Modified three-stage model for forecasting the demand for energy resources at various hierarchy levels of the economy

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Abstract. Forecasting of the demand for energy resources is a very important scientific area when determining adequacy of energy resources in the country, compiling the country’s energy balance, determining need for import of some energy resources for the country’s economy for types of economic activity (TEA) and regions. The pace of development and proportions in the country’s and the region’s economy may affect their levels of energy consumption, and the latter determine the extent of energy industry’s impact on the environment, i.e. these indicators are interdependent. The relevance of the work is related to creation of a mathematical model and tools for forecasting the demand for energy resources and determining the amount of emissions of harmful substances into the atmosphere as a result of fossil fuels combustion. The methods and tools for forecasting the demand for energy resources for various types of economic activity or regions take into account the following factors: impact of changes in the structure of the economy on fuel and energy consumption as well as on technological re-equipment of industries that together form the overall energy saving capacity and structures of electricity production sources and heat energy supply sources to ensure their production. The authors propose a three-level model for forecasting the demand for energy resources (electricity, heat, fuel in total and its types: coal, natural gas and other fuels). This model uses a double agreement of forecasts: between the third (types of economic activity in regions), the second (regions) levels, and the subsequent agreement with the top (country) level. The calculations performed using this model demonstrate the feasibility of this approach. This model was tested on retrospective data with an error of less than 5%. Calculations under this model show a forecast of savings of 8.7 million tons of coal by 2040 due to structural and technological changes (2.272 million tons and 6.428 million tons, respectively). Reduction of coal consumption will reduce emissions of pollutants into the atmosphere (thousand tons): nitrogen oxides – 19.671; sulfur oxides – 295.06; carbon monoxide – 393.414; solid dispersed particles – 104.255; carbon dioxide – 5271.75.

1. Introduction
Many Ukrainian and foreign scientists are engaged in forecasting of energy consumption in the world [1–17]. For example, in [1], it is proposed a deterministic-stochastic model for forecasting the demand for electricity based on the detection of dependences in electricity consumption for the retrospective period. A comprehensive model for estimating energy consumption in regions was proposed in [2,3], but this model clearly does not determine the impact of structural changes
in the economy on the volume and structure of energy consumption, although development of energy-intensive types of economic activity (metallurgy, chemistry, etc.) promotes increase in the industry’s energy consumption. The method of exponential smoothing is proposed in [4] as the best method for predicting electricity consumption in the food industry. Methods of regression analysis in combination with the use of neural networks are proposed in [5–7] for prediction of electricity consumption based on the history of energy use. These models require very accurate history of observations of energy consumption for various groups of consumers in retrospect and are developed taking into account the specificities of certain consumers. Some other models, such as Gray-specific models [8] for forecasting of electricity consumption in cities of China and STL-model [9] for monthly campus electricity consumption that takes into account seasonal and trend-based components are focused on specific facility as well. Most of existing works are focused on short-term forecasting methods for individual sectors of the economy [5,6,8,10–14]. Long-term forecasts of energy consumption are developed for some sectors of the world economy and for individual regions of the world [7,9,15–17]. The Institute of General Energy at the National Academy of Sciences of Ukraine has proposed a comprehensive method for forecasting energy consumption based on the two-stage method [17] and its development based on the three-stage method [18].

2. Description of the mathematical model

This paper describes a model that combines two structures of the economy: regional structure and structure for types of economic activity, which is presented for the first time.

The studied hierarchical levels of the economy are as follows: Level I (macro level) – the country; Level II (meso level 1) - types of economic activity in the country, Level III (meso level 2)- economy of a region. Accordingly, key parameters are as follows: Country’s gross value added (\(GVA_T\)), energy intensity of GVA (\(eGVA_T\)); gross value added of the type of economic activity - TEA (\(GVA_i\)), energy intensity (\(eGVA_i\)). For regions – Region’s gross value added (\(GVA_r\)), energy intensity of the Region’s GVA (\(eGVA_r\)).

A modified three-stage model has been developed. Its structure is shown in figure 1.

![Figure 1](image)

**Figure 1.** Structure of the three-stage model for forecasting the demand for energy resources for types of economic activity and regions.

Thus, the presented structure of the mathematical model allows moving from energy consumption for the country to energy consumption by types of economic activity in the country and to regional levels and vice versa. The model is flexible and convenient for obtaining forecasts. For various configurations of economic structures and volumes of technological energy savings, level I is compared with two other levels (II and III). In reality, they are not the same even for the base year (the difference between energy consumption statistics for the country and the total for all types of economic activity and the total for all the regions is about 5%). In the long run, this difference additionally grows.

