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Resilience of Energy Systems to External and Internal Shocks

Energy systems are typically complex structures with a large number of elements and interconnections between them. On the one hand, the ability to build capacity and resource reserves makes it possible to ensure a higher level of reliability for the system as a whole than for each individual component. On the other hand, a high degree of interdependence between components can lead to a cascading effect: the failure of a single element may trigger the shutdown of others and disrupt the operation of the entire system.

Therefore, reliability is a key factor for complex energy systems. This requirement becomes even more critical given the high social importance of energy supply, as people's well-being, health, and even lives depend on it. Even short-term interruptions in electricity supply can result in significant losses.

This paper analyzes potential internal and external shocks, identifies the most dangerous among them, and formulates measures that contribute to overcoming these shocks and minimizing their possible consequences.

The main types of energy resources consumed in the Republic of Belarus are natural gas and oil.

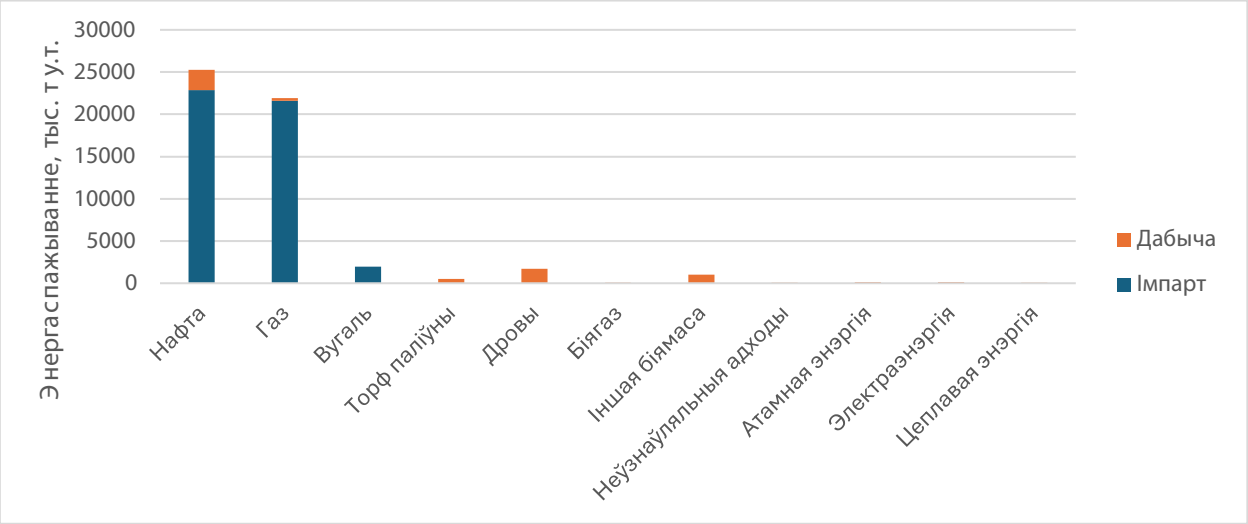

Figure 1 - Energy sources

A significant share of oil and almost all natural gas are imported, with the entire volume supplied by the Russian Federation, which acts as the sole supplier due to economic and partly technological reasons. Domestic oil production is limited, amounting to about 2 million tons per year. There is no targeted production of natural gas; however, associated gas released during oil extraction is utilized.

In addition, a small amount of coal is used in the energy system, mainly for technological needs; the entire volume of coal is also imported from Russia. Other types of energy resources, such as wood fuel, biogas, and hydropower, are almost entirely of local origin.

The largest share of final energy consumption (by organizations and households) is accounted for by thermal energy (see Figure 2), which is consumed almost equally by industry and households.

Three other major types of energy carriers—natural gas, diesel fuel, and electricity—are used in relatively similar amounts (around 4 million tons of oil equivalent). At the same time, natural gas is predominantly consumed by households, diesel fuel by the transport sector, and electricity by industry.

