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ASSESSMENT OF THE ENERGY SAVING POTENTIAL BY REGIONS OF UKRAINE (METHODOLOGY AND PREDICTIVE ASSESSMENT)

Abstract. *The purpose of the research is the develop methods and tools for long-term forecasting of electricity consumption based on the improved comprehensive method of demand for energy resources, taking into account the peculiarities of electricity use in the regions of Ukraine and their impact on the country's electricity consumption. The scientific novelty of the obtained results is the consideration of the technological potential of regional electricity conservation by means of electricity conservation measures typical for the regions. Thus, a complex method, a mathematical model, and a methodology for determining the forecast demand for electricity for three hierarchical levels of the economy were further developed. In these levels, the following groups of indicators are distinguished for forecasting electricity consumption: country, region, local level, or types of economic activity in the region. The formed three-level model (level I, level II, level III) takes into account both the general potential of electricity conservation (from structural and technological changes) in the country as a whole, and peculiarities at the regional level (region, city, village, settlement, territorial community) in certain (selected) types of economic activity in production (service provision). In the course of the work, material was collected on energy-saving measures in energy-intensive industries and forecasts of the development of certain types of production and service provision. These estimates determined the technological potential of energy saving in the regions. The 12 regions with the largest electricity consumption are highlighted, and the other regions are combined. In the region, the potential of electricity saving was distributed according to the structure of electricity consumption according to the types of economic activity inherent in this region. The technological potential of electricity conservation in the country will reach 10.35 billion kWh.*
Keywords: region, electricity-saving, electricity-saving potential, forecasting, energy efficiency, electricity.

1. Introduction

Nowadays providing the economy with high-value, exhaustive, time and volume-limited fuel and energy resources (FER) on a timely and sufficient basis has become a critical factor in the survival of the country, regions, and its population. First of all, it concerns electrical energy. The constant increase in the cost of electricity, its insufficiency due to the armed aggression of Russia, and its destruction of generating and transmission devices cause drastic changes in the structure of electricity consumption, which is important in determining the need for electrical energy at all hierarchical levels of the economy.

The issue of forecasting the demand for FER (including electricity) in the regions in the event of structural shifts and technological changes in the medium and long-term perspective becomes one of the factors of sustainable development of the entire country and its regions, the existence of them and population since reasonable forecasts are an effective tool for long-term planning and management of the economy. Recently, the economy of the regions of Ukraine has been characterized by vigorous dynamics of changes in the volume and structure of consumption of energy resources, including electricity. It should be noted that energy-saving

measures of general and locally-driven nature at the regional level have a significant impact on the overall electricity demand.

Many papers by domestic and foreign scientists are dedicated to energy consumption forecasting [1–16]. Most scientific papers are devoted to short-term forecasting in certain sectors of the economy [5–6, 8, 10–14]. For a long-term perspective, forecasts for energy resource consumption are developed by sectors of the world economy and individual regions of the world [7, 9, 15–18].

The comprehensive method of forecasting the demand for energy resources [17], which was developed at the General Energy Institute of the National Academy of Sciences of Ukraine, allows to development of the consensus forecast of the consumption of energy resources (including electricity) at two hierarchical levels of the economy: country and types of economic activity (TEA). There is sometimes a problem with assessing regional levels of energy consumption in view of the peculiarities of their economic development, since each region has its land, natural, energy resources, and peculiarities of the structure of electricity and heat supply, energy-saving programs are developed at the regional level. Considering the development of state-local government policy in the country and the greater financial independence of the regions, modification of the comprehensive method with the inclusion of the regional level becomes especially urgent. The assessment of electricity consumption forecasts for regional levels becomes necessary for the assessment of greenhouse gas emissions from burned fuel not only by the country and sectors of the economy (types of economic activity) but also in the regions of the country to develop measures to reduce them. In this assessment, accounting of total electricity saving potential consisting of the structural and technological parts (structural potential of electricity saving and technological potential of electricity saving in the economy in general and in TEA of the country) plays a significant role. When calculating relevant forecasts of electricity consumption volumes for regions, the total electricity saving potential in the region is also divided into structural and technological, at the same time total energy saving potential of the country is the sum of the electricity saving potentials of each region.

2. The main part

The purpose of the study is to develop methods and tools for long-term forecasting of electricity consumption based on an improved advanced method, taking into account the peculiarities of energy use in the regions of Ukraine and their impact on electricity consumption in the country.

Study methods: system analysis, economic and mathematical modeling, analytical and statistical method, scenario method, normative method, comprehensive method, and direct counting method.

The scientific novelty of the obtained results is the development of a comprehensive method, a mathematical model, and a methodology for determining the forecast demand for electricity for three hierarchical levels of the economy, which take into account the technological potential of regional electricity saving based on typical electricity saving measures for the regions.

