# Forecasted Petroleum Products Consumption in Ukraine and Estimated Greenhouse Gas Emissions from Their Use

**Olena Maliarenko, Natalia Ivanenko, Natalia Maistrenko, Oleksandr Teslenko, and Artur Zaporozhets**

## 1 Introduction

The petroleum products supply is great importance for the country's economy, since so far the transport and agricultural machinery of any country consume mainly gasoline, diesel fuel, kerosene, liquefied gas (i.e. petroleum products). During the cold winter season, boilers and thermal power plants (TPPs and CHPs) can use fuel oil or diesel fuel as back-up fuel in the case of a shortage of natural gas. Fuel oil is also used as an additional high-calorie fuel at the start-up of coal-fired boilers. The application area for petroleum products is therefore transport, agriculture, energy and industrial energy.

In Ukraine, during 2014–2020, the consumption of gasoline (taking into account sales through petrol-gas stations) decreased from 3.1 to 1.8 million tons and fuel oil from 0.1 to 0.09 million tons [1]. However, during 2017–2020, the consumption of diesel fuel (including sales through petrol-gas stations) increased from 5.4 to 6.1 million tons and liquefied gas (including sales through petrol-gas stations) from 0.9 to 1.3 million tons [1]. This is clearly the result of high fuel prices and the availability of low-cost second-hand diesel cars from Europe.

According to the data of the State Statistics Service of Ukraine, the total consumption of petroleum products in Ukraine has increased, while the consumption of crude oil for petroleum processing has significantly decreased (Fig. 1) [2].

The export of oil refining products from Ukraine in January–June 2021 increased to 203 thousand tons (a 1.8-fold increase compared to the same period in 2020), including 126.1 thousand tons of fuel oil [3]. The share of oil exports of the

O. Maliarenko (✉) · N. Ivanenko · N. Maistrenko · O. Teslenko · A. Zaporozhets
General Energy Institute of NAS of Ukraine, Kyiv, Ukraine
e-mail: malyarenlena@gmail.com

A. Zaporozhets
Green Technology Research Center, Yuan Ze University, Taoyuan, Taiwan



S. Boichenko et al. (eds.), *Modern Technologies in Energy and Transport*, Studies in Systems, Decision and Control 510, https://doi.org/10.1007/978-3-031-44351-0_6

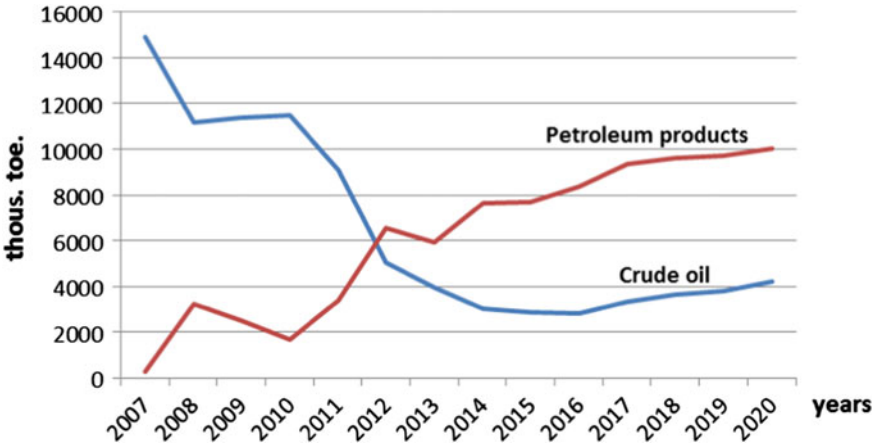


**Fig. 1** Total supply of crude oil and petroleum products to Ukraine in 2007–2020 [2]

Kremenchug oil refinery was 114.7 thousand tons, and that of the state-owned corporation "Ukrgazvydobuvannya" was 11.4 thousand tons. In June 2021, exports of petroleum refining products from Ukraine amounted to 34.5 thousand tons, which is three times more than in June 2020. At the same time, as a result of large-scale military operations, total exports of goods from Ukraine have been reduced by half [4].

In 2021, 5 million tons of petroleum products were sold at Ukrainian petrol-gas stations, which is 12% more than in 2020 (4.46 million tons of all types of fuels) [5]. In 2021, sales of A-95 gasoline saw the greatest growth from 1.76 (2020) to 2.1 million tons (23%). The sale of A-92 gasoline increased by 10% (from 0.60 to 0.66 million tons (data on the sale of A-98 gasoline stopped being published as of the end of 2019) [3]. The sale of diesel fuel increased significantly by 19% (from 1.76 to 2.1 million tons). However, the sale of liquefied gas decreased for the first time in seven years: in 2021, its sales were 3% less than in 2020 [3].

According to Ukraine's product balance sheets [6], the consumption structure of petroleum products has changed with increasing fuel prices. Higher gasoline prices have stimulated the import of diesel vehicles into Ukraine and the upgrading of gasoline engines for the use of liquefied gas.

Taking into account the difficulty of forecasting price changes for certain types of fuel, this article first analyzes the total consumption of petroleum products in Ukraine and by types of economic activity. Then the trends of changes in the structure of consumption of types of petroleum products are determined. The forecast structure of consumption of petroleum products was evaluated, taking into account the military actions in Ukraine and the post-war recovery of the country. Expected changes in the structure of the country's economy and small amounts of energy savings are taken into account. Energy saving involves reducing the specific consumption of fuel oil for the production of electricity at TPPs and CHPs, and the loss of petroleum products during their transportation and distribution.

**Table 1** Actual and forecast consumptions for petroleum products in Ukraine for 2020 relative to 2015, million toe [6, 7]

| Indicators | 2020 actual | 2020 forecast |
|---|---|---|
| Ukraine (total) | 10.019 | 11.5–11.7 |
| Agriculture, forestry and fishing | 1.016 | 1.490 |
| Mining and quarrying | 0.127 | 0.305 |
| Manufacturing industry | 1.580 | 1.423 |
| Supply of electricity, gas, steam and air conditioning; water supply; sewerage, waste management | 0.154 | 0.577 |
| Transport, warehousing, postal and courier activities | 6.842 | 7.652 |
| Other types of economic activity | 0.159 | 0.286 |

The previous forecast of petroleum products was carried out in 2015 and is given in the publication [7]. A comparison of the accuracy of forecasts with actual data is considered using the example of 2020 (the latest available statistical data on the country's energy balance on the website of the State Statistics Service of Ukraine [6]). The results of the comparison of the forecast and actual data for 2020 are given in the Table 1.

As can be seen from the Table 1, the sections "Manufacturing industry" (up to 10%), "Transport" (11.8%), by country (14.8–16.8%) have a satisfactory forecasting error. Other sections of the economy have a significant difference. It is clear that the COVID pandemic has significantly affected economic indicators around the world, so there is an obvious expediency in reviewing forecasts made more than 5 years ago.