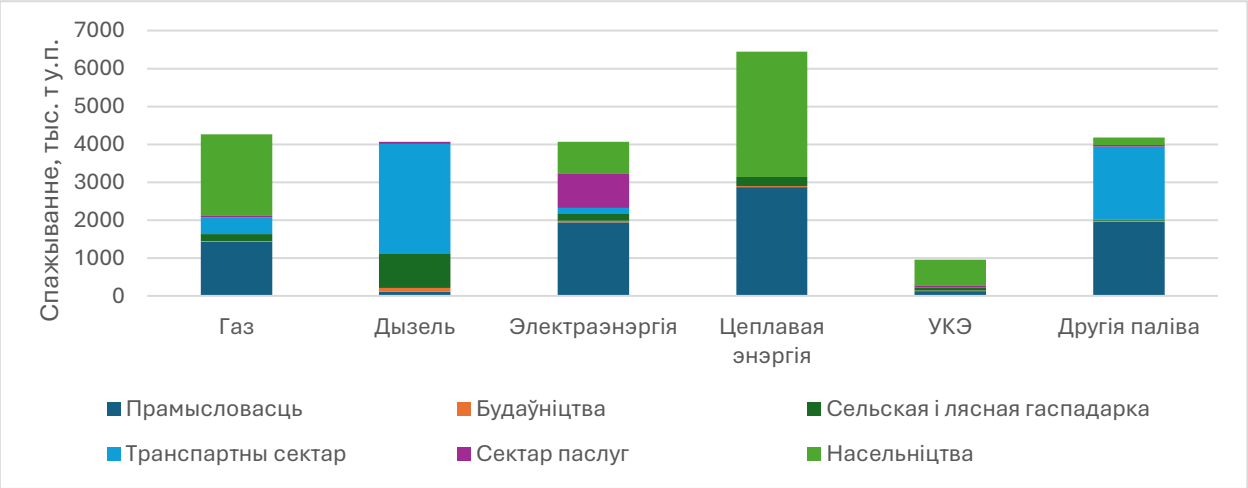

Figure 2 - Final consumption by fuel type

Other fossil fuels account for roughly the same amount of energy as each of the fuels mentioned above, while renewable energy sources represent only about a quarter of that volume, with the majority of renewable energy being consumed by households.

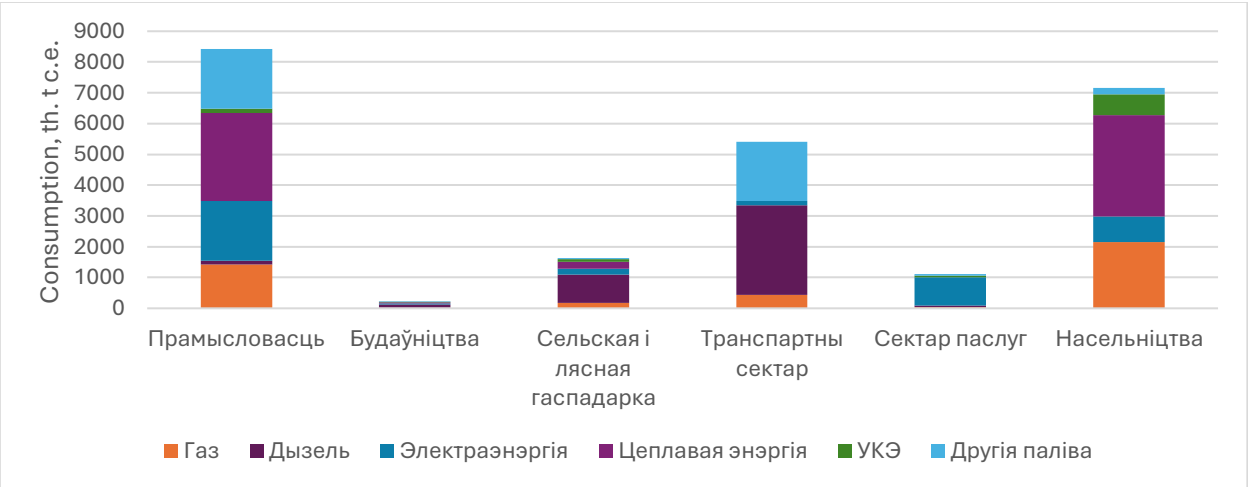

Figure 3 - Final consumption by consumer type

The largest energy consumer in the Republic of Belarus is industry. In second place is the population, which primarily uses thermal energy and natural gas. The transport sector ranks third, with consumption consisting mainly of diesel fuel and gasoline.

At the same time, according to official statistics, fuel consumption in the transport sector includes usage by both organizations and households.

The main fuel used for the production of thermal and electric energy in Belarus is natural gas. Biomass and fuel oil also account for a significant share.

As of 2020, the share of nuclear energy was negligible, amounting to only 0.6%. However, by 2024 its share had increased substantially due to the commissioning of the nuclear power plant and its reaching planned operating capacity.