3. Findings of the study

Methodical approaches to forecasting electricity consumption at different hierarchical levels of the economy

The choice of methodological approaches for forecasting electricity consumption begins primarily with the study of the system of national accounts (SNA) as a system that includes interdependent indicators and is used to describe and analyze the economic processes at the macro level.

In general terms, the SNA confines the calculation of generalized indicators at the level of the country – gross domestic product (GDP), at the level of regions – gross regional product (GRP). Currently, GRP is calculated using the production method.

Calculations of regional indicators following international standards are based on the following methods: a) the ‘down-top’ method; b) the ‘top-down’ method; c) the mixed method.

The following groups of indicators are distinguished for forecasting electricity consumption at the levels: country, regions, local level or TEA in the region:

1st level: macro-level – country: GDP power intensity (or gross value added – total (total GVA)), power intensity of the product release at the country level;

2nd level: meso-level – regional level: sectors (integrated sections), GRP power intensity according to TEA in the region, power intensity of the product release at the level of TEA in the region;

3rd level: micro level – local or regional level, products (types of works, services) according to the State Classifier of Goods and Services DK 016-2010 on energy-consuming types of products, goods, and services, or sections, groups, classes in TEA at the regional level (regional structure of the economy), power intensity of certain TEA in the region, power intensity of the product release at the level of TEA in the region.

At the regional level, the generalized indicator that characterizes the level of economic development in the region is the gross regional product (GRP).

The existing forecasting methods (regression analysis, direct count, normative method) for application in forecasting tasks at the TOP and DOWN levels use various indicators of energy efficiency: at the country level – indicators of GDP power intensity and their types (GDP power intensity, GDP gas intensity, etc.), at lower levels – indicators of electricity capacity of gross value added (GVA) in regions by types of economic activity (TEA), and product release (service provision) at lower levels – local level.

The development of a general forecast for FER and determination of energy efficiency indicators at different levels of the economy consists of several parts; the stages of the forecast at the country level are taken into account. The first stage is the development of a nominal GRP forecast for the region for a period of 15–20 years (medium-term perspective). The study of the nominal GRP takes into account the trends of the economy, its rates, and proportions and includes data from the leading scientific institutions at the country level, forecast estimates for the development of regions, and budgetary and non-budgetary programs for financing activities in the regions. Materials are used to calculate the country's macroeconomic indicators in relation to their possible application in the region.

Further, to determine one of the main indicators of energy efficiency – GRP power intensity (for the region) using a normative method, taking into account the potential for electricity saving from structural changes in the economy $\sum \Delta E_s^{b-t}$, forecast levels of electricity consumption (TOP level) are determined based on the indicators of GRP power intensity of the base year (total GVA of the region) and calculated potentials for electricity saving/excessive consumption of electricity from structural changes by stages of the forecast period with forecast GRP volumes. GRP power intensity in the forecast year, taking into account structural changes, is determined by the volume of electricity consumption (*j*-type of TEA) in the forecast year and the volume of GRP created for the forecast year.

Forecast levels of electricity consumption at the level of aggregate TEA by sections (DOWN level) are determined by the indicators of GVA power intensity in the region of the base year and forecast volumes of GVA of the region, taking into account the potential of electricity saving from structural changes in the economy by sections under TEA, until the end of the forecast period.

GVA power intensity of the region ($e^t_{GVA_{sij}}$) (GRP power intensity) in the forecast year *t*, taking into account structural changes, is determined by the formula (1):

$$e^t_{GVA_{sij}} = \frac{E^t_{ij}}{V^t_{GVA_{sij}}}, \quad (1)$$

where E^t_{ij} means volumes of electricity consumption in the forecast (*t*-th) year *j*-th type of FER (electricity) in the *i*-sector of the region's economy, $V^t_{GVA_{sij}}$ means forecast of the gross value added (GVA) of the country (total for TEA) in the *t*-th year for *s*-th structure of the economy *j*-th type of FER (electricity) in the *i*-sector of the region's economy.

The methodical approach, which is based on the improved normative method proposed for forecasting the levels of electricity consumption in the region, is based on energy efficiency indicators both by the types of primary fuel – gas intensity, oil intensity, coal intensity of GDP, as well as power intensity and heat capacity.