After February 24, 2022, the war in Ukraine made significant adjustments to the volumes of consumption of petroleum products according to the directions of their use, but there is still no state statistical reporting on these issues.

## 2 The Purpose of the Study and Methods

The aim of the study was to update petroleum product forecast (2015) for further balance forming, clarification of methodological approaches to obtaining activity data and projecting petroleum product demand in the energy sector under the destruction of energy facilities in the wake of Russian economic activity against Ukraine.

Many scientists have studied the problems of forecasting the consumption of fuel and energy resources, in particular Kulyk, Piriashvili, Rozen, Kasyanova, Podolets, Lear, Nechaeva, Leshchenko and others [8–20].

At the global level, research on the oil products market is presented in the analytical materials of international organizations (for example, the Organization of the

Petroleum Exporting Countries (OPEC), the International Monetary Fund (IMF), the International Energy Agency (IEA), the Organization for Economic Cooperation and Development (OECD)). At the same time, significant attention of scientists is given to the problems of evaluating monopolization, consideration of the structure of the world oil market, issues of pricing on the world oil market, the manifestation of crisis phenomena in this market and their consequences for Ukraine, analysis of global trends in energy, opportunities for the development of the oil refining industry in Ukraine, etc. However, in their research there is no calculation of the volumes of current consumption of oil and oil products in the sections of the economy of Ukraine and in the country as a whole, corresponding forecast volumes of consumption that depend on structural and technological changes (structural and technological potentials of energy saving), since for the formation of the price factor forecasts are decisive in the economy of Ukraine.

In the General Energy Institute of the National Academy of Sciences of Ukraine, Kulyk developed a complex method of forecasting energy resource consumption [8, 21, 22]. This method is also called two-stage, as it involves forecasting energy consumption by known methods at the same time on two hierarchical levels of the economy (TOP-level and DOWN-level) with further matching of the obtained forecasts by Kulyk's vector iterative-free method [21]. The two-stage method usually uses the traditional regulatory method or the direct account method. In this study, the traditional normative method was used to forecast petroleum products. Forecasts obtained at two levels were subsequently agreed using the Kulyk's method of forecasting decisions. The need for coordination arises when there is a significant discrepancy in statistical data by country and by type of economic activity. Since statistical reporting on types of economic activity in 2020 has not been published by the State Statistics Service of Ukraine, the initial data for economic sectors was formed from the Energy Balance of Ukraine in 2020. It should be noted that the energy balance of the country and the product balance of oil products have differences in the given data; therefore the initial data for the country and for the sectors of the economy were obtained from the same source—the Energy Balance of Ukraine in 2020.

## 3 Mathematical Model of Forecasting the Petroleum Products Consumption

In the paper [7], a comprehensive method [21] based on a two-stage method of forecasting the consumption of energy resources was used to forecast consumption of petroleum products (base year—2015). According to this method, two forecasts are made at the DOWN (types of economic activity) and at the TOP (country) levels of the economy with subsequent reconciliation using Kulyk's vector method [8, 21].

Two approaches can be used to determine the forecasted consumption of petroleum products. The first approach: separately determine the consumption of

each type of petroleum product, and then sum them up in the same units, as in the energy balance according to the Eurostat format. 'The second approach: immediately determine the consumption of petroleum products together, since the total volume of consumption of petroleum products is a fairly constant value, and only the structure of consumption changes, which is mainly affected by the price of fuel. The structure of petroleum product consumption for the future can be determined by the scenario method. The second approach is used in this paper.

For each economy section $i$ (according to the classifier of types of economic activity) with the consumption of petroleum products for transport (in internal combustion engines) without conversion into other types of energy (electricity, heat), the forecast of the consumption of the each petroleum product type $\boldsymbol{j}$ is determined by formula:

$$E^t_{i,j} = \sum_i e^b_{GVAij} V^t_{GVAi} \mp \sum_i \Delta e^{b-t}_{GVAij} V^t_{GVAi} - \sum_i \Delta e^t_{GVAij} V^t_{GVAi} \pm E^t_{subtj}, \tag{1}$$

where $e^b_{GVAij}$—the energy intensity of GVA (Gross Value Added) of the energy resource type $j$ of the economy section $i$ in the base year $b$, MJ/UAH; $V^t_{GVAi}$—forecasted GVA of the economy section $i$ in year $t$ at constant prices (adjusted to the prices of the base year b according to [21–23], thousand UAH; $\sum_i \Delta e^{b-t}_{GVAij} V^t_{GVAi}$—total decrease or increase in energy consumption of the energy resource type $j$ in year $t$ due to changes in the structure of the economy and the structure of its sectors [21–26], MJ/UAH; $\sum_i \Delta e^t_{GVAij} V^t_{GVAi}$—decrease in consumption of energy resource type $j$ in year $t$ due to technological changes, MJ/UAH [21, 26]; $E^t_{subsj}$—volumes of substitution of energy resource of type $j$ in year $t$, GJ [21].

The energy saving potential due to structural changes when determining the forecast consumption for all types of petroleum products was calculated based on the change in the structure of the economy in the forecast years. The calculation of the technological potential of energy saving for each consolidated type of economic activity takes into account the reduction in the consumption of petroleum products due to the reduction of losses during storage, transportation and distribution of petroleum products.

For the economy section $i$, which mainly use petroleum products for conversion into other types of energy in power plants: section D "Supply of electricity, gas, steam and air conditioning", section C "Manufacturing industry", partly other sections, forecast levels of consumption of the petroleum product type $j$ are determined depending on the forecast structure of electricity and heat generation sources and the forecast consumption of electricity and heat energy by the economy [7, 21]:

$$E^t_{convj} = \sum_j \left( \sum_{i=1}^{n} B^t_{wfj} + \sum_{m=1}^{n} B^t_{qmj} + B^t_{eothj} \right) = k_{fj} W^t_f b^t_{wj} + k_{mj} Q^t_m b^t_{qj} + \sum k_{oth} B^t_{othj}, \tag{2}$$

where $B^t_{wfj}$—consumption of petroleum products type $j$ (diesel fuel, fuel petroleum) for electricity generation of type $f$ (thermal power plant, thermal power plant, other electricity generators on petroleum fuel) in forecast year $t$; $B^t_{qmj}$—consumption of petroleum products type $j$ for heat generation of type $m$ (CHP, thermal power plants, other petroleum-fueled heat generators) in forecast year $t$; $B^t_{eothj}$—other needs of petroleum products type $j$ in sections; $k_{fj}$—share of electricity produced by power generation facilities using petroleum products type $j$; $W^t_f$—the amount of electricity (gross) produced by power generation capacities of type $f$ in year $t$; $b^t_{wj}$—specific consumption of petroleum products type $j$ for the production of electricity in the power system in year $t$; $k_{mj}$—share of heat energy produced by heat generating facilities using petroleum products type $j$; $Q^t_m$—amount of thermal energy produced by heat-generating capacities of the type $m$ in year $t$; $b^t_{qj}$—specific consumption of petroleum products type $j$ for the production of thermal energy in the centralized heat supply system in year $t$; $k_{oth}$—share of petroleum products type $j$ used in sections for other needs (lubricants, solvents, etc.); $B^t_{othj}$—consumption of petroleum products type $j$ for other needs in sections in year $t$.