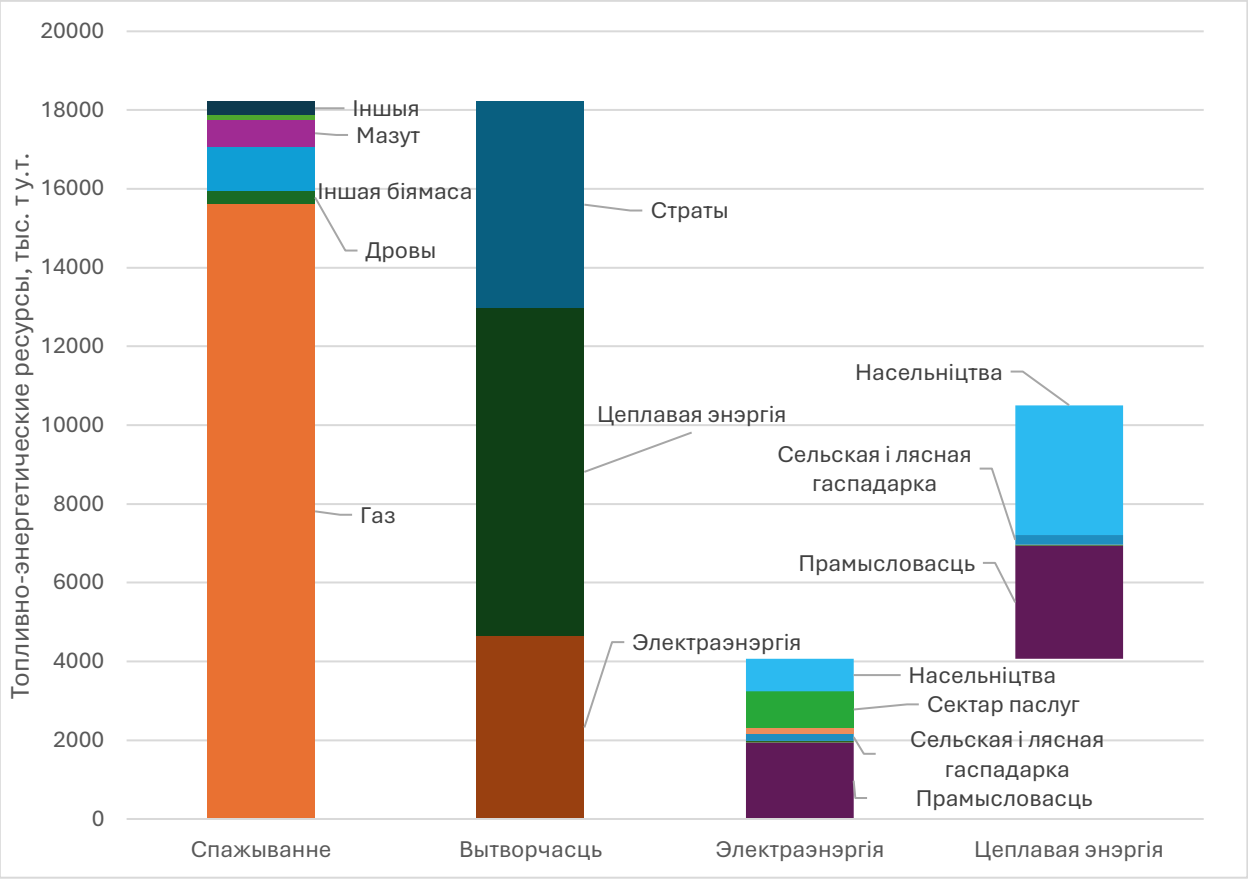

Figure 4 - Consumption structure and generation in the heat and electricity conversion sector

In the structure of energy production, thermal energy predominates. In energy-equivalent terms, the volume of electricity generation is approximately equal to the volume of losses, which is a normal situation, as losses in electricity generation can reach up to 60%.

The main consumer of electricity is industry, which accounts for about half of total consumption. Consumption of thermal energy is almost entirely distributed between industry and households.

The oil refining sector consists of two refineries, a network of filling stations, and oil extraction enterprises. Belarus produces around 2 million tons of oil per year, while the remaining volume is imported from Russia. Until 2020, domestically produced oil was largely exported, as it was of higher quality and could be sold at a higher price. After 2020, oil exports were halted. A significant share of gasoline and diesel fuel was also exported prior to 2020. Following the introduction of sanctions against the oil sector, exports continued, but their volumes decreased substantially and became highly dependent on market conditions.

Oil is supplied from Russia to Belarus via the Druzhba pipeline. The main flow is directed to the Mozyr Oil Refinery, as well as via a branch line to the Novopolotsk Oil Refinery.

Between the two refineries, there is an interconnecting oil pipeline laid across the territory of Belarus. It provides the ability to pump oil between the refineries in cases where supplies can be delivered to only one of the plants.