The forecast stages include the following components of the calculation: determination of the forecast consumption of a *j*-th type of FER (electricity) at the level of energy efficiency of the base year; change in the forecast level of consumption of a *j*-th type of FER (electricity) from the change in the forecast structure of the region economy. This component can both increase and decrease the consumption of fuel resources in the production of electricity due to the change in the share of GVA in the economic structure of the region. The next stage corresponds to the technological potential of energy saving of the *j*-th type of FER (electricity) in the *i*-th sector of the economy in the region. The forecast consumption of a *j*-th type of FER (electricity) by the population in a *t*-th year is also calculated, taking into account the energy saving. The final stage calculates the forecast volumes of substitution of the *j*-th type of FER for scarce types (for example, imported ones) for electricity. The last component balances the consumption of electricity, reducing scarce types of fuel for its production while increasing the consumption of available types of fuel and energy.

Electricity consumption at all hierarchical levels is forecasted using an improved normative method. It creates the forecast of electricity consumption at the relevant level as the sum of forecasts at the level of regions or types of economic activity in the region and the forecast of electricity consumption for the population, respectively, at the level of the country or region.

The created three-tier model (tier I, tier II, tier III) takes into account both the total potential energy saving (from structural and technological changes) in the country as a whole, and peculiarities at the regional level (region, city, village, settlement, territorial community) in certain (selected) TEA in the provision of services (production).

For tier I – countries, the forecast level of electricity consumption is determined by the formula (2):

$$P_s^t = e_{GVAs}^b V_{GVAs}^t - \Delta E_s^t + P_p^t, \tag{2}$$

where e_{GVAs}^b means GVA power intensity in the country in the *t*-th year for *s*-th structure of the economy; V_{GVAs}^t means forecast of the gross value added of the country (total for TEA) in the *t*-th year for *s*-th structure of the economy; ΔE_s^t means volumes of electricity reduction due to structural and technological changes (energy saving potential) in the *t*-th year for *s*-th structure of the economy; P_p^t means forecast of electricity consumption by the population, which is determined according to a certain methodology.

The GVA power intensity of the country is determined from the formula (3):

$$e_{GVAs}^b = \frac{P_s^b}{V_{GVAs}^b}, \tag{3}$$

where P_s^b means electricity consumption by country for the base year for *s*-th structure of the economy; V_{GVAs}^b means gross value added of the country (total for TEA) in the base year for the *s*-structure of the economy.

The gross value added was forecasted at the General Energy Institute of the National Academy of Sciences of Ukraine.

For tier II – regions of the country, the general equation (4) is used: (4):

$$P_s^t = \sum_f P_f^t + P_p^t, \tag{4}$$

where P_f^t mean forecast demand for electricity in the *t*-th year for the *f*-th region of Ukraine.

Forecast demand for electricity in the regions is determined from the formula (5):

$$\sum_f P_f^t = \sum_f e_{GVAf}^b V_{GVAf}^t - \sum_f \Delta E_f^t, \tag{5}$$

where e^{b}_{GVAf} means GVA power intensity of the base year for the *f*-th region of Ukraine; V^{t}_{GVAf} means GVA forecast in *t*-th year for *f*-the region of Ukraine; it is determined by the rate of change of the indicator at retrospect and estimates of international economic organizations; $\sum_{f}\Delta E^{t}_{f}$ means forecast the total potential of energy saving in *t*-th year for all *f*-th regions in the forecast year for all economies, which is determined from the formula (6):

$$\sum_{f}\Delta E^{t}_{f} = \sum_{f}\Delta FE^{t}_{f} + \sum_{fa}E^{t}_{fa}, \tag{6}$$

where $\sum_{f}\Delta E^{t}_{f}$ means forecast energy saving potential in the *t*-th year in each region, which includes electricity saving measures common to all settlements and types of economic activity (reduction of losses in networks, in production, in the provision of services, reduction in the electricity used to maintain administrative and industrial premises, street lighting, etc.) for the *f*-th region; $\sum_{fa}E^{t}_{fa}$ means forecast energy saving potential in *t*-th year, which is taken into account at the lower stages of the construction of the administrative structure of the country of *f*-th region (measures for energy saving, which are typical for the production of the region).

For tier III, the electricity consumption forecast for the regions is determined by the general formula (7):

$$P^{t}_{f} = \sum_{f}P^{t}_{qf}, \tag{7}$$

where in addition to the above designations; *q* means the type of economic activity of the regions according to the applicable Classifier of Economic Activities (CEA) KVED-2010.

Forecast total electricity consumption by types of economic activity (TEA) in the region is determined by the formula (8):

$$P^{t}_{qf} = \sum_{q}e^{b}_{GVAqf}V^{t}_{GVAqf} - \sum_{q}\Delta E^{t}_{qf}, \tag{8}$$

where e^{b}_{GVAqf} means GVA power intensity of *i*-th type of economic activity in the *f*-th region; V^{t}_{GVAqf} means GVA volume in the *f*-th region in the forecast year determined by the forecast structure of GVA; ΔE^{t}_{qf} means total forecast potential of energy saving in the *t*-th year for all *q*-th types of economic activity in the forecast year for the economy of the *f*-th region.