Only petroleum products (fuel petroleum, petroleum refinery gas) burned in heating furnaces of petroleum refineries are taken into account in the production of "Petroleum Refining". The volumes of crude oil processing should be taken into account when determining the need for petroleum. This is a separate forecast.

The total consumption of petroleum products at the DOWN-level (consolidated sections of the economy) includes the sum of consumption according to Eqs. (1) and (2):

$$E^t = \sum\nolimits_i E^t_{i,j} + E^t_{convj}. \tag{3}$$

It is necessary to note about the formation of the forecast of the consumption of petroleum products for the energy sector. To determine the forecast trend, the volumes of consumption of petroleum products were analyzed in separate directions according to the energy balances of Ukraine for 2015–2020 (Table 2).

**Table 2** Consumption of petroleum products for conversion in the energy sector for the retrospective period, thous. toe

| Conversion enterprises | 2015 | 2017 | 2018 | 2019 | 2020 | Average over 5 years |
|---|---|---|---|---|---|---|
| TPP | 127 | 64 | 132 | 119 | 27 | 94 |
| CHP | 158 | 471 | 156 | 37 | 57 | 176 |
| Boilers | 141 | 46 | 37 | 32 | 34 | 58 |
| Other conversion enterprises | 3 | 120 | 118 | 135 | 10 | 77 |
| Total for conversion | 429 | 701 | 443 | 323 | 128 | 346.6 |

As can be seen from Table 2, petroleum products were used as a fuel substitute in the past period, especially this is evident from the dynamics of consumption of petroleum products at TPPs. Taking into account the uncertainty with the volumes of imported gas supplies, and we can expect an increase in the consumption of petroleum products in the energy sector in 2025. In any case, it is desirable to have a reserve. Therefore, in the forecast of the consumption of petroleum products for conversion at TPPs, CHPs, boiler rooms and other enterprises, the average value of the consumption of petroleum products for 5 years with a further decrease in their consumption to the level of 2020 was adopted for 2025.

The results of calculations by types of economic activity and by DOWN-level (country) according to the given model are shown in Table 3 [26].

The forecasted consumption of petroleum products for the country level (DOWN—level) is calculated according to the forecast indicators of the energy intensity of the country's GVA and the volume of the country's GVA:

$$E^t_{T_j} = e^b_{GVAT_j} V^t_{GVAT_s} \pm \Delta e^{b-t}_{GVA_{ij}} V^t_{GVAT_s} - \sum_{i=1}^{I} \Delta e^t_{GVA_{T_{sj}}} V^t_{GVAT_{is}} \pm \sum E^t_{subj}, \quad (4)$$

where $e^b_{GVAT_j}$—the GVA energy intensity of petroleum products type $j$ at the country level in the base year $b$; $V^t_{GVAT_s}$—the forecast of GVA volumes of the country, created with the forecast economy structure $s$ in year $t$; $\Delta e^{b-t}_{GVA_{ij}}$—change in the country's GVA energy intensity of petroleum products type $j$ in the forecast year $t$ under the structural chancing of the economy relative to the structure of the base year $b$; $\Delta e^t_{GVA_{T_{sj}}}$—change in the country's GVA energy intensity of petroleum products type $j$ in the forecast year $t$ under the technological restructuring of the economy; $E^t_{subj}$—volumes of substitution of petroleum products type $j$ with other types of fuel due to its shortage or high price.

To the Eq. (4) for the selection of the forecast structure, a restriction on the country's GVA energy intensity is added $e^t_{GVAT_j} \leq e^b_{GVAT_j}$.

The impact of structural changes on the country's energy consumption level is determined by the second component of formula (4), which can have a "+" sign in the case of overspending of the economy under a certain structure or "−" in the case of fuel and energy savings. Technological potential (component 3) and replacement volumes are determined only by individual technologies and are summed up. Table 4 includes forecasted petroleum products consumption (low level) taking into account structural and technological energy saving potentials.

Forecasts obtained by the normative method at the upper and lower levels have minor differences of 1.41% in 2020 and 1.13% in 2040. Such minor differences can be ignored and not reconciled. The reason for the small difference is that since the State Statistics Service did not provide the form of statistical reporting by types of economic activity for 2020, the initial data for sectors of the economy were formed from the Energy Balance of Ukraine for 2020. Therefore, the received forecasts have a convergence of about 1% and do not need to be reconciled.

**Table 3** Forecasted petroleum products demand by the KEA to 2040 (low level) under the updated GDP forecast with structural and technological changes in 2016 prices, thous. toe

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| *Agriculture. forestry and fishing* | | | | | | |
| Forecasted GWA with 2020 economy's structure in 2016 prices, bln UAH | 263.0 | 266.0 | 343.9 | 435.1 | 521.8 | 590.3 |
| Forecasted GWA with structural economy's changes in 2016 prices, bln UAH | 263.0 | 266.0 | 317.0 | 451.7 | 597.7 | 681.6 |
| *Forecasted petroleum products consumption by section, thous. t* | | | | | | |
| I Consumption with 2020 economy's structure and petroleum products intensity | 1278.0 | 1016.0 | 1313.4 | 1661.7 | 1992.8 | 2254.4 |
| II Consumption with structural economy's changes and 2020 petroleum products intensity | 1278.0 | 1016.0 | 1210.7 | 1725.1 | 2282.7 | 2603.1 |
| Under and overconsumption due to structural changes | 0.0 | 0.0 | 102.7 | −63.4 | −289.8 | −348.7 |
| Technological energy saving potential | 0.0 | 0.0 | 13.1 | 33.2 | 59.7 | 112.7 |
| III.I Consumption with 2020 economy's structure and technological changes | 1278.0 | 1016.0 | 1300.3 | 1628.5 | 1933.0 | 2141.7 |
| III.II Consumption with structural and technological changes | 1278.0 | 1016.0 | 1197.5 | 1691.9 | 2222.9 | 2490.4 |
| Forecasted petroleum products intensity of GVA, kg/UAH | 0.0054 | 0.0038 | 0.0038 | 0.0037 | 0.0037 | 0.0036 |
| *Mining and quarrying* | | | | | | |
| Forecasted GVA with 2020 economy's structure in 2016 prices, bln UAH | 94.8 | 120.6 | 181.6 | 229.8 | 275.5 | 311.7 |
| Forecasted GVA with structural economy's changes in 2016 prices, bln UAH | 94.8 | 120.6 | 153.9 | 163.6 | 172.8 | 158.5 |

(continued)