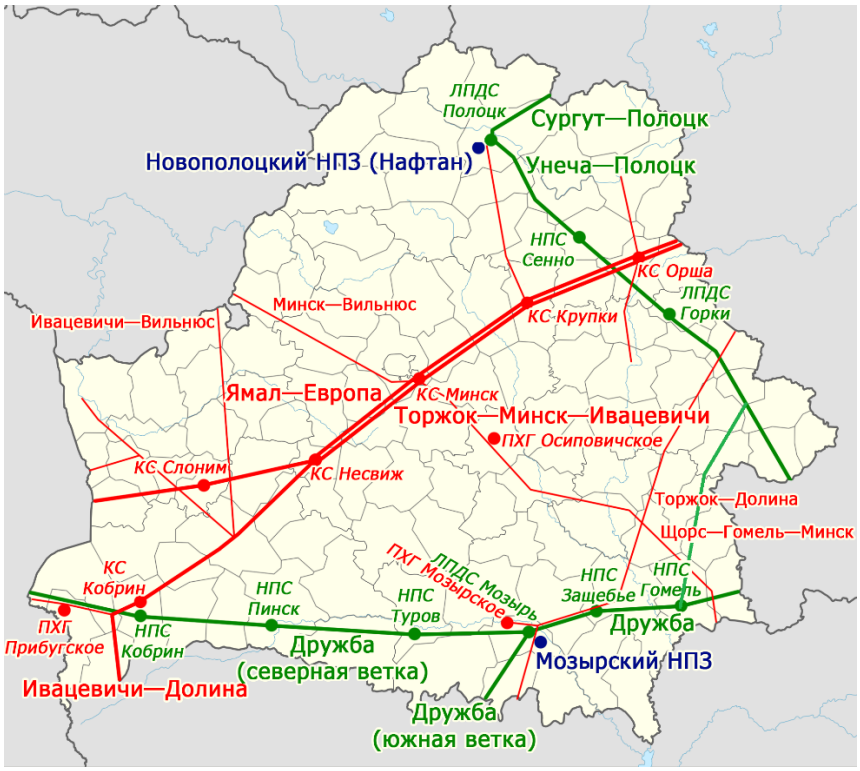

Figure 5 - Map of oil and gas pipelines

Supplies of natural gas to Belarus are delivered via several main trunk gas pipelines, the network of which is well developed across the country. In addition to domestic consumption, the gas pipeline infrastructure is used for the transit of Russian gas through Belarus and Lithuania to the Kaliningrad region of Russia. At the same time, gas transit via the Yamal–Europe pipeline was halted in 2022 and has not been resumed to date.

To analyze potential threats, the PESTEL approach was applied, which involves examining factors across six dimensions: political, economic, social, technological, environmental, and legal (the methodology's name is derived from the first letters of the English terms Political, Economic, Social, Technological, Environmental, and Legal).

To assess the potential impact of threats, a block diagram of the fuel and energy complex was developed. Based on this diagram, a risk analysis was conducted for each element of the system as well as for the connections between them.

The analysis of a wide range of threats showed that they can be grouped into two main categories, the impact of which extends beyond the energy sector itself:

1. Threats related to restrictions on energy resource supplies;
2. Threats associated with sharp increases in energy prices.

In addition, the study revealed the particular importance of external threats, which is explained by the high degree of dependence of Belarus's fuel and energy complex on imported energy resources.

Within the proposed model, external threats are defined as those that may cause shocks to infrastructure elements connecting Belarus's energy system with the energy systems of neighboring countries. Such threats may arise as a result of geopolitical, economic, or technological developments outside Belarus, while still having a significant impact on domestic energy security.

Since Russia is simultaneously both the supplier of energy resources and the owner of the main transport infrastructure, there is no need to artificially separate these two components as distinct external elements. From the perspective of Belarus as a consumer, limitations either in production (supply volumes) or in transport capacity from Russian territory have an identical effect on the stability of the fuel and energy complex.

For countries of the European Union, the situation differs from that of Russia. First, they are not owners of energy resources and mainly act as transit territories. Energy resources are purchased on the global market, which is sufficiently diverse and deep, meaning that the ability to acquire resources at market prices is almost always available (approaching 100%).

However, despite access to resources, the risk of transport restrictions across EU territory remains. This is particularly relevant for Poland and Lithuania, whose infrastructure was not originally designed to ensure energy supplies to Belarus. As a result, certain route segments may have insufficient capacity to transmit the required volumes.

Therefore, for routes passing through EU countries, more detailed modeling is required, taking into account technical constraints and potential bottlenecks in transport infrastructure.

In addition, the European Union has established a system that ensures a very low degree of dependence of infrastructure owners on owners of oil products and political actors. As a result, the availability of EU transport infrastructure is considered more reliable and is mainly constrained by commercial and technical factors.

Thus, a significant number of threats to energy infrastructure facilities can be grouped into several main categories depending on their consequences. The most severe consequences arise when threats related to imported energy flows materialize.