It should be noted that the GDP of the country and the gross regional product (GRP), calculated at the country level, are the same value, and according to the energy consumption levels, the consumption volumes for the regions are not identical to the amount in the country.

In the region *f*, for the *q*-th sections of the economy, forecast electricity consumption can be determined by the lower components of TEA: sections, classes, and groups of types of economic activity (9):

$$P^{t}_{qf} = \sum_{r}P^{t}_{rf}, \tag{9}$$

where *r* means section, class, or group in the type of economic activity in the region, included in a certain section *q* in the country, according to the applicable Classifier of Economic Activities KVED-2010; $\sum_{r}P^{t}_{rf}$ means total electricity consumption in the region *f* by regional classes, groups included in types of economic activity (TEA) *r*, and is determined from the formula (10):

$$\sum_{r}P^{t}_{rf} = \sum_{r}e^{t}_{GVArf}V^{t}_{GVArf} - \sum_{r}\Delta E^{t}_{rf}, \tag{10}$$

where e^{t}_{GVArf} means GVA power intensity of *r*-th section, class, or group in the type of economic activity in the base year, which is included in a certain region *f*; V^{t}_{GVArf} means GVA volume in the forecast year for section, class, or group in the type of economic activity (section) *r*, which is determined by the forecast GVA

structure in the region; $\sum_r \Delta E_{rf}^t$ means total forecast potential of energy saving in *t*-th year in region *f* for all *r*-th sections, classes, and groups in the types of economic activity (sections).

At a lower hierarchical level, the forecast of electricity consumption can be determined by energy-consuming types of *k*-th product, which is produced by the *r*-th division in the *q*-th section according to TEA, which develops in the *f*-th region in *t*-th year according to formula (11):

$$P_{krqf}^t = b_{jk}^t V_{krqf}^t , \tag{11}$$

where b_{jk}^t means specific costs of the *j*-th type of energy resource (electricity) in the production of a *k*-th type of products in a *t*-th year for the *r*-th type of economic activity of *q*-th section in TEA in the economy of the *f*-th region; V_{krqf}^t means forecast yield of the products of *k*-th type in *r*-th class, a group in the type of economic activity of *q*-th section in TEA in the *t*-th year of the economy of the *f*-th region.

For a three-tier system of the economy, the energy-saving potential (ESP) is determined according to the following algorithm:

at the level of *r*-th TEA of *f*-th region by *j*-th type of energy resource (electricity), ESP as a decrease in the consumption of *j*-th energy resource in *t*-th year relative to the base year is determined from the formula (12):

$$\Delta E_{GVArjf}^{b-t} = \left(e_{GVArjf}^b - \Delta e_{GVArjf}^{b-t} \right) V_{GVArjf}^t , \tag{12}$$

where ΔE_{GVArjf}^{b-t} means electricity saving potential of the *j*-th type of energy resource in *r*-th TEA of *f*-th region in *t*-th year; e_{GVArjf}^b means GVA power intensity of *j*-th type of energy resource in *r*-th TEA of *f*-th region in the base year; Δe_{GVArjf}^{b-t} means a reduction of the power intensity of TEA of *j*-th type of energy resource in *r*-th TEA of *f*-th region in a *t*-th year relative to the base year through the energy saving measures; V_{GVArjf}^t means forecast GVA volume in *r*-th TEA of *f*-th region in *t*-th year.

At the level of the *f*-th region for *j*-th type of energy resource in a *t*-th year relative to the base year (formula 13):

$$\Delta E_{GVArjf}^{b-t} = \left(e_{GVArjf}^b - \Delta e_{GVArjf}^{b-t} \right) V_{GVArjf}^t , \tag{13}$$

where ΔE_{GVAjf}^{b-t} means energy saving potential of the *j*-th type of energy resource in *f*-th region in *t*-th year; e_{GVArjf}^b means GVA power intensity of *j*-th type of energy resource of the *f*-th region in the base year; Δe_{GVArjf}^{b-t} means a reduction in GVA power intensity of *j*-th type of energy resource in the *f*-th region in a *t*-th year relative to the base year through the energy saving measures by types of economic activity of the regions and regional-wide measures; V_{GVArjf}^t means forecast GVA volume of the *f*-th region in the *t*-th year.