**Table 3** (continued)

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| *Forecasted petroleum products consumption by section, thous. t* | | | | | | |
| I Consumption with 2020 economy's structure and petroleum products intensity | 321.0 | 127.0 | 191.3 | 242.0 | 290.2 | 328.3 |
| II Consumption with structural economy's changes and 2020 petroleum products intensity | 321.0 | 127.0 | 162.1 | 172.3 | 182.0 | 166.9 |
| Under and overconsumption due to structural changes | 0.0 | 0.0 | 29.2 | 69.7 | 108.2 | 161.4 |
| Technological energy saving potential | 0.0 | 0.0 | 5.7 | 12.1 | 20.3 | 32.8 |
| III.I Consumption with 2020 economy's structure and technological changes | 321.0 | 127.0 | 185.5 | 229.9 | 269.9 | 295.5 |
| III.II Consumption with structural and technological changes | 321.0 | 127.0 | 156.4 | 160.2 | 161.7 | 134.1 |
| Forecasted petroleum products intensity of GVA, kg/UAH | 0.0034 | 0.0011 | 0.0010 | 0.00098 | 0.0009 | 0.0008 |
| *Manufacturing industry* | | | | | | |
| Forecasted GWA with 2020 economy's structure in 2016 prices, bln UAH | 239.1 | 292.9 | 372.4 | 471.2 | 565.0 | 693.3 |
| Forecasted GWA with structural economy's changes in 2016 prices, bln UAH | 239.1 | 292.9 | 289.3 | 331.0 | 364.2 | 401.5 |
| *Forecasted petroleum products consumption by section, thous. t* | | | | | | |
| I Consumption with 2020 economy's structure and petroleum products intensity | 1358.0 | 1570.0 | 1996.3 | 2525.9 | 3028.7 | 3427.0 |
| II Consumption with structural economy's changes and 2020 petroleum products intensity | 1358.0 | 1570.0 | 1550.8 | 1774.4 | 1952.3 | 2152.3 |
| Under and overconsumption due to structural changes | 0.0 | 0.0 | 445.5 | 751.6 | 1076.4 | 1274.7 |
| Technological energy saving potential | 0.0 | 0.0 | 99.8 | 176.8 | 302.9 | 514.0 |

(continued)

**Table 3** (continued)

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| III.I Consumption with 2020 economy's structure and technological changes | 1358.0 | 1570.0 | 1896.5 | 2349.1 | 2725.9 | 2913.0 |
| III.II Consumption with structural and technological changes | 1358.0 | 1570.0 | 1451.0 | 1597.5 | 1649.4 | 1638.2 |
| Forecasted petroleum products intensity of GVA, kg/UAH | 0.0057 | 0.0054 | 0.0050 | 0.00483 | 0.0045 | 0.0041 |
| *Supply of electricity, gas, steam and air conditioning; water supply; sewerage, waste management* | | | | | | |
| Forecasted GWA with 2020 economy's structure in 2016 prices, bln UAH | 83.1 | 56.7 | 96.5 | 122.0 | 146.3 | 165.6 |
| Forecasted GWA with structural economy's changes in 2016 prices. bln UAH | 83.1 | 56.7 | 110.8 | 148.0 | 182.1 | 211.3 |
| *Forecasted petroleum products consumption by section, thous. t* | | | | | | |
| *Own energy sector consumption without conversion* | | | | | | |
| I With 2020 economy's structure and petroleum products intensity (own consumption) | 121.0 | 36.0 | 61.3 | 77.4 | 92.9 | 105.1 |
| II With structural economy's changes and 2020 petroleum products intensity (own consumption) | 121.0 | 36.0 | 70.3 | 93.9 | 115.6 | 134.1 |
| Energy saving potential with structural changes | 0.0 | 0.0 | −9.1 | −16.5 | −22.7 | −29.0 |
| *Demand for conversion* | | | | | | |
| TPPs demand | 127.0 | 27.0 | 93.8 | 90.0 | 45.0 | 25.0 |
| Technological energy saving potential for TPPs | 0.0 | 0.0 | 0.7 | 1.0 | 1.1 | 1.4 |
| CHPs demand, including | 158.0 | 57.0 | 176.0 | 150.0 | 100.0 | 50.0 |
| –electricity production (0.328) | 51.8 | 18.7 | 57.7 | 49.2 | 32.8 | 16.4 |

(continued)

**Table 3** (continued)

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| –heat production (0.672) | 106.2 | 38.3 | 118.3 | 100.8 | 67.2 | 33.6 |
| Technological energy saving potential for CHPs | 0.0 | 0.0 | 3.2 | 4.9 | 5.3 | 7.0 |
| Total technological energy saving potential for TPPs and CHPs | 0.0 | 0.0 | 3.9 | 5.9 | 6.4 | 8.4 |
| Total petroleum products demand for electricity production at TPPs and CHPs taking into account potential | 178.8 | 45.7 | 147.6 | 133.3 | 71.4 | 33.0 |
| Petroleum products demand for heat production at boilers | 141.0 | 34.0 | 58.0 | 48.0 | 40.0 | 30.0 |
| Total petroleum products demand for heat production at CHPs and boilers | 247.2 | 72.3 | 176.3 | 148.8 | 107.2 | 63.6 |
| Total petroleum products demand for electricity and heat production (conversion) | 429.0 | 128.0 | 400.9 | 342.1 | 208.6 | 106.6 |
| I. Consumption with 2020 economy's structure and conversion in energy sector | 550.0 | 164.0 | 462.2 | 419.6 | 301.5 | 211.7 |
| II. Consumption with structural changes and conversion in energy sector | 550.0 | 164.0 | 471.2 | 436.1 | 324.2 | 240.7 |
| III.I Consumption with 2020 economy's structure and conversion in energy sector with technological changes | 550.0 | 164.0 | 458.2 | 413.7 | 295.0 | 203.2 |
| III.II Consumption with structural and technological changes and conversion in energy sector | 550.0 | 164.0 | 467.3 | 430.2 | 317.8 | 232.2 |
| Forecasted petroleum products intensity of GVA under scenarios III.II, kg/UAH | 6.6 | 2.9 | 4.2 | 2.9 | 1.7 | 1.1 |
| *Transport, warehousing, postal and courier activities* | | | | | | |
| Forecasted GWA with 2020 economy's structure in 2016 prices, bln UAH | 131.2 | 143.9 | 205.7 | 260.3 | 312.2 | 353.2 |

(continued)

