169	-72	48	124	162	297

In addition, taking into account the condition and deterioration of existing generating capacities, it is planned to commission new generating capacities with a capacity of 250 MW by 2020 [75].

6.3.2. Setting the goal of the commissioning of the new renewable energy capacities and analyzing its availability and the electrical power output profile from RES

Because of the significant lack of the generation capacities this region is ideal for the installing renewable energy sources production facilities. Especially, here is the good potential for them. According to the performed analysis of the availability of the renewable energy resources, modern technologies, wind and PV solar energy sources will be considered only (Fig. 6.4–6.5).

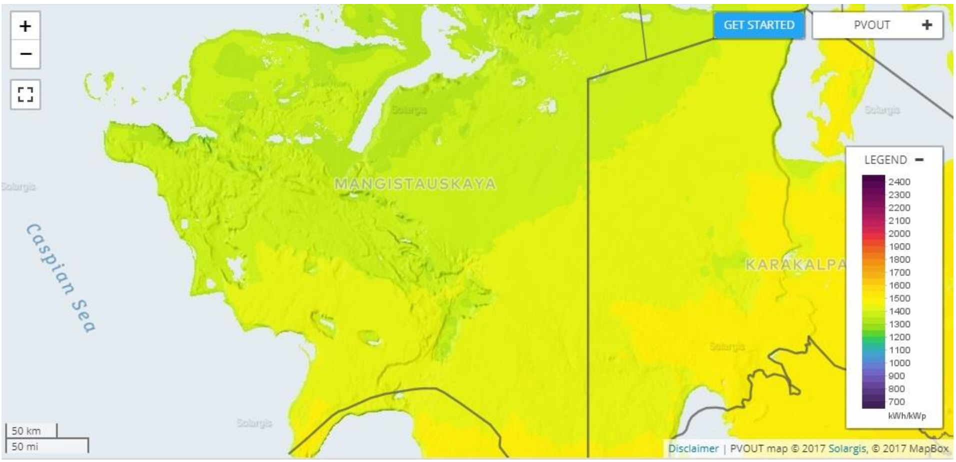


Fig. 6.4. Photovoltaic electricity output potential of the Mangistau region [42]

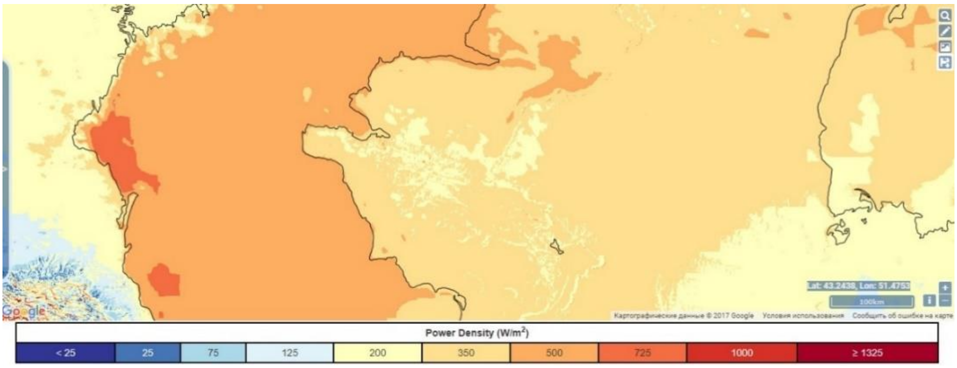


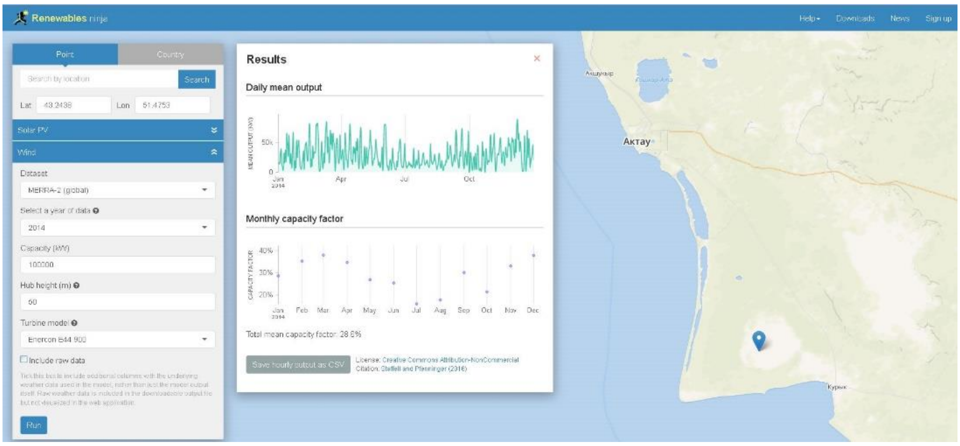
Fig. 6.5. Wind energy potential of the Mangistau region, aggregated mean power density at an altitude of 50 m from the earth's surface. W/m^2 [47]

As was mentioned, it is important to get the precise forecast of the electrical power output from the renewable energy sources. For getting such information in this work the Renewables.ninja [76] open web tool was used. Such tool allows you to run simulations of the hourly power output from wind and solar power plants located anywhere in the world.

The Renewables.ninja tool is using weather data from global reanalysis models and satellite observations. Solar irradiance data is converted into power output using the GSEE model (Global Solar Energy Estimator) [77]. Wind speeds are converted into power output using the VWF model (Virtual Wind Farm) [78].

In the simulation and for getting the power output profile from renewables two days will be considered: in summer (22.06.2014) and in winter (22.12.2014).

According to the analysis of the wind, solar potential, the electrical network scheme and the presence of the consumers, a measurement point with coordinates: Latitude 43.2498, Longitude 51.4753 for the wind and solar plant output profile simulation has been chosen (Fig. 6.6–6.7).



Lat 43.2438 Lon 51.4753

Dataset: MERRA-2 (global)

Select a year of data: 2014

Capacity (kW): 100000

Hub height (m): 60

Turbine model: Enercon E44 900

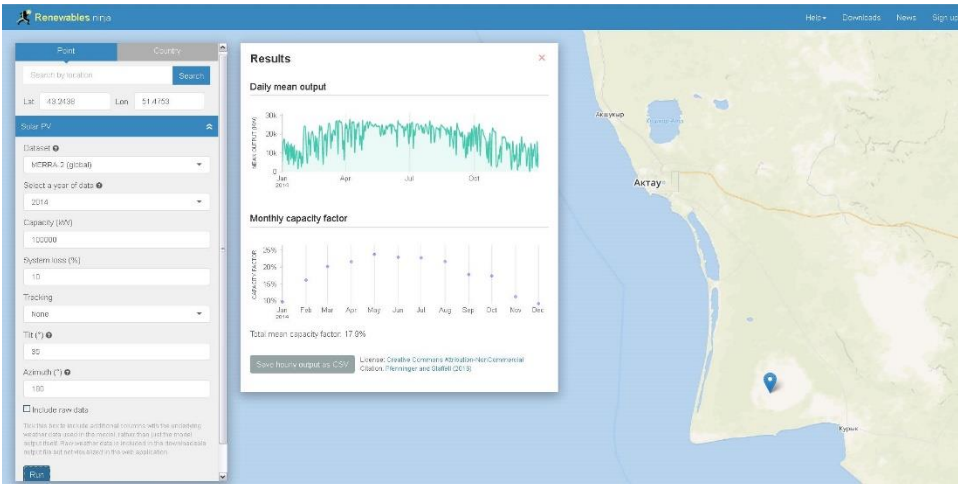
☐ Include raw data

Tick this box to include additional columns with the underlying weather data used in the model, rather than just the model output itself. Raw weather data is included in the downloadable output file but not visualized in the web application.

Total mean capacity factor: 28.8%

License: Creative Commons Attribution-NonCommercial
Citation: Staffell and Pfenninger (2016)

Fig. 6.6. Renewables.ninja wind farm power output profile simulation [76]



Lat 43.2438 Lon 51.4753

Dataset: MERRA-2 (global)

Select a year of data: 2014

Capacity (kW): 100000

System loss (%): 10

Tracking: None

Tilt (°): 35

Azimuth (°): 180

☐ Include raw data

Tick this box to include additional columns with the underlying weather data used in the model, rather than just the model output itself. Raw weather data is included in the downloadable output file but not visualized in the web application.

Total mean capacity factor: 17.9%

License: Creative Commons Attribution-NonCommercial
Citation: Pfenninger and Staffell (2016)

Fig. 6.7. Renewables.ninja PV solar power plant power output profile simulation [76]

The results of the simulation are represented on the Fig. 6.8–6.11. Wind and solar facilities in the simulation have 100 MW power output. But the received power output profile can be applied for any installed capacity.

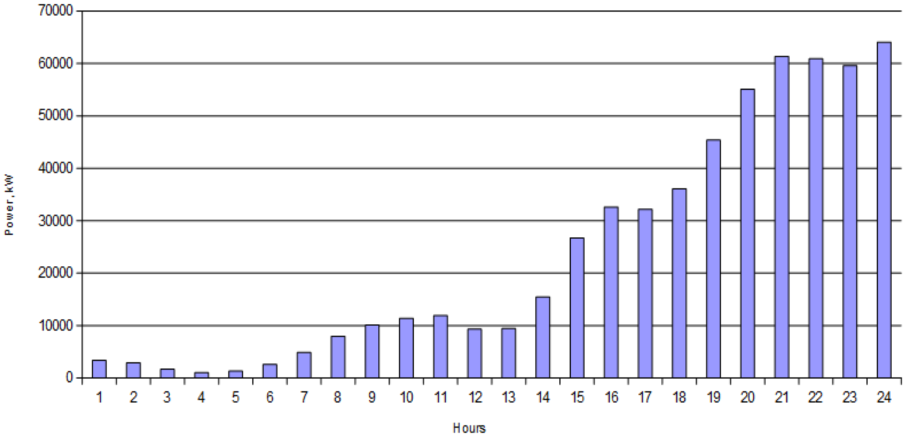


Fig. 6.8. Renewables.ninja 100 MW wind farm power output profile simulation on 22.06.2014 [76]

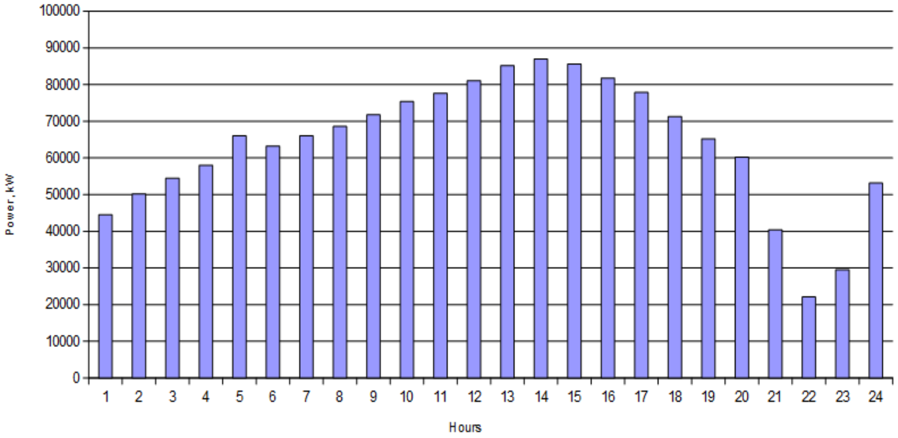


Fig. 6.9. Renewables.ninja 100 MW wind farm power output profile simulation on 22.12.2014 [76]

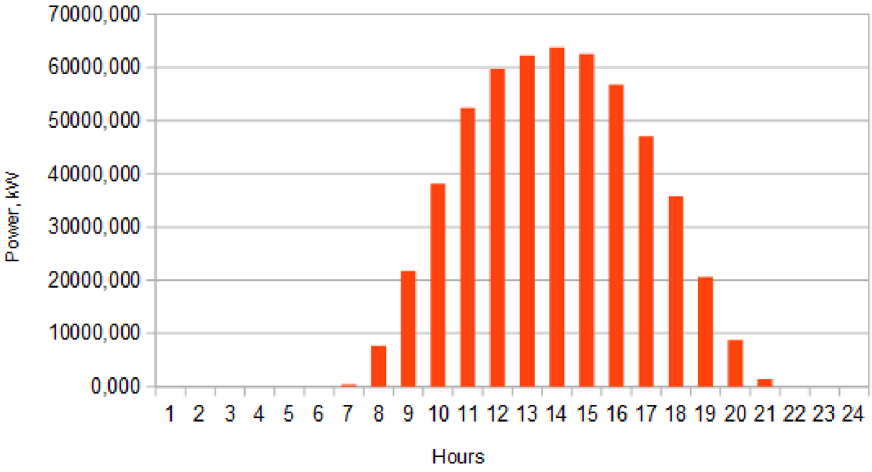


Fig. 6.10. Renewables.ninja 100 MW PV solar plant power output profile simulation on 22.06.2014 [76]

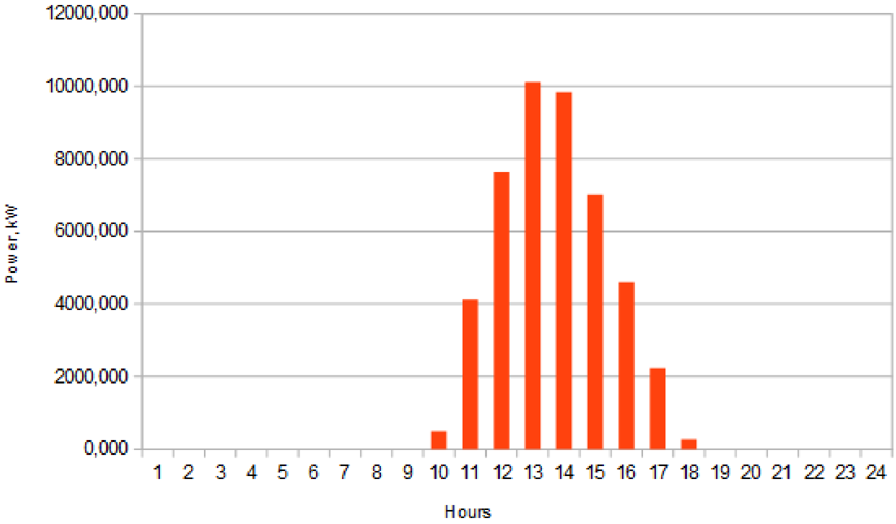


Fig. 6.11. Renewables.ninja 100 MW PV solar plant power output profile simulation on 22.12.2014 [76]

To simulate UC with RES and to test the possibility of replacing the newly installed generating capacity with RES capacity, the RES of 250 MW installed power facilities will be modeled. Also, to test the possibility of covering the electricity deficit in the western zone, the installation of 297 MW of RES power capacity as well as the total power of 547 MW will be modeled with the corresponding load values.

6.3.2. Mathematical methods and software selection

For the UC problem solution ang network simulation the MATPOWER and MOST packages, working in the MATLAB environment with a GUROBI solver, are used. Initially it was developed by Ray Zimmerman, Carlos E. Murillo-Sanchez and Deqiang Gan from the Power Systems Engineering Research Center (PSERC) at Cornell University under Roberts. J. Thomas with significant contributions from Daniel Munoz-Alvarez and Alberto J. Lamadrid [79], [80].

MATPOWER is using for solving power flow and optimal power flow problems and can be easily used and modified.

MOST is using for solving problems as simple as a deterministic, single period economic dispatch problem with no transmission constraints or as complex as a stochastic, security-constrained, combined unit commitment and multiperiod optimal power flow problem with locational contingency and load following reserves, ramping costs and constraints, deferrable demands, lossy storage resources and uncertain renewable generation [79], [80].

Such software performs the UC problem as a mixed-integer nonlinear optimization problem, where the objective is to minimize the objective function f(x) where the optimization variable x consists of the numbers of variables.
The unit commitment variables are binary and the rest continuous. For simplicity, the in the program formulation restricts the treatment of costs, deviations, ramping and reserves to consider only active power.
The objective function can be written as [81]:

$$\min_{\boldsymbol{x}} \boldsymbol{f}(\boldsymbol{x}) \tag{6.1}$$

where $f(x)$ consists of seven components (6.2):

$$\boldsymbol{f}(\boldsymbol{x}) = \boldsymbol{f_p}(\boldsymbol{p}, \boldsymbol{p_+}, \boldsymbol{p_-}) + \boldsymbol{f_z}(\boldsymbol{r_z}) + \boldsymbol{f_z}(\boldsymbol{r_+}, \boldsymbol{r_-}) + \boldsymbol{f_\delta}(\boldsymbol{p}) + \boldsymbol{f_{lf}}(\boldsymbol{\delta_+}, \boldsymbol{\delta_-}) \\ + \boldsymbol{f_s}(\boldsymbol{s_0}, \boldsymbol{p_{sc}}, \boldsymbol{p_{sd}}) + \boldsymbol{f_{UC}}(\boldsymbol{u}, \boldsymbol{v}, \boldsymbol{w}) \tag{6.2}$$

Each part of the function can be expressed as follows:
Expected cost of active power dispatch and redispatch (6.3).

$$\boldsymbol{f_p}(\boldsymbol{p}, \boldsymbol{p_+}, \boldsymbol{p_-}) = \sum_{t\in T} \sum_{j\in J^t} \sum_{k\in K^{tj}} \boldsymbol{\psi_\alpha^{tjk}} \sum_{i\in I^{tjk}} [\widetilde{\boldsymbol{C}}_{\boldsymbol{P}}^{\boldsymbol{ti}}(\boldsymbol{p^{tijk}}) + \boldsymbol{C_{P+}^{ti}}\left(\boldsymbol{p_+^{tijk}}\right) + \\ \boldsymbol{C_{P-}^{ti}}(\boldsymbol{p_-^{tijk}}) \tag{6.3}$$

where t – index of time periods; T– set of indices of time periods in planning horizon; j–index over scenarios; J^t – set of indices of all scenarios considered at time t; k– index over post-contingency cases (k = 0 for base case, i.e. no contingency occurred); K^{tj}– set of indices of contingencies considered in scenario j at time t, including base case (k = 0); i – index over injections (generation units, storage units and dispatchable or curtailable loads); I^t – indices of all units (generators, storage and dispatchable or curtailable loads) available for dispatch in any contingency at time t; I^{tjk} – indices of all units available for dispatch in post-contingency state k of scenario j at time t; p^{tijk} - active injection for unit i in post-contingency state k of scenario j at time t; p_+^{tijk}, p_-^{tijk} –upward/downward deviation from active power contract quantity for unit i in post-contingency state k of scenario j at time t; ψ_α^{tjk}– probability ψ^{tjk} of contingency k in scenario j at time t adjusted for α; α – investment cost; $\tilde{C}_P^{ti}$ – modified cost function for active injection i at time t with the no load cost subtracted; C_{P+}^{ti}, C_{P-}^{ti}– Cost for upward/downward deviation from active power contract quantity for unit i at time t.

Cost of zonal reserves (6.4).

$$\boldsymbol{f_z(r_z) = \sum_{t\in T} \sum_{j\in J^t} \sum_{k\in K^{tj}} \psi_\alpha^{tjk} \sum_{i\in I^{tjk}} C_z^{ti}\left(r_z^{tijk}\right)} \tag{6.4}$$

where C_z^{ti} – cost function for zonal reserve purchased from unit i at time t; r_z^{tijk} – zonal reserve quantity provided by unit i in post-contingency state k of scenario j at time t.

Cost of endogenous contingency reserves (6.5).

$$\boldsymbol{f_z(r_+, r_-) = \sum_{t\in T} \gamma^t \sum_{i\in I^t}[C_{R+}^{ti}(r_+^{ti}) + C_{R-}^{ti}(r_-^{ti})]} \tag{6.5}$$

where γ^t – probability of making it to period t without branching off the central path in a contingency in periods 1 . . . t – 1; C_{R+}^{ti}, C_{R-}^{ti} – cost function for upward/downward contingency reserve purchased from unit i at time t; r_+^{ti}, r_-^{ti} – upward/downward active contingency reserve quantity provided by unit i at time t.

Expected cost of load-following ramping (wear and tear) (6.6).

$$\boldsymbol{f_\delta(p) = \sum_{t\in T} \gamma^t \sum_{\substack{j_1\in J^{t-1}\\ j_2\in J^t}} \Phi^{tj_2j_1} \sum_{i\in I^{tj_0k}} C_\delta^i\left(p^{tij_20} - p^{(t-1)ij_10}\right)} \tag{6.6}$$

where $\Phi^{tj_2j_1}$ – probability of transitioning to scenario j_2 in period t given that scenario j_1 was realized in period t – 1; C_δ^i – quadratic, symmetric ramping cost on the difference between the dispatches for unit i in adjacent periods.

Cost of load-following ramp reserves (6.7).

$$\boldsymbol{f_{lf}(\delta_{+}, \delta_{-}) = \sum_{t \in T} \gamma^{t} \sum_{i \in I^{t}} [C^{ti}_{\delta+}(\delta^{ti}_{+}) + C^{ti}_{\delta-}(\delta^{ti}_{-})]} \tag{6.7}$$

where $C^{ti}_{\delta+}$, $C^{ti}_{\delta-}$ – cost of upward/downward load-following ramp reserve for unit i at time t for transition to time t + 1; δ^{ti}_{+}, δ^{ti}_{-} – upward/downward load-following ramping reserves needed from unit i at time t for transition to time t + 1.

