

A Simulation Model for Compiling Projected Regional Energy Balances

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Abstract — The great uncertainty in the values of technical and economic indicators of energy sector development hinders the compilation of projected (calculated) regional energy balances. To address this issue, we propose using the indicator-based analysis aided by simulations to develop projected regional energy balances. This study contributes a simulation model for compiling projected balances, which is meant to facilitate projections of energy sectors of the regions of Russia. The model determines the necessary volumes of extraction, production, and imports of energy resources to ensure that the projected levels of consumption and exports of energy resources outside the region are maintained. The presented model was used to construct indicative fuel and energy balances of the Asian regions of Russia for 2050.

Index Terms — Energy sector, energy balance, Asian regions of Russia, indicator-based analysis, simulation model, projection.

I. INTRODUCTION

The Order of the Ministry of Energy of the Russian Federation No. 1169 dated October 29, 2023 [1] obliges the executive branch agencies of subjects of the Russian Federation and local municipal authorities to prepare projected energy balances every five years. The balances

are made up of interrelated indicators that reconcile in quantitative terms the supplies of fuel and energy resources (FER) and their consumption within the area of a subject of the Russian Federation, or a municipality. They establish the distribution of FER among different supply systems (electricity, heating, fuel), as well as among individual FER consumers and their groups, and determine the efficiency of their use.

Due to the high degree of inherent uncertainty of projections of the development of the energy sector in a region, the compilation of projected balances becomes an extremely arduous task [2, 3]. We propose to solve it with the aid of the indicator-based analysis that sets the value of key projected parameters (indicators) that need to be achieved to meet the region's needs for fuel and energy resources and to ensure the required exports.

II. SIMULATION MODEL OF THE PROJECTED ENERGY BALANCE

In order to construct the energy balance of a region, one needs to make a scenario-based projection of key technical and economic indicators, structural changes, as well as imports and exports of energy resources. Based on the above data, the demand for fuel and energy resources (FER) is calculated for each of the considered scenarios and the volumes of extraction and production of energy resources required to meet this demand are determined.

We propose using a simulation model to implement the indicator-based approach to projecting the energy balance of a region. The simulation model solves consecutively the expressions (1)–(21).

The construction of regional indicator-based energy balances relies on projected balances of final consumption of fuel and energy as input data:

$$\sum_{i=1}^I B_i^{fc} + W^{fc} + Q^{fc} = B^{fc}, \quad (1)$$

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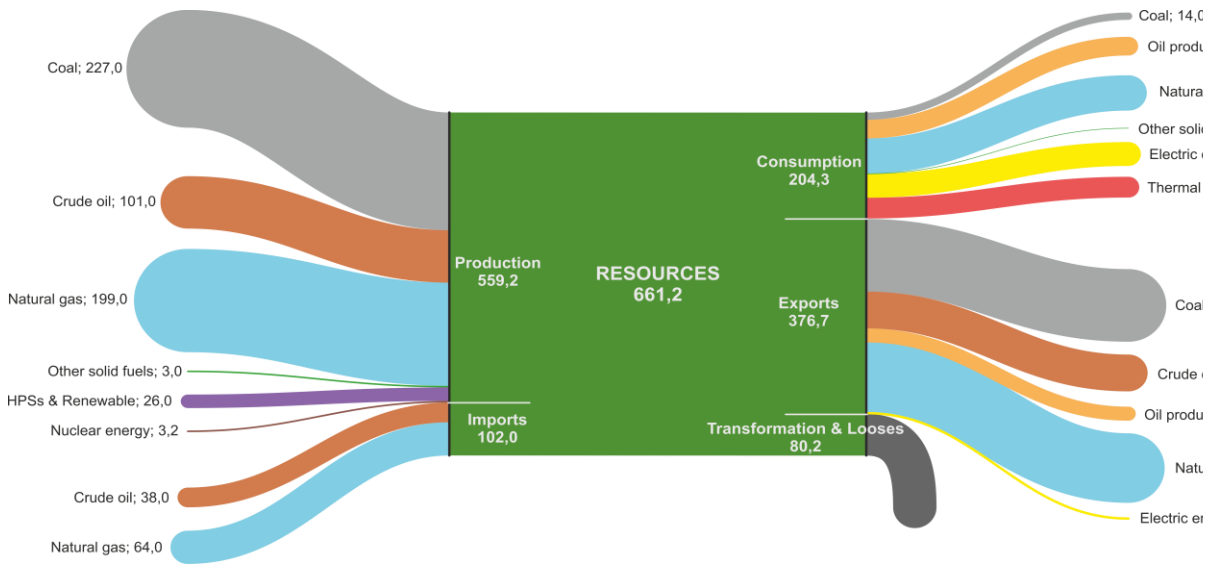