When modeling energy consumption by types of energy resources, the scenario method is used. It considers two or three scenarios of the economy’s development: the existing structure for the base year, which is determined as a percentage of energy consumption by a particular
sector of the economy (by group of economic activity types) to energy consumption by the whole country, prospective (taking into account retrospective trends and/or global trends taking into account technical and raw material bases). The index s is variable. For each s(s = 1, 2, ..., n), it is set the ratio of sectorial gross value added (GVA) for the economic sector to the country’s GVA [17]. Moreover, the scenarios are used for calculating the volume of possible implementation of technological energy saving. All components in formulas (1)-(10), which depend on the variable tth, are calculated for tth year depending on the structure of the economy s and probable reduction in the energy intensity of GVA at given volumes of technological energy saving implementation for appropriate scenarios [17, 18]. For the purpose of forecasting by regions, it is also taken into account structure of their economies within the country’s economy and typical energy saving measures.

The novelty of the presented model consists in the determining of reconciled forecasted levels of energy consumption both by sectors of the economy and by regions, taking into account their regional economic structure. The reconciliation of the received forecasts and the number of these reconciliations are determined by parameters of the base year and by discrepancy between the consumption for the country as a whole, total by types of economic activities and total by regions. In examples provided, it is expedient to do reconciliation between the total forecast in the regions and the country level with further distribution of reconciled results between regions (using consumption structure coefficients in regions for forecasted years determined by changes in energy consumption structure of regions) and coefficients of forecasted structure of the country’s economy TEA sectors. Both parts of the model (see figure 1) have been tested on retrospective data and showed acceptable accuracy of forecasts (error did not exceed 5%).

For Level I - country (Top-level) forecasted energy consumption shall be determined by the formula [17]:

$$P_{sTOP}^t = e_{GVAs}^b V_{GVAs}^t - \sum \Delta E_i^t + P_{pop}^t,$$

(1)

where $e_{GVAs}^b$ is the energy intensity of country’s GVA in the base year for sth structure of the economy: $e_{GVAs}^b = \frac{\sum E_i^b}{\Sigma V_{GVAs}^i}$;

$E_i^b$ is energy consumption for ith type of economic activity (TEA) in accordance with KVED-2010 classifier in the base year;

$V_{GVAs}^i$ – Gross Value Added of ith TEA of the economy in the base year;

$V_{GVAs}^t$ – forecasted county’s Gross Value Added (total by all TEAs) in tth year for sth structure of the economy;

$\sum \Delta E_i^t$ – scope of reduction in energy consumption due to structural and technological changes (energy saving capacities) in the tth year;

$P_{pop}^t$ – forecasted energy resources consumption by the population to be determined using a special methodology set forth in [17].

For Level II - types of economic activity (DOWN1). Forecasted demand for types of economic activity shall be determined as follows:

$$\sum P_i^t = \sum e_{GVAi}^b V_{GVAi}^t - \sum \Delta E_i^t,$$

(2)

where $e_{GVAi}^b$ – GVA energy intensity for ith type of economic activity under KVED-2010 classifier in the base year for sth structure of the country’s GVA;

$V_{GVAi}^t$ – forecasted GVA of ith type of economic activity under KVED-2010 classifier in tth year for sth structure of the country’s GVA;

$\sum \Delta E_i^t$ – scope of reduce in energy resources consumption if structural ($\Delta E_s^b$) and technology ($\Delta E_T^b$) changes (energy saving capacity) takes place in tth year for sth structure of the country’s GVA taking into account the package of technology-related energy saving activities:
\[ \sum \Delta E^t_i = \Delta E^{b-t}_{s} + \Delta E^t_{T}, \]  
(3)

To move from the type of economic activity level to the country’s level, the equation (2) needs to be appended with the following component: \( P^t_{pop} \). This sum will be the country’s demand when calculating it bottom-to-top:

\[ P^t_{s\text{DOWN}} = \sum P^t_i + P^t_{pop}, \]  
(4)

Depending on the type of energy resource, an indicator of specific consumption of fuel or electricity per capita, or specific consumption of thermal energy for heating and ventilation of residential and office premises (per 1 sqm or 1 cbm) may be used when forecasting energy consumption. Consumption of hot water by the population is calculated per 1 person. The methodology of calculating the forecasted demand for the population is described in [17].