Cost of initial stored energy and value (since it is negative) of expected leftover stored energy in terminal states (6.8).

$$\boldsymbol{f_{s}(s_{0}, p_{sc}, p_{sd}) = C^{T}_{s0} s_{0} - (C^{T}_{ts0} s_{0} + C^{T}_{tsc} p_{sc} + C^{T}_{tsd} p_{sd})} \tag{6.8}$$

where s_0 – initial stored energy (expected) in storage; C_{s0} – vector of costs by storage unit associated with starting out with a given level of stored energy s_0 in the storage units at time t = 0; C_s – vector of prices by storage unit for contributions to terminal storage from charging or discharging in non-terminal states.

No load, startup and shutdown costs (6.9).

$$\boldsymbol{f_{UC}(u, v, w) = \sum_{t \in T} \gamma^{t} \sum_{i \in I^{t}} (C^{ti}_{P}(0) u^{ti} + C^{ti}_{v} v^{ti} + C^{ti}_{w} w^{ti}]} \tag{6.9}$$

where C^{ti}_{P} – cost function for active injection i at time t; u^{ti} – binary commitment state for unit i in period t, 1 if unit is on-line, 0 otherwise; v^{ti}, w^{ti} – binary startup and shutdown states for unit i in period t, 1 if unit has a startup/shutdown event in period t, 0 otherwise; C^{ti}_{v}, C^{ti}_{w} – startup and shutdown costs for unit i at time t in \$ per startup/shutdown.

The minimization is subject to the numbers of constraints and for the purpose of this works the constraints related to the storage and unit commitment will be considered.
Storage has the following constraints [81]:
Storage dispatch definition and limits (6.10, 6.11, 6.12).

$$\boldsymbol{p^{tijk} = p^{tijk}_{sc} + p^{tijk}_{sd}} \tag{6.10}$$

$$\boldsymbol{p^{tijk}_{sc} \leq 0} \tag{6.11}$$

$$\boldsymbol{p^{tijk}_{sd} \geq 0} \tag{6.12}$$

where p^{tijk}_{sc}, p^{tijk}_{sd} – Charge/discharge power injections of storage unit i in post-contingency state k of scenario j at time t.

Energy bound limits (6.13, 6.14).

$$\boldsymbol{s_-^{ti} \geq S_{min}^{ti}} \tag{6.13}$$
$$\boldsymbol{s_+^{ti} \leq S_{max}^{ti}} \tag{6.14}$$

where s_-^{ti}, s_+^{ti} – endogenously computed upper/lower bounds on the energy stored in storage unit i at the end of period t. For $t = 0$ this is a fixed input parameter representing the bounds at the beginning of the first period; S_{min}^{ti}, S_{max}^{ti} – stored energy (in MWh) max/min limits for storage unit i at time t.

Storage dispatch vs. base scenario energy bounds (6.15, 6.16).

$$\boldsymbol{s_-^{ti} \leq \beta_1^{ti}\left[p^{ti}s_-^{(t-1)i} + \left(1 - p^{ti}\right)s_I^{-tij0}\right] + \beta_2^{ti}s_\Delta^{tij0}} \tag{6.15}$$
$$\boldsymbol{s_+^{ti} \geq \beta_1^{ti}\left[p^{ti}s_+^{(t-1)i} + \left(1 - p^{ti}\right)s_I^{-tij0}\right] + \beta_2^{ti}s_\Delta^{tij0}} \tag{6.16}$$

where β_1^{ti}, β_2^{ti}– storage parameters; s_Δ^{tij0}– Net increase in stored energy due to charging or discharging for unit i in post-contingency state k of scenario j at time t; s_I^{-tij0} – expected stored energy in storage unit i in base scenario i at the beginning of period t.

Storage dispatch vs. contingency scenario energy limits (6.17, 6.18).

$$\boldsymbol{S_{min}^{ti} \leq \beta_5^{ti}\left[p^{ti}s_-^{(t-1)i} + \left(1 - p^{ti}\right)s_I^{-tij0}\right] + \beta_4^{ti}s_\Delta^{tij0} + \beta_3^{ti}s_\Delta^{tijk},\; k \neq 0} \tag{6.17}$$
$$\boldsymbol{S_{max}^{ti} \geq \beta_5^{ti}\left[p^{ti}s_+^{(t-1)i} + \left(1 - p^{ti}\right)s_I^{-tij0}\right] + \beta_4^{ti}s_\Delta^{tij0} + \beta_3^{ti}s_\Delta^{tijk},\; k \neq 0} \tag{6.18}$$

where β_3^{ti}, β_4^{ti}, β_5^{ti} – storage parameters.

In addition, storage has two option constrains.
Unit commitment constrains:
Injection limits and commitments (6.19, 6.20).

$$\boldsymbol{u^{ti}P_{min}^{tijk} \leq p^{tijk} \leq u^{ti}P_{max}^{tijk}} \tag{6.19}$$
$$\boldsymbol{u^{ti}Q_{min}^{tijk} \leq q^{tijk} \leq u^{ti}Q_{max}^{tijk}} \tag{6.20}$$

where u^{ti} – initial stored energy (expected) in storage unit i; P_{min}^{tijk}, P_{max}^{tijk} – limits on active injection for unit i in post-contingency state k of scenario j at time t; Q_{min}^{tijk}, Q_{max}^{tijk} – limits on reactive injection for unit i in post-contingency state k of scenario j at time t; p^{tijk}, q^{tijk} – active/reactive injection for unit i in post-contingency state k of scenario j at time t.

Startup and shutdown events (6.21, 6.22, 6.23).

$$\boldsymbol{u^{ti} - u^{(t-1)i} = v^{ti} - w^{ti}} \tag{6.21}$$
$$\boldsymbol{0 \le v^{ti} \le 1} \tag{6.22}$$
$$\boldsymbol{0 \le w^{ti} \le 1} \tag{6.23}$$

Minimum up and down times (6.24, 6.25).

$$\boldsymbol{\sum_{y=t-T_i^{+}+1}^{t} v^{yi} \le u^{ti}} \tag{6.24}$$
$$\boldsymbol{\sum_{y=t-T_i^{-}+1}^{t} w^{yi} \le 1 - u^{ti}} \tag{6.25}$$

Integrality constraints (6.26).

$$\boldsymbol{u^{ti} \in \{0, 1\}} \tag{6.26}$$

More full and detailed information can be found in the Matpower Optimal Scheduling Tool MOST 1.0 User's Manual [81].

6.3.3. Collecting the initial data for the performing modeling and solving the UC problem

For the UC problem simulation and its solving the all required data should be inserted in the MOST tool program package. The data needed for the problem, is not typically created directly, but rather is assembled from numerous other files or data structures [81].

For the chosen network simulation and UC problem solving the following conditions and assumptions will be used:

- two days will be simulated and considered: in summer (22.06.2014) and in winter (22.12.2014);
- wind and solar generation will be simulated both separately and together;
- only active power will be considered;
- the installed renewable capacity will be connected to the bus of the load as well as a storage unit;
- on the basis of the law on support of renewable energy sources for the RES energy sources will be set zero power generation costs [60];
- thermal stations in the simulated system belong to the same owner, and use the same fuel, so economically generation parameters are assumed equal for all generation units, except startup costs [82], [83];

- for the process of UC, older aggregates require a large expenditure on the process of starting and stopping;
- the installation costs of the wind and solar power plants, as well as economic feasibility will not be taken in account.

The base point for the electrical networks and generation equipment capacities projecting is the load profile. For the considered model the following load profile is used: for 22.06.2014 – Tab. 6.2, Fig. 6.12., for 22.12.2014 – Tab. 6.3, Fig. 6.13. [75].

Tab. 6.2. 24 hours power consumption data in the Mangistau region on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Power, MW	539	527	528	530	529	527	530	478	476	486	483	481
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Power, MW	487	483	484	485	465	475	474	476	521	526	524	518

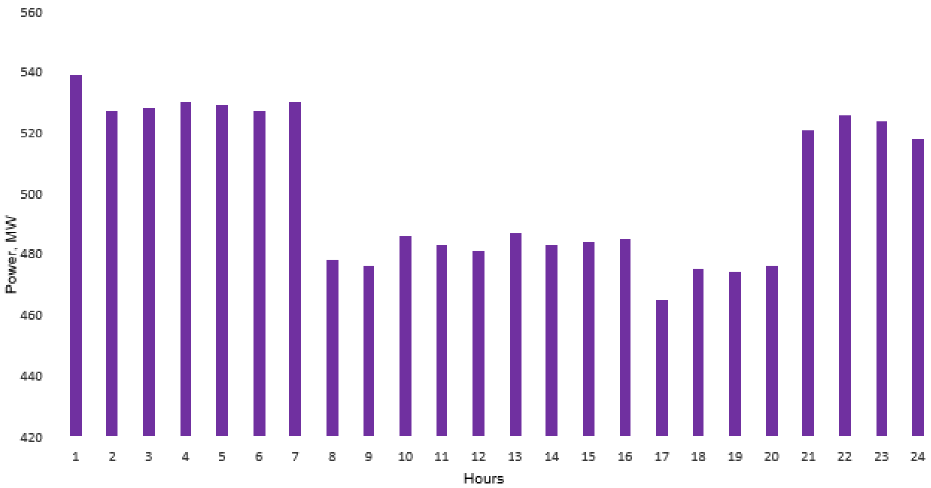


Fig. 6.12. 24 hours power consumption profile in the Mangistau region on 22.06.2014 [75]

Tab. 6.3. 24 hours power consumption data in the Mangistau region on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Power, MW	681	671	666	681	681	676	676	587	572	576	580	574
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Power, MW	576	572	578	569	571	562	571	677	663	663	651	641

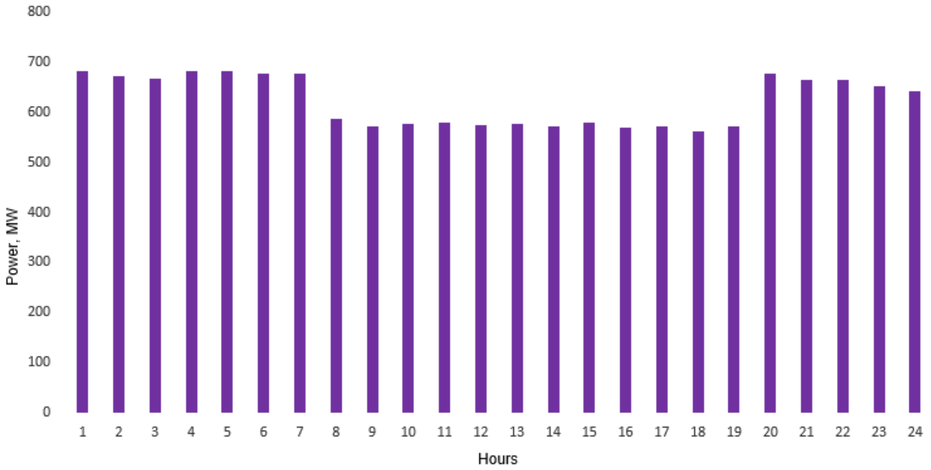


Fig. 6.13. 24 hours power consumption profile in the Mangistau region on 22.12.2014 [75]

Another important data is the power output profile from renewables. Such profiles were received from the Renewables.ninja simulation resource [76]. There are no differences what generation power value of the renewables will be simulated – the output profile will be the same. That is why for the simulation process the data from the profile will be converted to the relative units (Tab. 6.4., 6.5., 6.6., 6.7.) But the power of the renewable generation for each simulation case will be set in absolute units.

Tab. 6.4. 24 hours power generation profile from the solar PV power source simulation in the Mangistau region on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Relative units	0,000	0,000	0,000	0,000	0,000	0,000	0,004	0,076	0,218	0,382	0,525	0,597
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Relative units	0,622	0,638	0,625	0,568	0,471	0,358	0,206	0,087	0,015	0,000	0,000	0,000

Tab. 6.5. 24 hours power generation profile from the solar PV power source simulation in the Mangistau region on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Relative units	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,005	0,041	0,076
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Relative units	0,101	0,098	0,070	0,046	0,022	0,003	0,000	0,000	0,000	0,000	0,000	0,000

Tab. 6.6. 24 hours power generation profile from the wind power source simulation in the Mangistau region on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Relative units	0,034	0,029	0,017	0,010	0,013	0,026	0,049	0,080	0,101	0,114	0,119	0,093
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Relative units	0,094	0,155	0,267	0,326	0,322	0,361	0,454	0,551	0,613	0,609	0,596	0,641

Tab. 6.7. 24 hours power generation profile from the wind power source simulation in the Mangistau region on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Relative units	0,445	0,502	0,545	0,580	0,660	0,632	0,660	0,686	0,718	0,754	0,777	0,811
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Relative units	0,852	0,870	0,856	0,818	0,779	0,713	0,652	0,602	0,404	0,221	0,295	0,531

The required generators data represented in Tab. 6.8., 6.9. [75], [83], [84], [85].

Tab. 6.8. Generators data

GEN BUS	**PG**	**GEN STATUS**	**PMAX**	**PMIN**	**RAMP 10**	**RAMP 30**
bus number	real power output (MW)	machine status, > 0 = machine in-service; ≤ 0 = machine out-of-service	maximum real power output (MW)	minimum real power output (MW)	ramp rate for 10 minute reserves (MW)	ramp rate for 30 minute reserves (MW)
bus	Pg	status	Pmax	Pmin	ramp_10	ramp_30
1	465	1	465	186	30	90
1	450	1	450	180	30	90
2	72	1	72	28,8	30	90

Tab. 6.9. Generators cost data

MODEL	STARTUP	NCOST	MODEL = 2
cost model: 1 = piecewise linear; 2 = polynomial	startup cost in US dollars	number of cost coefficients for polynomial cost function, or number of data points for piecewise linear	(MODEL = 2) ⇒ cn, . . . , c1, c0 n + 1 coefficients of n-th order polynomial cost, starting with highest order, where cost is f(p) = cnp n + · · · + c1p + c0
2	startup	n	c(n-1)
2	21462	2	78
2	20769	2	78
2	3323	2	78

The required bus data represented in Tab. 6.10. [74], [75].

Tab. 6.10. Bus data

BUS I	BASE KV	VMAX	VMIN
bus number	base voltage (kV)	maximum voltage magnitude (p.u.)	minimum voltage magnitude (p.u.)
bus_i	baseKV	Vmax	Vmin
1	220	1,05	0,95
2	110	1,05	0,95
3	220	1,05	0,95

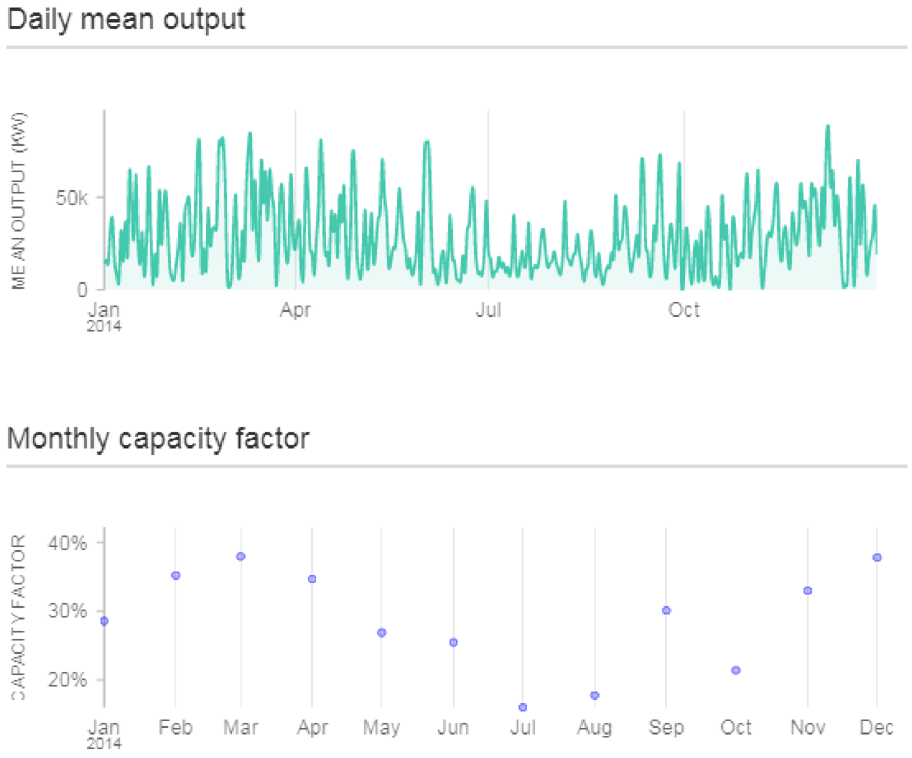
The required branch data represented in Tab. 6.11. [74], [86].

Tab. 6.11. Branch data

F BUS	T BUS	BR R	STATUS
“from” bus number	“to” bus number	resistance (p.u.)	initial branch status, 1 = in-service; 0 = out-of-service
fbus	tbus	r	status
1	2	0,005	1
1	3	0,005	1
2	3	0,005	1

6.3.4. Optimal combination of the RES search and storage unit capacity choosing

According to the analysis for the region, the most relevant are the use of wind and solar energy. To simulate the process of UC with combined production of solar and wind energy, it is necessary to find the optimal fraction of the generation of solar and wind generation. To do this, it is necessary to analyze the generation of wind and solar energy in the proposed location of the installation for a certain period. For the purposes of this study, a period of one year is taken. Using the Renewables.ninja [76] tool, the following data was obtained, which are presented in the Fig. 6.14., 6.15. The table (Tab. 6.12.) gives the same data given in relative units.



Total mean capacity factor: 28.6%

Fig. 6.14. Renewables.ninja 100 MW wind farm power output profile simulation for the year 2014 [76]

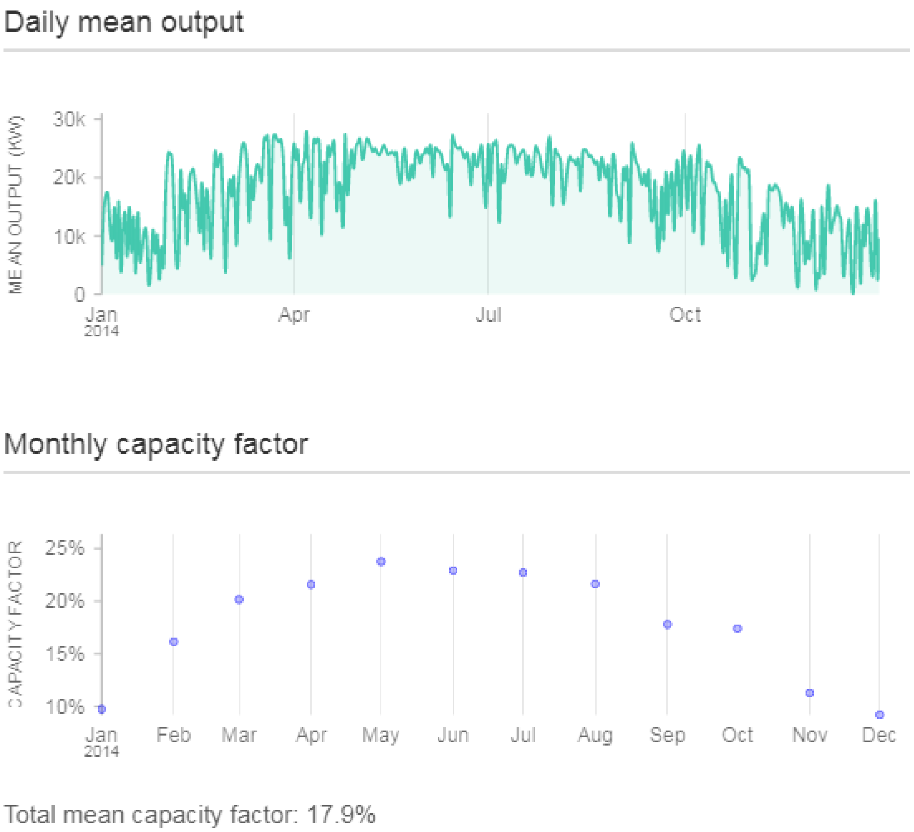


Fig. 6.15. Renewables.ninja 100 MW PV solar plant power output profile simulation for the year 2014 [76]

Tab. 6.12. 12 months power generation profiles from the wind and PV solar plant sources simulation in the Mangistau region for the year 2014 [76]

Months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Wind, Relative units	0,2858	0,3521	0,3795	0,3467	0,2689	0,2546	0,1604	0,1779	0,301	0,2143	0,3198	0,3779
Solar, Relative units	0,0975	0,1618	0,2016	0,2159	0,2376	0,2292	0,2272	0,2165	0,1781	0,1742	0,1129	0,0922

The solution of this problem can be represented as a solution to the problem of nonlinear optimization (NLP). There are many mathematical methods for solving such problems. According the studies [87] one of the most suitable methods is the Generalized Reduced Gradient Method (GRG). The basic idea of GRG method can be explained as a linearizing the non-linear objective and constraint functions at a local solution with Taylor expansion equation. Then, the concept of reduced gradient method is employed which divides the variable set into two subsets of basic and non-basic variable and the concept of implicit variable elimination to express the basic variable by the non-basic variable. Finally, the constraints are eliminated, and the variable space is deduced to only non-basic variables. The processes repeat again until it fulfills the optimal conditions [87]. In general case mathematically, the method can be written as [88]:

$$\min \boldsymbol{f}(\boldsymbol{x}) \tag{6.27}$$

$$\text{subject to } g_i(X) = 0,\ i = 1, \dots, m \tag{6.28}$$

$$l_i \le X_i \le u_i,\ i = 1, \dots, n \tag{6.29}$$

where X in n – vector and l_i, u_i are given upper and lower bounds $u_i > l_i$.