Fig. 1. Fuel and energy flows diagram for Asian regions of Russia for 2050, million t.c.e.

where B_i^{fc} is the final consumption of the i -th type of fuel (coal, gas, oil, etc.);
 W^{fc} is the final consumption of electricity;
 Q^{fc} is the final consumption of heat.

The first step in building the energy balance is to determine the required volumes of electricity and heat production. These volumes can be calculated based on the following relations:

$$W = W^{fc} + W^{aux} + W^{nl} + W^{exp} - W^{imp} + W^{EB}, \quad (2)$$

$$Q = Q^{fc} + Q^{aux} + Q^{nl}, \quad (3)$$

where W and Q are the required volumes of electricity and heat production, respectively;

W^{aux} and Q^{aux} are auxiliary consumption of electricity and heat by their producers (power plants and boiler plants);

W^{nl} and Q^{nl} are losses in electric and heat networks;

W^{imp} are electricity imports from outside the region;

W^{exp} are electricity exports from the region;

W^{EB} is electricity consumption at electric boiler plants.

Auxiliary consumption and network losses are determined by predicting or specifying the percentages (standardized values) of losses. Auxiliary consumption of electricity and heat as well as losses are calculated according to the next expressions:

$$W^{aux} = n^{aux}W, \quad (4)$$

$$W^{nl} = n^{nl}(W - W^{aux}), \quad (5)$$

$$Q^{aux} = m^{aux}Q, \quad (6)$$

$$Q^{nl} = m^{nl}(Q - Q^{aux}) \quad (7)$$

where n^{aux} is the percentage of auxiliary electricity consumption;

n^{nl} is percentage of electricity losses in networks;

m^{aux} is percentage of auxiliary heat consumption;

m^{nl} is percentage of heat losses in distribution networks.

The volumes of electric (W) and thermal (Q) energy production are determined from the given relations (2)–(7).

Electric and thermal energy production at power plants and boiler plants of various types is calculated using the balance relations:

$$W = W^{TPP} + W^{HPP} + W^{NPP} + W^{ncRES}, \quad (8)$$

$$Q = Q^{TPP} + Q^{boil} + Q^{EB} + Q^{NPP} + Q^{HRP}, \quad (9)$$

where W^{TPP} , W^{HPP} , W^{NPP} , W^{ncRES} are electricity production at TPPs, HPPs, NPPs, and non-conventional renewables, respectively; Q^{TPP} , Q^{boil} , Q^{EB} , Q^{NPP} , Q^{HRP} are heat production at TPPs, boiler plants, NPPs, electric boilers, and heat recovery plants, respectively.

All the above values are specified in calculations, except for electricity production at TPPs and heat production at TPPs and boiler plants.

Heat production at TPPs (Q^{TPP}) and boiler plants (Q^{boil}) is determined by specifying their percentage in heat production:

$$Q^{TPP} = p^{TPP}(Q - Q^{EB} - Q^{NPP} - Q^{HRP}), \quad (10)$$

$$Q^{boil} = p^{boil} (Q - Q^{Eb} - Q^{NPP} - Q^{HRP}), \quad (11)$$

$$p^{TPP} + p^{boil} = 1, \quad (12)$$

where p^{TPP} , p^{boil} are percentages of heat production at TPPs and boiler plants.

Having determined the volumes of electricity and heat production at TPPs and boiler plants, we calculate the demand for fuel required for electricity and heat production. To that end, we use metrics such as the projected fuel consumption rate for heat production at boiler plants (b^{boil}) and the efficiency of power plants (η^{TPP}):

$$B^{TPP} = \frac{W^{TPP} + Q^{TPP}}{\eta^{TPP}}, \quad (13)$$

$$B^{boil} = Q^{boil} b^{boil}. \quad (14)$$

To determine the demand for specific types of fuel i at TPPs and boiler plants, we specify the mix of fuel consumption (τ_i^{TPP} and τ_i^{boil}):

