Qualitative scenario analysis of development of energy storage systems in Russia until 2035

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Abstract. A stationary energy storage boom is forecast for the next two decades, according to a report by the US consulting firm Bloomberg New Energy Finance (BNEF). BNEF analysts believe that energy storage around the world will grow exponentially, from a modest 9 GW / 17 GWh commissioned by 2018 to 1,095 GW / 2,850 GWh by 2040. Experts call the ongoing global changes a “contributory revolution”. The development of energy storage systems is related to trends in the energy sector, energy costs, political and environmental conditions in the world. Moreover, energy storage technologies can face both general and specific risks. The authors of the article took into account possible risks and carried out a qualitative scenario analysis of the development of energy storage systems in Russia in the future until 2035. The authors used a probability scale to avoid cognitive biases in the scenario assessment. The most likely scenario for the development of ESS today we consider the basic.

1. Introduction
Energy storage systems (ESS) are the reason for the global transformation of the electric power industry, which is being launched all over the world and is becoming relevant for Russia now. There are several reasons for the beginning of the energy transition and the rapid development of storage systems. One, the most significant of them, has been the change in the attitude of many countries towards the used energy resources in the past few years. A prerequisite for this was the adoption in 2015 of the Paris Agreement, which united the efforts of world powers to deterrence climate change on the planet. Many countries have made commitments and developed new strategies to reduce greenhouse gas emissions by using renewable energy (RES) power plants and replacing carbon-fueled cars with electric vehicles. The task of developing ESS has become relevant for several areas of application at once.

The highlighting of such a trend as RES has pushed the development of distributed generation, digitalization and intellectualization of energy systems. The emerging need for ESS led to a sharp decrease in the cost of almost all known energy storage systems to 85% in the period 2010-2018. According to BNEF, the cost of ESS will continue to decline as demand for them grows. The decline in the cost of ESS, in turn, influenced the trends in the global electric power systems. Global think tanks are looking at storage as part of a new energy fabric and smart energy technologies. “Smart storage systems” claim to change the traditional understanding of the global energy, accelerating and facilitating its digital transition: the development of energy and capacity markets; expanding the range of ser-
vices, the use of aggregators, demand management (Demand Response); increase in the share and support of renewable energy sources in the energy balance, smoothing of daily and annual load schedules, replacement of grid and generating capacities.

2. Materials and Methods

A forecast of scenarios and main parameters of the technical and economic development of energy storage systems for the period up to 2035 was developed in the composition of three main options – negative, basic and innovative.

The negative scenario does not envisage radical changes in ESS technologies, it is expected that the current priorities of the energy policy of large producers will be maintained, and the pace of development of energy storage units will be rather slow. There will be no noticeable improvements in the area of storage systems.

According to the basic scenario, there is no technological revolution, but the introduction of technologies that are already being tested at the present time is expected. A gradual increase in the economic efficiency of the technologies already in use is expected. The transfer of technologies to developing countries is complicated (the average term of technology transfer remains at the level of 10-12 years). Environmental and energy efficiency trends that have emerged in recent years are helping to strengthen the position of ESS in the energy markets.

The innovative scenario implies the accelerated development of new technologies and halving the time of their transfer from developed countries to developing ones. This scenario implies the full use of the ESS potentials and the fastest increase in their market share, the accelerated development of new technologies, their cost reduction, and active support from the state.

To compile a scenario analysis in the field of energy storage systems in Russia, we applied correlation analysis. It allows you to numerically assess the influence of various factors on the development of ESS and to assess the likelihood of the occurrence of each of the three proposed development scenarios. The influencing factors are grouped according to five criteria: politics, economics, ecology, risks, technologies. Since the factors we have identified can affect both all types of ESS as a whole, as well as a specific technology, the concept of “weight” of a factor has been introduced. “Weight” is calculated as follows: “weight” = “correlation coefficient” x “share in ESS”. The “share in the ESS” refers to the part of the ESS technologies that is affected by the factor under consideration. The correlation coefficient is calculated as follows:

\[ r = \frac{n \sum xy - \sum x \sum y}{\sqrt{(n \sum x^2 - (\sum x)^2)(n \sum y^2 - (\sum y)^2)}} \]

where \( r \) is the correlation coefficient, and \( x \) and \( y \) are the factors themselves between which a correlation is established.