To find the optimal proportion of wind and solar generation by implementing GRG method the Microsoft Excel Solver will be used [89]. Since the data for the simulation is represented in relative units, the following restrictions will be imposed, and the formulation of the result can be written as:

$$P_{Ai} = P_{wi} \cdot l_i + P_{si} \cdot u_i,\ i = 1, \dots, n \tag{6.30}$$

$$0 \le l_i \le 1 \tag{6.31}$$

$$0 \le u_i \le 1 \tag{6.32}$$

$$P_{Ai} \le 1 \tag{6.33}$$

where P_{Ai} is an aggregated power from wind and solar sources for the period; P_{wi} – is a power from wind source for the period; P_{si} – is a power from solar source for the period; n – number of periods.

According to the results of calculations, in order to achieve the installed capacity of the combined installation of a solar and wind power plant in 100%, the share of each type of energy should be 100%. This means that, say, to obtain a capacity of 100 MW, from wind and sun at the same time, the installed capacity of 100 MW of both a solar power plant and a wind power station is needed. The results of the calculation in relative units are represented in Tab. 6.13. and Fig. 6.16.

Tab. 6.13. 12 months aggregated power generation profile from the wind and PV solar plant sources in the Mangistau region for the year 2014

Months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Aggregated, Relative units	0,3833	0,5139	0,5811	0,5626	0,5065	0,4838	0,3876	0,3944	0,4791	0,3885	0,4327	0,4701

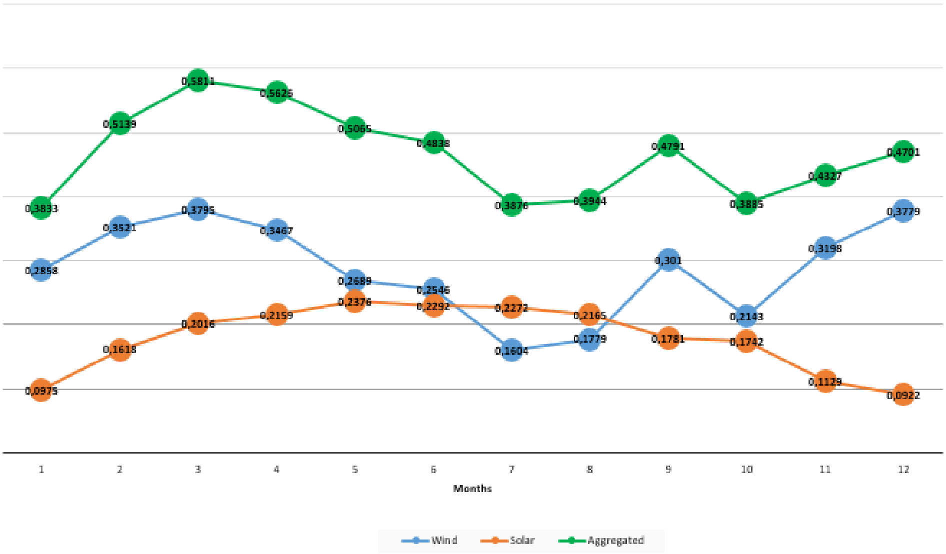


Fig. 6.16. 12 months aggregated power generation profile from the wind and PV solar plant sources in the Mangistau region for the year 2014. Source: author's calculations

For the purpose of the UC simulation, daily power output profile from the aggregated power sources with the 100% of wind and solar capacities impact were calculated for the specified days. The results of the calculation in relative units are represented in Tab. 6.14., 6.15. and Fig. 6.17., 6.18.

Tab. 6.14. 24 hours aggregated power generation profile from the wind and PV solar plant sources in the Mangistau region on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Relative units	0,034	0,029	0,017	0,01	0,013	0,026	0,053	0,156	0,319	0,496	0,644	0,69
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Relative units	0,716	0,793	0,892	0,894	0,793	0,719	0,66	0,638	0,628	0,609	0,596	0,641

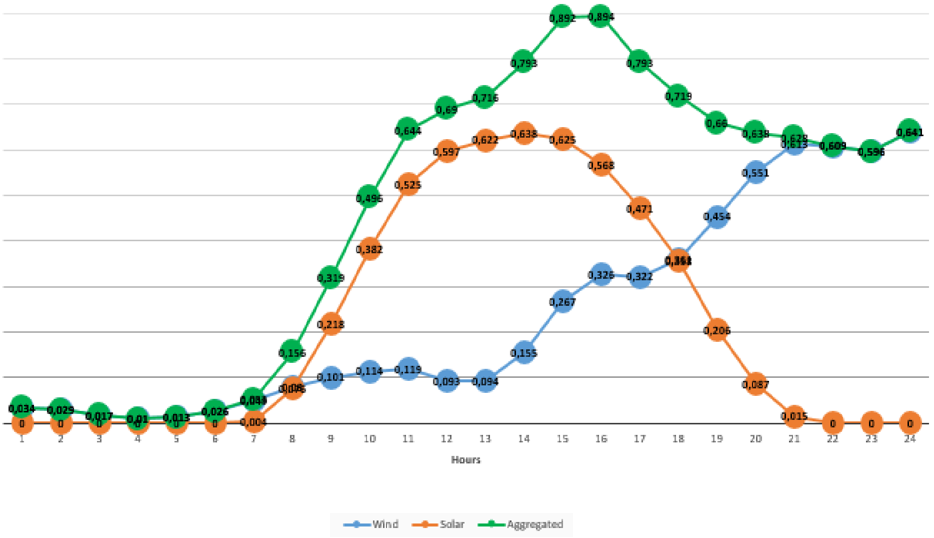


Fig. 6.17. 24 hours aggregated power generation profile from the wind and PV solar plant sources in the Mangistau region on 22.06.2014. Source: author’s calculations

Tab. 6.15. 24 hours aggregated power generation profile from the wind and PV solar plant sources in the Mangistau region on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Relative units	0,445	0,502	0,545	0,58	0,66	0,632	0,66	0,686	0,718	0,759	0,818	0,887
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Relative units	0,953	0,968	0,926	0,864	0,801	0,716	0,652	0,602	0,404	0,221	0,295	0,531

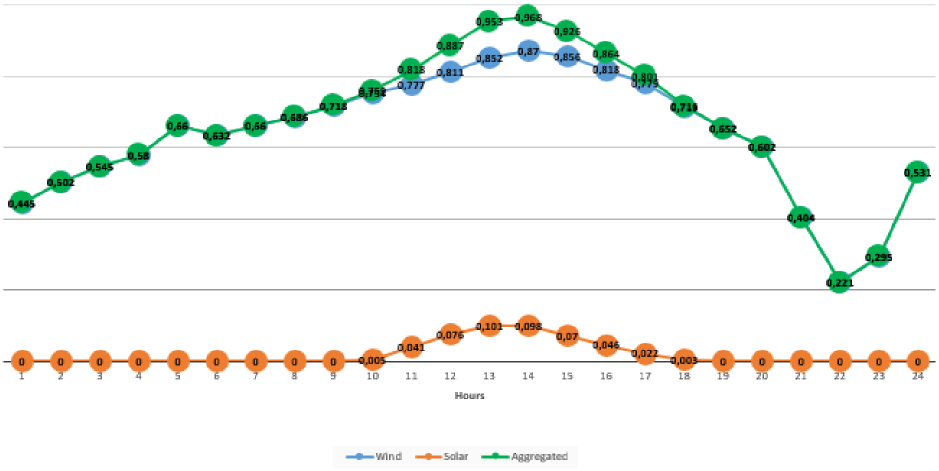


Fig. 6.18. 24 hours aggregated power generation profile from the wind and PV solar plant sources in the Mangistau region on 22.12.2014. Source: author’s calculations

The energy, produced from the RES can be characterized as variable generation (VG) and as already mentioned, this creates certain difficulties for the involvement of RES in the overall generation. One of the solutions to this problem is the creation of a power storage facilities. The main purpose of the power storage facility is to smooth out the peaks of electricity generation and consumption. That is why a lot of types of storage technologies are being developed and implemented during the past decades with different characteristics Tab. 6.16. [90].

Tab. 6.16. Characteristics of various types of electricity storage facilities

Conversion	Storage type	EUR/kWh	EUR/kW	Cycles (100%)	Efficiency
Mechanical	Supercapacitor	3,800–4,000	100–400	10,000–100,000	95–100 %
	Flywheels	1,000–3,000	300	20,000–60,000	90–95 %
	Pumped Hydro	60–150	500	20,000–50,000	70–85 %
	Compressed Air	30–120	550	9,000–20,000	70–80 %
Electrochemical	Nickel-metal hydride	700–800	–	500–3,000	65 %
	Nickel-Cadmium	350–800	175	1,000–3,000	60–70 %
	Sodium-Sulfur	200–900	150	2,000–3,000	85–90 %
	Lithium-Ion	200–500	175	3,000–6,000	95–100 %
	Vanadium Redox-Flow	100–1,000	175	2,000–3,000	75–85 %
	Zinc-Bromine	50–400	175	> 2,000	70 %
	Zinc-Bromine	50–300	175	200–1,100	75 %

Such facilities seem expensive but the price for storage energy installations continuously goes down Fig. 6.19. [91].

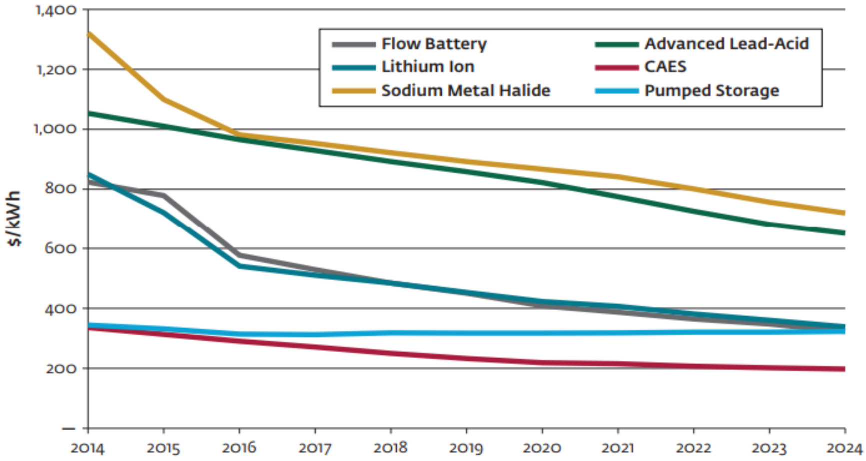


Fig. 6.19. Storage energy facilities systems installation price trends [91]

The average price for stored energy for consumers nowadays is about 300–500 \$/MWh. The lowest price is 190 \$/MWh [92]. So, in the simulation will be considered a central large-scale stationary battery with endogenous capacity and conversion efficiency factor 75% with a price of storage energy of 190 \$/MWh. Therefore, to cover the peaks of electricity fluctuations, the installed capacity of the storage should be 25% greater than its nominal capacity. To calculate the nominal capacity of the electric power storage, it is proposed to use and approbate in the model of the method, which can be expressed by the formula

$$P_S = P_{dRESmax} - P_{dRESmin} \tag{6.34}$$

where P_S – nominal power of the storage unit; $P_{dRESmax}$ – daily maximum power output from RES; $P_{dRESmin}$ – daily minimum power output from RES.

The results of calculations of the initial data for the electric power storage for each case of modeling of RES involvement are presented in Tab. 6.17.

Tab. 6.17. — Input data for the energy storage unit

RES power, MW	$\boldsymbol{P_S \cdot 1.25}$**, wind**	$\boldsymbol{P_S \cdot 1.25}$**, PV solar**	$\boldsymbol{P_S \cdot 1.25}$**, aggregated**
250	269	214	299
297	319	255	356
547	588	469	655

6.3.5. UC simulation with different constraints

The UC simulation will be executed for the cases specified in Tab. 6.15.

Tab. 6.15. UC simulation cases

RES type	**RES power, MW**	**Storage capacity, MW**	**Load, region**	**Period, winter, 22.12.2014**	**Period, summer, 22.06.2014**
Wind	250	269	Mangistau	X, storage	X, storage
Solar	250	214	Mangistau	X, storage	X, storage
Aggregated	250	299	Mangistau	X, storage	X, storage
Wind	297	319	West	X, storage	X, storage
Solar	297	255	West	X, storage	X, storage
Aggregated	297	356	West	X, storage	X, storage
Wind	547	588	West	X, storage	X, storage
Solar	547	469	West	X, storage	X, storage
Aggregated	547	655	West	X, storage	X, storage

For the 'West' load cases the following load profile will be used (Tab. 6.16., 6.17.). These profiles include the total load of the west region of the electrical network of Kazakhstan.

Tab. 6.16. 24 hours power consumption data for the West region on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Power, MW	836	824	825	827	826	824	827	775	773	783	780	778
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Power, MW	784	780	781	782	762	772	771	773	818	823	821	815

Tab. 6.17. 24 hours power consumption data for the West region on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Power, MW	978	968	963	978	978	973	973	884	869	873	877	871
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Power, MW	873	869	875	866	868	859	868	974	960	960	948	938

Network simulation scheme with RES and the energy storage is represented on Fig. 6.20.

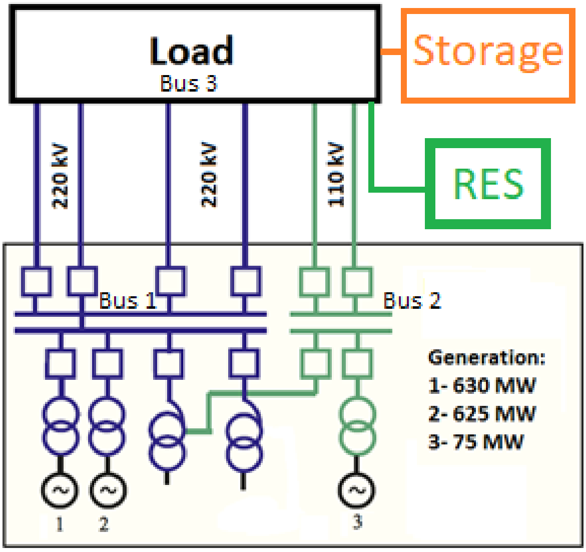


Fig. 6.20. Electrical scheme of the modeling part of the electrical grid with RES and the energy storage. Source: author's calculations

Estimation of the efficiency of the use of different types of renewable energy sources will be performed on such parameters as: the share of each type of the RES in daily generation during the control periods, the possibility of replacing traditional generating capacities with RES and the absence of electricity flows to the external network.

The simulation results for the case with RES wind 250 MW, storage capacity 269 MW, load region – Mangistau on 22.12.2014 are represented in Tab. 6.18., 6.19. and Fig. 6.21., 6.22.

Tab. 6.18. 24 hours power generation profile for the case with RES wind 250 MW, load region – Mangistau on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	389.75	365.5	356	356	338	338	302	235.5	212.5	207.5	205.75	191.25
Gen 2, MW	180	180	180	180	180	180	180	180	180	180	180	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	-6.25	0.00	-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	196.25	203.75	228	300.5	382	427.75	397.25	328.25
Gen 2, MW	180	180	180	180	180	180	180	180	180	180	180	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	-3.00	-11.50	-2.00	-1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

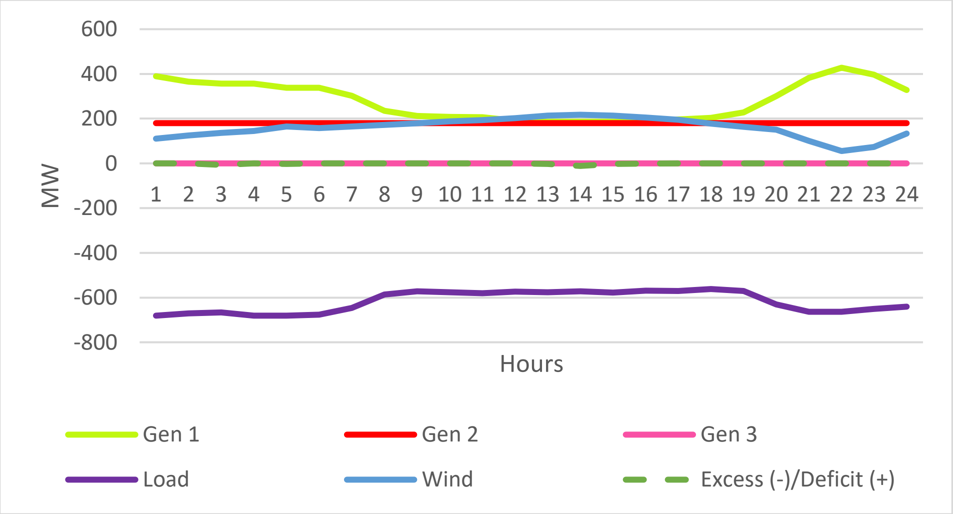


Fig. 6.21. 24 hours power generation profile for the case with RES wind 250 MW, load region – Mangistau on 22.12.2014. Source: author's calculations

Tab. 6.19. 24 hours power generation profile for the case with RES wind 250 MW, storage capacity 269 MW, load region – Mangistau on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	450.75	450.75	450.75	450.75	445	445	410	386.7	372.4	372.4	372.4	372.4
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	72	72	72	72	72	72	72	28.8	28.8	28.8	28.8	28.8
Storage charge (-) /discharge (+)	47	22.75	7	13.25	-1	1	0	0	-8.7	-13.7	-15.45	-29.95
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	372.4	372.4	372.4	372.4	372.4	372.4	372.4	423.5	465	465	465	436
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	35.6	57	57	62.75	62.75	62.75
Storage charge (-) /discharge (+)	-38.2	-46.7	-37.2	-36.7	-24.95	-17.45	0	0	40	80	49.5	9.5
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

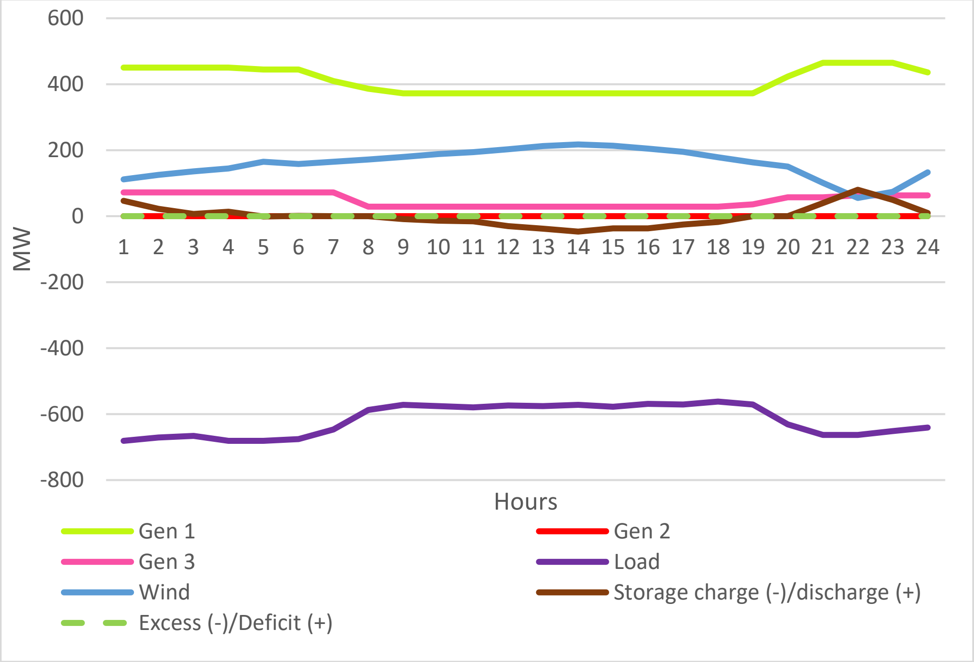


Fig. 6.22. 24 hours power generation profile for the case with RES wind 250 MW, storage capacity 269 MW, load region – Mangistau on 22.12.2014. Source: author's calculations

The simulation results for the case with RES wind 250 MW, storage capacity 269 MW, load region – Mangistau on 22.06.2014 are represented in Tab. 6.20., 6.21. and Fig. 6.23., 6.24.