Restrictions on supplies:

- Oil pipelines from Russia (the Druzhba pipeline system);
- Gas pipelines from Russia;
- Supply of nuclear fuel.

Increases in energy prices:

- Oil pipelines from Russia (the Druzhba pipeline system);
- Gas pipelines from Russia;
- Supply of nuclear fuel.

Since other infrastructure facilities (those associated with EU countries and Ukraine) are currently not used to supply energy to Belarus, they cannot directly affect supplies or generate shocks within the country's energy system.

However, it should be taken into account that these facilities may influence the ability to mitigate the consequences of other shocks, including through their potential use as alternative routes or reserve transport corridors:

- Oil terminals in Lithuania;
- Rail transport through Lithuania;
- Oil terminals in Poland;
- The Gdańsk–Płock pipeline;
- Transit through Poland (Druzhba);
- The Klaipėda LNG terminal;
- The gas transmission system of Lithuania;
- The Świnoujście LNG terminal.

Internal shocks are understood as factors that may affect the normal functioning of infrastructure facilities, changes in state financial support, as well as possible disruptions in the supply of energy resources extracted within the country.

The analysis covered 20 facilities and groups of facilities, among which the most significant are internal networks (gas, oil, and electricity), oil refineries, power plants, peat industry facilities, as well as systems for the distribution and export of petroleum products.

To assess the significance of internal shocks, a three-parameter approach was used. Each parameter had a qualitative description and a corresponding quantitative value, allowing for a comprehensive determination of risk levels.

Each shock was evaluated according to the following criteria:

Probability – how likely and feasible the realization of a given shock is

- Very high – 3 – the shock is expected within the next 2–3 years or occurs every 2–3 years;
- High – 2 – the shock is expected within the next 10 years or has occurred within the past 10 years;
- Medium – 1 – the shock has not occurred in Belarus but has occurred in other countries;
- Low – 0 – the shock is unlikely but potentially possible.

Vulnerability – how easily the shock can affect the normal functioning of energy systems

- Very high – 3 – the facility is a single enterprise, compactly located, with a single administrative and organizational structure, and dependent on budgetary support;
- High – 2 – one of the above conditions is not met, or the facility is spatially dispersed (pipelines, lines, networks, etc.), or it does not depend on budgetary support;
- Medium – 1 – the facility consists of several enterprises distributed across the country, with different management structures, and without dependence on budgetary support;
- Low – 0 – more than 10 facilities nationwide, independent from each other and without budgetary support.

Losses – how significant the losses from the realization of a given shock may be

- Very high – 3 – realization of the shock leads to losses beyond purely economic damage and results in the cessation of energy supplies to households, including electricity and thermal energy;
- High – 2 – losses affect all sectors of the economy;
- Medium – 1 – realization of the shock leads to higher energy prices or increased budgetary support requirements, without a significant impact on the economy as a whole;
- Low – 0 – realization of the shock does not lead to significant economic changes in the energy sector.

The overall level of risk is determined by multiplying the quantitative values of all three parameters.

Based on the results of the analysis, shocks were ranked according to their degree of impact. Table 1 presents the ten most significant and influential shocks.

Table 1 – Shocks

No.	Facility	Shock	Risk
1	Gas pipelines from Russia	Suspension or restriction of supplies	18
2	Oil pipelines from Russia (Druzhba system)	Suspension or restriction of supplies	18
3	Power grids	Shutdown of operations	9
4	Boiler houses	Termination of subsidies	8
5	Oil pipelines from Russia (Druzhba system)	Increase in oil prices	6
6	Gas pipelines from Russia	Increase in energy prices	4
7	Oil refining	Shutdown of operations	3
8	Exports	Shutdown of operations	3
9	Condensing power plants (CPP)	Shutdown of operations	3
10	Combined heat and power plants (CHP)	Shutdown of operations	3

A significant share of these shocks is not unique to the Belarusian energy system and has previously occurred in various countries at different times and with varying intensity. To develop a set of measures aimed at overcoming and mitigating their consequences, an analysis of energy crises in other countries was conducted. For example, the energy crises in Texas and China in 2021, caused by extreme weather conditions (severe cold in Texas and heat waves in China), were examined. However, the primary focus was placed on energy crises in Eastern Europe. The following events were analyzed:

- The energy crisis in Lithuania in 1990;
- Energy crises in Belarus in 2002, 2004, 2006–2007, 2010, and 2020;
- Energy crises in Ukraine in 2005, 2009, and 2014. Later conflicts were not considered, as they occurred under conditions of direct military confrontation between Russia and Ukraine;
- Energy crises in Moldova in 2021–2022 and 2025;
- The European energy crisis of 2022–2023.