At Level III (DOWN2), the forecasted regional demand is determined using equation [18]:

\[ P^t_{s\text{DOWN}} = \sum r P^t_r + P^t_{pop}, \]  
(5)

where \( P^t_r \) is forecasted demand for the energy resource in tth year for rth region of Ukraine. Forecasted demand for energy resources for regional economies shall be determined as follows [18]:

\[ \sum r P^t_r = \sum r e^{b}_{GVA_r} + V^t_{GVA_r} - \sum r \Delta E^t_r, \]  
(6)

where \( e^{b}_{GVA_r} \) is GVA’s energy intensity for the base year for economy of rth region of Ukraine;
\( V^t_{GVA_r} \) is the forecasted GVA in tth year for economy of rth region of Ukraine, it is determined by pace of changes of the indicator in retrospect and by estimations of international economic organizations;
\( \sum r \Delta E^t_r \) is the total forecasted energy saving capacity in tth year for economies of all rth regions in the forecasted year t. It is determined by the sum of energy resources savings as a result of energy saving activities typical for all the regions. With this, reduction of energy intensity shall be chosen taking into account existing examples of new technology implementation and results that can actually be achieved.

The structural energy saving capacity for regional energy consumption shall be determined by the following formula:

\[ \Delta E^{b-t}_{r} = e^{b}_{GVA_r}(V^b_{GVA_r} - V^t_{GVA_r}), \]  
(7)

where \( e^{b}_{GVA_r} \) is GVA’s energy intensity for rth region in the base year;
\( V^b_{GVA_r} \) is the volume of GVA in rth region for structure of the base year (region’s GVA to country’s GVA ratio as in the base year) at forecasted value of GDP in tth year;
\( V^t_{GVA_r} \) is the volume of GVA for rth region for structure of forecasted tth year with the same value of the forecasted GDP.

The structural energy saving capacity for energy consumption by types of economic activity shall be is determined by the following formula [17]:

\[ \Delta E^{b-t}_{TEA_i} = e^{b}_{GVA_i}(V^b_{GVA_i} - V^t_{GVA_i}), \]  
(8)

where \( e^{b}_{GVA_i} \) is GVA’s energy intensity for ith type of economic activity in the base year.
V_{GVA_i}^b$ is volume of GVA for $i^{th}$ type of economic activity under KVED-2010 classifier for the structure of the base year (GVA to GDP ratio as in the base year) with forecasted value of GDP in $t^{th}$ year;

$V_{GVA_i}^t$ is volume of GVA in $i^{th}$ sector with the structure of forecasted $t^{th}$ year with the same value of forecasted GDP.

For the three-stage model of economy, the technological energy saving capacity (ESC) shall be determined using the following algorithm:

- at the country’s level:

$$\Delta E_{j}^{b-t} = (e_{GVA_j}^b - e_{GVA_j}^t)V_{GVA_j}^t,$$

where $E_{j}^{b-t}$ is energy saving capacity of $j^{th}$ type of energy resource in the country in $t^{th}$ year;

$e_{GVA_j}^b$ is the country’s GVA energy intensity for $j^{th}$ type of energy resource in the base year;

$e_{GVA_j}^t$ is the forecasted energy intensity of the country’s GVA for $j^{th}$ type of energy resource in $t^{th}$ year, taking into account energy saving activities by types of economic activity, regional-wide and national activities;

$V_{GVA_j}^t$ is the forecasted volume of the country’s GVA in $t^{th}$ year;

- at the level of types of economic activity:

$$\Delta E_{TEA_i}^{b-t} = (e_{GVA_i}^b - e_{GVA_i}^t)V_{GVA_i}^t,$$

where $\Delta E_{TEA_i}^{b-t}$ is the energy saving capacity for $i^{th}$ TEA in $t^{th}$ year;

$e_{GVA_i}^b$ is the GVA’s energy intensity for $i^{th}$ TEA in the base year;

$e_{GVA_i}^t$ is the forecasted GVA’s energy intensity for $i^{th}$ TEA in $t^{th}$ year taking into account energy saving activities;

$V_{GVA_i}^t$ is the forecasted volume of GVA for $i^{th}$ TEA in $t^{th}$ year;