Tab. 6.20. 24 hours power generation profile for the case with RES wind 250 MW, load region – Mangistau on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	465	465	465	463.25	458	455.25	395.5	395	395	395	395.25
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	65.5	58.75	58.75	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
Excess (-) /Deficit (+)	0.00	-4.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.75	0.00	-4.25	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	401	381.75	369.7	355.95	355.95	355.95	331.7	331.7	338.95	344.95	346.2	328.95
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	62.5	62.5	47.55	47.55	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	-0.25	0.00	0.00	-22.25	0.00	0.00	0.00	0.00

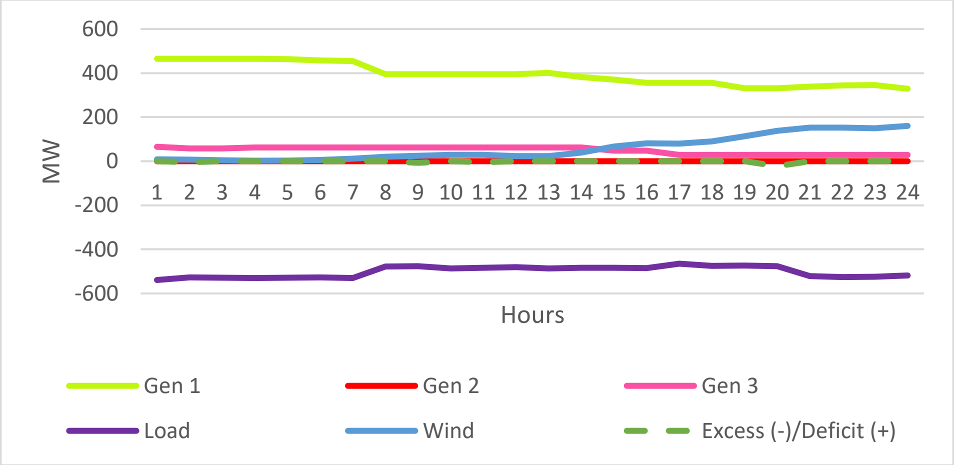


Fig. 6.23. 24 hours power generation profile for the case with RES wind 250 MW, load region – Mangistau on 22.06.2014. Source: author’s calculations

Tab. 6.21. 24 hours power generation profile for the case with RES wind 250 MW, storage capacity 269 MW, load region – Mangistau on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	456.41	456.41	456.41	456.41	456.41	456.41	456.41	429.2	427.75	427.75	427.75	427.75
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Storage charge (-) /discharge (+)	45.28	34.53	38.53	42.28	40.53	35.28	32.53	0	-5.8	0.95	-3.3	1.2
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	427.75	416.35	416.35	403.5	401.41	401.41	401.41	401.41	401.41	401.41	401.41	401.41
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	28.8	28.8	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	6.95	-0.9	0.9	0	-16.91	-16.66	-40.91	-63.16	-33.66	-27.66	-26.41	-43.66
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

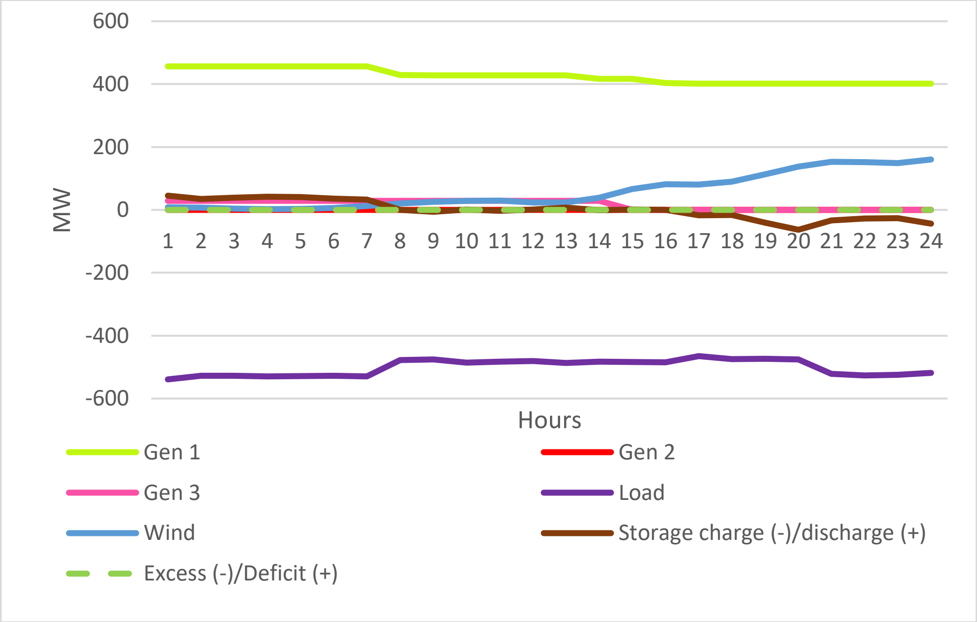


Fig. 6.24. 24 hours power generation profile for the case with RES wind 250 MW, storage capacity 269 MW, load region – Mangistau on 22.06.2014. Source: author’s calculations

The simulation results for the case with RES solar 250 MW, storage capacity 214 MW, load region – Mangistau on 22.12.2014 are represented in Tab. 6.22., 6.23. and Fig. 6.25., 6.26.

Tab. 6.22. 24 hours power generation profile for the case with RES solar 250 MW, load region – Mangistau on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	462.2	457.2	465	465	460	438.2	378.2	363.2	365.95	360.95	346.2
Gen 2, MW	180	180	180	180	180	180	180	180	180	180	180	180
Gen 3, MW	36	28.8	28.8	36	36	36	28.8	28.8	28.8	28.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	341.95	341.95	351.7	351.7	356.7	353.2	353.2	401.2	433.2	433.2	433.2	432.2
Gen 2, MW	180	180	180	180	180	180	189	189	189	189	189	180
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	40.8	40.8	40.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	-3.25	0.00	-3.00	0.00	-0.75	0.00	0.00	0.00	0.00	0.00	0.00

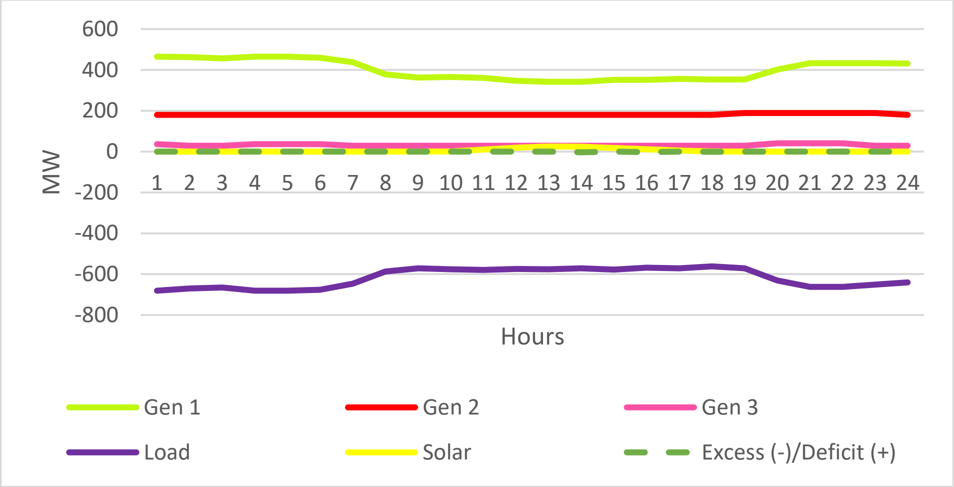


Fig. 6.25. 24 hours power generation profile for the case with RES solar 250 MW, load region – Mangistau on 22.12.2014. Source: author’s calculations

Tab. 6.23. 24 hours power generation profile for the case with RES solar 250 MW, storage capacity 214 MW, load region – Mangistau on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	407	407	407	407	407	407	407	407	401.77	401.77	401.77	401.77
Gen 2, MW	208	208	208	208	208	208	180	180	180	180	180	180
Gen 3, MW	60	60	60	60	60	60	60	0	0	0	0	0
Storage charge (-) /discharge (+)	6	-4	-9	6	6	1	0	0	-9.77	-7.02	-12.02	-26.77
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	401.77	401.77	401.77	401.77	401.77	401.77	401.77	401.77	401.77	401.77	401.77	401.77
Gen 2, MW	180	180	180	180	180	180	180	206.43	206.43	206.43	206.43	206.43
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	-31.02	-34.27	-21.27	-24.27	-16.27	-20.52	-10.77	22.8	54.8	54.8	42.8	32.8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

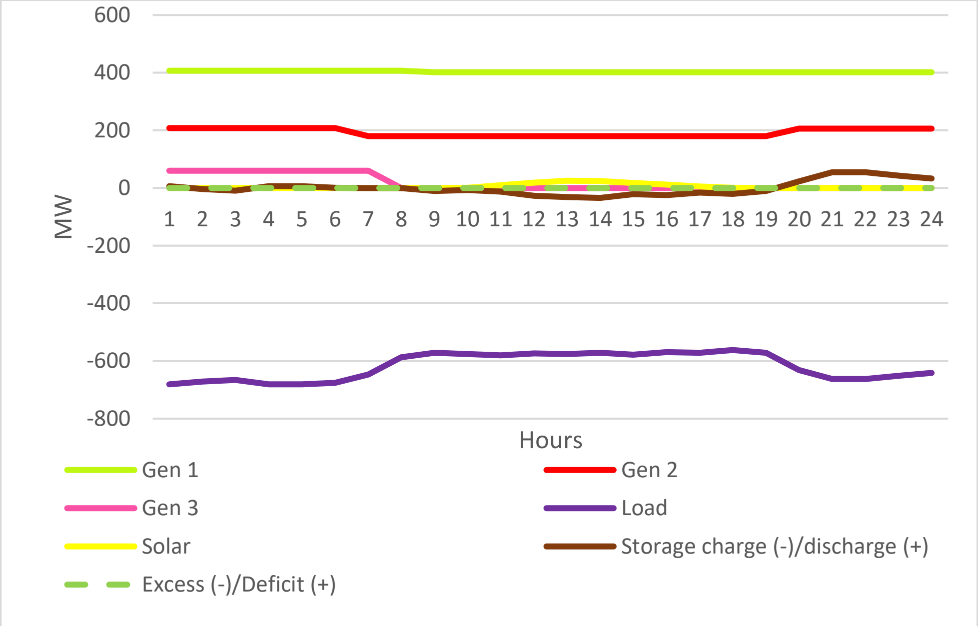


Fig. 6.26. 24 hours power generation profile for the case with RES solar 250 MW, storage capacity 214 MW, load region – Mangistau on 22.12.2014. Source: author's calculations

The simulation results for the case with RES solar 250 MW, storage capacity 214 MW, load region – Mangistau on 22.06.2014 are represented in Tab. 6.24., 6.25. and Fig. 6.27., 6.28.

Tab. 6.24. 24 hours power generation profile for the case with RES solar 250 MW, load region – Mangistau on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	359	347	348	348	347	345	347	277	239.5	210.5	186	186
Gen 2, MW	180	180	180	182	182	182	182	182	182	180	180	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-14.25	-34.25
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	186	205.5	242.5	274.25	335.25	344	344	338
Gen 2, MW	180	180	180	180	180	180	180	180	182	182	180	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	-34.50	-42.50	-38.25	-23.00	-18.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00

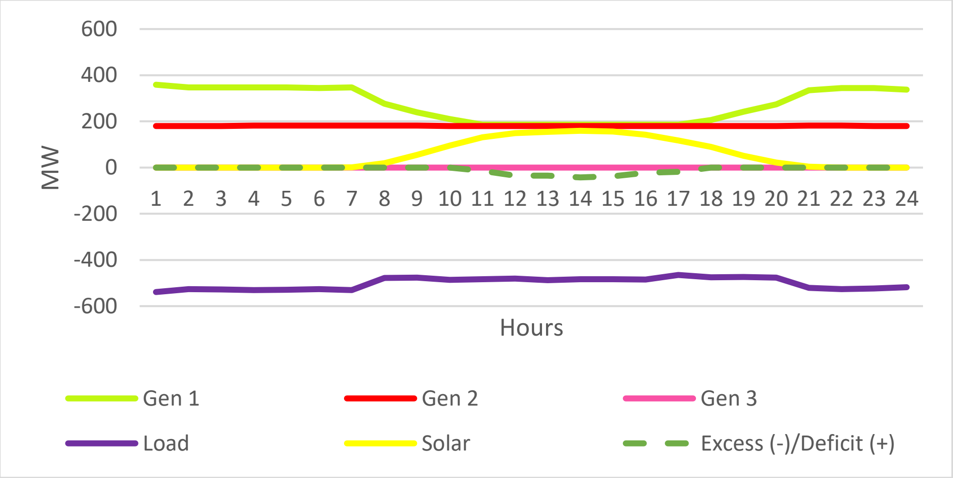


Fig. 6.27. 24 hours power generation profile for the case with RES solar 250 MW, load region – Mangistau on 22.06.2014. Source: author's calculations

Tab. 6.25. 24 hours power generation profile for the case with RES solar 250 MW, storage capacity 214 MW, load region – Mangistau on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	456.5	456.5	456.5	456.5	456.5	456	456	430.2	392.7	361.7	338.41	338.41
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	72	72	72	72	72	72	72	28.8	28.8	28.8	28.8	28.8
Storage charge (-) /discharge (+)	10.5	-1.5	-0.5	1.5	0.5	-1	1	0	0	0	-15.47	-35.47
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	338.41	338.41	338.41	338.41	338.41	338.41	411.99	420	443	443	443	443
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Storage charge (-) /discharge (+)	-35.72	-43.72	-39.47	-24.22	-19.97	18.28	-18.29	5.45	45.45	54.2	52.2	46.2
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

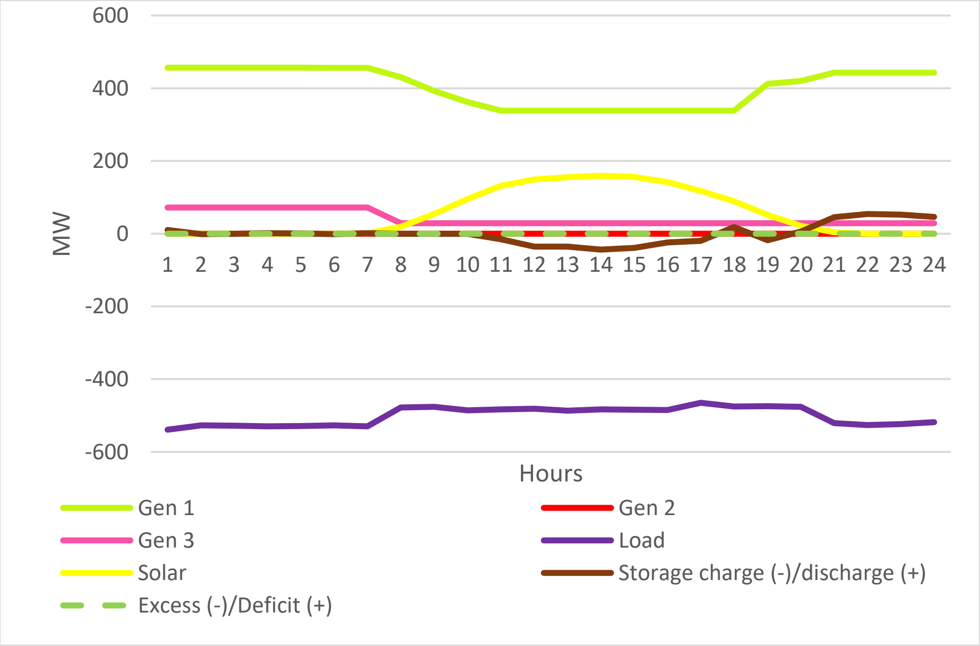


Fig. 6.28. 24 hours power generation profile for the case with RES solar 250 MW, storage capacity 214 MW, load region – Mangistau on 22.06.2014. Source: author's calculations

The simulation results for the case with RES aggregated 250 MW, storage capacity 299 MW, load region – Mangistau on 22.12.2014 are represented in Tab. 6.26., 6.27. and Fig. 6.29., 6.30.

Tab. 6.26. 24 hours power generation profile for the case with RES aggregated 250 MW, load region – Mangistau on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	346.5	322.25	312.75	312.75	294.75	294.75	258.75	192.25	192.25	186	186	186
Gen 2, MW	223.25	223.25	223.25	223.25	223.25	223.25	223.25	223.25	200.25	200.25	189.5	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	-6.25	0.00	-2.00	0.00	0.00	0.00	0.00	0.00	0.00	-13.75
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	190.75	203	228	300.5	351.5	397.25	397.25	328.25
Gen 2, MW	180	180	180	180	180	180	180	180	210.5	210.5	180	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	-28.25	-36.00	-19.50	-13.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

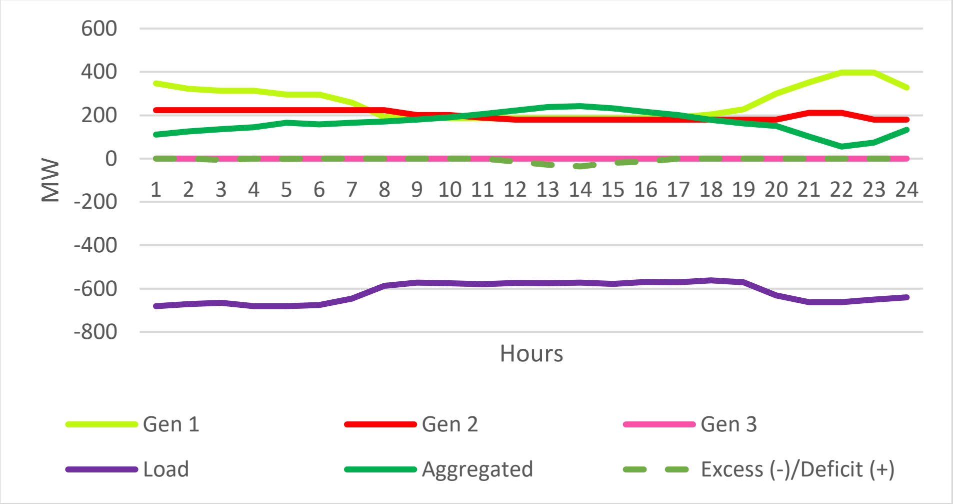


Fig. 6.29. 24 hours power generation profile for the case with RES aggregated 250 MW, load region – Mangistau on 22.12.2014. Source: author’s calculations

Tab. 6.27. 24 hours power generation profile for the case with RES aggregated 250 MW, storage capacity 299 MW, load region – Mangistau on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	445	445	445	445	445	445	410	343.5	320.65	320.65	320.65	320.65
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	52.75	28.5	12.75	19	-1	1	0	0	-0.15	-6.4	-17.15	-40.4
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	320.65	320.65	320.65	320.65	320.65	320.65	336	407.1	448.6	454.35	454.35	425.35
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	-54.9	-62.65	-46.15	-39.65	-21.9	-9.65	0	1.4	41.4	81.4	50.9	10.9
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

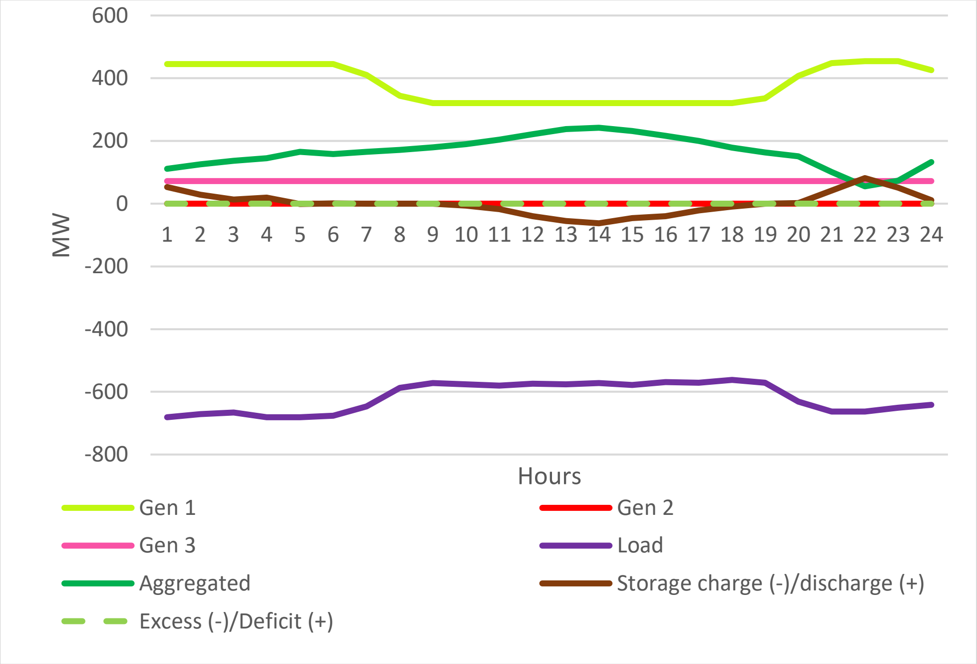


Fig. 6.30. 24 hours power generation profile for the case with RES aggregated 250 MW, storage capacity 299 MW, load region – Mangistau on 22.12.2014. Source: author's calculations

The simulation results for the case with RES aggregated 250 MW, storage capacity 299 MW, load region – Mangistau on 22.06.2014 are represented in Tab. 6.28., 6.29. and Fig. 6.31., 6.32.