**Table 3** (continued)

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Forecasted GWA with structural economy's changes in 2016 prices, bln UAH | 131.2 | 143.9 | 215.4 | 307.6 | 387.6 | 428.0 |
| *Forecasted petroleum products consumption by section, thous. t* | | | | | | |
| I Consumption with 2020 economy's structure and petroleum products intensity | 6302.0 | 6842.0 | 9778.4 | 12,374.0 | 14,841.2 | 16,790.2 |
| II Consumption with structural economy's changes and 2020 petroleum products intensity | 6302.0 | 6842.0 | 10,239.5 | 14,622.5 | 18,425.5 | 20,346.0 |
| Under and overconsumption due to structural changes | 0.0 | 0.0 | −461.1 | −2248.5 | −3584.3 | −3555.8 |
| Technological energy saving potential | 0.0 | 0.0 | 205.3 | 410.5 | 547.4 | 684.2 |
| III.I Consumption with 2020 economy's structure and technological changes | 6302.0 | 6842.0 | 9573.2 | 11,963.5 | 14,293.8 | 16,106.0 |
| III.II Consumption with structural and technological changes | 6302.0 | 6842.0 | 10,034.3 | 14,212.0 | 17,878.1 | 19,661.8 |
| Forecasted petroleum products intensity of GVA, kg/UAH | 0.0480 | 0.0475 | 0.0466 | 0.0462 | 0.0461 | 0.0459 |
| *Other types of economic activity* | | | | | | |
| Forecasted GWA with 2020 economy's structure in 2016 prices, bln UAH | 916.8 | 1256.0 | 1415.5 | 1791.1 | 2147.9 | 2430.1 |
| Forecasted GWA with structural economy's changes in 2016 prices, bln UAH | 916.8 | 1256.0 | 1569.6 | 2021.0 | 2442.3 | 2816.1 |
| *Forecasted petroleum products consumption by section, thous. t* | | | | | | |
| I Consumption with 2020 economy's structure and petroleum products intensity | 253.0 | 159.0 | 179.2 | 226.7 | 271.9 | 307.6 |

(continued)

**Table 3** (continued)

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| II Consumption with structural economy's changes and 2020 petroleum products intensity | 253.0 | 159.0 | 198.7 | 255.8 | 309.2 | 356.5 |
| Under and overconsumption due to structural changes | 0.0 | 0.0 | −19.5 | −29.1 | −37.3 | −48.9 |
| Technological energy saving potential | 0.0 | 0.0 | 4.8 | 9.5 | 12.7 | 15.9 |
| III.I Consumption with 2020 economy's structure and technological changes | 253.0 | 159.0 | 174.4 | 217.2 | 259.2 | 291.7 |
| III.II Consumption with structural and technological changes | 253.0 | 159.0 | 193.9 | 246.3 | 296.5 | 340.6 |
| Forecasted petroleum products intensity of GVA, kg/UAH | 0.0003 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| *Total KEA* | | | | | | |
| *Forecasted petroleum products consumption by sections, thous. t* | | | | | | |
| I Consumption with 2020 economy's structure and petroleum products intensity | 10,062.0 | 9878.0 | 12,024.3 | 15,100.8 | 18,000.4 | 20,406.3 |
| II Consumption with structural economy's changes and 2020 petroleum products intensity | 10,062.0 | 9878.0 | 13,733.2 | 18,809.4 | 23,173.0 | 25,351.4 |
| III.I Consumption with 2020 economy's structure and technological changes | 10,062.0 | 9878.0 | 11,791.4 | 14,629.6 | 17,353.8 | 19,552.2 |
| III.II Consumption with structural and technological changes—low level—$E^t_{DOWN}$ | 10,062.0 | 9878.0 | 13,500.4 | 18,338.1 | 22,526.4 | 24,497.4 |

* GVA for 2015 is given in 2015 prices

**Table 4** Forecast of consumption of petroleum products by types of economic activity until 2040 based on the updated forecast of GDP in 2016 prices and for structural and technological changes, thousand toe

| Indicators | 2015* actually | 2020 actually | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Agriculture, forestry and fisheries | 1278.0 | 1016.0 | 1197.5 | 1691.9 | 2222.9 | 2490.4 |
| Mining and quarrying | 321.0 | 127.0 | 156.4 | 160.2 | 161.7 | 134.1 |
| Manufacturing industry | 1358.0 | 1570.0 | 1451.0 | 1597.5 | 1649.5 | 1638.2 |
| Supply of electricity, gas, steam and air conditioning; water supply; sewerage, waste management | 550.0 | 164.0 | 467.3 | 430.2 | 317.8 | 232.2 |
| Transport, warehousing, postal and courier activities | 6302.0 | 6842.0 | 10,034.3 | 14,212.0 | 17,878.1 | 19,661.8 |
| Other types of economic activity | 253.0 | 159.0 | 193.9 | 246.3 | 296.5 | 340.6 |
| Together for types of economic activity (DOWN-level)—$E^t_{Down}$ | 10,062.0 | 9878.0 | 13,500.4 | 18,338.1 | 22,526.4 | 24,497.3 |
| Ukraine—(TOP-level)—$E^t_{Ts}$ | 10,062.0 | 10,019.0 | 13,504.3 | 18,441.7 | 22,704.7 | 24,777.0 |

* GVA for 2015 is given in 2015 prices

Table 5 includes the estimation of the emissions of greenhouse gases (GHG) from the forecasted petroleum products (gasoline, diesel, fuel oil, and propane-butane) consumption in 2040 of for the perspective of 2040 based on averaged indicators for. GHG emissions were determined according to the recommendations of the US Environmental Protection Agency [27, 28], Directive 2009/28/EC [29] and the methodological manual of the International Energy Agency [30] and the WRI/WBCSD manual [31, 32].

**Table 5** Actual and forecasted GHG emissions from petroleum products consumption

| Year | Petroleum products consumption, thous. toe | $CO_2$ emissions, thous. t | $CH_4$ emissions, thous. t | $N_2O$ emissions, thous. t | GHG emissions, thous t CO2 eq |
|---|---|---|---|---|---|
| 2015 | 10,062 | 30,493 | 1.3197429 | 0.277841 | 30,608.8 |
| 2020 | 10,019 | 30,362.7 | 1.3141029 | 0.276653 | 30,478 |
| 2025 | 13,504.3 | 40,924.9 | 1.7712387 | 0.372892 | 41,080.3 |
| 2030 | 18,441.7 | 55,887.8 | 2.4188334 | 0.509228 | 56,100 |
| 2035 | 22,704.7 | 68,806.8 | 2.9779732 | 0.626942 | 69,068.1 |
| 2040 | 24,777 | 75,087 | 3.2497783 | 0.684164 | 75,372.1 |

Determining directions for reducing the consumption of petroleum products and corresponding greenhouse gas emissions requires further additional research when forecasting the structure of consumption of petroleum products by individual species.

For forecasting petroleum products consumption by their types, it is necessary to analyze the consumption structure during the last years (Table 6).