For example, there is a link between GDP (\( x \)) and ESS investment (\( y \)). In this case, the correlation coefficient can be in the range from -1 to 1, where the “+” and “-” signs show a direct or inverse dependence of factors, and the absolute value of the correlation reflects how strong the link is. If the coefficient is close to 1, then the factors are completely dependent on each other, a value close to 0 indicates the absence of a link.

Excel and Matlab software products were used for calculations. The following is a detailed description of the scenario analysis performed.

2.1. Forecasting the development of ESS based on the analysis of economic, environmental, technological, political factors and risks.

2.1.1. Economic factors.

**Factor 1.** Reducing the cost of ESS technologies. According to the latest BNEF forecasts, by the year 30 the global ESS market will grow 6 times in comparison with the level of 2017 [1]. The energy storage market will develop along a trajectory that is similar to the development dynamics of the photo-
voltaic solar energy market in the period 2000-2015. By 2035, it is predicted that the cost of electrochemical ESSs will decrease on average to $300–350 per kWh from the current $500–600 per kWh. Figure 1 demonstrates the value of energy storage cost reduction over the lifecycle of an LCOS.

Thus, in the long term, the most probable decrease in the cost of ESS is considered with an increase in battery life, and an accelerated growth of ESS can be predicted. Decrease economic conditions could lead to moderate growth in ESS. Stagnation in the development of ESS is the least likely, since in the period from 2010 to 2016 the cost of batteries fell by almost 4 times - from 1,000 to 273 USD per kWh - and continues to decline on average to 20% per year [2].

**Factor 2.** The existence of a price difference for price arbitrage on the wholesale electricity market. The cost of electricity on the market depends on the time of consumption. During off-peak load hours (night, weekends), electricity is cheaper. In the Youth Forecast of Global Energy Development in 2019, the UPS of the Middle Volga was highlighted among the regions most suitable for the installation of ESS. The difference in prices for the UPS of the Middle Volga as of 05/01/2020 [3] at night and at peak hours is 193.4 rubles.

Since until 2035 the existence of peak consumption hours in the energy system of Russia and the difference in prices at night and daytime are most likely. Energy storage devices can profit from buying electricity at a low price and selling it at a high price. The most likely scenario is the basic scenario. The observed price difference is not large and is not able to determine the accelerated growth of ESS. The situation when the schedule of energy system consumption will be absolutely flat is unlikely by 2035, therefore the price difference will remain, and the negative scenario is the least likely.

**Factor 3.** GDP. GDP and investment are interconnected: a small investment recovery can provide a significant increase in gross domestic product. At the same time, a change in the country's GDP also affects investment activity in ESS projects [4]. Figure 2 shows the correlation of RF GDP and investment [5] in the period 2015-2018.

In this case, the actual correlation coefficient was $r = -0.39$. The sign "-" here shows that during the analyzed period, with an increase in GDP, the number of investments decreased in the proportion of 1 to 0.39.

In connection with the epidemiological situation in the Russian Federation, the International Monetary Fund predicts a decrease in Russia's GDP in 2020 by 5.5%. In 2021, the fund expects Russia's GDP to grow by 3.5%. In the long term, stabilization of GDP growth is considered most likely, and moderate growth of ESS can be predicted. On the other hand, given the epidemiological situation, the decline in GDP growth may be delayed and exceed current forecasts, which will lead to stagnation in the development of ESS. Accelerated ESS growth driven by rapid GDP growth is least likely.
Figure 2. Correlation between GDP and investment in the Russian Federation in the period 2015-2018.

**Factor 4.** Supply security. According to the report of Berenberg Thematics, a team of the oldest bank in Germany, focused on researching breakthrough technologies that may be of interest to investors, there is a risk of the security of supply of metals required for the production of lithium-ion batteries [6]. Metals with a high supply risk include cobalt and natural graphite. The risk arises from the fact that 56% of world cobalt production comes from Congo and 69% of natural graphite comes from China.