Tab. 6.28. 24 hours power generation profile for the case with RES aggregated 250 MW, load region – Mangistau on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	458.25	458.25	462	462	462	462	410.2	367.45	333.2	322	308.5
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	65.5	65.5	65.5	65.5	63.75	58.5	54.75	28.8	28.8	28.8	0	0
Excess (-) /Deficit (+)	0.00	-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	308	284.75	261.5	261.5	266.75	295.25	309	316.5	364	373.75	375	357.75
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	-0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

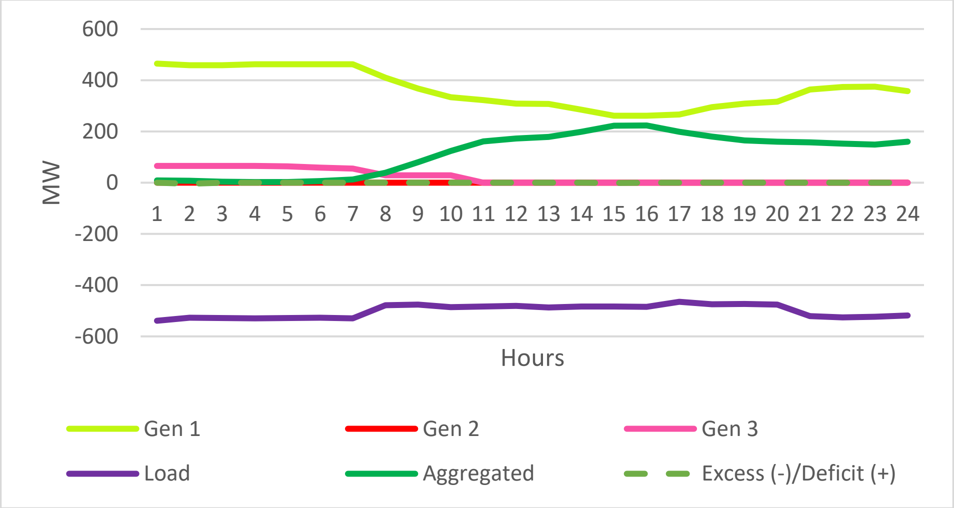


Fig. 6.31. 24 hours power generation profile for the case with RES aggregated 250 MW, load region – Mangistau on 22.06.2014. Source: author's calculations

Tab. 6.29. 24 hours power generation profile for the case with RES aggregated 250 MW, storage capacity 299 MW, load region – Mangistau on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	429.87	429.87	429.87	429.87	429.87	429.87	429.87	410.2	367.45	333.2	323.23	323.23
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	72	72	72	72	72	72	72	28.8	28.8	28.8	0	0
Storage charge (-) /discharge (+)	28.63	17.88	21.88	25.63	23.88	18.63	14.88	0	0	0	-1.23	-14.73
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	323.23	323.23	323.23	323.23	323.23	323.23	323.23	323.23	330.73	330.73	330.73	330.73
Gen 2, MW	0	0	0	0	0	0	0	0	0	0	0	0
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	-15.23	-38.48	-62.23	-61.73	-56.48	-27.98	-14.23	-6.73	33.27	43.02	44.27	27.02
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

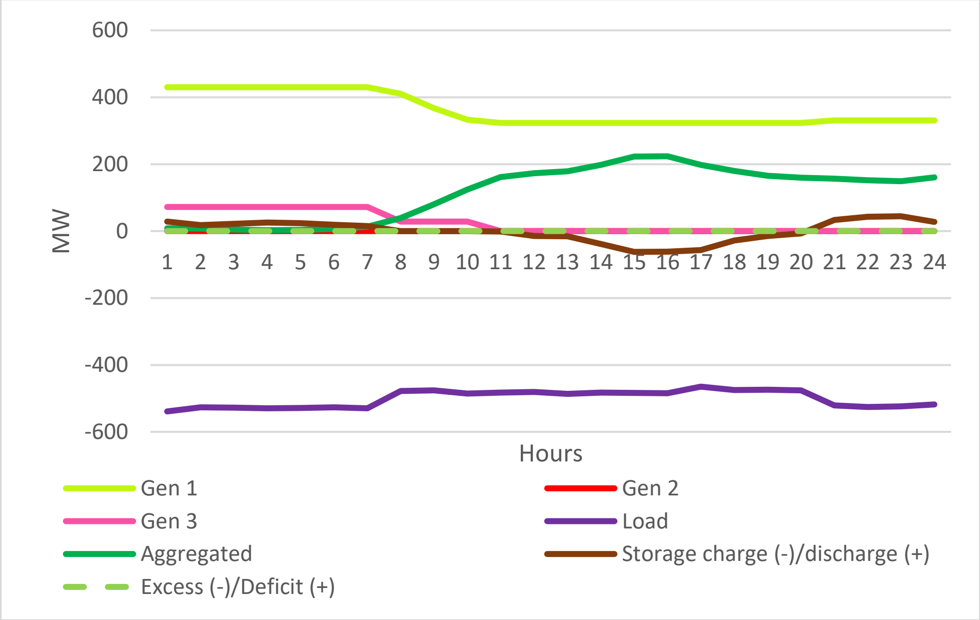


Fig. 6.32. 24 hours power generation profile for the case with RES aggregated 250 MW, storage capacity 299 MW, load region – Mangistau on 22.06.2014. Source: author's calculations

The simulation results for the case with RES wind 297 MW, storage capacity 319 MW, load region – West on 22.12.2014 are represented in Tab. 6.30., 6.31. and Fig. 6.33., 6.34.

Tab. 6.30. 24 hours power generation profile for the case with RES wind 297 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	459.67	432.74	419.58	419.58	399.13	399.13	361.82	294.09	269.59	262.9	260.07	243.97
Gen 2, MW	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	0.00	-4.61	0.00	-3.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	233.79	233.79	234.6	236.89	250.47	261.08	288.19	319.84	410.65	465	431.02	422.93
Gen 2, MW	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36	357.36
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	72	72	72	72	0
Excess (-) /Deficit (+)	0.00	-9.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00

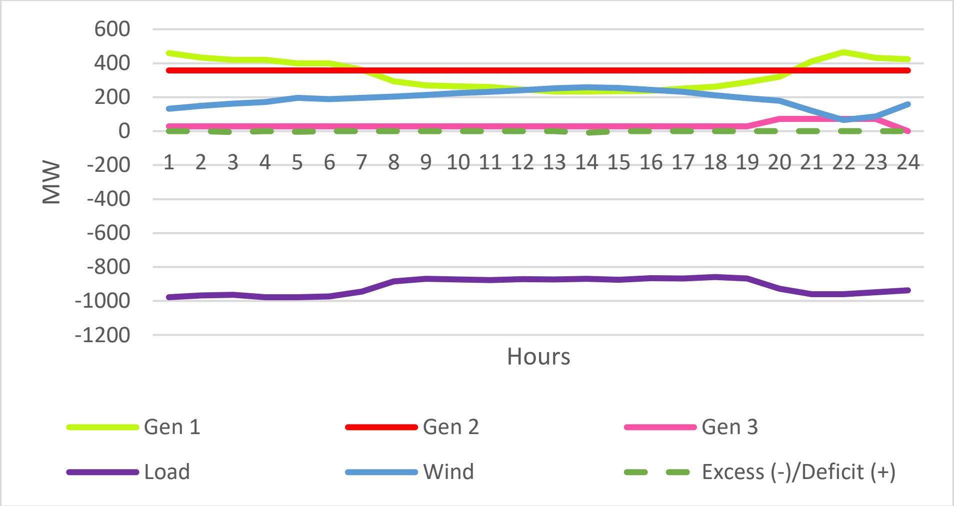


Fig. 6.33. 24 hours power generation profile for the case with RES wind 297 MW, load region – West on 22.12.2014. Source: author's calculations

Tab. 6.31. 24 hours power generation profile for the case with RES wind 297 MW, storage capacity 319 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	333.64	333.64	333.64	333.64	333.64	333.64	297.98	230.26	215.84	215.84	215.84	215.84
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	62.2	35.27	17.5	22.1	-1.66	1.66	0	0	-10.09	-16.78	-19.61	-35.71
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	215.84	215.84	215.84	215.84	215.84	215.84	224.36	297.23	348.04	362.39	362.39	322.29
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	-45.89	-55.24	-45.08	-42.79	-29.21	-18.61	0	1.98	41.98	81.98	48	8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

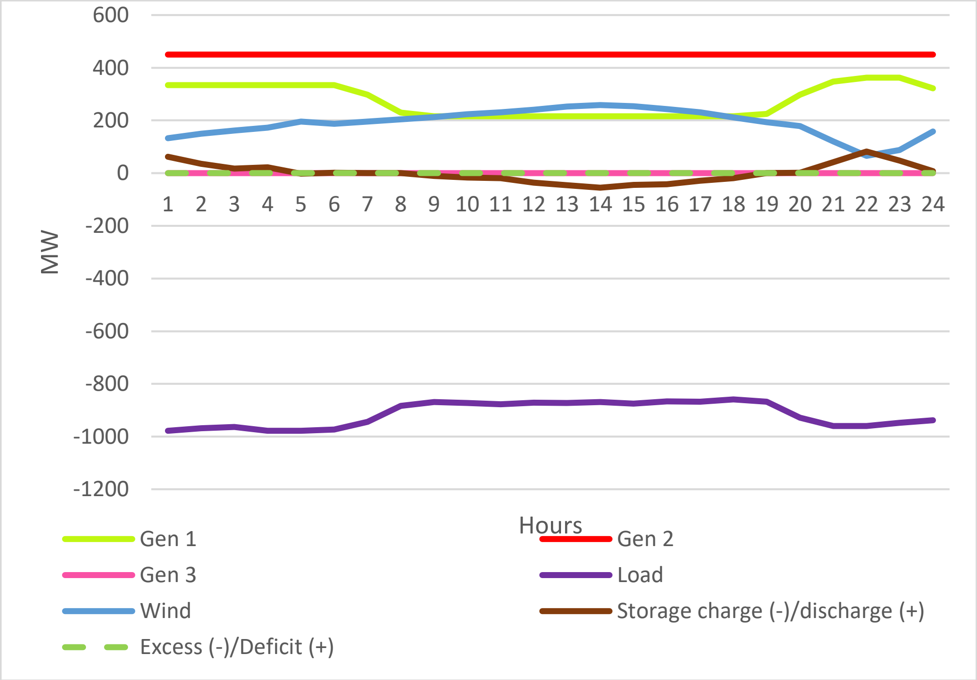


Fig. 6.34. 24 hours power generation profile for the case with RES wind 297 MW, storage capacity 319 MW, load region – West on 22.12.2014. Source: author's calculations

The simulation results for the case with RES wind 297 MW, storage capacity 319 MW, load region – West on 22.06.2014 are represented in Tab. 6.32., 6.33. and Fig. 6.35., 6.36.

Tab. 6.32. 24 hours power generation profile for the case with RES wind 297 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	375.9	374	374	374.03	372.14	366.28	362.45	301.24	301.24	301.24	301.24	302.48
Gen 2, MW	450	450	450	450	450	450	450	450	447.9	447.9	447.9	447.9
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	-8.61	-4.05	0.00	0.00	0.00	0.00	0.00	-6.14	0.00	-4.48	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	308.18	286.06	253.8	237.28	237.28	235.69	207.07	206.85	206.85	213.04	214.9	195.53
Gen 2, MW	447.9	447.9	447.9	447.9	429.09	429.09	429.09	429.09	429.09	429.09	429.09	429.09
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-26.59	0.00	0.00	0.00	0.00

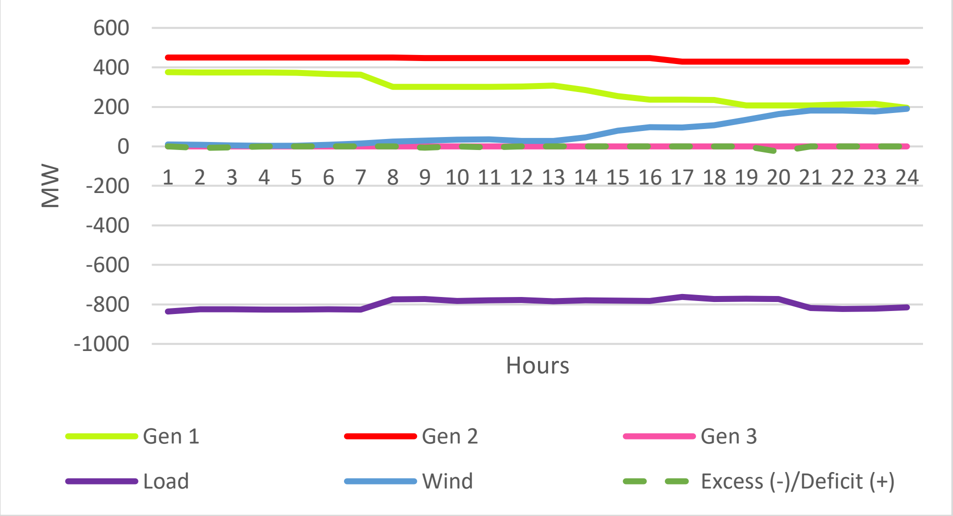


Fig. 6.35. 24 hours power generation profile for the case with RES wind 297 MW, load region – West on 22.06.2014. Source: author’s calculations

Tab. 6.33. 24 hours power generation profile for the case with RES wind 297 MW, storage capacity 319 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	465	465	465	465	465	465	443.17	443.17	443.17	443.17	443.17
Gen 2, MW	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88
Gen 3, MW	72	72	72	72	72	72	72	71.2	68.61	68.61	68.61	68.61
Storage charge (-) /discharge (+)	52.02	41.51	46.07	50.15	48.26	42.4	38.57	0	-5.65	0.49	-4	1.73
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	443.17	443.17	443.17	443.17	443.17	443.17	443.17	443.17	443.17	443.17	443.17	443.17
Gen 2, MW	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88	236.88
Gen 3, MW	68.61	53.92	28.8	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	7.43	0	-7.14	5.13	-13.68	-15.26	-43.88	-70.69	-44.1	-37.92	-36.06	-55.42
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

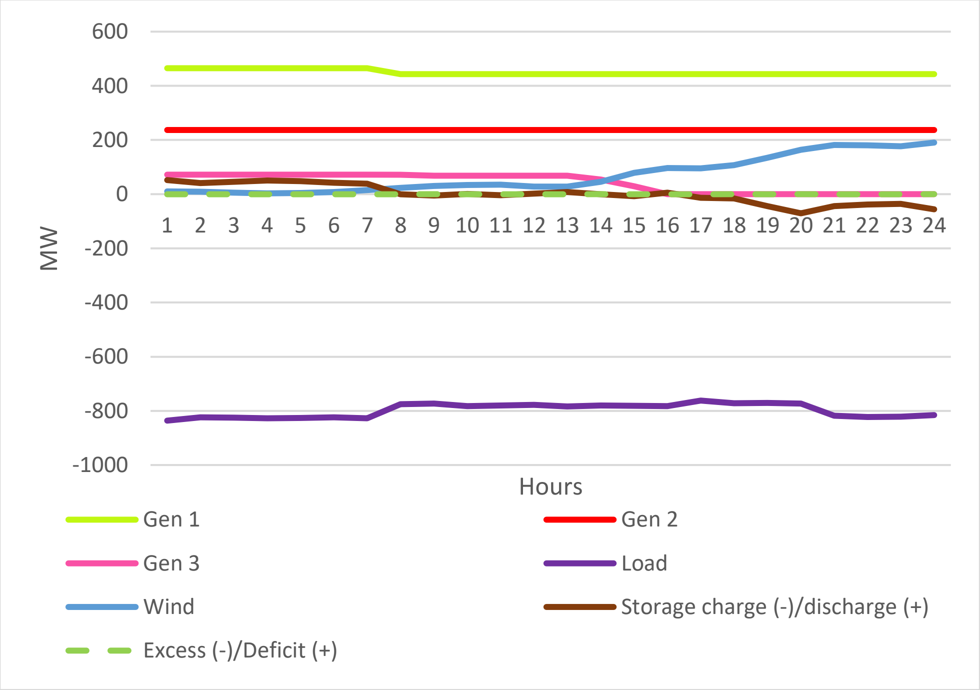


Fig. 6.36. 24 hours power generation profile for the case with RES wind 297 MW, storage capacity 319 MW, load region – West on 22.06.2014. Source: author's calculations

The simulation results for the case with RES solar 297 MW, storage capacity 255 MW, load region – West on 22.12.2014 are represented in Tab. 6.34., 6.35. and Fig. 6.37., 6.38.

Tab. 6.34. 24 hours power generation profile for the case with RES solar 297 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	455	450	465	465	460	431	405.2	390.2	392.71	386.02	369.63
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	63	63	63	63	63	63	63	28.8	28.8	28.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	364.2	364.2	375.41	375.41	382.67	380.2	389.2	433	465	465	453	443
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	45	45	45	45	45
Excess (-) /Deficit (+)	0.00	-3.11	0.00	-1.87	0.00	-0.89	0.00	0.00	0.00	0.00	0.00	0.00

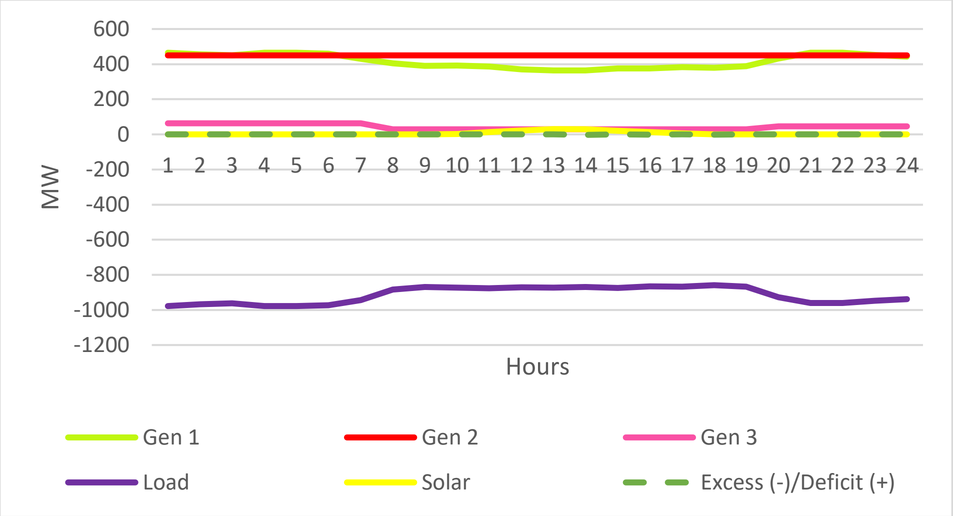


Fig. 6.37. 24 hours power generation profile for the case with RES solar 297 MW, load region – West on 22.12.2014. Source: author's calculations

Tab. 6.35. 24 hours power generation profile for the case with RES solar 297 MW, storage capacity 255 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	447.06	447.06	447.06	447.06	447.06	447.06	422	362	358.53	358.53	358.53	358.53
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	8.94	-1.06	-6.06	8.94	8.94	3.94	0	0	-11.53	-9.01	-15.7	-32.1
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	358.53	358.53	358.53	358.53	358.53	358.53	358.53	378.53	378.53	378.53	378.53	378.53
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	-37.52	-40.63	-26.32	-28.19	-19.06	-22.42	-12.53	27.47	59.47	59.47	47.47	37.47
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

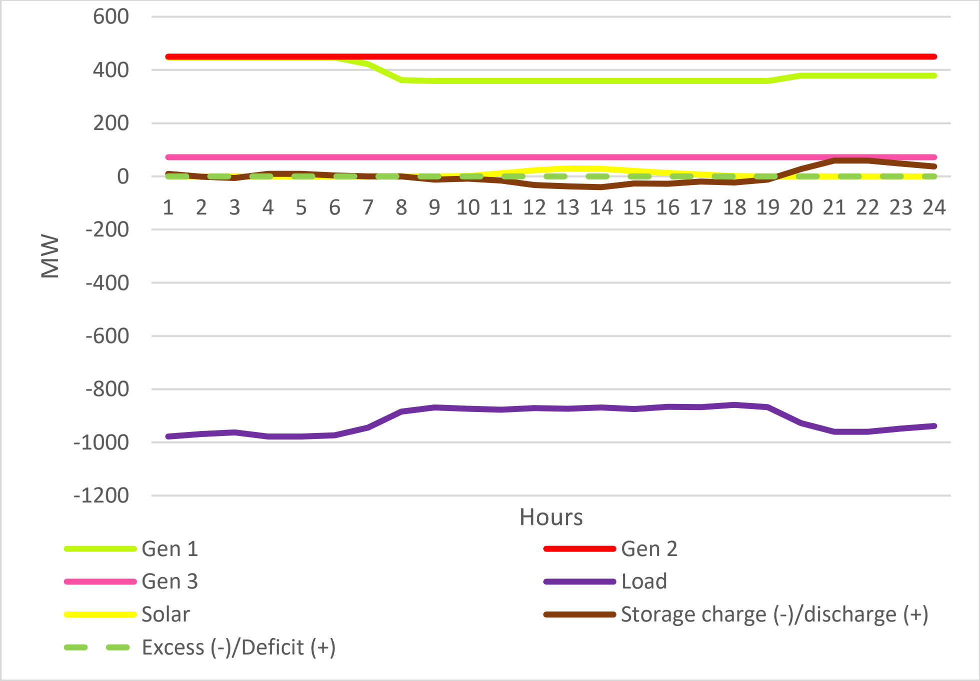


Fig. 6.38. 24 hours power generation profile for the case with RES solar 297 MW, storage capacity 255 MW, load region – West on 22.12.2014. Source: author's calculations

The simulation results for the case with RES solar 297 MW, storage capacity 255 MW, load region – West on 22.06.2014 are represented in Tab. 6.36., 6.37. and Fig. 6.39., 6.40.