Based on the system analysis and the review of international experience in overcoming energy crises, it is possible to formulate a list of effective measures. This list includes approaches and solutions that have proven effective during past energy crises in various countries, as well as the results of an analysis of emergency response plans developed in international practice.

The list includes the following measures:

1. Use of reserves of oil, oil products, gas, and other local fuels;
2. Maximization of the use of local energy sources at energy system facilities (peat, biomass, domestic oil);
3. Use of reserve fuels for power plants;
4. Search for and organization of supplies from alternative sources of gas, oil, oil products, or electricity;
5. Subsidization of the consumption of local energy sources;
6. Prioritization of consumers;
7. Restrictions on the use of non-essential equipment (air conditioners), external building lighting, street lighting, and electric heating where alternative sources are available;
8. Establishment of heated premises;
9. Limitation of market mechanisms. Price caps may be applied at a sufficiently high level that avoids shortages while preventing suppliers from earning windfall profits;
10. Introduction of compensation mechanisms for rising energy costs for vulnerable groups;
11. Rolling (rotational) energy outages;
12. Restrictions on the operation of enterprises.

Data from Table 1 show that the most vulnerable elements are supplies of natural gas and oil to Belarus. At the same time, gas and oil supplies are associated with two main shocks: supply restrictions and price increases. In the event of supply disruptions, the primary task becomes ensuring access to energy resources from alternative sources. However, such energy will most likely be priced in line with global market prices, which will automatically result in a price shock for energy resources.

In the case of rising energy prices, the action plan should include several groups of measures:

- Increasing the efficiency of natural gas consumption;
- Substituting natural gas with other types of fuel;
- Reducing the costs of gas supply.

To overcome this shock, a set of standard resources is required, such as operational resources (transport, communications, organization of meetings), qualified personnel, and others. However, in addition to standard resources, special resources are also needed, the preparation of which requires additional effort. In the case of rising energy prices, these are primarily financial resources for:

- Establishing a program for the urgent modernization of gas-consuming equipment;
- Establishing a program for the thermal insulation of residential buildings;
- Establishing a program for the modernization of boiler houses;
- Building up reserves of local fuels and biomass;
- Financing the construction of power transmission lines and high-voltage direct current (HVDC) links;
- Establishing a support fund to facilitate the transition of households to local fuels;
- Establishing a fund for the implementation of targeted subsidies.

Financial resources will be used to mitigate increases in gas tariffs and to launch programs aimed at improving the efficiency of gas use.

In the event of a suspension or restriction of gas supplies, all measures envisaged under the energy price increase scenario will be implemented, along with additional measures aimed at ensuring reliable gas supply for national needs.

Negotiations on gas supplies to Belarus will need to be conducted along three main directions:

- Negotiations on gas supply terms with Russia;
- Negotiations on gas supplies from European Union countries;
- Non-market reductions in gas consumption.

When organizing gas supplies from Europe, the Yamal–Europe pipeline may be used in reverse-flow mode. Its capacity is sufficient to meet all of Belarus's needs. In this case, gas prices would correspond to spot prices on European gas trading hubs.