- at the level of rth region, technology-based ESC is determined as decrease in energy resource consumption in $t^{th}$ year as compared with the base year and is calculated as follows:

$$\Delta E_{TEA_r}^{b-t} = (e_{GVA_r}^b - e_{GVA_r}^t)V_{GVA_r}^t,$$

where $\Delta E_{TEA_r}^{b-t}$ is the energy saving capacity for $r^{th}$ region in $t^{th}$ year;

$e_{GVA_r}^b$ is the GVA’s energy intensity in $r^{th}$ region in the base year;

$e_{GVA_r}^t$ is the forecasted GVA’s energy intensity in $r^{th}$ region in $t^{th}$ year, taking into account energy saving activities;

$V_{GVA_r}^t$ is the forecasted volume of GVA for $r^{th}$ region in $t^{th}$ year.

3. The results of the calculation and their analysis

The technology-based energy saving capacity for Ukrainian economy until 2040 is estimated in [17,18] and more precisely determined in this work when forecasting volume of coal required to meet the electricity and heat generation needs.

Examples of calculated forecasts for individual components of the model are provided in tables 1 and 2. As it can be seen from tables 1 and 2, there is a discrepancy in the forecasted figures obtained for various levels: country, as a whole, types of economic activity and the regional level. This means that there is a need for further improvement of forecasting methods and reconciliation of forecasts. As compared with the model described in [18], the presented three-stage model allows solving of two problems: forecasting of energy consumption at two DOWN levels, which may vary depending on the task. The improved three-stage model provides the same energy efficiency indicators at different hierarchical levels - GVA’s energy intensity at corresponding
Table 1. Forecasted demand for electricity for scenario-based economic structure and technology-based energy saving capacity identified at various hierarchical levels of the economy under pessimistic (structure of 2017) and conservative (structural changes happen) scenarios.

| No | Forecast indicators for scenarios I and II | 2030 (I*) | 2030 (II**) | 2040 (I*) | 2040 (II**) |
|----|------------------------------------------|-----------|-------------|-----------|-------------|
| 1  | GDP forecast in 2015 prices, UAH billion | 2904      | 2904        | 4298      | 4298        |
| 2  | The country’s GVA forecast in 2015 prices according to economic development scenarios, UAH billion | 2451      | 2549        | 3627      | 3821        |
| 3  | Electricity saving of from structural changes, billion kWh | 0         | 8.9         | 0         | 19.1        |
| 4  | Electricity savings from technological changes, billion kWh | 0         | 11.0        | 0         | 18.5        |
| 5  | Electricity consumption by country with population (TOP), billion kWh | 148.0     | 128.1       | 219.1     | 181.4       |
| 6  | Electricity consumption by the amount of consumption by type of economic activity (excluding population), billion kWh | 107.4     | 87.4        | 159.0     | 119.3       |
| 7  | Electricity consumption by the population, billion kWh | 32.2      | 32.4        | 32.0      | 34.0        |
| 8  | Electricity consumption by the amount of consumption by type of economic activity and for the population (DOWNi), billion kWh | 139.6     | 119.7       | 191.0     | 153.3       |
| 9  | Electricity consumption by amount of consumption by regions, billion kWh | 113.2     | 104.3       | 186.9     | 164.3       |
| 10 | Electricity consumption by the sum of consumption by regions and for the population (DOWNr), billion kWh | 145.4     | 136.7       | 218.9     | 198.3       |
Table 2. Forecasted demand for thermal energy for scenario-based economic structure and technology-based energy saving capacity identified at various hierarchical levels of the economy under pessimistic (structure of 2017) and conservative (structural changes happen) scenarios.