Tab. 6.36. 24 hours power generation profile for the case with RES solar 297 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	462	463	465	464	462	463.81	390.43	346.25	307.55	262.08	242.69
Gen 2, MW	338.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2
Gen 3, MW	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	28.8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	241.27	237.38	237.38	255.3	264.11	307.67	351.82	389.16	455.55	465	463	457
Gen 2, MW	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2	329.2
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	-4.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

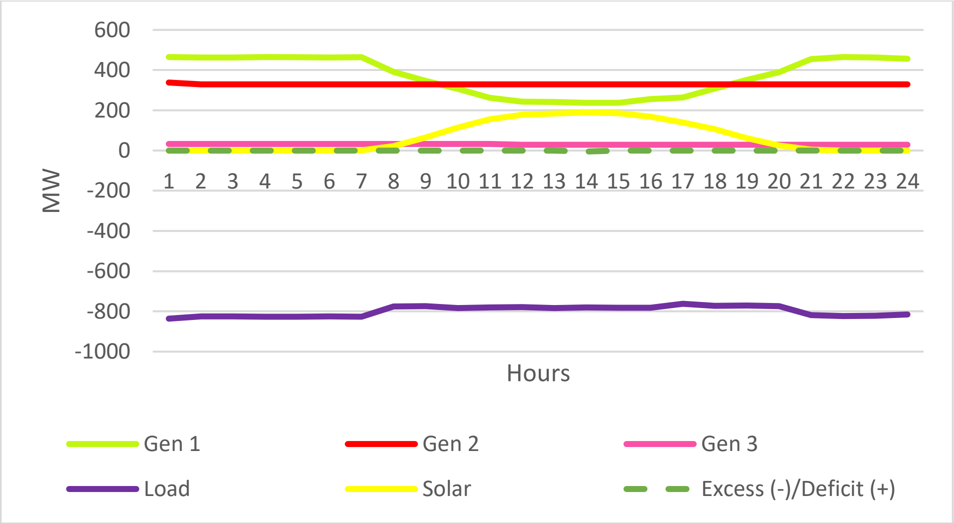


Fig. 6.39. 24 hours power generation profile for the case with RES solar 297 MW, load region – West on 22.06.2014. Source: author's calculations

Tab. 6.37. 24 hours power generation profile for the case with RES solar 297 MW, storage capacity 255 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	303.5	303.5	303.5	303.5	303.5	302.91	302.91	302.91	258.73	220.02	193.38	193.38
Gen 2, MW	450	450	450	450	450	450	450	420.72	420.72	420.72	420.72	420.72
Gen 3, MW	72	72	72	72	72	72	72	28.8	28.8	28.8	28.8	28.8
Storage charge (-) /discharge (+)	10.5	-1.5	-0.5	1.5	0.5	-0.91	0.91	0	0	0	-18.83	-42.22
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	193.38	193.38	193.38	193.38	193.38	196.94	279.51	284.41	284.41	284.41	284.41	284.41
Gen 2, MW	420.72	420.72	420.72	420.72	420.72	420.72	420.72	420.72	420.72	420.72	420.72	420.72
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	55.18	55.18	55.18	55.18
Storage charge (-) /discharge (+)	-43.64	-52.39	-47.53	-29.6	-20.79	19.21	-19.21	13.23	53.23	62.68	60.68	54.68
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

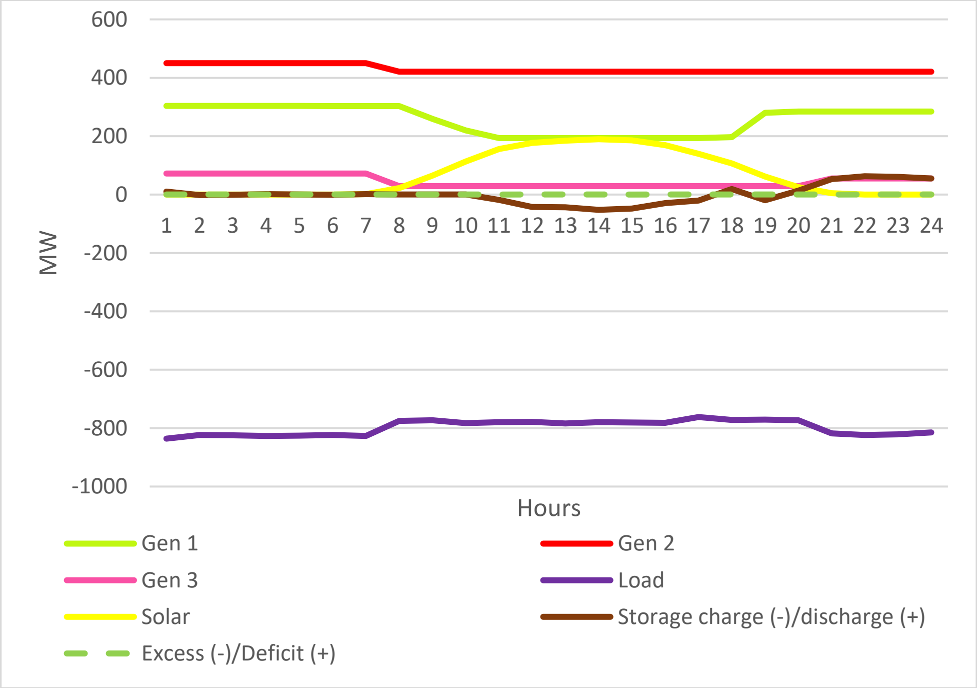


Fig. 6.40. 24 hours power generation profile for the case with RES solar 297 MW, storage capacity 255 MW, load region – West on 22.06.2014. Source: author's calculations

The simulation results for the case with RES aggregated 297 MW, storage capacity 356 MW, load region – West on 22.12.2014 are represented in Tab. 6.38., 6.39. and Fig. 6.41., 6.42.

Tab. 6.38. 24 hours power generation profile for the case with RES aggregated 297 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	441.88	414.95	401.78	401.78	381.34	381.34	344.02	276.3	251.8	243.62	230.1	203.6
Gen 2, MW	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Excess (-) /Deficit (+)	0.00	0.00	-4.61	0.00	-3.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	196.02	205.43	226.14	242.39	270.4	345.25	436.05	465	431.02	422.93
Gen 2, MW	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96	331.96	357.36	357.36	357.36
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	0
Excess (-) /Deficit (+)	0.00	-8.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00

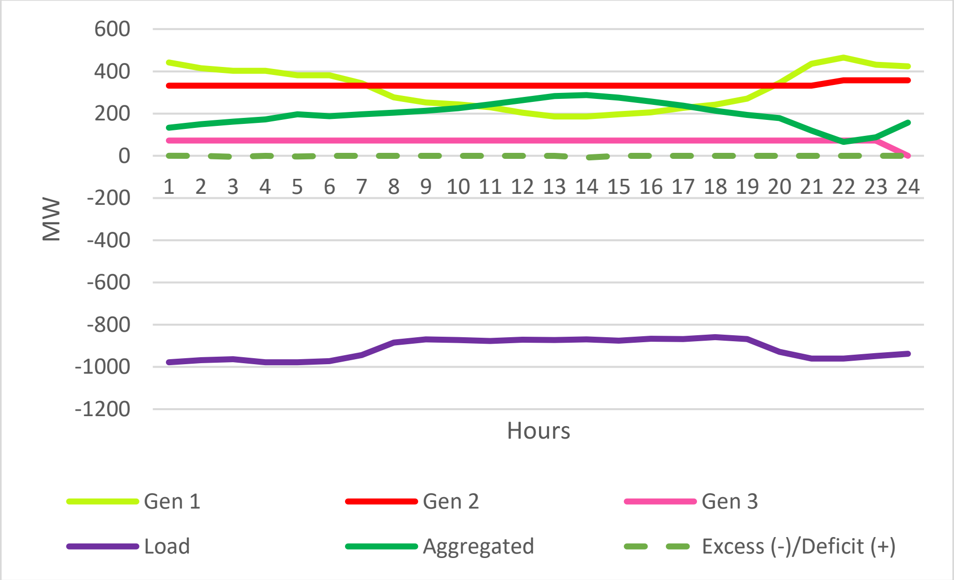


Fig. 6.41. 24 hours power generation profile for the case with RES aggregated 297 MW, load region – West on 22.12.2014. Source: author’s calculations

Tab. 6.39. 24 hours power generation profile for the case with RES aggregated 297 MW, storage capacity 356 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	261.64	261.64	261.64	261.64	261.64	261.64	225.98	210.43	186	186	186	186
Gen 2, MW	450	450	450	450	450	450	450	397.82	397.82	397.82	397.82	397.82
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	62.2	35.27	17.5	22.1	-1.66	1.66	0	0	-0.07	-8.25	-21.77	-48.26
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	186	186	204.53	270.01	282.99	282.99	282.99	242.89
Gen 2, MW	397.82	397.82	397.82	397.82	397.82	397.82	397.82	397.82	435.65	450	450	450
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	-65.87	-74.32	-55.85	-46.43	-25.72	-9.48	0	9.38	49.38	89.38	55.4	15.4
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

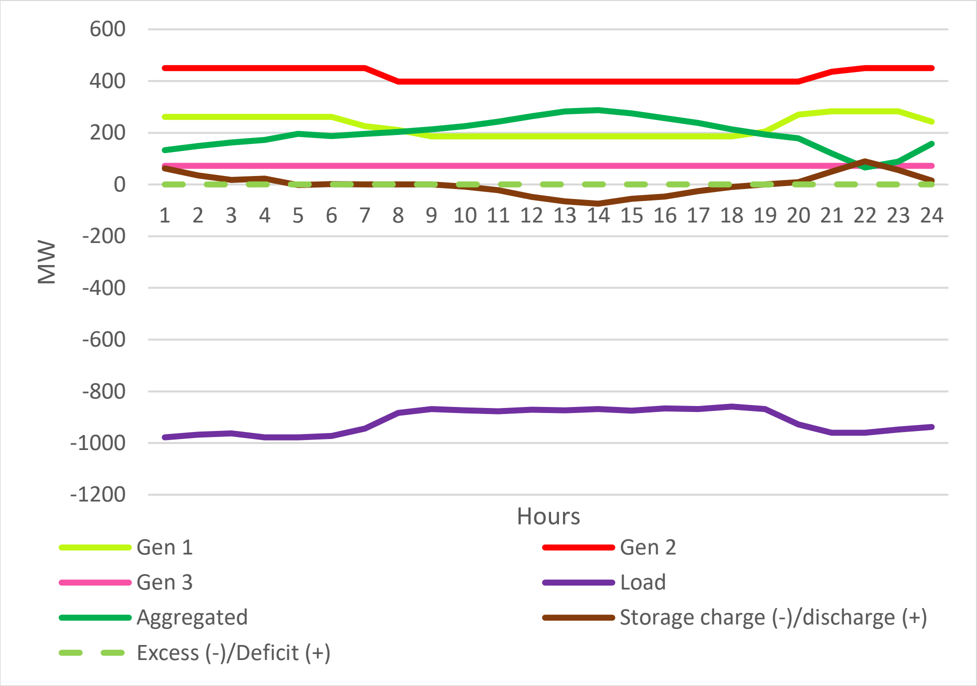


Fig. 6.42. 24 hours power generation profile for the case with RES aggregated 297 MW, storage capacity 356 MW, load region – West on 22.12.2014. Source: author's calculations

The simulation results for the case with RES aggregated 297 MW, storage capacity 356 MW, load region – West on 22.06.2014 are represented in Tab. 6.40., 6.41. and Fig. 6.43., 6.44.

Tab. 6.40. 24 hours power generation profile for the case with RES aggregated 297 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	460.67	460.67	460.67	464.75	462.86	457	451.98	369.39	347.78	305.21	258.25	242.59
Gen 2, MW	336.43	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	0	0	0	0
Excess (-) /Deficit (+)	0.00	-4.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	240.87	214	186	186	196	227.98	244.5	253.03	301	311.65	313.51	294.14
Gen 2, MW	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48	330.48
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	-0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

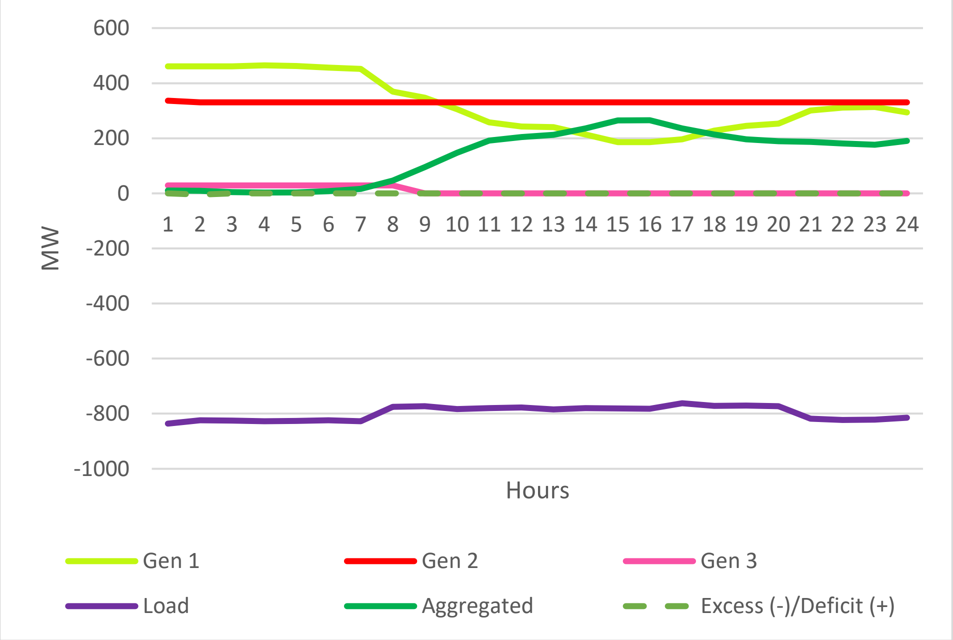


Fig. 6.43. 24 hours power generation profile for the case with RES aggregated 297 MW, load region – West on 22.06.2014. Source: author's calculations

Tab. 6.41. 24 hours power generation profile for the case with RES aggregated 297 MW, storage capacity 356 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	339.35	339.35	339.35	339.35	339.35	339.35	339.35	278.67	228.26	228.26	186	186
Gen 2, MW	450	450	450	450	450	450	450	450	450	407.43	404.96	404.96
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	36.55	26.04	30.6	34.68	32.79	26.93	21.91	0	0	0	-2.23	-17.89
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	186	186	186	186	186	186	186	186
Gen 2, MW	404.96	404.96	404.96	404.96	404.96	404.96	404.96	404.96	412.93	412.93	412.93	412.93
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	-19.62	-46.48	-74.89	-74.48	-64.48	-32.51	-15.98	-7.45	32.55	43.19	45.05	25.69
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

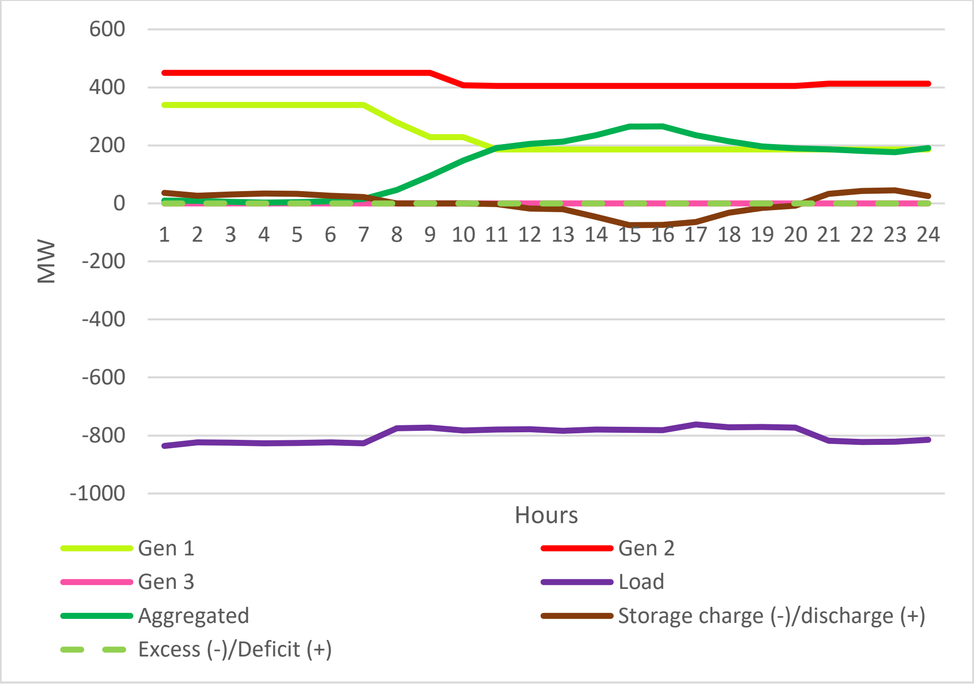


Fig. 6.44. 24 hours power generation profile for the case with RES aggregated 297 MW, storage capacity 356 MW, load region – West on 22.06.2014. Source: author's calculations

The simulation results for the case with RES wind 547 MW, storage capacity 588 MW, load region – West on 22.12.2014 are represented in Tab. 6.42., 6.43. and Fig. 6.45., 6.46.

Tab. 6.42. 24 hours power generation profile for the case with RES wind 547 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	429.44	400.92	396.77	363.33	363.33	319.01	244.79	212.29	196.59	188.01	188.01
Gen 2, MW	197.58	191.97	191.97	191.97	191.97	191.97	191.97	191.97	191.97	191.97	191.97	191.97
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	47.4
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	-10.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186.19	186	186	197.79	221.12	248.22	290.59	377.94	377.94	377.94	354.26	215.17
Gen 2, MW	191.97	191.97	191.97	191.97	191.97	191.97	191.97	191.97	332.27	432.37	432.37	432.37
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	0	0
Excess (-) /Deficit (+)	0.00	-13.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

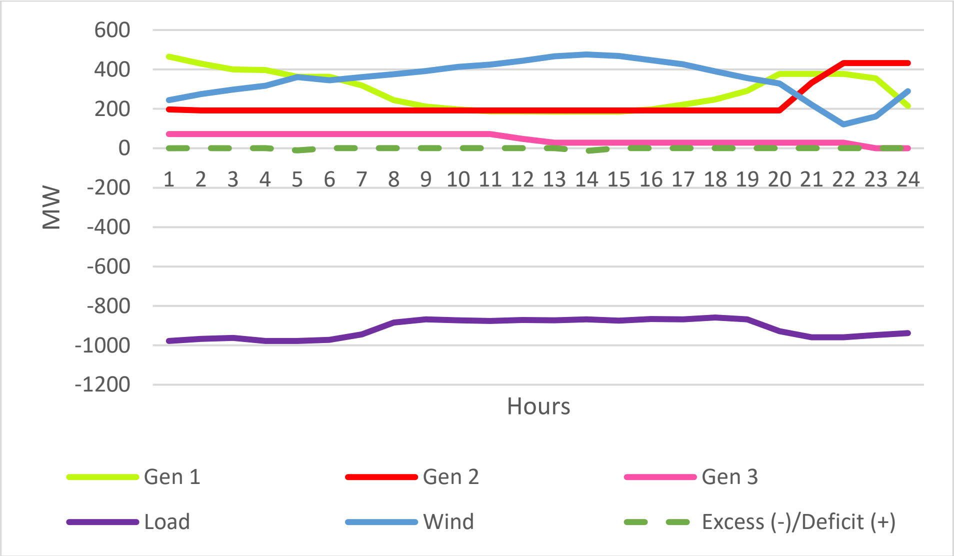


Fig. 6.45. 24 hours power generation profile for the case with RES wind 547 MW, load region – West on 22.12.2014. Source: author's calculations

Tab. 6.43. 24 hours power generation profile for the case with RES wind 547 MW, storage capacity 588 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	288.38	287.2	287.2	287.2	283.44	283.44	244.28	244.28	229.57	229.57	229.57	229.57
Gen 2, MW	266.7	266.7	266.7	266.7	266.7	266.7	266.7	192.48	192.48	192.48	192.48	192.48
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	107.51	67.51	38.99	34.84	-5.16	5.16	0	0	-17.79	-33.49	-42.07	-66.66
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	229.57	229.57	229.57	229.57	229.57	229.57	246.88	298.4	398.71	458.81	458.81	431.72
Gen 2, MW	192.48	192.48	192.48	192.48	192.48	192.48	192.48	192.48	192.48	192.48	180	180
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	0
Storage charge (-) /discharge (+)	-87.09	-100.94	-87.28	-75.49	-52.16	-25.06	-0.01	35.83	75.83	115.83	75.83	35.83
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

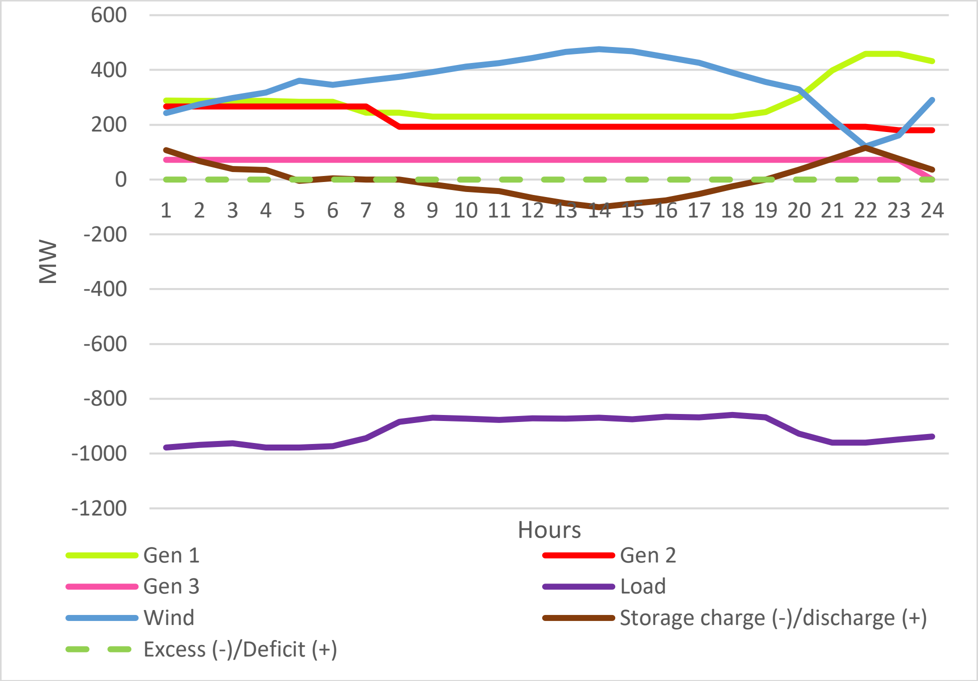


Fig. 6.46. 24 hours power generation profile for the case with RES wind 547 MW, storage capacity 588 MW, load region – West on 22.12.2014. Source: author's calculations

The simulation results for the case with RES wind 547 MW, storage capacity 588 MW, load region – West on 22.06.2014 are represented in Tab. 6.44., 6.45. and Fig. 6.47., 6.48.

