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ANALYSIS OF THE QUALITY OF BUILDING SHORT-TERM FORECASTS OF ENERGY BALANCES

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Annotation. The quality analysis of the short-term forecasts of energy balances, based on the results for 6 cycles, was carried out. The methodological approaches of the applied two methods – extrapolation and neural network models are described.

Keywords: energy balance, short-time forecast, quality, neural network models.

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АНАЛИЗ КАЧЕСТВА ПОСТРОЕНИЯ КРАТКОСРОЧНЫХ ПРОГНОЗОВ ЭНЕРГЕТИЧЕСКИХ БАЛАНСОВ

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Аннотация. Проведен качественный анализ краткосрочных прогнозов энергетических балансов, основанный на учреждении за 6 циклов. Описаны методологические подходы двух методов расследования – экстраполяции и нейросетевых моделей.

Ключевые слова: энергетический баланс, краткосрочный прогноз, качество, нейросетевые модели.

Introduction. Work on the implementation of short-term forecasts of energy balances began on the recommendations of the international INOGATE project, which took place in 2014–2015 in Eastern European and other countries, including Moldova. The project was aimed at harmonizing national statistics with European ones [1]. The issues of presentation energy balances according to a unified structure adopted by the International Energy Agency [2] were considered. The project also included several special trainings on a special section (TA-ESS [3]) of annual short-term forecasts of the energy balance (EB) within the framework of the activities of the Ministry of Economy. Such work was included in the work plans of the Ministry of Economy and began to be carried out annually in the country.

Relevance. Short-term forecasts of the energy balance are in demand by government organizations in the preparation of long-term documents for the next year or two. The energy balance of the previous year is published in the country with a delay of almost a year, so the forecast values of fuel consumption are used in the current year until the publication of the actual ones [4]. The short-term forecast of the energy balance is built annually for the next year as soon as the energy balance is published for the previous year (actual). At the same time, it is possible to compare published actual values with previously predicted ones and assess the quality of the previous forecast. Over the past years, 6 cycles of such calculations have been carried out and certain information has been accumulated, which makes it possible to carry out a generalized analysis of the quality of the Short-term forecasts of the energy balance for previous cycles [5–7]. An analysis of individual factors, methodological features and some related issues was described in [8–17].

The structure of the energy balance and the use of special software for assessing supply and demand are considered in the work of R. Podolets [8]. The issues of developing the methodology for medium-term forecasts of demand for electricity taking into account the dynamics of the development of the country's economy were studied in the work of A. Makarov [9]. Approaches to improving the validity of long-term forecasts for the development of the energy sector were studied in the work of Yu. Kononov [10]. The dynamics of changes in fuel flows in the world was analyzed in large collective monographs by ERI edited by A. Makarov [11]. The methodology and experience in developing intersectoral balance models are described in the work of D. Shapot, V. Malakhov [12].

Methodological approaches and a number of results of the works carried out in Moldova have been described in several publications [13–17]. Articles [13, 14] are devoted to the methodology of short-term forecasts; analysis of prospective consumption of biomass in the domestic sector – work [15]; the development of a special calculation module for reflecting fuel flows and, at the same time, pollutant emissions, using the data for Moldova and Belarus as an example, is described in [16]; application of neural network analysis for fuel consumption forecasts is in [17].

Materials and methods of research. *Energy security indicators by fuels.* Moldova's System of indicators for analyzing and monitoring the overall level of energy security, contains a number of fuel-related indicators. These are: the availability of fuel and energy resources (import and consumption), production of own fuel and energy resources, consumption for the production of electricity and heat, and a number of others. Some of them are direct indicators reflecting key values of energy balances, for example, Gross Consumption.

The energy balance is entirely used to build fuel consumption forecasts.

The fuel consumption dynamics during a ten-year period is given below.

Dynamics of fuel flows for a number of key indicators of energy balances. The National Bureau of Statistics provided annually the Energy Balances, which is the main source of activity data regarding fuel consumption in the Republic of Moldova (included data only for the territory on the right bank of the Dniester River).

The dynamics of gross consumption, final energy consumption, primary production, import and export in RM are shown in Fig. 1, 2.

Gross consumption of fuel in the Republic of Moldova registered an increasing trend – from 2633 (2010) to 3087 (2018) ktep and after tended to decrease up to circa 2857 ktep in 2020. Final energy consumption had the same decreasing trend during the period 2010–2020 as Gross Consumption (Fig. 1) and in 2020 it registered the value of 2670 ktep.

The *Primary production* in RM does not provide the country with the necessary energy and mainly include production of biofuel, oil product and electricity. In 2020, Primary production amounted 682 thousand (668 ktep Biofuels, 6 ktep oil products and 8 ktep electricity), which is cca 4 times less than the total amount of fuel consumed in the country (Fig. 1).

The volume of Imports varied from a minimum of 1766 ktep to maximum 2109 ktep between 2010 and 2020. The Republic of Moldova imported mostly natural gas and oil products (about 95 % from total imported fuel). Under the heading From other sources is meant only electricity which is produced in the territory of the left bank of the Dniester River at Moldavian Thermal Power Plant and during the analyzed period the value varied from 161 ktep to 286 ktep (Fig. 1).