| No | Forecast indicators for scenarios I and II | 2030 (I*) | 2030 (II**) | 2040 (I*) | 2040 (II**) |
|----|------------------------------------------|-----------|-------------|-----------|-------------|
| 1  | GDP forecast in 2015 prices, UAH billion | 2904      | 2904        | 4298      | 4298        |
| 2  | The country’s GVA forecast in 2015 prices according to economic development scenarios, UAH billion | 2451      | 2549        | 3627      | 3821        |
| 3  | Thermal energy saving from structural changes, PJ | 0         | 40.6        | 0         | 63.6        |
| 4  | Thermal energy saving from technological changes, PJ | 0         | 17.6        | 0         | 41.8        |
| 5  | Thermal energy consumption by country with population (TOP), PJ | 919.3     | 1081.4      | 1155.6    | 1404.9      |
| 6  | Thermal energy consumption by the amount of consumption by type of economic activity (excluding population), PJ | 245.5     | 288.7       | 331.8     | 432.8       |
| 7  | Thermal energy consumption by the population, PJ | 673.7     | 757.9       | 760.5     | 874.0       |
| 8  | Thermal energy consumption by the amount of consumption by type of economic activity and for the population (DOWNi), PJ | 919.2     | 1046.6      | 1092.3    | 1306.8      |
| 9  | Thermal energy consumption by amount of consumption by regions, PJ | 246.8     | 328.0       | 402.2     | 557.3       |
| 10 | Thermal energy consumption by the sum of consumption by regions and for the population (DOWNr), PJ | 920.1     | 1085.9      | 1162.7    | 1431.3      |
levels that per se already reduces the error in forecasts when using various indicators: energy intensity of GDP at TOP (national) level, GVA’s energy intensity for economic activities and energy intensity GRP for the regional level – that are traditionally used by economists.

Estimation of reliability of forecasts of heat energy consumption for 2020 in relation to 2017, obtained by the two-stage method, is presented in table 3 [19].

Table 3. Estimation of reliability of forecasts of heat energy consumption for 2020 in relation to 2017, obtained by the two-stage method, million Gcal.

| Type of economic activity (TEA) | 2017 (fact) | 2020 (forecast) | 2020 (fact) | Error forecast,% |
|--------------------------------|-------------|-----------------|-------------|------------------|
| Agriculture, forestry and fisheries | 2.18        | 2.4 – 2.7       | 1.74        | 27.5 – 35        |
| Mining and quarrying           | 2.17        | 2.4 – 2.3       | 1.75        | 27 – 23.9        |
| Manufacturing industry         | 36.0        | 39.8 – 37.1     | 38.0        | 5 – 2            |
| Supply of electricity, gas, steam and air conditioning. Water supply; sewerage, waste management | 3.2         | 3.6 – 3.7       | 2.1         | 41.6 – 30        |
| Transport, warehousing, postal and courier activities | 1.4         | 1.59 – 1.68     | 1.29        | 19 – 23          |
| Other TEA                       | 13.6        | 15.0 – 14.4     | 11.62       | 22.5 – 19.3      |
| Together for TEA               | 59.1        | 64.8 – 61.9     | 56.5        | 12.8 – 8.7       |
| Population (calculation)       | 160.8       | 170.0           | 170.0       | 0                |
| Total                          | 219.9       | 234.8           | 226.5       | 3.5 – 2.3        |

Data on heat energy consumption in 2021 on the website of the State Statistics Service of Ukraine are currently missing.

To assess the reliability of electricity forecasts in 2020, we used the comparison of forecasts and actual consumption for 2020, which is given in table 4 [19].

Thus, the model for forecasting the demand for energy resources by the two-stage method for heat gives very close forecasts for the country as a whole (error 2.3 – 3.5%), for economic activities together (error 8.7 – 12.8%) and large sections of the economy, in particular “Manufacturing” (2 – 5%). For small sections, the forecast error averages between 23 – 27%. For electricity, the situation is different: for large consumers, which include sectors of the economy “Mining and quarrying, Manufacturing, Population”, the calculation error is small and acceptable, as these sectors were able to withstand the worst corona crisis, for “Agriculture and Transport” it has significant the value explained by the extraordinary conditions of their operation at this time (almost complete cessation of passenger traffic and partial - freight), for the sectors of electricity, gas, steam and air conditioning, water supply; sewerage, waste management and other activities; In the country as a whole, the error is within acceptable limits. Thus, the forecasting model needs further development, but it shows a fairly acceptable level of forecast values, given the fact that in 2019-2020 there was a coronavirus pandemic that collapsed the economies of all
Table 4. Estimation of reliability of forecasts of electricity consumption for 2020 in relation to 2017, obtained by the two-stage method, million kWh.

| Type of economic activity (TEA) | 2017 (fact) | 2020 (forecast) | 2020 (fact) | Error forecast, % |
|--------------------------------|-------------|-----------------|-------------|------------------|
| Agriculture, forestry and fisheries | 2424.7 | 2918.9 | 2111.4 | 38.3 |
| Mining and quarrying | 12121.4 | 12571.3 | 12299.5 | 2.2 |
| Manufacturing industry | 36268.0 | 38311.3 | 35137.0 | 9.0 |
| Supply of electricity, gas, steam and air conditioning. Water supply; sewerage, waste management | 18975.9 | 22360.3 | 18219.7 | 22.7 |
| Transport, warehousing, postal and courier activities | 7060.8 | 7756.9 | 5432.0 | 42.8 |
| Other TEA | 12717.7 | 13679.7 | 10689.4 | 28.0 |
| Together for TEA | 89568.4 | 97598.3 | 83888.6 | 16.4 |
| Population (calculation) | 35019.9 | 34189.5 | 36436.0 | 6.2 |
| Total | 124588.3 | 131787.9 | 120324.6 | 9.5 |

countries and could not predict any organization in the world. Therefore, our forecasts are quite reliable.