$$\sum_{i=1}^I \tau_i^{TPP} = 1, \quad (15)$$

$$\sum_{i=1}^I \tau_i^{boil} = 1. \quad (16)$$

Therefore, the demand for a particular fuel type i is determined as follows:

$$B_i^{TPP} = \tau_i^{TPP} B^{TPP}, \quad i = 1, \dots, I, \quad (17)$$

$$Q_i^{boil} = \tau_i^{boil} Q^{boil}, \quad i = 1, \dots, I. \quad (18)$$

By specifying fuel imports (B_i^{imp}) and exports (B_i^{exp}), it is possible to determine the required fuel production (extraction) (B_i^{prod}):

$$B_i^{prod} = B_i^{fc} + B_i^{boil} + B_i^{TPP} + B_i^{exp} - B_i^{imp}, \quad i = 1, \dots, I. \quad (19)$$

If the production and imports of energy resources in the region are specified, possible exports are determined as follows:

$$B_i^{exp} = B_i^{prod} - B_i^{fc} - B_i^{boil} - B_i^{TPP} + B_i^{imp}, \quad (20)$$

or, in the case of specified production and exports, we find the required imports using the expression:

$$B_i^{imp} = B_i^{fc} + B_i^{boil} + B_i^{TPP} + B_i^{exp} - B_i^{prod}. \quad (21)$$

The compiled regional energy balance enables us to determine the volumes of extraction and production of energy resources and makeup of production and consumption of energy resources for the considered time horizon with respect to the specified indicator-based parameters of the region's energy sector development.

III. IMPLEMENTATION OF THE SIMULATION MODEL

Using the described model, a projected fuel and energy balance for 2050 was compiled for the Asian regions of Russia, including the territories of the Siberian and Far Eastern Federal Districts.

The following indicators were set as the main ones:

TABLE 1. Projected Fuel and Energy Balance for Asian Regions of Russia for 2050, Million t.c.e.

Indicators	Coal	Crude oil	Oil products	Natural gas	Other solid fuels	Hydro energy and NRES*	Nuclear energy	Electric energy	Thermal energy	Total
Production of fuel and energy resources	227	101	-	199	3	26	3.2	-	-	559
Imports	-	38	-	64	-	-	-	-	-	102
Exports	-140	-71	-27	-134	-	-	-	-4.7	-	-377
Primary energy consumption	87	68	-27	129	3	26	3.2	-4.7	-	285
Hydropower plants and NRES, nuclear power plants	-	-	-	-	-	-26	-1.9	28	-	-
Thermal power plants	-32	-	-0.8	-46	-1	-	-	29	23	-28
Boiler houses	-6	-0.2	-0.6	-12	-1.6	-	-	-	19	-1.4
Electric boiler houses and heat recovery units	-	-	-	-	-	-	-1.3	-0.8	3.6	1.5
Coal processing	-35	-	-	-	-	-	-	-	-	-35
Oil refining	-	-65	64	-	-	-	-	-	-	-1.0
Auxiliaries	-	-	-	-	-	-	-	-2.3	-2.1	-4.4
Transmission losses	-	-3	-	-4	-	-	-	-3.3	-3.1	-13
Final consumption of fuel and energy resources	14	-	35.9	68	0.4	-	-	46	40	204

* NRES – non-conventional renewable energy sources

- Final consumption of fuel and energy resources;
- Percentage of thermal and electrical energy losses in networks;
- Auxiliary consumption for the thermal and electric energy production;
- Specific fuel consumption for the thermal energy production at boiler houses;
- Efficiency of thermal power plants;
- Projected volumes of thermal energy production;
- Volumes of FER imports and exports;
- Structure of thermal energy production;
- Structure of fuel consumption at boiler houses and power plants;

For these indicator values, the required volumes of extraction/production of fuel and energy resources were established and a fuel and energy balance was projected for the Asian regions of Russia (Table 1).

In order to gain a deeper comprehension and visual representation of the energy balance table, we use Sankey diagrams. These diagrams show how resources are obtained from the production and import of FER and how they are distributed for final consumption, export, and losses. This is illustrated in Fig. 1, which represents the data from Table 1 as the fuel and energy flows for Asian regions of Russia in 2050, in million tons of coal equivalent.

IV. CONCLUSION

This approach is universally applicable and can be recommended for enhancing the methodology used to compile regional fuel and energy balances, especially in the face of high uncertainty regarding initial data to be projected.

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