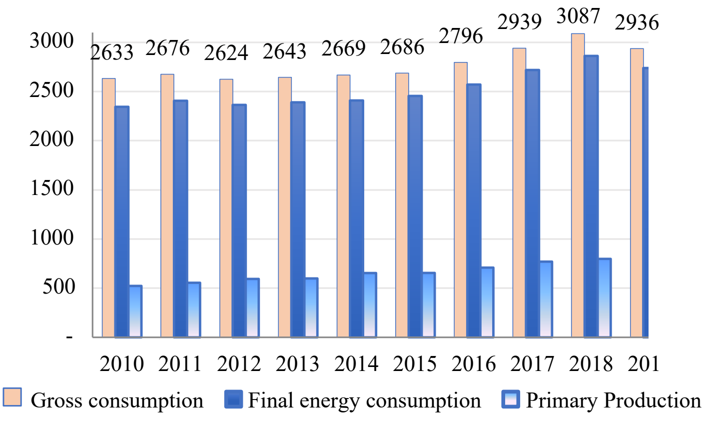


Fig. 1. Dynamics of Gross and Final energy consumption and primary production for 2010–2020, ktep

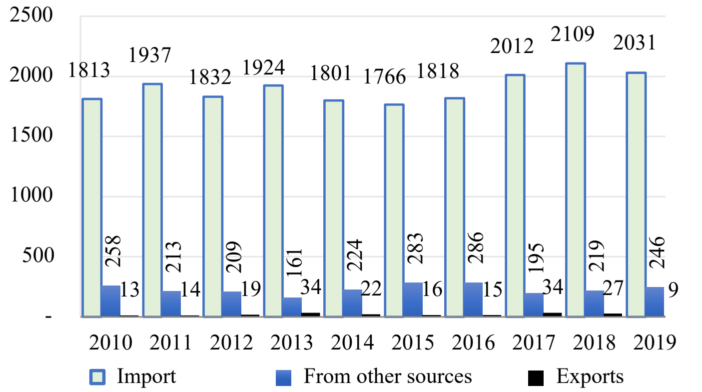


Fig. 2. Dynamics of Import and Export of fuel between 2010–2020, ktep

The Export volumes were and remain very small and mainly only oil products are exported (in some years export of biofuels and waste was registered also). In 2020 were exported 20 t of oil products and only 1 ton of biofuels and waste (Fig. 2).

Dynamics of natural gas, oil products, electricity and biomass consumption. The evolution of fuel consumption separately by type of fuel between 2010 and 2020 is presented below.

In 2020 the Gross consumption of natural gas constituted 872 ktep (Fig. 3). The natural gas consumption in Transformation Input is considered quite significant, since most power plants use this type of fuel mainly.

At the same time natural gas is also consumed in large volumes in the residential sector, which are reflected in Final energy consumption.

Between 2010 and 2020, the Final energy consumption of natural gas registered an increasing trend: from 456 ktep in 2010 to 496 ktep in 2020 (Fig. 4).

The consumption of **oil products** are mainly used in Transport sector, which is also reflected in the Final energy consumption. The total amount of oil products used

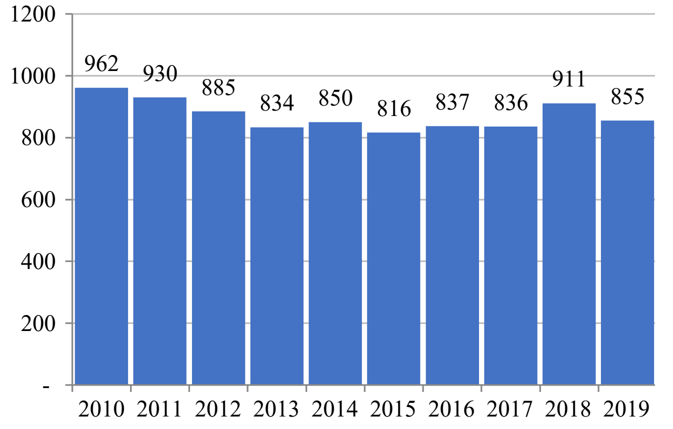


Fig. 3. Natural Gas – Gross Consumption, ktep

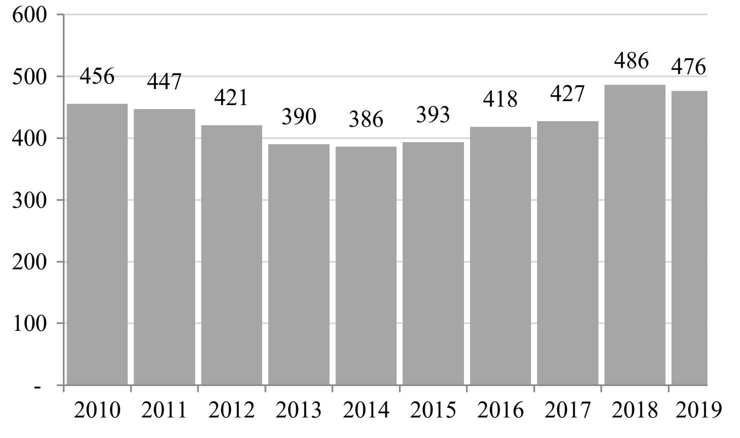


Fig. 4. Natural Gas – Final consumption, ktep

in 2020 amounted to 943 ktep, which is approximately 25 % more than was registered in 2010 (Fig. 5, 6).