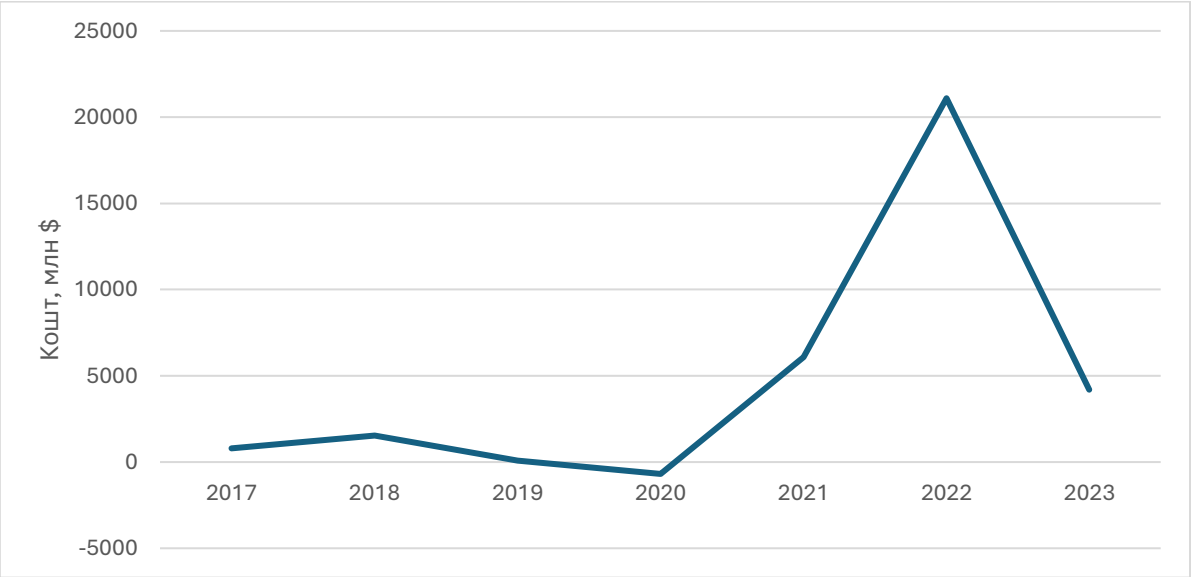

Figure 6 – Additional costs when purchasing gas in the EU

The difference between Belarus's actual expenditures on gas purchases and the potential expenditures that would have arisen had Belarus purchased gas at global market prices in 2023

amounts to USD 4.2 billion per year (Figure 6). At the same time, in 2022 this difference reached USD 20 billion. However, it can be observed that during the period from 2017 to 2020 the difference was insignificant, and in 2020 gas prices in the European Union were in fact lower than those in Belarus. This indicator is highly volatile, and the scale of financial losses may range from very large to almost negligible.

In the case of a shock related to rising costs of oil procurement, in addition to standard resources, additional resources are also required, the preparation of which involves special efforts. Among them, the following can be highlighted:

- An expanded bus fleet to increase the number of routes and the frequency of buses on existing routes;
- Additional financial resources to improve the availability of charging infrastructure for electric vehicles.

Belarus received oil from Russia at prices significantly below global market levels, especially during the period from 2011 to 2015. Following the introduction of the tax maneuver in Russia, oil prices for Belarus were gradually aligned with global prices, and at present the difference has become insignificant. Therefore, under current conditions, an increase in oil prices is unlikely to cause substantial economic consequences for the country.

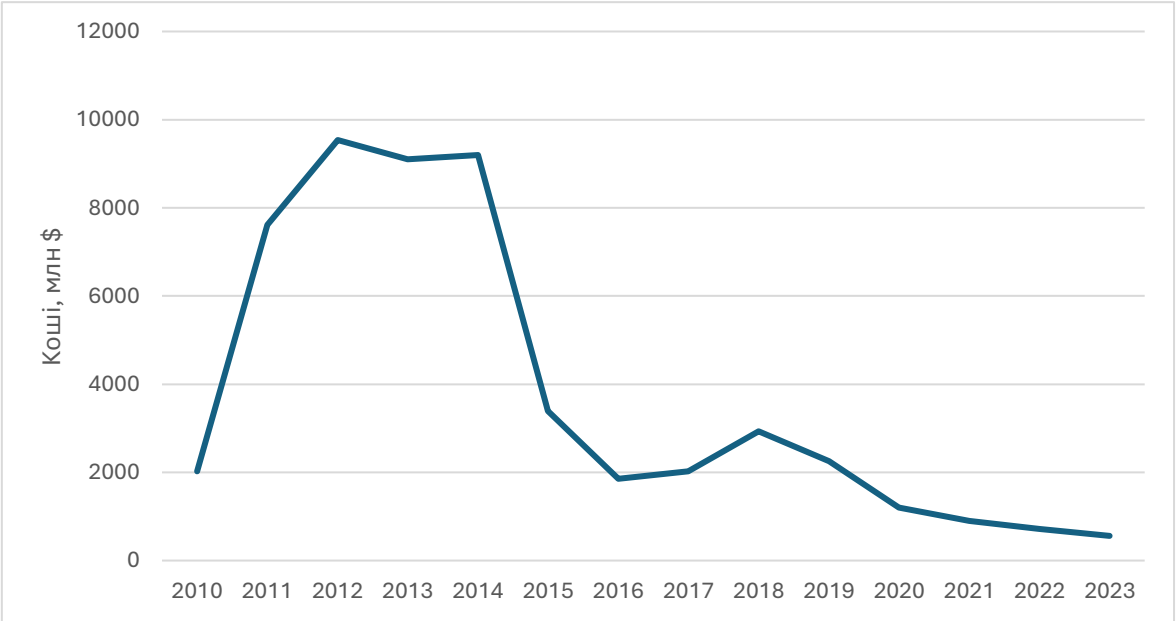

Figure 7 - Potential costs of oil supply

As can be seen from the chart, additional costs related to oil supplies in recent years have not been significant and, according to estimates, declined to USD 0.5 billion in 2023.

Another major threat is the shutdown of the electricity grid. This may take the form of a nationwide blackout (for example, as occurred in Spain in spring 2025), or localized outages in specific areas of Belarus, such as in the Mazyr District following a summer storm in 2024.