Tab. 6.44. 24 hours power generation profile for the case with RES wind 547 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	301.23	299.53	299.53	299.53	296.89	287.78	278.2	209.24	209.24	209.24	209.24	215.73
Gen 2, MW	450	450	450	450	450	450	450	450	439.4	439.4	439.4	439.4
Gen 3, MW	66.17	66.17	66.17	72	72	72	72	72	72	72	72	72
Excess (-) /Deficit (+)	0.00	-7.56	0.00	0.00	0.00	0.00	0.00	0.00	-2.89	0.00	-5.73	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	221.18	189.98	189.98	189.98	189.98	189.98	189.98	186	186	186	186	186
Gen 2, MW	439.4	433.23	372.97	372.97	355.15	343.82	303.88	303.88	303.88	303.88	308.99	278.37
Gen 3, MW	72	72	72	40.73	40.73	40.73	28.8	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-18.28	-7.19	0.00	0.00	0.00

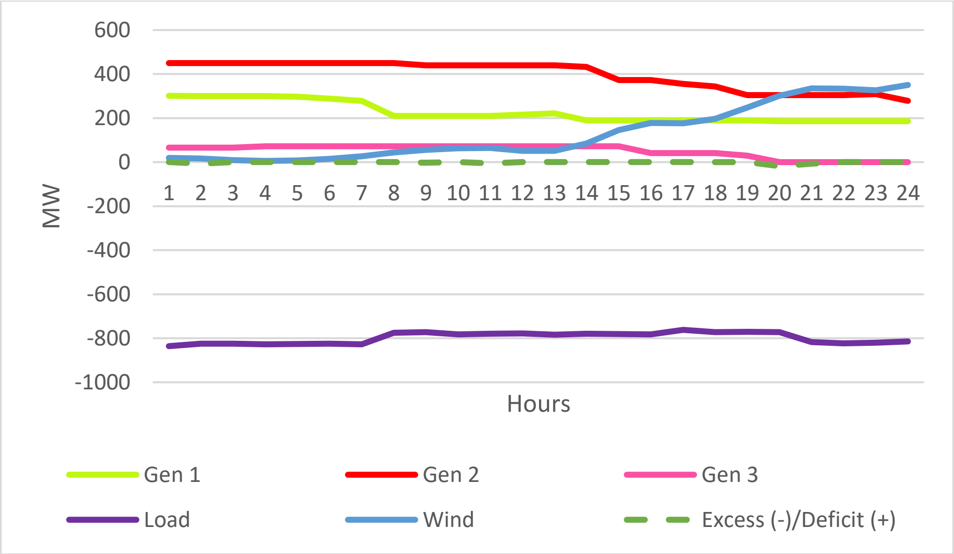


Fig. 6.47. 24 hours power generation profile for the case with RES wind 547 MW, load region – West on 22.06.2014. Source: author's calculations

Tab. 6.45. 24 hours power generation profile for the case with RES wind 547 MW, storage capacity 588 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	261.33	261.33	261.33	261.33	261.33	261.33	261.33	261.33	261.33	261.33	261.33	261.33
Gen 2, MW	450	450	450	450	450	450	450	421.04	421.04	421.04	421.04	421.04
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Storage charge (-) /discharge (+)	77.27	68.01	75.57	81.4	78.76	69.65	60.07	20.07	6.58	9.47	3.74	15.96
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	261.33	261.33	261.33	261.33	261.33	261.33	261.33	250.27	250.27	250.27	250.27	250.27
Gen 2, MW	421.04	405.09	373.62	342.35	338.81	338.81	326.94	326.94	326.94	326.94	326.94	326.94
Gen 3, MW	28.8	28.8	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	21.41	0	0	0	-14.28	-25.61	-65.61	-105.61	-94.52	-87.33	-82.22	-112.84
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

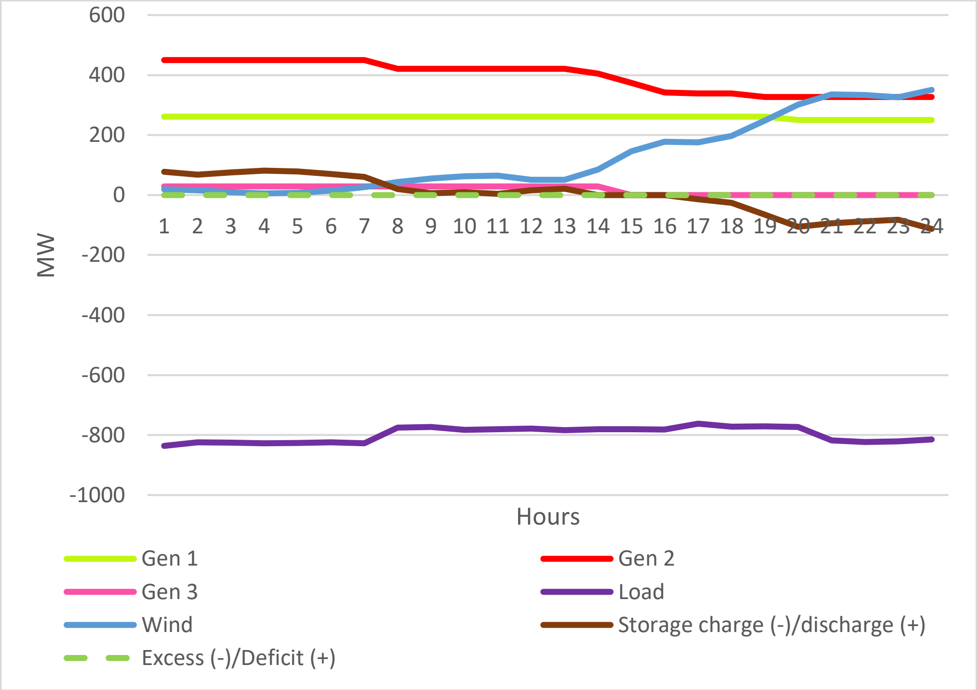


Fig. 6.48. 24 hours power generation profile for the case with RES wind 547 MW, storage capacity 588 MW, load region – West on 22.06.2014. Source: author's calculations

The simulation results for the case with RES solar 547 MW, storage capacity 469 MW, load region – West on 22.12.2014 are represented in Tab. 6.46., 6.47. and Fig. 6.49., 6.50.

Tab. 6.46. 24 hours power generation profile for the case with RES solar 547 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	455	450	465	465	460	431	405.2	390.2	391.46	375.77	350.63
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	63	63	63	63	63	63	63	28.8	28.8	28.8	28.8	28.8
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	338.95	338.95	357.91	362.04	377.17	378.56	389.2	433	465	465	453	443
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	28.8	28.8	45	45	45	45	45
Excess (-) /Deficit (+)	0.00	-2.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

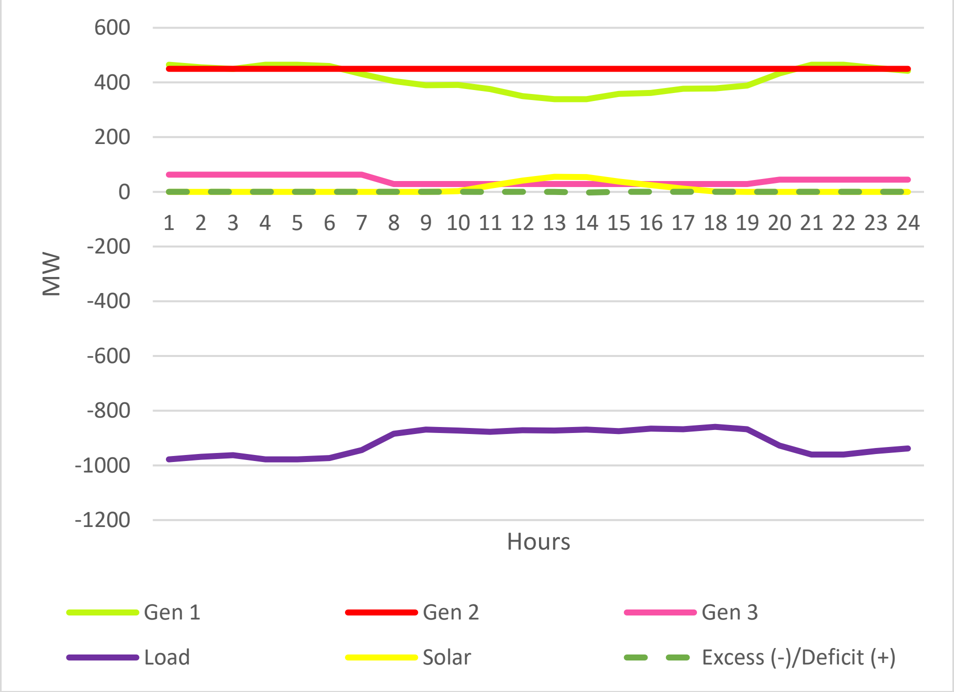


Fig. 6.49. 24 hours power generation profile for the case with RES solar 547 MW, load region – West on 22.12.2014. Source: author’s calculations

Tab. 6.47. 24 hours power generation profile for the case with RES solar 547 MW, storage capacity 469 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	406.84	406.84	406.84	406.84	406.84	406.84	406.84	367.02	367.02	367.02	367.02	367.02
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	49.16	39.16	34.16	49.16	49.16	44.16	15.16	-5.03	-20.03	-18.76	-34.45	-59.6
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	367.02	367.02	367.02	367.02	367.02	367.02	367.02	387.02	387.02	387.02	387.02	387.02
Gen 2, MW	450	450	450	450	450	450	450	450	450	450	450	450
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	72	72
Storage charge (-) /discharge (+)	-71.27	-73.63	-52.32	-48.19	-33.06	-31.67	-21.03	18.97	50.97	50.97	38.97	28.97
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

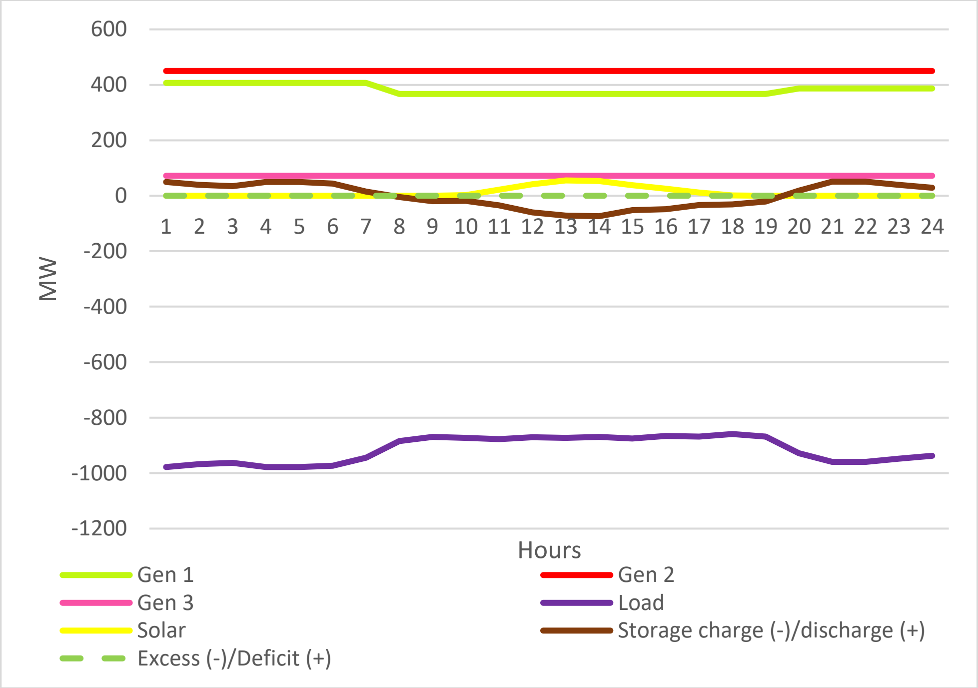


Fig. 6.50. 24 hours power generation profile for the case with RES solar 547 MW, storage capacity 469 MW, load region – West on 22.12.2014. Source: author's calculations

The simulation results for the case with RES solar 547 MW, storage capacity 469 MW, load region – West on 22.06.2014 are represented in Tab. 6.48., 6.49. and Fig. 6.51., 6.52.

Tab. 6.48. 24 hours power generation profile for the case with RES solar 547 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	462	463	465	464	462	462.81	462.81	400.63	320.92	239.7	198.32
Gen 2, MW	371	362	362	362	362	362	362	270.61	253.12	253.12	253.12	253.12
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	190.64	186	186	218.18	251.24	323.05	405.19	451.8	451.8	465	463	457
Gen 2, MW	253.12	253.12	253.12	253.12	253.12	253.12	253.12	273.61	358	358	358	358
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	-8.12	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00

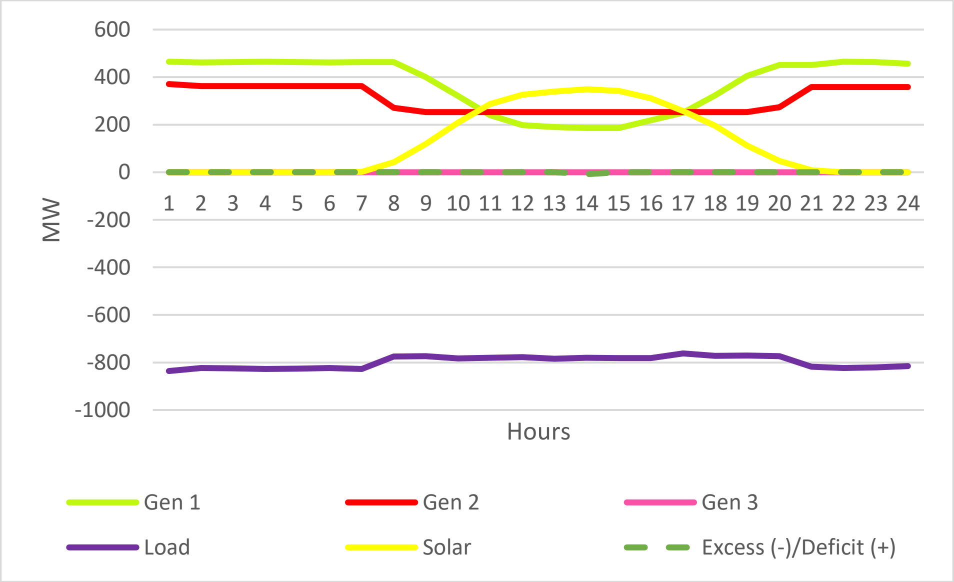


Fig. 6.51. 24 hours power generation profile for the case with RES solar 547 MW, load region – West on 22.06.2014. Source: author’s calculations

Tab. 6.49. 24 hours power generation profile for the case with RES solar 547 MW, storage capacity 469 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	408.24	408.24	408.24	408.24	408.24	408.24	408.24	360.46	309.59	229.88	186	186
Gen 2, MW	344.16	344.16	344.16	344.16	344.16	344.16	344.16	344.16	344.16	344.16	344.16	342.78
Gen 3, MW	72	72	72	72	72	72	72	28.8	0	0	0	0
Storage charge (-) /discharge (+)	11.59	-0.41	0.59	2.59	1.59	-0.41	0.41	0	0	0	-37.34	-77.34
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	186	233.4	304.97	332.06	376.45	376.45	376.45	376.45
Gen 2, MW	342.78	342.78	342.78	342.78	342.78	342.78	342.78	342.78	342.78	342.78	342.78	342.78
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	-85.02	-97.77	-89.66	-57.48	-24.42	0	10.57	50.57	90.57	103.77	101.77	95.77
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

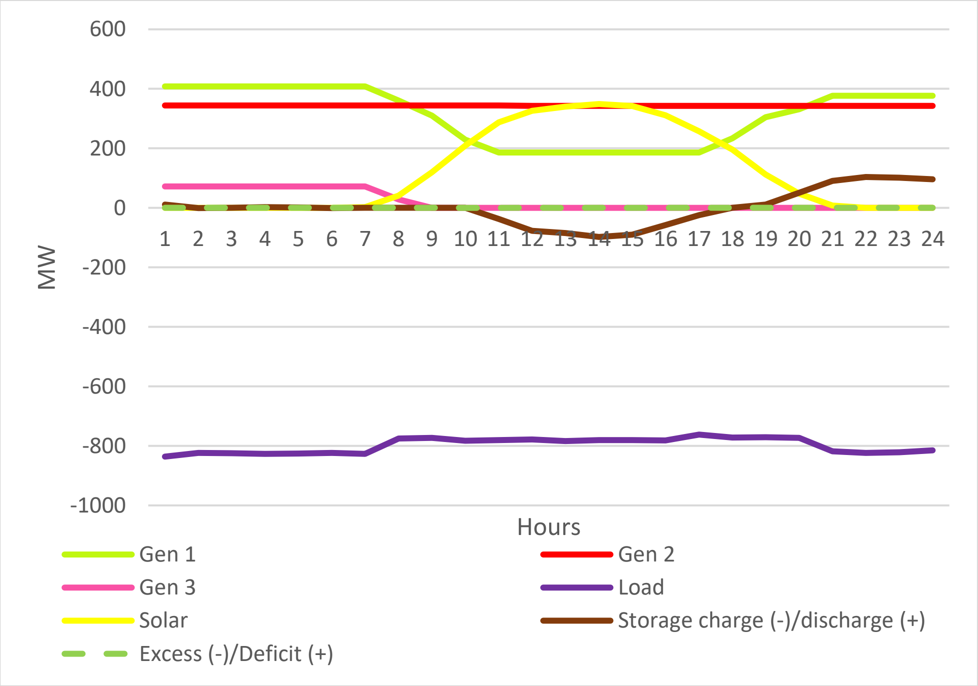


Fig. 6.52. 24 hours power generation profile for the case with RES solar 547 MW, storage capacity 469 MW, load region – West on 22.06.2014. Source: author's calculations

The simulation results for the case with RES aggregated 547 MW, storage capacity 655 MW, load region – West on 22.12.2014 are represented in Tab. 6.50., 6.51. and Fig. 6.53., 6.54.