Total Gross consumption of **biomass** registered an increasing trend from approximately 512 ktep to 787 ktep within 2010–2018, and decreased significantly cca 17 % in 2019–2020 (Fig. 7–8).

Biomass is the only type of fuel that is produced in the country in sufficient volume to cover the demand for Final consumption. The main biomass consumer is the residential sector.Between 2010 and 2020, Gross consumption and Final consumption of coal varied from a minimum of 75 ktep to 150 ktep, respectively from 74 ktep to 142 ktep (Fig. 9).

Based on the information presented above, the main fuel consumed on the Right Bank of the Dniester was Oil products, followed by the Biomass and Natural gas. It should be mentioned that the structure of fuel consumption didn't significantly changed during the analyzed period (Fig. 11, 11, *a*).

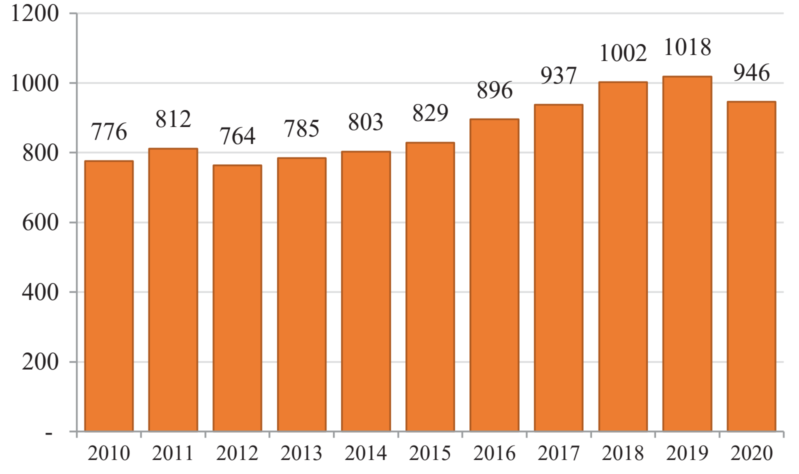


Fig. 5. Oil products – Gross Consumption, ktep

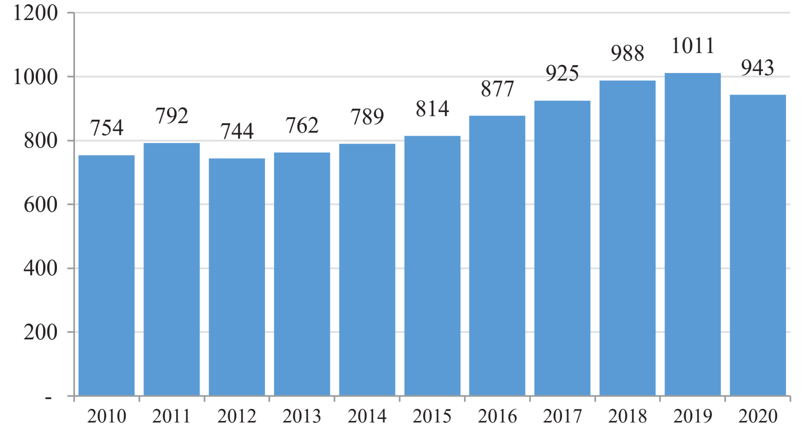


Fig. 6. Oil products – Final energy consumption, ktep

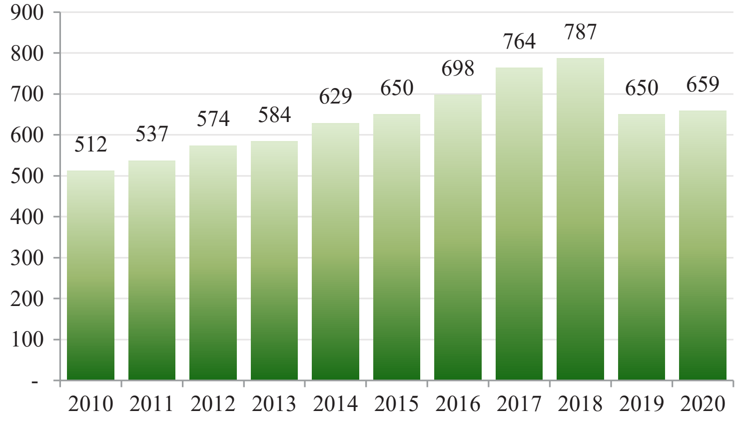


Fig. 7. Biomass – Gross Consumption, ktep