According to [21], the volumes of electricity consumption in 2021 were analyzed (table 5). Preliminary data provided in the table 5. The actual data may differ up to + 10% (will be published in the Statistical Collection of Ukraine for 2021). There is also a discrepancy between the content of certain indicators by areas of use provided by Ukrenergo and indicators by TEA. According to the calculations on the model "country-types of economic activity" (left branch of the model structure presented in Fig. 1), the calculated electricity forecast for 2021 by country (TOP level) relative to energy efficiency indicators in 2017 gave a very good coincidence of results – 1.9%.

The forecast of electricity consumption by DOWN-level - together by TEA with the population shows a brilliant coincidence of the forecast with the fact - 0.14%! The total amount of forecast of electricity consumption by TEA as a whole differs from the actual consumption by foreign trade by 5.5%, which is a good result.

The forecast of electricity consumption by the population was lower by 11.8% than the actual one, which is most likely due to the reduction of natural gas consumption by the population and the transition to using of electric stoves and electric heaters and insufficient consideration of corona-crisis restrictions in the forecast. This value is acceptable for the forecast. We can also talk about an acceptable error in forecasting of industrial production (mining and processing industries together) - 11.6% and the transport sector - 12.5%. More significant errors in the forecasting of electricity by agriculture and “Other TEA”.

Agriculture consumed 1.5 times more electricity, which is due to savings in fuel consumption: primarily natural gas. The share of electricity consumption in agriculture from the actual electricity consumption of Ukraine in 2021 is 2.9%. Even an error of 46.9% to 2.9% is not significant in the overall forecast.
Table 5. Estimation of reliability of forecasts of electricity consumption (net) for 2021, calculated according to the forecast of GVA in the prices of 2016, obtained by the two-stage method, thousand kWh.

| Type of economic activity (TEA) | 2021 (forecast) | 2020 (fact)* | Error forecast,% | forecast |
|-------------------------------|-----------------|--------------|-------------------|----------|
| Agriculture, forestry and fisheries | 1961.5 | 3695.4 | 21.0/46.9 |          |
| Industry, total **          | 46326.5 | 52392.0 | 11.6          |          |
| Transport                   | 6926.8  | 6159.4  | 12.5          |          |
| Other TEA (Supply of electricity, gas, steam and air conditioning, Water supply; sewerage, waste management. Trade, construction, financial, insurance, social services, education, health, public administration and defense) | 36431.0 | 24629.5 | 47.9 |          |
| Together for TEA            | 91645.8 | 86876.3 | 5.5           |          |
| Population                  | 34189.5 | 38778.5 | 11.8          |          |
| Together with the population (DOWN-level) | 125835.3 | 125654.8 | 0.14 |          |
| Country with population (TOP-level) | 127991.0 | 125654.8 | 1.9 |          |

* - preliminary data for January 2022 [21]  
** - included data on industry only (excluding TEA “Supply of electricity, gas, steam and air conditioning, Water supply; sewerage, waste management”)

Electricity consumption of group “Other TEA” in 2021 amounted to 19.6% of the actual electricity consumption of the country. We forecast higher electricity consumption by 47.9%, but energy saving measures reduced electricity consumption primarily for lighting (most of the replaced light sources for more energy efficient) and additional electric heating due to thermal modernization of state and municipal buildings.

The largest GVA is created by group “Industry”, which is also the largest consumer of electricity. As shown above, the forecast of electricity consumption for this group is acceptable. From all the above we can conclude that the presented model in the country as a whole gives almost close to the fact forecasts of electricity consumption.

For the sections with high GVA and electricity consumption, the calculated forecasts are acceptable (up to 12.5%). For small GVA and electricity consumption sections and the group “Other TEA”, the difference with the forecast is up to 50%, but it should be noted that this error applies to electricity consumption of 22.5% (agriculture 2.9% + Other TEA 19.6%). That is, the assessment of the adequacy of the model speaks of its relevance. The authors will continue to work on improving the forecasting model and improving its accuracy for all components.