Tab. 6.50. 24 hours power generation profile for the case with RES aggregated 547 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	465	465	465	465	447.3	447.3	402.98	328.76	296.25	277.83	249.55	205.81
Gen 2, MW	240.78	228.41	199.88	195.74	180	180	180	180	180	180	180	180
Gen 3, MW	28.8	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	-10.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	188.48	213.39	249.85	287.35	331.36	418.71	418.71	418.71	366.23	227.14
Gen 2, MW	180	180	180	180	180	180	180	180	320.31	420.41	420.41	420.41
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	-14.29	-26.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

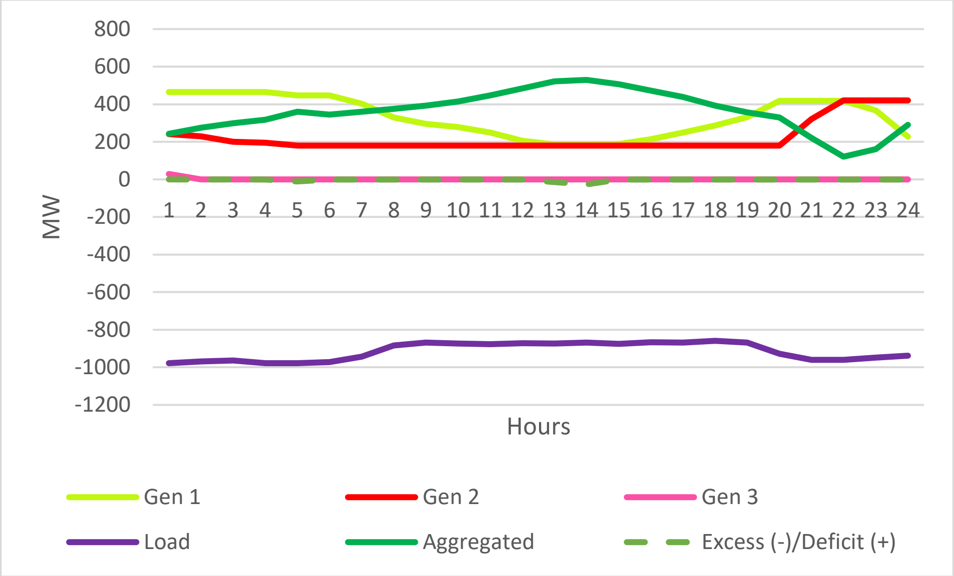


Fig. 6.53. 24 hours power generation profile for the case with RES aggregated 547 MW, load region – West on 22.12.2014. Source: author's calculations

Tab. 6.51. 24 hours power generation profile for the case with RES aggregated 547 MW, storage capacity 655 MW, load region – West on 22.12.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	291.24	290.06	290.06	290.06	290.06	290.06	290.06	215.84	215.84	215.84	215.84	212.1
Gen 2, MW	263.83	263.83	263.83	263.83	262.25	262.25	262.25	262.25	262.25	262.25	262.25	262.25
Gen 3, MW	72	72	72	72	69.82	69.82	30.66	30.66	0	0	0	0
Storage charge (-) /discharge (+)	107.51	67.51	38.99	34.84	-5.16	5.16	0	0	-1.84	-20.27	-48.54	-88.54
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	212.1	212.1	212.1	212.1	212.1	212.1	212.1	259.45	359.75	419.85	419.85	419.85
Gen 2, MW	262.25	262.25	262.25	262.25	262.25	262.25	291.57	291.57	291.57	291.57	279.09	180
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Storage charge (-) /discharge (+)	-122.64	-134.85	-105.88	-80.96	-44.5	-7.01	7.69	47.69	87.69	127.69	87.69	47.69
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

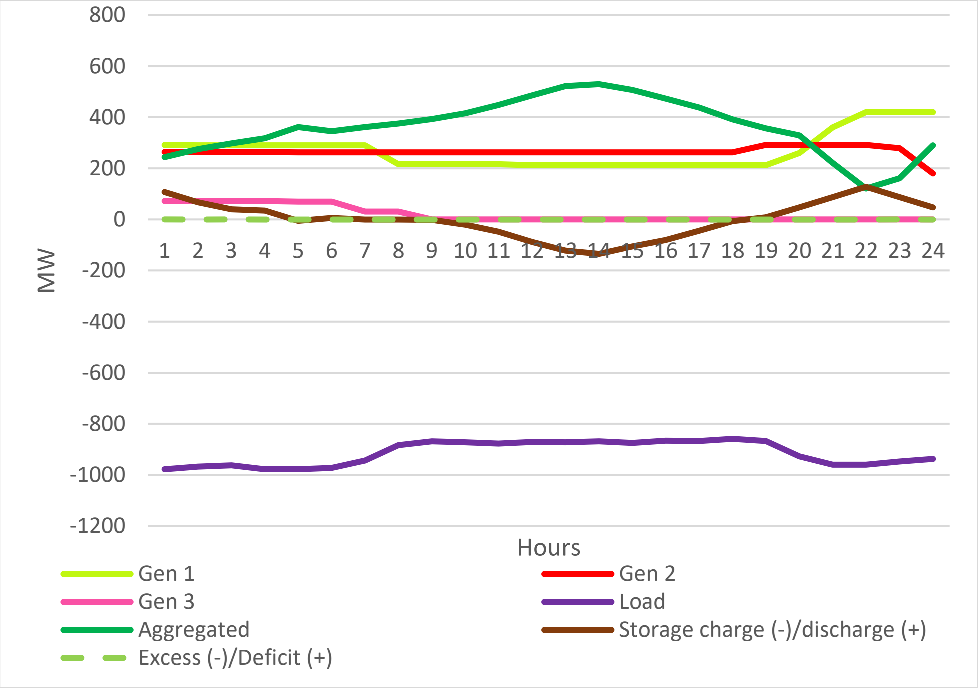


Fig. 6.54. 24 hours power generation profile for the case with RES aggregated 547 MW, storage capacity 655 MW, load region – West on 22.12.2014. Source: author's calculations

The simulation results for the case with RES aggregated 547 MW, storage capacity 655 MW, load region – West on 22.06.2014 are represented in Tab. 6.52., 6.53. and Fig. 6.55., 6.56.

Tab. 6.52. 24 hours power generation profile for the case with RES aggregated 547 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	460.87	459.17	459.17	465	465	455.89	444.12	335.78	244.62	186	186	186
Gen 2, MW	356.53	356.53	356.53	356.53	353.89	353.89	353.89	353.89	353.89	325.69	241.73	214.57
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	-7.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	186	186	186	186	186	198.71	198.71	212.74	212.74	212.74	217.85	187.24
Gen 2, MW	206.35	180	180	180	180	180	211.27	211.27	261.74	277.14	277.14	277.14
Gen 3, MW	0	0	0	0	0	0	0	0	0	0	0	0
Excess (-) /Deficit (+)	0.00	-19.77	-72.92	-73.02	-37.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00

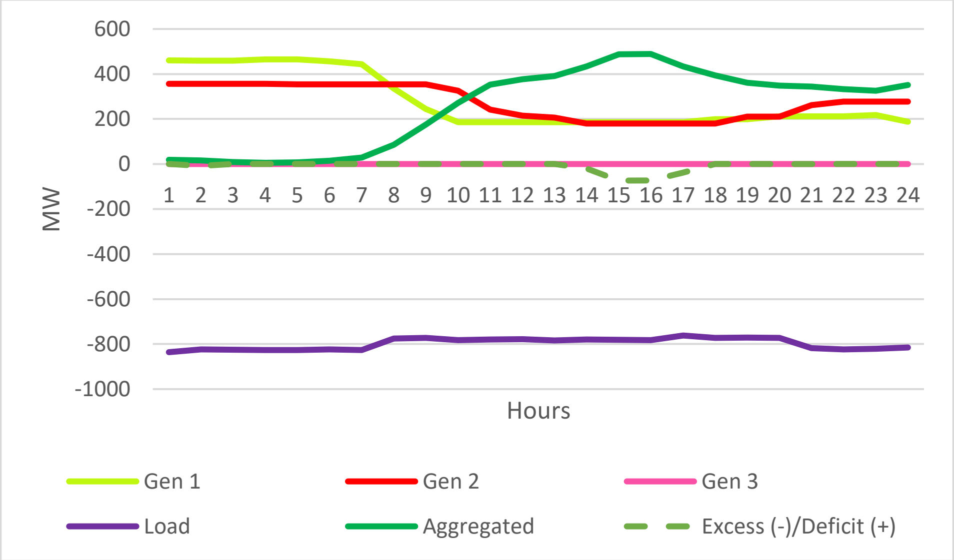


Fig. 6.55. 24 hours power generation profile for the case with RES aggregated 547 MW, load region – West on 22.06.2014. Source: author’s calculations

Tab. 6.53. 24 hours power generation profile for the case with RES aggregated 547 MW, storage capacity 655 MW, load region – West on 22.06.2014

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Gen 1, MW	237.02	237.02	237.02	237.02	237.02	237.02	237.02	237.02	237.02	237.02	237.02	237.02
Gen 2, MW	434.13	434.13	434.13	434.13	434.13	434.13	434.13	365.79	289.48	202.67	180	180
Gen 3, MW	72	72	72	72	72	72	72	72	72	72	28.8	28.8
Storage charge (-) /discharge (+)	74.25	64.98	72.55	78.38	75.73	66.62	54.85	14.85	0	0	-18.09	-45.25
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Gen 1, MW	237.02	230.9	217.75	217.75	217.75	217.75	217.75	217.75	217.75	217.75	217.75	217.75
Gen 2, MW	180	180	180	180	180	180	180	180	190.47	190.47	190.47	190.47
Gen 3, MW	28.8	28.8	28.8	28.8	28.8	34.52	34.52	34.52	34.52	34.52	34.52	34.52
Storage charge (-) /discharge (+)	-53.47	-93.47	-133.47	-133.57	-93.57	-53.57	-22.3	-8.26	31.74	47.13	52.24	21.63
Excess (-) /Deficit (+)	0.00	0.00	0.00	0.00	-4.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00

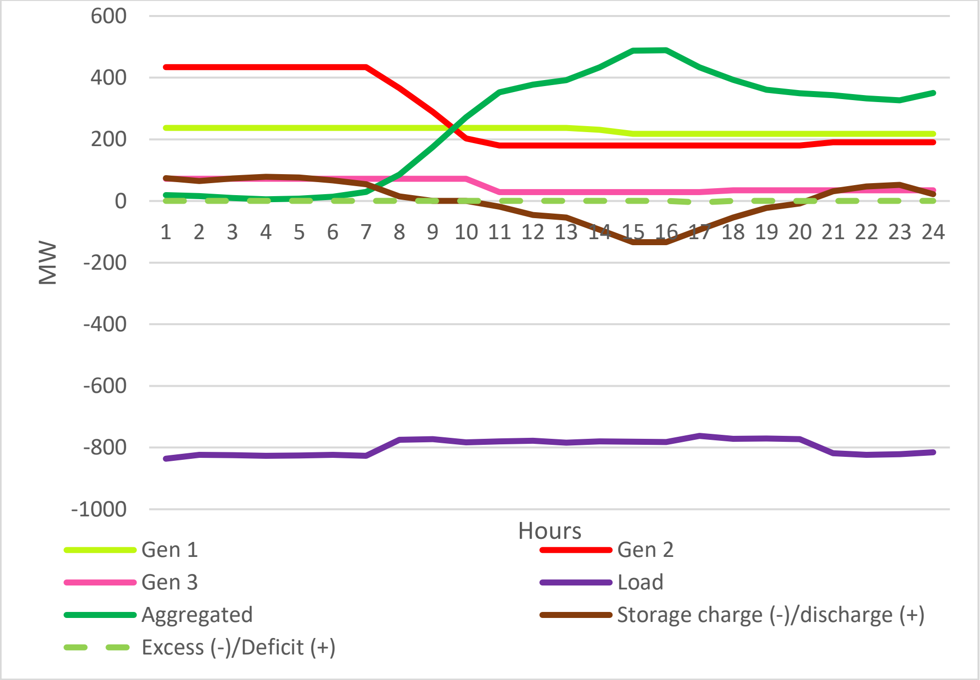


Fig. 6.56. 24 hours power generation profile for the case with RES aggregated 547 MW, storage capacity 655 MW, load region – West on 22.06.2014. Source: author's calculations

6.3.6. UC simulation results summery

The shares of each type of the RES in daily generation during the winter and summer periods, maximum values of the excess or deficit of electrical energy and the information about the possibility of replacing traditional generating capacities with RES represented in Tab. 6.54., 6.55.

Tab. 6.54. Simulation results summery for winter period on 22.12.2014

Simulation case (RES type; RES power, MW; Storage capacity, MW; Load, region.	**Period, winter, 22.12.2014**						
					with storage unit		
	% of RES generation	**Max (Excess (-)), MW**	**Max (Deficit (+)), MW**	**Gen #, NOT in operation during the period**	**Max (Excess (-)), MW**	**Max (Deficit (+)), MW**	**Gen #, NOT in operation during the period**
Wind, 250, 269, Mangistau	25.84	-11.50	0.00	3	0.00	0.00	2
Solar, 250, 214, Mangistau	0.78	-3.25	0.00	0	0.00	0.00	0
Aggregated, 250, 299, Mangistau	26.45	-36.00	0.00	3	0.00	0.00	2
Wind, 297, 319, West	20.75	-9.35	0.01	0	0.00	0.00	3
Solar, 297, 255, West	0.62	-3.11	0.00	0	0.00	0.00	0
Aggregated, 297, 356, West	21.38	-8.46	0.01	0	0.00	0.00	0
Wind, 547, 588, West	38.21	-13.66	0.00	0	0.00	0.00	0
Solar, 547, 469, West	1.15	-2.36	0.00	0	0.00	0.00	0
Aggregated, 547, 655, West	39.31	-26.50	0.00	0	0.00	0.00	0

Tab. 6.55. Simulation results summery for summer period on 22.06.2014

Simulation case (RES type; RES power, MW; Storage capacity, MW; Load, region.	**Period, summer, 22.06.2014**						
					with storage unit		
	% of RES generation	**Max (Excess (-)), MW**	**Max (Deficit (+)), MW**	**Gen #, NOT in operation during the period**	**Max (Excess (-)), MW**	**Max (Deficit (+)), MW**	**Gen #, NOT in operation during the period**
Wind, 250, 269, Mangistau	11.75	-22.25	0.00	2	0.00	0.00	2
Solar, 250, 214, Mangistau	11.02	-42.50	0.00	3	0.00	0.00	2
Aggregated, 250, 299, Mangistau	22.98	-4.00	0.00	2	0.00	0.00	2
Wind, 297, 319, West	8.77	-26.59	0.00	3	0.00	0.00	0
Solar, 297, 255, West	8.36	-4.87	0.00	0	0.00	0.00	0
Aggregated, 297, 356, West	17.15	-4.56	0.00	0	0.00	0.00	3
Wind, 547, 588, West	16.16	-18.28	0.00	0	0.00	0.00	0
Solar, 547, 469, West	15.39	-8.12	0.01	3	0.00	0.01	0
Aggregated, 547, 655, West	31.25	-73.02	0.00	3	-4.75	0.00	0

To analyze the efficiency of the use of different types of renewable energy sources in general it is necessary to do analyses for both periods. For the share of each type of the RES in daily generation parameter found the average value for two periods. The possibility of replacing generation with the help of RES was analyzed on the basis of the following condition: the same generator did not work for two periods. Maximum values of the excess or deficit of electrical energy were analyzed for two periods. The results are represented in Tab. 6.56.

Tab. 6.56. Simulation results summery for both periods

Simulation case (RES type; RES power, MW; Storage capacity, MW; Load, region.	**Average % of RES generation for two periods**	**Max (Excess (-)), MW**	**Max (Deficit (+)), MW**	**Max (Excess (-)), MW**	**Max (Deficit (+)), MW**	**Gen #, NOT in operation during two periods**	
		Without		**With**		**Without**	**With**
		storage unit					
Wind, 250, 269, Mangistau	18.79	-22.25	0.00	0.00	0.00	0	2
Solar, 250, 214, Mangistau	5.90	-42.50	0.00	0.00	0.00	0	0
Aggregated, 250, 299, Mangistau	24.72	-36.00	0.00	0.00	0.00	0	2
Wind, 297, 319, West	14.76	-26.59	0.01	0.00	0.00	0	0
Solar, 297, 255, West	4.49	-4.87	0.00	0.00	0.00	0	0
Aggregated, 297, 356, West	19.26	-8.46	0.01	0.00	0.00	0	0
Wind, 547, 588, West	27.19	-18.28	0.00	0.00	0.00	0	0
Solar, 547, 469, West	8.27	-8.12	0.01	0.00	0.00	0	0
Aggregated, 547, 655, West	35.28	-73.02	0.00	-4.75	0.00	0	0

6.4. Conclusion

6.4.1. The results of the work

The work performed showed that the thesis “*By solving the UC problem in a dispersed power system with RES, it is possible to cover the shortage of power generation capacities by increasing the share of RES in generating electricity instead of building traditional power facilities”* can be carried out.

For solving the UC problem with RES were analyzed the features of RES as an energy source and elaborated the common approach for solving the UC with RES in a dispersed electrical power system. According the approach were done the following steps:

- identification of the impact factors on the development and implementation of RES;
- initial data analyzing and selection of the network part for modeling;
- setting the goal of the commissioning of the new renewable energy capacities and analyzing its availability and the profile of the electrical power output from RES;
- mathematical methods and software selection;
- getting all required information and the input data for the performing modeling and solving the UC problem;
- optimal combination of the RES search and storage facilities capacity selection;
- performing the UC simulation with different constraints and getting the results.

Analyzing the results, the following conclusions can be done:

- it is possible to introduce new renewable energy capacities instead of traditional energy sources to cover the electricity deficit in the region if there is a reserve of power on the traditional sources of generation, which remains in the power system. The capacity reserve and the characteristics of the generators at existing stations allow this to be done. In all cases of simulation, the problem of UC was solved;
- the most appropriate source of renewable energy is the wind. In cases of the same installed capacity, the effectiveness of wind energy in the region is much greater than the solar one. However, if the task is to output certain generators at certain time periods, then the use of aggregated generation from RES makes it possible to do this in a larger number of cases;
- if the current load profile remains unchanged and the 250 MW wind or aggregated RES is put into operation and the energy storage capacity is used, even the 450 MW generator # 2 can be withdrawn from operation;
- because of the characteristics of the power facilities not every part of the real dispersed power system can be considered as a microgrid;
- the use of a power storage facility, the power calculated according to the proposed method, in practically all cases will make the work of a part of the power system autonomous.

6.4.2. Achievements of the thesis and the author

During the performing of the thesis the following achievements were reached:

- for the first time the problem of RES involvement in Kazakhstan was considered from the perspective of the Sufficiently General Control Theory [93] according to which, the necessary condition is the analysis of the current state of the system and the identification of environmental factors on the system;
- a common approach for the UC problem solving in a dispersed power system involving RES on the example of Kazakhstan to fill the shortage of generating capacity and more fully use the potential of RES was developed;
- in detail, the factors influencing the development of renewable energy in Kazakhstan were analyzed, and the influence of global and regional trends was assessed;
- the potential for RES in Kazakhstan was comprehensively evaluated and the most promising sources of renewable energy sources were identified for their use. The analysis relied on both global data and data obtained in Kazakhstan;
- an assessment of the current state of the energy system of Kazakhstan was carried out, the most problematic areas were identified;
- the tools have been found to produce an accurate profile of the renewable energy generation;
- to simulate the process of UC, the MOST program was modified to obtain the results, according to the proposed method;
- in the initial data for the simulation, legislative aspects were taken into account, such as unhindered consumption of electricity from RES;
- the methodology for selecting the combination of RES was proposed and tested, based on the Generalized Reduced Gradient Method (GRG);
- a method for choosing the electric power storage was proposed and tested, which is based on calculating the difference between the maximum and minimum values of generation of electricity from RES for the period;
- in the work it was shown the possibility of substitution and withdrawal from the generation of traditional energy sources with their replacement by RES;
- it was shown the possibility of transferring part of the dispersed power system to an autonomous mode with the involvement of RES and the use of the power storage.

7. Summary

In the paper, it was verified that by solving the UC problem in a dispersed power system with RES, it is possible to cover the shortage of power generation capacities by increasing the share of RES in generating electricity instead of building traditional power facilities. A common approach for the UC problem solving in a dispersed power system involving RES on the example of Kazakhstan to fill the shortage of generating capacity and more fully use the potential of RES was developed. The proposed approach and methodology will help all interested organizations and structures to see the possibility of covering the shortage of power generation capacities by increasing the share of renewable energy sources in generating electricity and their parallel work with the existing generation facilities instead of commissioning of traditional energy sources.

According the approach were analyzed world and regional energy trends. It was found that two main opposite processes: population growth and energy intensity of GDP will affect on the future energy consumption and production in the world and EAEU region, which includes Kazakhstan. The energy demand will grow constantly, and the task of energy sector is to ensure the production of electricity in accordance with demand. Developing of the nuclear and RES will be the priority for the upcoming decades.

By analyzing Kazakhstan’s energy sector structure was found that it has some problems the most significant of which is the power deficit and the lack of sufficient reserve, maneuvering capacity.

Analyzing the potential for RES, it was revealed that Kazakhstan has a significant potential for the renewable energy sources development. According the analysis of the characteristics of renewable energy sources, their potential, Kazakhstan's location, territory, industrial facilities distribution, landscape and climate conditions and the current level of the electrical infrastructure in Kazakhstan can be concluded that the most prospective energy sources now are wind and solar power.

The legislation of Kazakhstan was studied as one of the significant factors affecting the operation of RES in the power system. According to the legislation the RES has guaranteed access to points of connection to electrical networks; priority of electricity transmission from RES through electric networks; purchase the entire amount of RES energy at a fixed tariff for 15 years.

Kazakhstan has all the possibilities for the development of renewable energy, but involving RES into generation raises the problem of UC with RES. Because of its huge territory, history, population and industry distribution and the electrical power system of Kazakhstan can be characterized as dispersed and the UC problem can be characterized as the UC problem in a dispersed power system with RES.

Solving this problem according to the proposed method, the following results were obtained:

- it is possible to introduce new renewable energy capacities instead of traditional energy sources to cover the electricity deficit in the region. The capacity reserve and the characteristics of the generators at existing stations allow this to be done. In all cases of simulation, the problem of UC was solved.
- the methodology for selecting the combination of RES was proposed and tested, based on the Generalized Reduced Gradient Method (GRG). By the results of the simulation it was revealed that the most appropriate source of renewable energy in the simulated region is the wind.
- a method for choosing the electric power storage was proposed and tested, which is based on calculating the difference between the maximum and minimum values of generation of electricity from RES for the period. The use of a power storage facility, the power calculated according to the proposed method, in practically all cases will make the work of a part of the power system autonomous.

Additionally, in view of the significant role of the power storage facility in the involvement of RES and the solution of the UC problem, a proposal is made to change the legislation in Kazakhstan regarding RES. It is necessary to include in the category of RES renewable energy storage facilities, with their joint implementation into the power grid and provide appropriate support.

Proceeding from the foregoing, the proposed work is relevant and important from scientific and practical point of view.

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