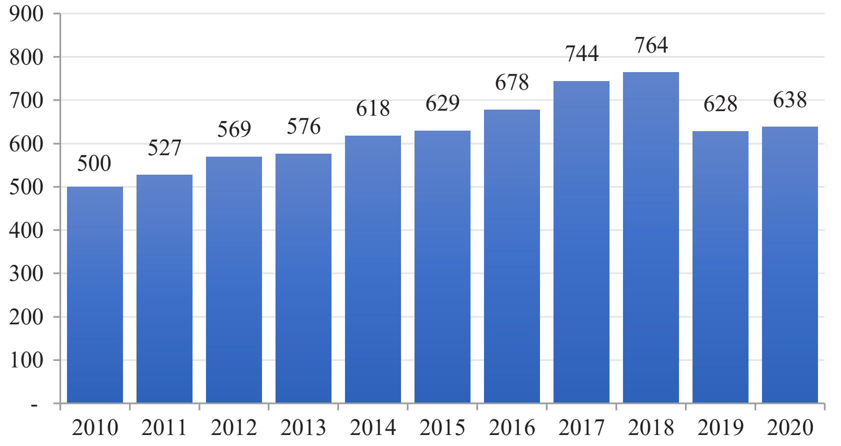


Fig. 8. Biomass – Final energy consumption, ktep

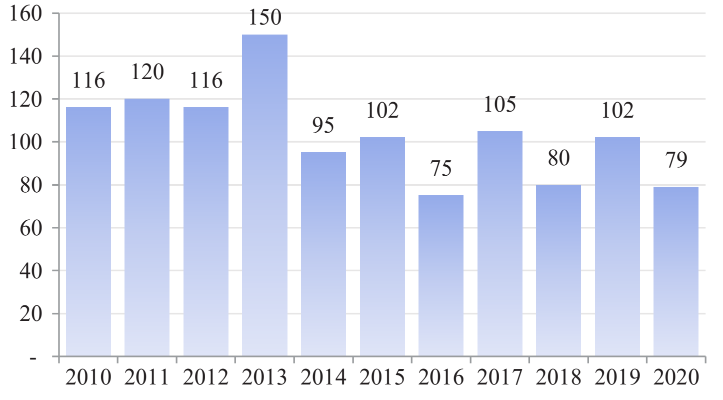


Fig. 9. Coal – Gross Consumption, ktep

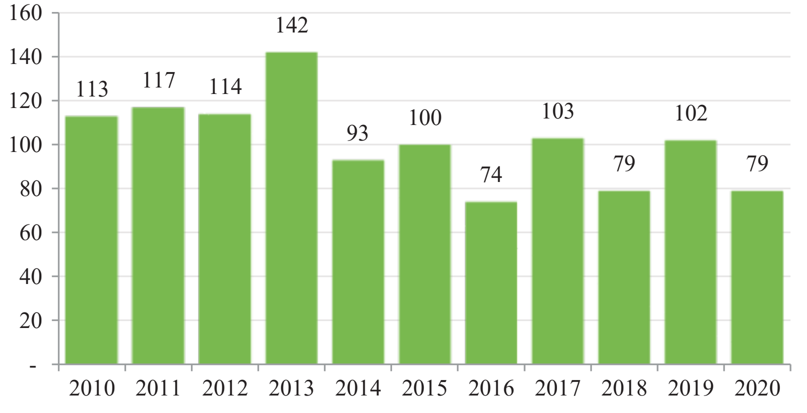


Fig. 10. Coal – Final energy consumption, ktep

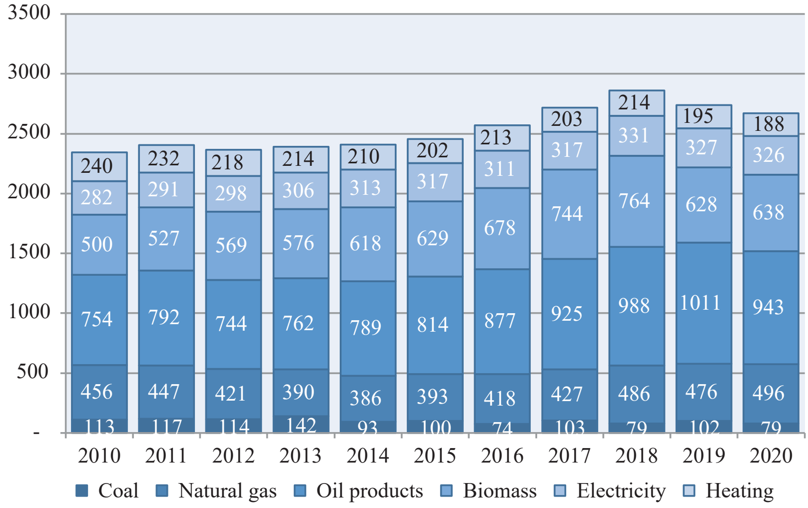


Fig. 11. Final Energy Consumption by energy products, ktep

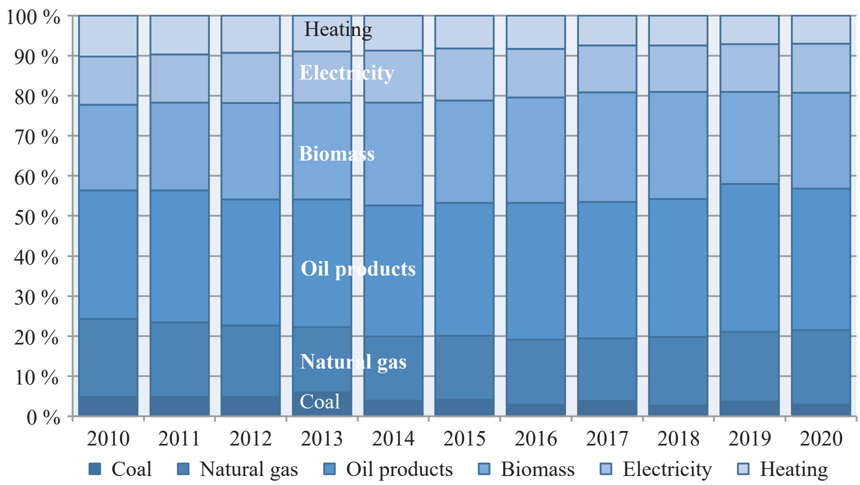


Fig. 11a. Final Energy Consumption by energy products, %

Thus, the Final energy consumption of heating decreased from 240 ktep in 2010 to 188 ktep in 2020, the consumption of coal decreased from circa 113 ktep in 2010 up to circa 79 ktep in 2020; at the same time, the consumption of gaseous fuels, liquid fuel, biofuels and electricity increased and in 2020 amounted to:

Gaseous fuels – 496 ktep;

Liquid fuel – 943 ktep;

Biofuels – 638 ktep;

Electricity – 326 ktep.

The fuel consumption by economic sectors between 2010 and 2020 is presented below (Fig. 12, 12a). The distribution of final energy consumption by sectors had the following trends:

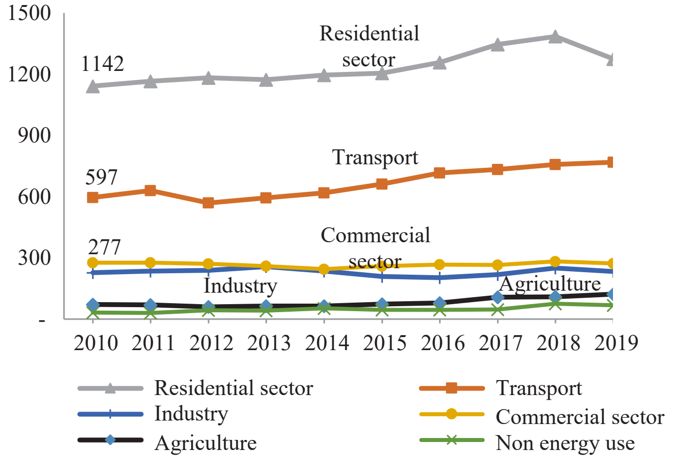


Fig. 12. Final Energy Consumption by sectors, ktep