**Table 6** Petroleum products consumption by their types in 2015–2020 [33–38]

| Petroleum product | 2015 [33] | 2016 [34] | 2017 [35] | 2018 [36] | 2019 [37] | 2020 [38] |
|---|---|---|---|---|---|---|
| Gasoline, thous. t | 2360.8 | 2229.4 | 1985.9 | 1767.2 | 1711.6 | 1767.7 |
| thous. toe*** | 2455.2 | 2318.6 | 2065.3 | 1837.9 | 1780.1 | 1838.4 |
| Fraction in end use—$\beta_1$ | 0.26 | 0.24 | 0.21 | 0.17 | 0.17 | 0.19 |
| Diesel fuel, thous. t | 4770.9 | 4968.6 | 5148.6 | 5366.1 | 5791.7 | 5173.9 |
| Thous. toe | 4866.3 | 5068.0 | 5251.6 | 5473.4 | 5907.5 | 5277.4 |
| Fraction in end use—$\beta_2$ | 0.51 | 0.53 | 0.52 | 0.52 | 0.56 | 0.54 |
| Heavy fuel oil, thous. t | 367.3 | 669.3 | 584.8 | 244.4 | 86.7 | 98.2 |
| Thous. toe | 374.6 | 682.7 | 596.5 | 249.3 | 88.4 | 100.2 |
| Fraction in end use—$\beta_3$ | 0.04 | 0.07 | 0.06 | 0.02 | 0.008 | 0.01 |
| Liquefied propane and butane, thous. t | 675.8 | 778.4 | 896.1 | 1014.1 | 1184.9 | 1384.1 |
| Thous. toe | 743.4 | 856.2 | 985.7 | 1115.5 | 1303.4 | 1522.5 |
| Fraction in end use—$\beta_4$ | 0.08 | 0.09 | 0.1 | 0.1 | 0.12 | 0.16 |
| Total petroleum products, thous. toe | 8439.6 | 8925.5 | 8899.1 | 8676.1 | 9079.4 | 8738.5 |
| Fraction in end use—$\Sigma\beta_j$ | 0.89 | 0.93 | 0.89 | 0.81 | 0.858 | 0.9 |
| End use* consumption of petroleum products according to Energy Balance—$\Sigma E_{kj}$ | 9455.0 | 9630.0 | 10,060.0 | 10,599.0 | 10,613.0 | 9695.0 |
| Fraction in end use **—$\alpha$ | 0.94 | – | – | – | – | 0.97 |

* End use does not include non-energy consumption, losses and consumption by energy sector for own

** Consumption is evaluated as the difference between resources (import + domestic production) and conversion to other fuel and energy types

*** Conversion factors from t to toe are as follows: gasoline—1.04, diesel and heavy oil—1.02, liquefied propane and butane—1.1 according to [39]

As can be seen from the Table 6, the final consumption of petroleum products, the sum of the consumption of the main types of petroleum products and their share of the final consumption are values that change slowly. Over 5 years, the final consumption of petroleum products increased by 2.5%. The amount of the main types of petroleum products increased during the same period by 3.5%, mainly due to the increase in the consumption of diesel fuel and propane-butane mixture. Most likely, such trends will persist for the next 5 years and stabilize by 2030. In the future, after the end of the war and post-war recovery, we can expect a decrease in diesel consumption and some growth of gas mixture and gasoline. Currently, it is difficult to predict the replacement of petroleum motor fuel with electricity, since the electric power system was destroyed during the war, and the term of its restoration can be up to 10 years.

It is possible to consider only forecast scenarios of the final consumption of the main types of petroleum products. At the same time, it should be noted that during the war, military equipment consumes diesel, and trucks, which are needed for post-war revival, mostly also consume diesel. Therefore, according to the basic scenario, it is assumed that until 2030 the volume of diesel consumption will be maintained at $\beta_2 = 0.55$, or even increase until 2025. After 2030, with the stabilization of the country's economy, the country's environmental policy will return to compliance with environmental requirements, i.e. a reduction consumption of heavy motor fuel—diesel to the volume of $\beta_2 = 0.44$ and stabilization of the final consumption of fuel oil $\beta 3 = 0.01$. The volume of gasoline may increase after 2030 to the volume of 2015: $\beta_1 = 0.25$. Propane-butane will also increase slightly to the fraction $\beta_4 = 0.2$.

Forecasted petroleum product consumption by country, except for formula (4), can be estimated as follows [40]:

$$E_{Ts}^{t} = \sum_{j} E_{kj}^{t} + E_{othj}^{t}, \tag{5}$$

where $\sum_j E^t_{kj}$—total final petroleum product consumption; $E^t_{othj}$—other petroleum product consumption, non-energy, own consumption and distribution losses.

Accordingly for forecasting petroleum products by fuel type, you the following dependence can be used:

$$\sum_{j} E_{kj}^{t} = \propto E_{Ts}^{t}, \tag{6}$$

where $\propto$—end use fraction from total consumption; according to energy balances $\propto = 0.94 \ldots 0.97$.

Therefore, the final consumption of the *j*th petroleum product will be determined by the dependence:

$$E_{kj}^{t} = \beta_j \sum_{j} E_{kj}^{t}, \tag{7}$$

where $\beta_j$—the fraction of the $j$-th petroleum product from the final consumption according to energy balances; $j = 1$—gasoline, $j = 2$—diesel, $j = 3$—heavy oil, $j = 4$—propane and butane mixture for road transportation. The calculated factors are given in Table 6.

The forecast of the main types of petroleum product consumption is given in Table 7.

The forecasted greenhouse gas emissions (GHG) up to were determined in accordance with the recommendations of the Intergovernmental Panel on Climate Change [41], the US Environmental Protection Agency [28], Directive 2009/28/EC [29] and the WRI/WBCSD manual [31]. The results of calculations of GHG emissions in thousand tons of $CO_2$ eq./year for the main types of petroleum products are shown at Figs. 2, 3, 4 and 5.

As can be seen from the Figs. 2, 3, 4 and 5, the largest emissions of greenhouse gases in thousand tons of $CO_2$-eq. provides diesel fuel, the emissions of which are almost twice as high as the emissions from gasoline consumption and greater than the total emissions from the consumption of gasoline and liquefied propane-butane together. To restore the war-damaged industry and infrastructure of Ukraine, diesel fuel will definitely be needed for transportation, but after the recovery of the economy, the volume of diesel fuel should be reduced and replaced by more environmentally friendly fuels.

**Table 7** The forecast of the main types of petroleum product consumption in 2030–2040

| Petroleum product type | 2030 | 2035 | 2040 |
|---|---|---|---|
| Gasoline, thous. t | 3268.1 | 4658.8 | 5777.3 |
| Thous. toe | 3398.8 | 4845.2 | 6008.4 |
| Fraction in end use—$\boldsymbol{\beta_1}$ | 0.19 | 0.22 | 0.25 |
| Diesel fuel, thous. t | 9470.3 | 10,579.9 | 10,367.5 |
| Thous. toe | 9659.7 | 10,791.5 | 10,574.8 |
| Fraction in end use—$\boldsymbol{\beta_2}$ | 0.54 | 0.49 | 0.44 |
| Heavy fuel oil, thous. t | 175.4 | 215.9 | 235.6 |
| Thous. toe | 178.9 | 220.2 | 240.3 |
| Fraction in end use—$\boldsymbol{\beta_3}$ | 0.01 | 0.01 | 0.01 |
| Liquefied propane and butane, thous. t | 2602.0 | 3603.8 | 4369.7 |
| Thous. toe | 2862.2 | 3964.2 | 4806.7 |
| Fraction in end use—$\boldsymbol{\beta_4}$ | 0.16 | 0.18 | 0.2 |
| Total petroleum products, thous. toe | 16,099.7 | 19,821.1 | 21,630.0 |
| Fraction in end use—$\boldsymbol{\Sigma\beta_j}$ | 0.9 | 0.9 | 0.9 |
| End use consumption of petroleum products according to Energy Balance, thous. toe—$\boldsymbol{\Sigma E_{kj}}$ | 17,888.5 | 22,023.5 | 24,033.7 |
| Fraction in end use from total—$\boldsymbol{\alpha}$ | 0.97 | 0.97 | 0.97 |