The emergence of international and internal political conflicts in exporting countries can cause trade wars in the producing countries, which, in turn, can cause military clashes. Any of the wars will damage the economies of the countries as a whole and may affect the cost of production of ESS. Despite the existence of such a risk, the 2018-19 trade war between the United States and China did not lead to an increase in the cost of ESS, which indicates a low correlation between risk and the development of ESS. Therefore, in the long term, it is believed that the decrease in the cost of ESS will continue, and the basic scenario of the growth of lithium-ion storage systems can be predicted with high probability. At the same time, if a larger number of countries are involved in a trade war, as in one of the well-known stories of the 19th century trade war of the USA, England and France against China [7], then the probability of the predicted decrease in the cost of Li-ion ESS decreases, and, consequently, decreases the probability of an innovative scenario and accelerated growth in the use of lithium-ion storage. In the event of global conflicts between countries, the probability of which until 2035 is low, it can be predicted that the probability of a pessimistic scenario for lithium-ion storage devices is small.

**Factor 5.** Emergency situations of a global nature. Today, the whole world is experiencing a crisis associated with the COVID-19 pandemic. Against the background of the general economic downturn, the pace of implementation of ESS projects may also slow down. The pandemic has led to a decrease in the consumption of resources, and in particular of oil. For the Russian economy, which is dependent on energy prices, this scenario means a depreciation of the ruble. Since ESS technologies often require the import of components, for Russian companies this will mean an increase in the costs of projects being implemented. Analyzing the link of investments [8] in the Russian energy sector with oil prices of Brent, we obtained a correlation coefficient equal to 0.82. The graph of changes in oil prices and the volume of investments by years is shown in Figure 3. According to experts, the recovery of demand for oil products to the level preceding the pandemic will not occur until 2021.

Thus, under the influence of the current crisis until 2035, accelerated growth in the number of ESS projects can be expected with the least probability. At the same time, due to forecasts of a recovery in oil demand in 1-2 years, the probability of moderate growth in the long term in the field of new projects is higher than the probability of stagnation.
2.1.2. Ecological factors.

**Factor 1.** The volume of CO₂ emissions. If the graph of CO₂ changes for the last 10 years is scaled, superimposed on the graph of changes in the power accumulated by ESS [9], one can notice the correlation between them (Fig. 4 a). The linear correlation coefficient between the two data sets is 0.7, which indicates a high degree of dependence - the development of energy storage systems in renewable energy sources is dictated by environmental problems.

**Factor 2.** Increase in air temperature. Considered above in relation to CO₂ emissions is also relevant for an increase in the average temperature over the earth (Fig. 4 b).

Based on the forecast of BP [10] and ENERS Future [11], we have compiled three scenarios. In the negative scenario, over the next 20 years, the growth rate of CO₂ emissions will be approximately 3.5 times lower than the growth rate over the past two decades. The temperature will rise by 0.2-0.3⁰ by 2035 and by 1⁰ by the end of the century. This means that the growth of RES and ESS will remain and will be moderate, although fossil fuels will remain a competitive and attractive source of energy. Most likely scenario.

![Figure 3](image-url) **Figure 3.** Dynamics of prices for Brent oil and volumes of investments in the Russian electric power industry in 2010-2019.

![Figure 4](image-url) **Figure 4.** Graph of CO₂ and ESS changes (a); graph of CO₂ and temperature changes (b) for 2008-2017.
In the basic scenario, a 13% reduction in carbon dioxide emissions compared to 2020 would result in a cooling of about 0.2 °C. The events that led to such a huge decrease in emissions can either be associated with a significant increase in RES and ESS. A significant increase in RES and ESS can only be achieved by investing enormous funds in these industries. But given the recent sharp decline in economies, this scenario has an average probability.

According to the innovative scenario, CO2 emissions will be reduced by up to 30% of the current level. This will cause a cooling of about 0.5 °C. This scenario is even more optimistic when viewed from an environmental point of view. From the point of view of the ESS, the difference from the basic scenario is small. Such a global reduction in human carbon dioxide emissions into the atmosphere is unlikely due to an increase in RES and ESS. From our point of view, the probability of such a scenario is low.

2.1.3. Technological factors.

Our team is aware of a wide variety of technological characteristics, the improvement of which can significantly affect the development of ESS, we did not set ourselves the goal of considering all existing technologies. We considered the technologies of promising ESS and the most popular in 2020.