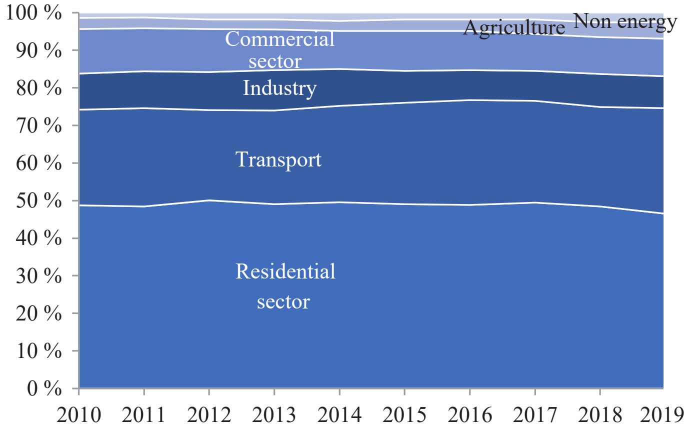


Fig. 12a. Final Energy Consumption by sectors, %

for residential sector – an increase from 1 142 (2010) to 1 296 (2020) ktep;
for transport sector – an increase from 597 (2010) to 681 (2020);
for commercial – a decrease from 277 (2010) to 254 (2020).

The residential sector has a 50 per cent share in the total final energy consumption, while transport and industry sector taken together account for 30 per cent.

The share of agriculture, non-energy and commercial sectors in the structure of total final energy consumption is relatively small (Fig. 12a).

Methodology of short-term forecasts of fuel consumption. Main approaches. The National Bureau of Statistics draws up annual energy balances based on actual data. Forecasts of fuel consumption for 1–2 years ahead are built on its basis.

The energy balance (EB) can be analyzed both in the form of a table and in the form of a flow diagram, which allows to visualize and simplify the perception of the of fuel flows by sectors of the economy. The structure of the energy balance is shown in fig. 13.