At the level of the country (formula 14):

$$\Delta E_j^{b-t} = \left(e_{GVAj}^b - \Delta e_{GVAj}^{b-t} \right) V_{GVAj}^t , \tag{14}$$

where ΔE_j^{b-t} means energy saving potential of the *j*-th type of energy resource in the country in *t*-th year; e_{GVAj}^b means GVA power intensity of the country of *j*-th type of energy resource in the base year; Δe_{GVAj}^{b-t} means a reduction in GVA power intensity of *j*-th type of energy resource in a *t*-th year relative to the base year through the energy saving measures by types of economic activity of the regions and regional-wide measures; V_{GVAj}^t means forecast GVA volume of the country in *t*-th year.

As for the general economic situation in Ukraine, as a result of Russia's full-scale invasion, Ukraine's GDP fell by – 29.1 % in 2022 (according to the latest data from the Ministry of Economy, although this figure will change over time). The nine most affected regions account for 30 % of the national GDP. Subject to the NBU report, the economy will gradually return to sustainable growth: in 2023, real GDP is expected to grow by 2.0 %, then to 4.3 % in 2024 and 6.3 % in 2025 (April–May 2023). According to the Ministry of Economy, the majority of essential economic activities showed positive results in 2023. This is due to the low statistical base of last year's comparison and the high ability of businesses to adapt to new challenges during the war, as well as assistance from the government and international partners. Separately, the Ministry of Economy noted that economic activity is recovering in many sectors of the manufacturing industry, which was crucial during the war. In general, the manufacturing sector, which suffered damage and destruction during the war, is gradually recovering. GDP growth in September 2023 was about 9.1 % compared to September 2022. As a result, in January-September 2023, growth is estimated at 5.3 % compared to the same period last year. In September, the security situation, the production facilities destruction at some enterprises (mainly in the east of the country), and logistical constraints for exporters remained the biggest deterrents to economic growth [22–25].

Ukraine's GDP growth in 2024 is forecast at 4 % by the Ministry of Economy, and this forecast is included in the draft state budget for 2024. The World Bank forecasts Ukraine's GDP to grow by 3.5 % in 2023 and 4.0 % in 2024. Dragon Capital Investment Company's analysts expect Ukraine's GDP growth to be around 2–3 %, but no more than 5 % instead of 8 % due to the longer duration of the hot phase of the war with Russia [26–28]. In June 2023, the IMF forecasted that Ukraine's gross domestic product growth in 2023 would be between 1 % and 3 %. The growth is now expected to be closer to 3 %, according to the IMF [29].

Stable summer electricity supply, increased government spending, large foreign aid, a better-than-expected harvest, and rising consumer and business confidence contributed to a gradual pick-up in activity in the first to third quarter of this year following a sharp decline a year ago. Modest growth in Ukraine resumed in the second quarter of 2023 for the first time since the Russian invasion, reinforced by a rise in public consumption and some recovery in sectors benefiting from military spending and improved electricity supply. In agriculture, higher-than-expected growth was supported by favorable weather conditions. A shift to alternative export routes bypassing Black Sea ports eased some logistical burdens; however, the suspension of the Black Sea Grain Initiative in July affected exports. Wage pressures have intensified amid widespread growth in labour demand and tight labour supply, according to the World Bank's (WB) updated economic forecast. According to the forecast, Ukraine's economic growth is expected to reach 6.5 % in 2026. WB experts believe that the forecasts depend on the availability of foreign financial support and the expected duration of the Russian invasion. Economic policy is expected to remain tight to contain inflation and widening external imbalances, while private consumption is expected to make only a modest contribution to economic growth over the forecast horizon.

It is noted that economic conditions in Ukraine remain in an extremely difficult state amid escalating security risks, additional damage to infrastructure, renewed pressure on energy prices, and restrictions on the capacity of grain transportation routes to international markets.

Two structures of the post-war economy were developed at the Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine [30]. In the paper [31], the authors present their vision of economic processes that will be more moderate by 2030 with a slower recovery rate (conservative scenario), this forecast is based on the cessation of hostilities by the end of 2025.

According to Ukrenergo's preliminary data, electricity consumption by the Ukrainian economy and population is estimated at 106.2 billion kWh in 2022 (to be specified later by Ukrenergo), and production – 119.5 billion kWh.

Ukrainian **agriculture** is a direct victim of Russian aggression, as fighting often takes place in Ukrainian fields and farms. About 13 % of Ukraine's territory is mined by Russians. There is a risk of a protracted war in Luhansk, Donetsk, Zaporizhzhia, and Kherson regions, which account for 23 % of wheat production, 3 %

of corn, 21 % of barley and 20 % of sunflower seeds. Currently, the decline in production in monetary terms is estimated at 10 % in 2023 compared to 2022.