**Factor 1.** Increasing the efficiency of electrolysis systems for hydrogen production. According to the Concept for the Development of the Electricity Storage Systems Market in the Russian Federation, one of the priority scientific and technical tasks is the development of highly efficient water electrolyzers and systems for compact storage and transportation of hydrogen. Many researches are underway to improve the efficiency of electrolytic systems. For example, a research team from Ulsan National Institute of Science and Technology, Korea Institute for Energy Research and Sukmun University improved an already existing design called a Solid Oxide Electrolysis Cell (SOEC) by making both electrodes solid, like the electrolyte that serves as an ion conductor. They retained all the positive qualities of the existing cell and developed a new hybrid system, called Hybrid-SOEC, which is four times more efficient than the existing one [12].

The authors analyzed the correlation between hydrogen production and the growth in commissioning of ESS projects (it was 0.9), the graph is shown in Figure 5a, which indicates that the improvement of hydrogen production technology should affect the accelerated growth of ESS projects.

![Graph](image)

**Figure 5.** Change in the growth of ESS projects and hydrogen production (a) and the volume of the PEMFC cell market (b) for 2010-2020.

At the same time, the methods of producing hydrogen are diverse and only 5% of hydrogen from water by electrolysis due to the high cost of the technology. Therefore, despite significant scientific developments in the field of efficiency of electrolysis systems, the most likely scenario is the stagnation of this technology, since at the moment, historically, more profitable methods of producing hy-
hydrogen (catalytic steam reforming) have developed. In the long term, moderate development can take place, provided that the study and implementation of more technologically advanced methods of producing hydrogen (in this case, precisely by electrolysis), accompanied by an increase in efficiency, continues.

**Factor 2.** Hydrogen-air proton exchange membrane fuel cell (PEMFC). The second technology, the improvement of which we have considered, is also related to hydrogen ESS. We considered a hydrogen-powered electromagnetic cell with two electrodes and a polymer membrane as the electrolyte - PEMFC. The growth of the PEMFC market is mainly driven by the downward trend in greenhouse gas emissions coupled with favorable government initiatives. Similarly, the increasing demand for clean fuel vehicles to limit carbon emissions is one of the main factors driving the industry forward. PEMFCs use oxygen as an oxidizing agent and are charged with pure hydrogen, which results in the release of harmless chemicals other than heat and water vapor [13].

PEMFC systems are primarily the preferred choice for the production of hydrogen-powered vehicles due to their fast start-up combined with high energy output density for efficient engine operation, while at the same time being predicted to be used as zero-emission hydrogen ESS. Key companies are: Ballard Power Systems; Plug Power; Hydrogenics. Our team analyzed the volume of the market in billion $ PEMFC and ESS for 2015-20 (Fig. 5 b), the correlation was determined = 0.93, which indicates a high degree of influence of the development of technology on the ESS. At the same time, as in the previous factor, the share of the use of technology is currently very small, therefore it is not able to have a significant impact on the development of ESS globally, despite its significant improvement. Therefore, in the long term, a high probability of technology stagnation is predicted. The accelerated growth of this technology, as in the previous factor, is limited by the current situation in the hydrogen fuel market, the lack of infrastructure and unresolved safety issues.

**Factor 3.** Modernization of electrodes of lithium-ion storage devices. Lithium-ion energy storage devices are today the leaders in the world market for electrochemical storage devices. Credit Suisse estimates that by 2035 more than 75% of Li-ion battery (LIB) demand will come from the electric vehicle sector [14].

Experts from the Energy Center of the Skolkovo Business School say that with the expansion of the electric vehicle market, the LIB market will increase. In this regard, work is underway to improve LIB technologies to reduce the cost of electric cars, which should lead to greater demand for them. One of the areas of technical improvement is the modernization of electrodes.

The most promising technology in the short term is solid-state LIB technology. Storage devices made with the use of solid electrolytes have a number of advantages over storage devices with liquid electrolyte. These include an accelerated charging process, an extended life cycle, the ability to perform in different forms, the absence of the probability of electrolyte leakage.

However, today the main problem with solid-state LIBs is their high cost and small size. Solid-state batteries of small dimensions have been created, which are used as backup power in computer electrical circuits.