Using the two-level model “country-types of economic activity”, it was estimated forecasted required volumes of coal by 2040, in particular, the coal needs for thermal power plants and CHP plants under condition of intensive development of renewable sources of energy (optimistic scenario).
Table 6 shows results of assessing probable coal savings if the optimistic scenario takes place as compared with the pessimistic scenario (development of Ukrainian economy with the structure of 2017).

**Table 6.** Forecasted decrease in the coal consumption and pollutant emissions in Ukraine by 2040, thousand t.

| Indicators | 2017 – act | 2021-est. | 2025 | 2030 | 2035 | 2040 |
|------------|------------|-----------|------|------|------|------|
| Coal consumption for the country (structure of 2017; consumption by the population is included) | 42664.6 | 40004.6 | 39059.5 | 41850.6 | 44472.4 | 44163.8 |
| Coal consumption for the country, taking into account structural and technological changes (consumption by the population is included) | 42664.6 | 38947 | 36583 | 37704.4 | 37741.2 | 36348.1 |
| Decrease in coal consumption as a result of structural changes (forecasted for the structure of economy 2017) | | 364.6 | 794.6 | 1338.0 | 1921.4 | 2272.1 |
| Decrease in coal consumption as a result of technological changes (forecasted for the structure of economy 2017, consumption by the population is included) | | 693.0 | 1681.9 | 2808.2 | 4809.9 | 5543.7 |
| Total coal savings with structural and technological changes happen | | 1057.6 | 2476.5 | 4146.2 | 6731.3 | 7815.8 |
| Decrease in pollutant emissions as a result of decrease in coal consumption | | | | | | |
| - nitrogen oxides (NOx) | 2.7 | 6.4 | 10.6 | 16.8 | 19.7 |
| - sulfur oxides (SOx) | 39.7 | 96.6 | 159.2 | 251.7 | 295.1 |
| - carbon oxide (CO) | 52.9 | 128.8 | 212.2 | 335.7 | 393.4 |
| - particulate matter (PM10) | 14.0 | 34.1 | 56.2 | 88.9 | 104.3 |
| - carbon dioxide (CO2) | 709.1 | 1725.9 | 2843.7 | 4497.9 | 5271.8 |

As calculations show, the forecasted reduction in coal consumption may amount to 7.8 million tons by 2040 due to structural and technological changes (2.272 million tons and 5.544 million tons, appropriately). The reduction in coal consumption will reduce emissions of pollutants into the atmosphere, which were calculated in accordance with the guidelines [20,22] (thousand tons): nitrogen oxides - 19.7; sulfur oxides 295.1; carbon monoxide - 393.4; particulate matter - 104.3; carbon dioxide - 5271.8.

The authors’ article [23], published in 2021, provides the expected forecast of coal
consumption in Ukraine in 2021 in relation to energy efficiency indicators in 2017 and the projected GVA of the country. According to the presented data [23], coal consumption in 2021 was expected in the amount of 38,947.0 (TOP level) – 38,504.8 thousand tons (DOWN level) in the baseline scenario. According to the State Statistics Service of Ukraine [24], the consumption of coal in Ukraine in the amount of consumption by months for January-December 2021 actually amounted to 39,164.5 thousand tons of coal. Thus, the forecast of coal differed by 0.5 – 1.7% from actual consumption. This confirms the relevance of the results of the forecasting model to the actual data.

4. Conclusions
Solving the problem of forecasting is a necessary condition for drawing up any development programs: for the country, regions and types of economic activity (economic sectors). This necessitates further development and improvement of methods for forecasting and reconciliation of the forecasts. The presented three-stage model allows solving of two tasks: forecasting energy consumption at the TOP-level (for the country level) and forecasting of energy consumption at two lower levels, which may be changed depending on the task: types of economic activity or regions. The three-stage model ensures the same energy efficiency indicators at different hierarchical levels - energy intensity of gross value added at the appropriate level (country, region and type of economic activity), which reduces the error of forecasts when using various indicators. The proposed model allows forecasting of changes in energy consumption due to structural and technological changes in the country’s economy, which makes it possible to determine forecasted changes in emissions of pollutants into the atmosphere related to combustion of fossil fuels, including coal.

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