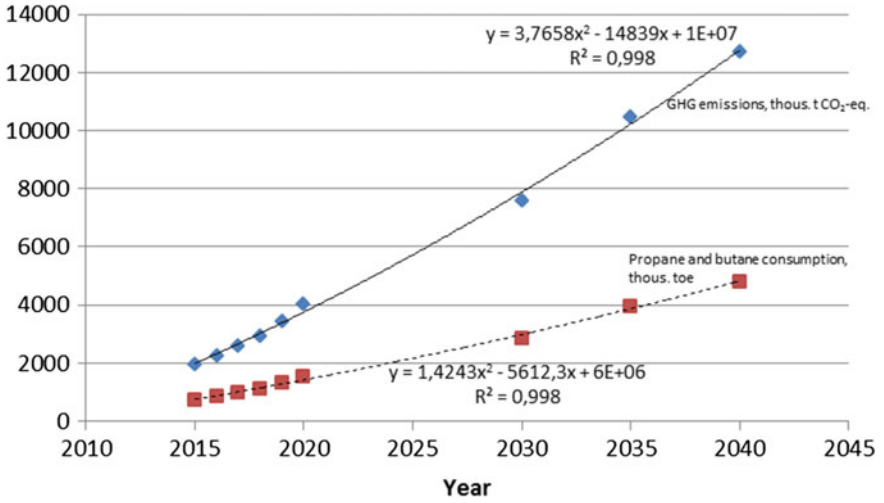


**Fig. 2** Propane and butane consumption as well as GHG emissions in 2015–2020 and forecast in 2030–2040

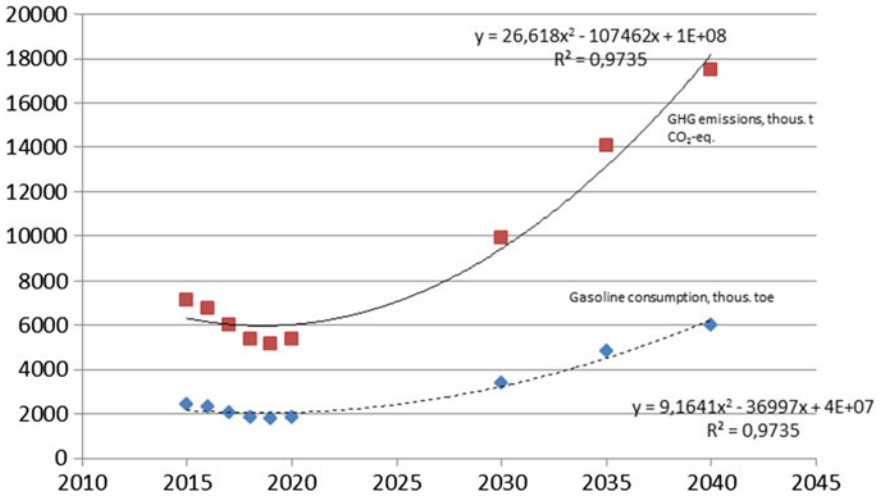


**Fig. 3** Gasoline consumption as well as GHG emissions in 2015–2020 and forecast in 2030–2040

## 4 Results

The Table 4 contains the results of the calculation of forecasted consumption of petroleum products until 2040 by consumer groups (country, types of economic activity), adjusted relative to the actual consumption of petroleum products in 2020 (according to the energy balance).

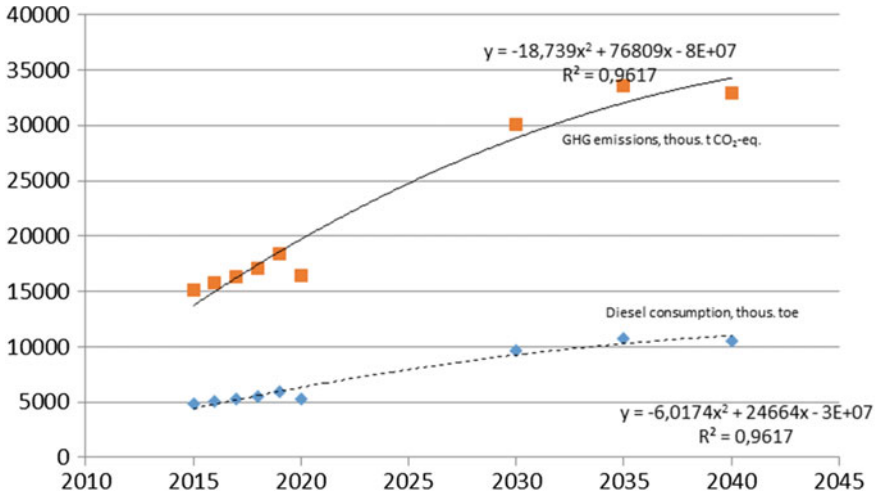


**Fig. 4** Diesel fuel consumption as well as GHG emissions in 2015–2020 and forecast in 2030–2040

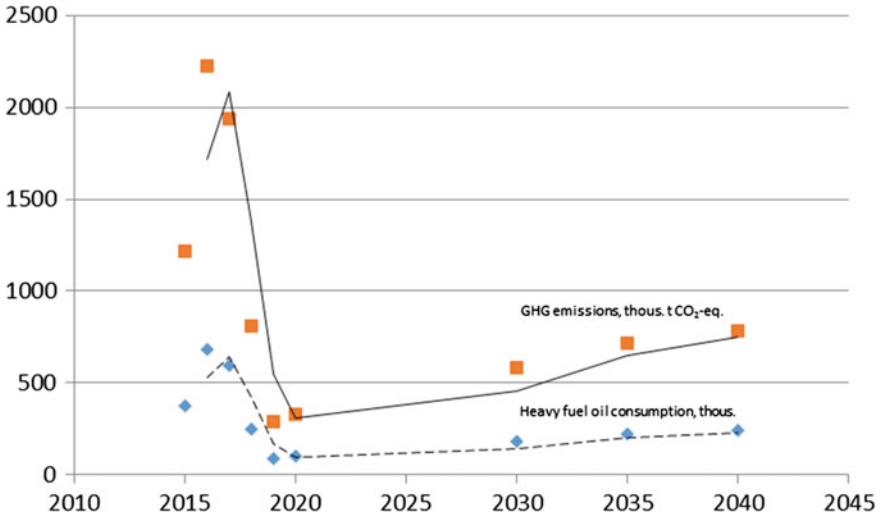


**Fig. 5** Heavy fuel oil consumption as well as GHG emissions in 2015–2020 and forecast in 2030–2040

The 2019–2020 was marked by the COVID pandemic, which led to a drop in macroeconomic indicators almost all over the world. In this regard, the Institute of General Energy of the National Academy of Sciences of Ukraine has adjusted macroeconomic indicators, presented in the publication [42] on the base of analysis of the forecasts of the world's leading financial institutions (the International Monetary Fund, the World Bank, etc.).