Due to the limitations and lack of mass commercial samples, it is impossible to achieve accelerated growth of projects with solid-state LIBs in the near future. However, TAIYO YUDEN and Samsung are already announcing designs that could take the technology to a new level in the electrochemical storage market. Due to the high interest of world leaders in the technology sector in solid state LIBs, a breakthrough in technology can be expected in the coming years. This scenario can lead to the approach of solid-state LIBs to their theoretical energy capacity of 1000 kWh / kg and their moderate growth in ESS projects.

### 2.1.4. Political factors.

**Factor 1.** Incentive instruments (R&D, grants, etc.). Currently, incentive instruments aimed at the development of ESS are actively developing, in particular, their number and funding are increasing. World experience shows that most countries (USA, Germany, etc.) have successfully used this method in the last decade. In particular, a large number of grants are allocated for the implementation of pro-
jects related to ESS [15]. The implementation of these practices over the past years shows their effectiveness and practical significance - the characteristics of technologies are increasing, thereby reducing costs for manufacturers and a gradual reduction in the cost of ESS technologies. In Russia, there are state RFBR, RSF, FFI, and other funds, which distribute grants for R&D. In recent years, large domestic companies (Rosneft, Gazprom, Mail.ru Group, etc.) have joined this practice. Thus, the most likely scenario for the development of incentive instruments is an innovative one, since the state and business are interested in the development of energy efficient technologies that can increase the reliability of energy systems and ensure the economic growth of industry.

**Factor 2.** Benefits (subsidies, loans, special programs, government procurement, accelerated depreciation, etc.) A variety of benefits in the area of ESS management system helps to implement pilot energy storage projects in different countries. Such incentive measures can increase the economic efficiency of the introduction of ESS in the electric power industry, especially given the high share of capital costs in the total cost of their operation in the life cycle. This will allow for wider application and faster adoption of the technology in other countries. This factor directly affects ESS. Today, in the Russian Federation, pilot projects for the application of ESS are implemented mainly by state-owned companies, which find it easier to use benefits than others. However, there is a trend in the development of ESS technologies, which will contribute to the expansion of benefits for the entire list of industrial companies in the Russian Federation. Thus, the most likely scenario for the development of benefits for ESS is a conservative one, since the actualization of ESS increases every year, which will contribute to the development of preferential conditions for ESS, at least in the coming years.

**Factor 3.** Integration of ESS into the system services market and into the wholesale electricity and power market. The integration of ESS into the system services market and the wholesale electricity and power market is widely discussed in Russian companies. NeP “Market Council” and JSC “ATS” are developing amendments to the regulations governing the activities of the wholesale electricity and power market entities, aimed at integrating the ESS. In 2018-2019, at a meeting of the commission for managing innovative development of the Rosseti company, analytical work was done to determine the most promising schemes and directions for introducing ESS at power facilities. As a result, the list of pilot projects planned for implementation in IDGC of Center, IDGC of Center and Volga Region, Lenenergo, IDGC of Urals was approved. Thus, the most likely scenario for the development of integration of electricity supply systems into the market of system services and in the wholesale electricity and power market is an innovative one, since there is an interest of large energy companies of the Russian Federation and non-profit structures.

**Factor 4.** Customs policy instruments. To reduce the impact of customs policy on ESS technologies, work is currently underway to eliminate customs barriers within the EnergyNet roadmap (Order No. 830-r dated April 28, 2018). As an action plan to improve legislation and remove administrative barriers, the roadmap aims to introduce new technologies in the energy sector and improve the quality of energy supply services. The most likely scenario for the development of customs policy instruments is a conservative one, since the domestic political sector will facilitate the regulation of various instruments by means of legislative acts, roadmaps, etc., but more likely there will be resistance from the outside (sanctions and other complicating instruments).

### 3. Results

According to the analysis and the calculations performed, the most likely scenario for the development of ESS is the basic. All the data used for the calculation are presented in Table 1. Multiplying the factor weight by the probability for each scenario and then summing the values obtained within each scenario for all factors, we obtained the final scenario rating.