Industry. The damage to industrial assets is at least $ 6.7 billion (about a hundred industrial enterprises were reported damaged or destroyed). The metallurgy industry has lost at least 50 % of its assets. There are estimates of up to 65 %. Among the largest losses: were "Azovstal" and "Ilyich Iron and Steel Works of Mariupol", Ukraine's second and third largest steel plants, respectively. Other steel mills are operating intermittently due to the unstable electricity and water supply situation. In 2022, Ukrainian enterprises produced 6.3 million tonnes of steel, just 30 % of the 2021 figure. In the first two months of 2023, Ukrainian ferrous metals producers reduced production by almost 80 % on average compared to January–February of the previous year. At the end of 2021, the industry accounted for 23 % of electricity consumption in the country. The rest of the industry accounted for 18.6 % of consumption. Production will drop to 5 % by the end of 2023 without a sharp deterioration in the situation. Only machine building is growing by 10 % compared to 2022.

Energy sector. It suffered significant damage over the period from autumn 2022 to spring 2023. The amount of damage is being clarified, the economy section is operating, providing the necessary amount of electricity supply for spring 2023, emergency shutdowns have been stopped, several NPP and TPP units are undergoing current and medium repairs, Zaporizhzhia NPP is occupied, 5 units are in a cold shutdown state, Energoatom is eager to put 1 unit in this mode, however, the occupation administration prevents this. The fate of the cooling pond at this NPP and the NPP itself after the Kakhovka HPP explosion is unknown. The overall forecast for electricity supply before the heating season is stable, after the start of this season it is uncertain, depending on the state of hostilities.

Transport. Freight and passenger traffic is growing. By the end of 2023, the forecast is favorable, with grain, ore (export) resumption, and coal transportation. The section's GVA is expected to grow by 7–8 % in 2023 compared to 2022.

The sector of Other foreign economic activity. The sector is gradually resuming operations, which is responsible for stabilizing the economy, halting its decline, and increasing employment and salaries. The forecast is favorable until the end of the year.

Exports. In 2022, Ukraine exported 99.8 million tonnes of goods worth $44.1 billion, while the value of exports fell by 35 % and physical volumes decreased by 38.4 % compared to 2021.

The author has developed a forecast of Ukraine's GDP until 2030, which is presented in Table 1.

Table 1. Forecast of Ukraine's GDP by 2030 in 2016 prices

Indicators	2020 (actual)	2021 (actual)	2022 (actual)	2023	2024	2025	2030
GDP forecast at 2016 prices, UAH bn	2,509.8	2,596.3	1,841.9	1,878.7	1,959.5	2,083.0	2,827.2

Paper [31] provides a forecast of the structure of gross value added to be created in the country's economy by 2030. The materials used were those of the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine, the Ministry of Economy, the World Bank, the IMF, the National Bank of Ukraine, and Dragon Capital Investment Company [32]. Given the forecasted structure of gross value added, the forecast of electricity consumption at the state level in Ukraine until 2030 is presented (Tables 2, and 3). Table 2 shows the forecast of electricity demand in terms of energy intensity of GDP and energy intensity of GVA, where 2022 is chosen as the base year, and the forecast of GDP and GVA at the state level in constant prices of 2016 until 2030. Gross electricity consumption is given in a range since the energy intensity of GDP and GVA differ. The corresponding forecast was also calculated in the economic sections for the same forecast period (Table 3). However, in the absence of the necessary statistical data for the country's economic sectors for 2022, the base year in this table is 2020, which is the latest available with the required information. This explains the significant difference in the calculated values of these tables. It is possible to calculate such a forecast for the long term, and if the necessary statistical data are available, it can be presented for the regions using modified methods [34].

Table 2. Forecast of electricity demand at the country level in Ukraine until 2030 at the TOP level, calculated according to Ukrenergo's operational data

Indicators	2020 (actual)	2021 (actual)	2022 (actual)	2023	2025	2030
GDP forecast at 2016 prices, UAH bn	2,509.8	2,596.3	1,841.9	1,878.7	2,083.0	2,827.2
GVA forecast in total at 2016 prices, UAH bn			1,618.8	1,653.3	1,853.8	2,516.2
Gross electricity consumption by electricity intensity of GDP in 2022, million kWh		-	106,200.0*	108,307.0	120,085.0	162,990.0
Gross electricity consumption by electricity intensity of GVA in total 2022, million kWh		-	106,200.0*	108,457.0	121,609.0	165,063.0
Actual consumption, million kWh	120,324.6	125,654.8				
Total gross electricity consumption (gross)	147,801.4	156,601.0	127,440.0	129,968.0 130,148.0	144,102.0 145,931.0	192,328.0 194,774.0

*Ukrenergo's operational data, calculated based on monthly consumption

Table 3. Forecast of electricity demand in Ukraine until 2030 (2020 – baseline) at the TOP and DOWN levels in Ukraine*