In the event of an electricity grid shutdown, the required resources largely fall outside the financial domain. The most critical among them include:

- Stocks of equipment and spare parts for repairing damaged electrical infrastructure;

- Diesel generators, including mobile units, to provide backup power supply to the most critical consumers;
- Reserves of diesel fuel and the organization of its delivery;
- Organization of supplies of other critical resources—water, food, medicines, etc.

The tariff for thermal energy for households in June 2025 amounted to 27.23 rubles per Gcal, while the full tariff covering all economically justified costs stood at 134.94 rubles per Gcal. The level of subsidization of household thermal energy consumption reaches 80%, which makes the suspension or reduction of these subsidies a significant shock to the heat supply system.

These subsidies are partially covered by higher tariffs for thermal energy charged to industry. For combined heat and power plants (CHPs), this does not pose a major problem, as they have a substantial share of industrial consumers. However, boiler houses, which are often located in districts and lack industrial consumers, sell thermal energy primarily to households. In such a situation, boiler houses would incur losses from heat sales, but their costs are compensated from district budgets. Therefore, a reduction in budgetary support may negatively affect the economic performance of boiler houses.

In the event of a suspension or reduction of subsidies, several groups of measures must be implemented:

- Increasing the efficiency of thermal energy consumption;
- Compensating consumers for rising heat supply costs.

In addition to standard resources, additional resources are required whose preparation demands extra effort. For this shock, these include:

- Building up stocks or reserve production capacities for materials aimed at improving the energy efficiency of residential buildings (insulation materials, energy-efficient windows and glazing, etc.);
- Financial resources to develop a program for thermal insulation of residential and administrative buildings;
- Financial resources to establish a support fund for the transition of households to local fuels;
- Financial resources to establish a fund for targeted subsidies.

In 2020, household consumption of thermal energy amounted to 23,121 thousand Gcal. There are no precise data on how much of this volume was produced by boiler houses; however, across Belarus as a whole, boiler houses generated 37% of total thermal energy output.

If thermal energy production is conditionally distributed evenly between consumers—households and others—it follows that boiler houses produced around 8,500 thousand Gcal for household needs. Under these assumptions, the total volume of subsidies is estimated at approximately USD 305 million.

The analysis of energy crises revealed another important feature. The most severe and prolonged energy crises were those that arose not from natural or technological causes, but in situations involving an active initiator. Technical systems regularly undergo stress testing and are therefore relatively resilient to accidental outages or adverse weather conditions. However, when a second actor is involved (in this region, this role is often played by Russia—the main supplier of energy resources), the parties may act in ways that aggravate or deliberately prolong the crisis.

The main directions of action of an active initiator include:

- Delaying the start of active preparation and implementation of crisis mitigation measures through the imitation of negotiation processes;
- Depleting available reserves before the onset of the acute phase of the crisis;
- Using assets located within the country (energy systems, storage facilities, other suppliers, etc.) that belong to the initiating country in order to complicate crisis mitigation;
- Conducting information campaigns aimed at undermining trust in crisis response measures;
- Obstructing the organization of negotiations with other countries;
- Hindering the implementation of measures to reduce consumption;
- Synchronizing pressure from different energy companies specializing in different types of fuel.

Some of these actions are typically carried out after the acute phase of the crisis has already begun (price increases or supply restrictions). However, certain actions require prior preparation. These actions may serve as indicators of preparations for initiating such a type of crisis. These indicators may include:

- Depletion of gas storage facilities below normal levels;
- Planning large-scale repairs on transport corridors;
- Unjustified booking of available gas transport capacities in neighboring countries by dubious entities;
- Suspicious concessions regarding the resumption of gas supplies via the Yamal–Europe pipeline or oil supplies via the Druzhba pipeline;
- Increased demand for fuel oil in Belarus from foreign companies;
- Signing contracts for the supply of gas-intensive products (steel, nitrogen fertilizers, electricity) to Russia in significant volumes without clear economic justification;
- Searching for a pretext (a non-politicized situation) to reduce oil supplies in order to decrease oil volumes in storage;
- Signing contracts for the supply of petroleum products to Russia in significant volumes without clear economic justification;
- Acts of sabotage on railways, oil pipelines, and gas pipelines in neighboring countries.

To this list should be added events such as the approach of the expiration date of an existing contract without the initiation of negotiations on concluding a new one. However, such actions are already considered the first stage of crisis formation. The direct actions listed above, when occurring in parallel with difficulties in preparing a new contract (upon expiration of the existing one), are indicators of deliberate crisis preparation rather than merely an attempt to secure more favorable terms for energy supply contracts.