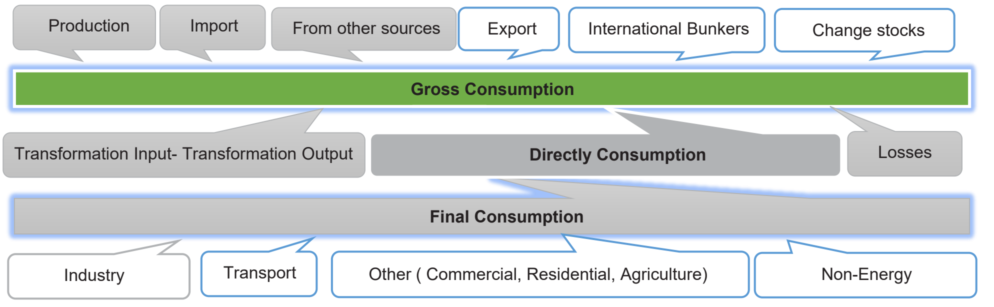


Fig. 13. Energy balance structure and fuel flows

The general formula includes the calculation of Gross Consumption using two formulas:

for the top part of the balance (top to bottom):

Gross Consumption = *Production* + *Import* + *From other sources* –
– *Export* – *International Bunkers* – *Change stocks*

for the second part of the balance (from bottom to top):

Gross Consumption = *Final Consumption* +
+ *(Transformation Input-Transformation Output)* + *Losses*.

Time series of values by years (7–8 years) are used to build forecasts, for extrapolation method is recommended INOGATE project (section TA-ESS) on harmonizing with European standards [3]. But other methods can also be used and two approaches are used in the work:

extrapolation coefficients – when taking into account fuels in the annual context;

neural network analysis – when taking into account fuel consumption by months.

Features and results of both methods are described below.

Methodology for calculating short-term forecasts of fuel accounting by years. Calculations of values for 2 forecast years, taking into account fuels by years, are carried out using the formula of extrapolation coefficients CAGR (Compound Annual Growth Rate) for time-sheet series of values with active dynamics:

$$CAGR = \left[\frac{V}{V_0}\left[\frac{1}{(t-t_0)}\right]\right] - 1, \qquad (1)$$

where: V – the final value of the indicator; V_0 – initial value of the indicator; t – final year; t_0 – initial year.

This approach also uses two additional coefficients LKV and LKS.

LKV – “last known value” – is used for series with small values (1–2 ktep). LKS – “last known consumption pattern” (for example, for industry) – is used if CAGR is applied to the sector ‘total’ and it is necessary to determine the values by every branch.

The forecast is performed for each line separately and for each part of the balance (top: from top to bottom, bottom: from bottom to top). At the same time, for both parts of the balance, the values of the final Gross consumption are determined, the values in which must match. The balancing line is the position of Imports or Production of fuels.

The predicted values for the 1st approach (taking into account fuels by years) or the top part of the energy balance are given in the table 1.

Table 1. **Forecast of Gross consumption and first 7 rows (upper part) of the energy balance for 2022, ktep**

Total products-2022	Coal	Natural gas	Oil products	Biofuels and waste	Electricity	Heat	Total
Primary Production	–	–	5	688	8	–	**701**
From other sources	–	–	–	–	293	–	**293**
Imports	74	866	1009	2	14	–	**1965**
Exports	–	–	20	–	–	–	**20**
International bunkers	–	–	–	–	–	–	–
Stock changes	–	–	–	–	–	–	–
Gross consumption	**74**	**866**	**994**	**690**	**315**	**–**	**2940**

The Gross consumption forecast is built on the basis of retrospective series of values for 2010–2020 and is illustrated in the fig. 14, and Final consumption – in the fig. 15. There was a decline in Gross consumption from 3 087 to 2 857 ktep in the period 2018–2020, but in 2022 a slight increase to 2940 ktep is expected. The situation is similar for *Final consumption*.

The described method was used to forecasts several times (6 cycles). The predicted values were annually compared with the actual consumption for all fuel groups when the next energy balance was issued, and discrepancies were determined.