Indicators	2020	2021	2022	2023	2025	2030
	actual	estimated	estimated	forecast		
GDP forecast in 2016 prices, UAH bn	2,509.8	2,596.3	1,841.9	1,878.7	2,083	2,827.2
Gross electricity consumption in the country, taking into account structural and technological energy saving at the TOP level, million kWh	124,141.6	128,480.4	105,500.0	107,610.0	113,526.0	141,512.1
Forecast of gross electricity consumption by types of economic activity according to the electricity capacity of the GVA in 2020, million kWh						
Agriculture, hunting, forestry; fisheries	2,111.4	2,246.3	1,198.9	1,342.2	1,570.7	2,244.1
Industry	65,655.8	72,456.4	49,063.9	50,528.1	56,777.4	78,531.9
including						
mining	12,299.5	16,946.3	10,707.3	10,535.1	11,684.0	15,281.7
processing	35,137	32,079.9	16,792.7	20,285.4	22,739.0	32,219.6
production and distribution of electricity, gas, heat, and water; water supply, sewerage, waste management	18,219.7	23,430.3	21,563.9	19,707.5	22,354.4	31,030.6
Transport	5,432.0	5,292.3	2,711.6	3,189.7	3,774.2	8,004.2
Other types of economic activity	14,506.7	14,821.4	12,391.6	12,051.9	12,711.2	16,074.0
Total by types of economic activity	87,705.9	94,816.5	65,366.1	67,111.9	74,833.6	104,854.3
Population	36,435.7	36,263.0	35,140.6	33,672.8	33,586.5	33,500.1
Total gross electricity consumption by types of economic activity and population, taking into account structural and technological energy saving at the DOWN level, million kWh	124,141.6	131,079.5	100,506.7	100,784.7	108,420.0	138,354.4

* – calculation based on the structure of Ukraine's economy in 2020 and electricity intensity in 2020

Table 4. The technological potential of electricity saving in the economy of Ukraine until 2040 relative to 2017,bln kWh

Indicators	2020	2025	2030	2035	2040
The technological potential of electricity saving	2,418.6	7,021.2	10,993	15,175.7	18,548.0

Table 5. The technological potential of electricity saving in the economy of Ukraine until 2040 relative to 2020, listed taking into account the situation after 2022, bln kWh

Indicators	2020	2025	2030	2035	2040
The technological potential of electricity saving	-	1,000.0	2,800.0	6,900.0	10,350.0

Estimates obtained as a whole for the country were distributed among the regions of Ukraine in proportion to the amount of energy resource (electricity) consumption.

Twelve regions with the largest electricity consumption are highlighted; the other regions are combined. In the region, the electricity saving potential was distributed according to the structure of electricity consumption in terms of TEA in the regions (Table 6). In the table.4 shows the potential of electric saving in these very regions, but without taking into account the relocation of enterprises, since such statistics are not available at the moment. Calculations are given for 2020.

Table 6. Forecast potential of electricity saving in Ukraine until 2040 relative to 2017, bln kWh

Regions	Forecast potential of electricity saving relative to 2017				
	2020	2025	2030	2035	2040
Ukraine	2,418.6	7,021.2	11,162.9	15,175.7	20,547.8
Vinnytsia	51.5	149.5	237.7	323.1	437.5
Dnipropetrovsk	622.4	1,806.9	2,872.8	3,905.5	5,288.1
Donetsk	251.6	730.3	1,161.1	1,578.6	2,137.4
Zaporizhzhia	240.7	698.8	1,110.9	1,510.3	2,044.9
Ivano-Frankivsk	67.2	195.2	310.3	421.8	571.1
Kyiv (region)	80.3	233.0	370.5	503.6	681.9
Lviv	73.3	212.8	338.1	459.7	622.4
Odesa	74.9	217.3	345.5	469.8	636.1
Poltava	109.8	318.7	506.7	688.8	932.6
Kharkiv	110.4	320.5	509.6	692.8	938.1
Cherkasy	52.3	151.8	241.4	328.1	444.3
Kyiv (city)	137.4	399.0	634.4	862.4	1,167.7
Other regions (total)	546.8	1,587.4	2,523.9	3,431.2	4,645.7

Table 7. Forecast potential of electricity saving in Ukraine until 2040 relative to 2020, recalculated taking into account the situation after 2022, bln kWh*