The negative scenario scored 15 points, the basic - 24, the accelerated - 19. Thus, the most likely scenario for the development of ESS today we consider the basic.
Table 1. Numerical assessment of the probabilities of scenarios.

| Factor name                                                                 | Factor significance | Scenario probability* | Factor contribution to scenario |
|-----------------------------------------------------------------------------|---------------------|-----------------------|---------------------------------|
|                                                                             | Correlation | Share in ESS factor weight | negative | basic | innovative | negative | basic | innovative |
| Reducing the cost of ESS technologies                                       | 1          | 0.5                    | 0.5      | 1     | 2          | 3        | 0.5   | 1          | 1.5       |
| The difference in prices for the wholesale electricity and power market    | 1          | 1                      | 1        | 1     | 3          | 2        | 1     | 3          | 2         |
| GDP                                                                         | 0.39       | 1                      | 0.39     | 2     | 3          | 1        | 0.78  | 1.17       | 0.39      |
| Supply security                                                             | 0.4        | 0.37                   | 0.148    | 1     | 3          | 2        | 0.148 | 0.44       | 0.3       |
| Emergencies of a global nature                                              | 0.82       | 1                      | 0.82     | 2     | 3          | 1        | 1.64  | 2.46       | 0.82      |
| CO2 emissions                                                               | 0.7        | 1                      | 0.7      | 3     | 2          | 1        | 2.1   | 1.4        | 0.7       |
| Temperature                                                                 | 0.7        | 1                      | 0.7      | 3     | 2          | 1        | 2.1   | 1.4        | 0.7       |
| Increasing the efficiency of electrolysis systems for hydrogen production   | 0.9        | 0.05                   | 0.045    | 3     | 2          | 1        | 0.135 | 0.09       | 0.045     |
| PEMFC fuel cell                                                             | 0.93       | 0.016                  | 0.015    | 3     | 1          | 2        | 0.044 | 0.015      | 0.03      |
| Solid State LIB                                                             | 1          | 0.37                   | 0.37     | 1     | 3          | 2        | 0.37  | 1.11       | 0.74      |
| R&D, grants, etc.                                                           | 1          | 1                      | 1        | 1     | 2          | 3        | 1     | 2          | 3         |
| Privileges                                                                  | 1          | 1                      | 1        | 1     | 3          | 2        | 1     | 3          | 2         |
| Integration of ESS into the wholesale electricity and power market          | 1          | 1                      | 1        | 1     | 2          | 3        | 1     | 2          | 3         |
| Integration of ESS into the system services market                          | 1          | 1                      | 1        | 1     | 2          | 3        | 1     | 2          | 3         |
| Customs policy                                                              | 1          | 1                      | 1        | 2     | 3          | 1        | 2     | 3          | 1         |
| Scenario rating                                                            | **15**     | **24**                 | **19**   |        |            |          |       |            |           |

* A qualitative scale was used: 1 - high probability of occurrence, 2 - medium probability of occurrence, 3 - low probability of occurrence.
4. Conclusion

Energy storage systems provide an energy transition characterized by the emergence of new types of electric power entities, an increase in the share of renewable energy sources in the energy balance and the spread of new types of technological solutions. The direction of accumulation systems in 2020 is extremely relevant. The highlighted risks that were included in the scenario analysis criteria, namely ecology, economics, politics and technology, were used to make forecasts for the development of ESS technology. It should be noted that two types of scenarios are most often used in world practice: the best and the worst. The authors decided to use more than two scenarios. This was a dangerous situation, because people, by their very nature, tend to give the highest degree of probability to the average of the scenarios. Therefore, it was extremely important to introduce a scale of probabilities that avoided cognitive distortion. It was thanks to this approach that it was possible to determine the confidence intervals for each of the scenarios as accurately as possible, and the introduced weight scale allowed us to determine that the most significant of the factors influencing the scenario were global emergencies, climate change on the planet, prices on energy markets and all political factors (benefits, grants, customs policy, regulations).

In the context of the transformation of the world's energy systems with deep decentralization of electricity production, the introduction of energy storage systems will determine the shape of the electricity industry of the future. To reduce dependence on oil products, Russia needs to diversify its economy by developing production, including mastering the production of energy storage devices. Such a decision on the wave of general development and the transition to a new technological order will allow Russia to maintain a competitive position in the global market.

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