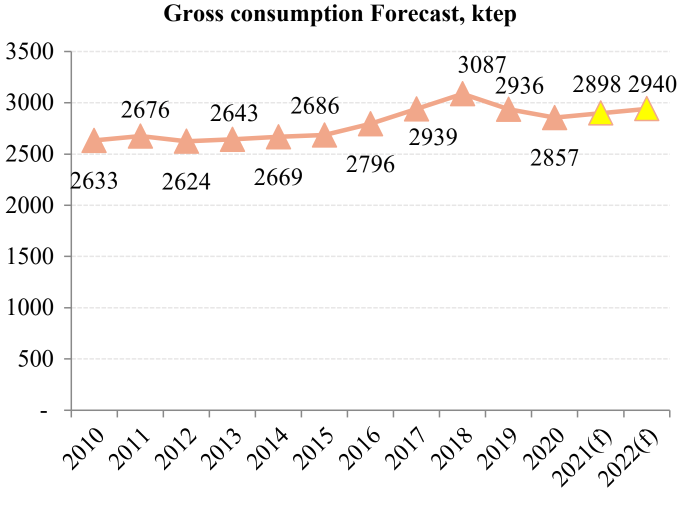


Fig. 14. Gross consumption forecast, ktep

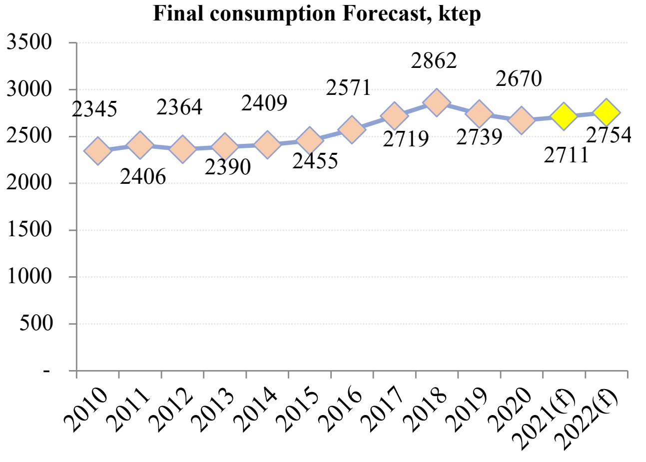


Fig. 15. Final consumption forecast, ktep

This allows to draw conclusions about the quality of forecasts and the applicability of the method. Such an analysis is carried out further in a separate section below.

In addition, attempts have been made to apply neural network modeling of fuel consumption in the country using monthly data.

Neural networks for short-term forecasting of the energy balance using monthly data. The methodology using extrapolation factors does not take into account seasonal fluctuations in fuel consumption, and the trend is usually a smooth function, most often a linear one.

Since 2015, the National Bureau of Statistics has been keeping records of consumed fuels by months with a delay of 2 months (from the current month) for the same EB lines, the dynamics of which were discussed above: Import-Export, Production, Gross consumption, Final Consumption for 4 groups of fuels (natural gas, oil products, coal and electricity).

Unfortunately, such accounting for biomass and heat energy is not presented, which are also usually included in the short-term forecast of the fuel and energy balance.

The experiments were carried out for Gross consumption of natural gas and oil products, as well as for Electricity generation and Electricity Gross consumption.

Data series for the interval from 2015–2021 (11 months) – 76 points and 2015–2022 (4 months) – 88 points were used. The forecast is built on 12 or 24 points ahead (1 or 2 years).

Experiment models were carried out in cycles with the simulation of 50 variants of models with the selection of 5 best ones under different specified conditions:

number of hidden layers (from 2 to 8);

types of *input* function (hyperbolic, logistic, identical);

types of *output* function (hyperbolic, logistic, identical).

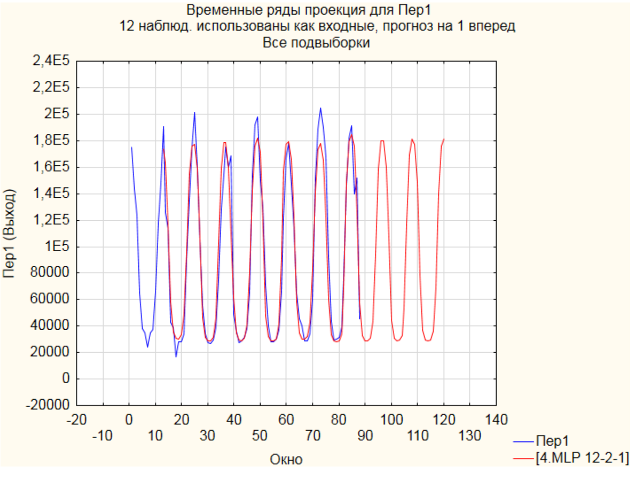
Calculations are carried out until the best coincidence of the points of the modeling functions with the actual values for 12 control points is obtained. The network is considered satisfactory if the coincidence is 2,5 %.

Table 2. **Coincidence of the calculated points of the models with the actual values of the control sample**

Fuel	Coincidence of the calculated points of the models with the actual ones in the control sample 12 values	
	Range of values 76 points, %	Range of values 88 points, %
Gross consumption, Natural gas	6,98	13,68
Gross consumption, Oil products	5,62	5,8
Gross consumption, Electricity	2,4	5,13

For one function such a result has been obtained, but for other groups of fuels, such a match has not yet been achieved (Table 2).

The best modeling function and forecast of *natural gas* consumption for 2 years are shown in the fig. 16 (left).



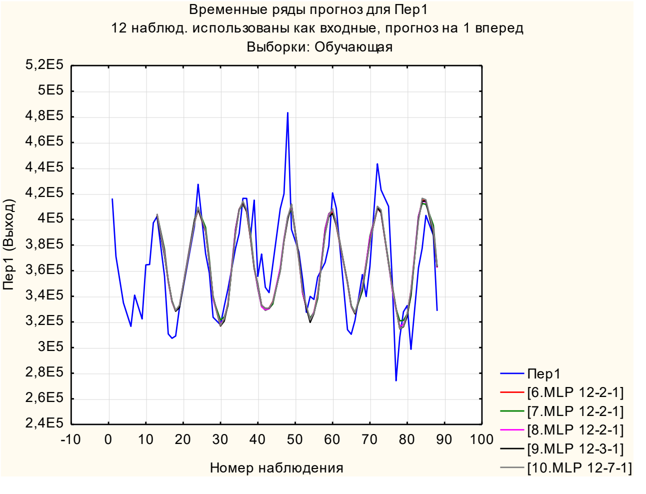


Fig. 16. Predictive neural network models for Gross consumption (on the left – natural gas; on the right – electricity)

The five best neural network models and *electricity* consumption forecasts are shown in the fig. 16 (right).