Regions	Forecast potential of electricity saving relative to 2020			
	2025	2030	2035	2040
Ukraine	1,000.0	2,800.0	6,900.0	10,350.0
Vinnytsia	21.3	59.4	147.0	220.4
Dnipropetrovsk	257.3	720.2	1,775.7	2,663.6
Donetsk	104.0	291.2	717.7	1,076.6
Zaporizhzhia	99.5	278.6	686.7	1,029.8
Ivano-Frankivsk	27.8	77.5	421.8	343.5
Kyiv (region)	33.2	93.0	229.0	343.5
Lviv	30.3	84.6	209.0	313.5
Odesa	31.0	86.5	213.6	319.8
Poltava	45.3	127.1	313.2	470.0
Kharkiv	45.6	127.8	315.0	472.5
Cherkasy	21.6	60.6	149.2	223.8
Kyiv (city)	56.8	159.1	392.1	588.2
Other regions (total)	226.3	634.4	1,330.0	2,598.3

* – the data are provided subject to de-occupation of the territory of the regions until 2025

The list of technological measures aimed at reducing the electricity consumption in the regions in the sections of the economy for the forecast period of 2040 includes as follows: introduction of energy-efficient

process equipment and household appliances instead of existing energy-consuming ones; introduction of energy-saving pumps with automatic control systems based on frequency regulation (energy saving is possible in the amount of 30–50 % of the consumption of pumping units using throttling and changing the number of working units); use of automatic systems for regulating equipment operation modes, recording and controlling the use of electricity; application of energy-saving lighting configurations using LED lamps (such replacement of lighting systems is primarily necessary in budget institutions, as well as for the population. When introducing energy-saving lamps to replace the existing ones in the amount of 326.5 bln units, it is possible to save annually 40 billion kWh of electricity); and replacement of existing computer equipment with low-power "green" computers.

Advanced energy-saving technologies in the housing and utilities sector of the regions include thermal modernization of residential and household buildings, which involves modernization of engineering equipment (including pumps) of heating, ventilation, air conditioning, and hot water supply systems; introduction of highly efficient energy-saving technologies that completely replace the use of natural gas and coal in heat-generating sources with technologies with direct use of electricity (electric boilers, electric heaters and other equipment), which can be used as independent heat-generating sources for individual use.

4. Conclusion

As a result of the study, an improved comprehensive method of demand for energy resources was developed in terms of peculiarities of the energy use in the regions of Ukraine and their impact on the electricity consumption in the country. This method, unlike the existing one, harmonized the forecasts obtained by the normative method at two levels of the economy: the upper (country) and the lower (types of economic activity) taking into account the structural and technological potential of energy saving in the types of economic activity, considers an improved normative method of forecasting consumption of the fuel and energy resources (FER), including electricity, on three hierarchical levels: country, regions, types of economic activity in the regions.

For the relevant hierarchical levels, a three-tier economic and mathematical model and a methodology for forecasting electricity consumption, taking into account the regional features of the economy, a system of energy efficiency indicators has been developed. The calculation of energy-saving potentials at the regional level made it possible to more accurately take into account the scope of implementation of energy-saving measures since energy-saving programs (including electricity saving) are developed precisely at the regional level. Energy-saving measures typical for most regions are taken into account for the technological potential of energy-saving at all hierarchical levels. For the regions of Ukraine, the technological potential of electricity saving was distributed in proportion to the energy consumption and according to their structure in line with the list of the main energy-saving measures according to TEA in the regions. The technological potential of electricity saving in the country will reach 10.35 bln kWh per year.

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ОЦІНКА ПОТЕНЦІАЛУ ЕЛЕКТРОЗБЕРЕЖЕННЯ ЗА РЕГІОНАМИ УКРАЇНИ (МЕТОДОЛОГІЯ ТА ПРОГНОЗНА ОЦІНКА)

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Анотація. *Метою цього дослідження є розвиток методів і засобів довгострокового прогнозування електроспоживання на основі удосконаленого комплексного методу прогнозування попиту на енергоресурси з урахуванням особливостей електровикористання регіонів України і їх впливу на електроспоживання країни. Науковою новизною отриманих результатів є врахування технологічного потенціалу регіонального електрозбереження за типовими для регіонів заходами з електрозбереження. Сформована трирівнева модель (рівень I, рівень II, рівень III) враховує як загальний потенціал електрозбереження (від структурних і технологічних зрушень) в країні в цілому, так і особливості на регіональному рівні (область, місто, село, селище, територіальна громада) у певних (вибраних) видах економічної діяльності у виробництві (наданні послуг). При виконанні роботи було зібрано матеріал щодо заходів з електрозбереження в енергоємних виробництвах та прогнозах розвитку окремих видів виробництва та надання послуг. Ці оцінки використано при визначенні технологічного потенціалу енергозбереження в регіонах. Виділено 12 найбільших за споживанням електроенергії регіонів, інші регіони об'єднані разом. Технологічний потенціал електрозбереження по країні досягне 10,35 млрд кВт·год.*
Ключові слова: регіон, електрозбереження, потенціал електрозбереження, прогнозування, енергетична ефективність, електроенергія.

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