As can be seen from the table above, the best functions were obtained for the production of electricity, and for a time series of 76 points. Increasing the length of the series to 88 points did not lead to an improvement in the result. Experiments based on 88 points can be considered only as intermediate ones, and it is necessary to continue modeling.

Research results. *Comparison of predicted values of gas, oil products and electricity consumption by 2 methods*. For oil products, it is possible to compare the results of forecasts using 2 methods – extrapolation and neural networks, for which the best result was obtained for a series of 76 points (with a 5,62 % coincidence with the actual values), table 3.

Table 3. **Comparison of the predicted values of gas, oil products and electricity consumption by 2 methods**

Gross consumption oil production	Method 1-extrapolation	Method 2-neural network model
	ktep	ktep
2020	946 (fact)	972
2021	969 (forecast)	987
2022	994 (forecast)	996

Forecasts of Gross consumption of *oil products* for 2022 by both methods have similar values (994 and 996 ktep). This allows us to draw conclusions about the applicability of both methodological approaches for further similar experiments.

Forecast quality analysis for 6 working cycles. Predicted values of fuel consumption for each year compared with the actual ones and the discrepancies for each group of fuels were presented in Table 4.

Table 4. **Discrepancies between the predicted and actual values by fuel groups for 6 completed cycles**

	Circle 6 (2021–2022)	Circle 5 (2020–2021)	Circle 4 (2019–2020)	Circle 3 (2018–2019)	Circle 2 (2017–2018)	Circle 1 (2016–2017)
Coal	–20,70 %	+16,3 %	–	–	–	–
Natural gas	–2,2 %	–6,3 %	–9,99 %	1,95 %	5,4 %	–
Oil products	–8,9 %	–2,1 %	–3,39 %	3,01 %	6,3 %	–
Biofuels	–0,2 %	–20,5 %	2,54 %	3,68 %	–	–
Electricity	–5,9 %	–1,6 %	0	–0,67 %	–1,0 %	–

Symbol: «–» – a greater value was predicted than the actual fact (overestimated); «+» – a lower value was predicted than the fact turned out (underestimated).

Forecasts of *coal* consumption have the largest discrepancy with the actual data. For several cycles, it was not possible to make a comparison at all, since the energy balance publications contained recalculations for previous years, as well as jumps in time series.

Natural gas consumption forecasts differ from actual values by 2 % in 2 cycles; at the level of 5–6 % – in 2 cycles; at the level of 10 % – in 1 cycle.

Consumption of *oil products* has a discrepancy with the actual values at the level of 3 % in 3 cycles; at the level of 6 % – in 2 cycles; at the level of 9 % – in 1 cycle.

Biomass has a discrepancy at the level of 3 % in 3 cycles; at the level of 20 % – in 1 cycle.

Electricity best matched the forecast and the fact. Full match is in 1 cycle, discrepancy within 0,6–2 % is in 3 cycles; at the level of 3–6 % is in 1 cycle;

Heating has a discrepancy at the level of 0–3 % in 2 cycles; at the level of 6 % is in 2 cycles; at the level of 9 % is in 1 cycle.

If we consider all the values in the table 4, then can be noted the following: full "hit" –1 time; match at 0–1 % – 3 times, 1,01–3 % –6 times, match at 3.01–6 % – 6 times, match at 6,01–7 %, –3 times, match at level of 7,01–10 % – 3 times, the maximum discrepancy (16–20 %) occurred 3 times. There are 8 "overestimated" values, and the rest are "underestimated".

For each group of fuels, conclusions can be drawn about the quality of the forecast, and, accordingly, about the adequacy of the forecasting method used. In particular, it can be noted the necessary to use other methodological approaches to coal forecasts.

Conclusions. Short-term forecasts of fuel consumption in the form of special annual documents based on a proven European methodology have been prepared in Moldova for the last 7 years. This made it possible to perform an analysis of the quality of forecasts of energy balances for 6 cycles.

The dynamics of fuel flows for 4 groups of fuels and a 10-year time series has a general growth trend, and for 2 groups (coal and heat) a decreasing trend.

Two methods were used to forecasts: extrapolation (European methodology) based on accounting for fuels by years and neural network analysis based on accounting for fuels by months.

Neural network analysis was considered for two variants of time series (76 and 88 points) for 3 indicators – natural gas, oil products, electricity (Gross consumption). More adequate results were obtained for a time series of 76 points. A comparison is made of the forecasts obtained by 2 methods for oil products.

Comparisons are also made of the actual values of the energy balances of the current year with those predicted in the previous cycle to generalize conclusions on the adequacy of the applied methodology. It is shown that satisfactory results were obtained for 5 groups of fuels, and unsatisfactory for coal.

The analysis carried out is important for the further development of works in the country, and may also be useful to scientists of similar works in other countries.

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