The peculiarity of the forecast presented in the article is an increase in the consumption of petroleum products in the future in the energy sector of Ukraine, since more than 30% of the energy infrastructure facilities in Ukraine have been destroyed as a result of military operations in Ukraine, and the government must have a reserve of the necessary fuel. These volumes were estimated according to petroleum products consumption trends in the transformation sector of the energy balances of Ukraine transformation sector for 2015–2020 (Table 3). Since the energy infrastructure is being destroyed by the aggressor every day, the forecasts of the structure of electricity and heat generating capacities [18] made earlier at the Institute of General Energy of the National Academy of Sciences of Ukraine are not applicable now. They should be revised after the end of the war.

In the sections of the economy, a moderate technological potential of energy saving is assumed, because in wartime it is impossible to invest money in the reconstruction of enterprises. Based on the results of the forecasted petroleum products consumption, the total emissions of greenhouse gases were determined (Table 5), which are adjusted with the increase in the consumption of petroleum products. A methodical approach to determining the forecast structure of consumption of petroleum products by types of petroleum fuel is presented, and the forecast structure of consumption of petroleum products by individual types is determined, taking into account trends in their consumption that have developed in the retrospective period. The task of replacing oil fuel with other low-carbon fuels and electricity to reduce greenhouse gas emissions, especially from the consumption of diesel fuel, which produces the largest amount of these emissions, is also relevant.

## 5 Conclusions

The forecasted demand for petroleum products at the TOP and DOWN levels were carried out using the normative method and taking into account a separate algorithm for forecasting the demand for petroleum products in the section “Supply of electricity, etc.”, in which the need for the conversion to other energy types is calculated according to the trend of consumption over the last five years. This is due to the impossibility of using the existing forecasts of structures of energy generating capacities as a result of military operations, damage and destruction of energy facilities. The forecasts obtained at the two levels have very close values with an error of about 1%, which can to some extent justify their reliability. Estimated overspending of oil products as a result of structural changes, which should ensure the development of key sectors of the economy: agriculture, industry, transport sector, will allow to restore the economy after the war and increase its energy efficiency. The forecasted greenhouse gas emissions are determined and the directions for their reduction are outlined.

## References


1. Howthe consumption of fuel products changed in Ukraine in 2014–2021. https://www.slovoidilo.ua/2021/05/13/infografika/ekonomika/yak-zminyuvalosya-spozhyvannya-palyvnyx-produktiv-ukrayini-2014-2021-rokax
2. Total supply of primary energy for 2007–2020. https://www.ukrstat.gov.ua/
3. Ukrainian export of petroleum products increased by 1.8 times in six months. https://www.slovoidilo.ua/2021/07/24/novyna/ekonomika/ukrayinskyj-eksport-naftoproduktiv-pivroku-zbilshyvsya-18-raza
4. Ukraine halved exports due to the war unleashed by Russia—Ministry of Economy. https://agropolit.com/news/23560-ukrayina-udvichi-skorotila-eksport-cherez-viynu-rozvyazanu-rosiyeyu-mineoknomiki
5. Salesvolumesofpetroleumproductsincreasedby12%in2021. https://ua-energy.org/uk/posts/obsiahy-prodazhu-naftoproduktiv-v-2021-rotsi-zrosly-na-12
6. Energy balance of Ukraine for 2020. https://www.ukrstat.gov.ua/
7. Maliarenko, O.Y., Maistrenko, N.Y., Stanytsina, V.V., Bohoslavska, O.Y.: An improved comprehensive method of forecasting energy consumption for the long term. Energy: Econ., Technol., Ecol. **3**, 53–61 (2019)
8. Kulyk, M.M.: Methods of coordinating predictive solutions. Probl. Gen. Energy **2**(37), 5–12 (2014)
9. Pyriashvili, B.Z., Voronchuk, M.M., Galinovsky, et al.: Simulation modeling in energy; under the editorship BM Danylyshyn (Kyiv: Naukova dumka) 303 p. (2008)
10. Rosen, V.P., Kramarenko, E.R., Chernyavskyi, A.V.: Fuel-energy balance as a tool for energy efficiency analysis. Metallurgical Heat Engineering: Collection of Scientific Works of the National Metallurgical Academy of Ukraine. In two books. Book one. Dnipropetrovsk: Porogy, pp. 387–392 (2005)
11. Kasyanova, N.V., Levshova, Yu.O.: Complex model of energy consumption assessment in the region. Sci. Bull. Donbas State Mach.-Build. Acad. **2**, 164–171 (2014)
12. Podolets, R.Z.: Energy modeling: foreign experience and future research directions in Ukraine. Econ. Forecast. **1**, 126–140 (2006)
13. Lear, V.E.: Energy balance as a basis for economic analysis and forecasting of the state's energy supply. Econ. Forecast. **1**, 91–102 (2000)
14. Nechaeva, T.P.: Model and structure of the long-term development of generating capacities of the electric power system taking into account the dynamics of input-output of capacities and changes in their technical and economic indicators. Probl. Gen. Energy **3**, 5–9 (2018). https://doi.org/10.15407/pge2018.03.005
15. Ch, L.I., Spitkovskyi, A.I.: Application of the Pyramid-V system for solving the problems of forecasting the development of the gas industry of Ukraine. Probl. Gen. Energy **1**, 25–31 (2010)
16. Bezugla, K., Kostyuchenko, N.: Global market of petroleum products: current state and perspectives of development. Visnyk Sumy State University. Econ. Ser. **3**, 27–39 (2020). https://visnyk.fem.sumdu.edu.ua/en/3-2020
17. Omelchenko, V.: The crisis state of the oil products market: reasons, conclusions, recommendations (2022). https://razumkov.org.ua/statti/kryzovyi-stan-rynku-naftoproduktiv-prychyny-vysnovky-rekomendatsii
18. Vashchenko, V.V.: Forecasting the development of the state reserve in the long-term period.—Dissertation for obtaining the scientific degree of candidate of economic sciences on the specialty 08.00.03 "Economics and management of the national economy". National University of Bioresources and Nature Management of Ukraine. Kyiv (2020)
19. Yaroschuk, L.D., Tyurina, E.O.: Modeling and management of adsorptive purification of oils and lubricants in the mode of changing raw materials. In: Bulletin of NTUU "KPI named after Ihor Sikorskyi". Chemical Engineering, Ecology and Resource Conservation, Issue no 3, pp. 56–68 (2022). https://doi.org/10.20535/2617-9741.3.2022.265361

20. Khomenko, A.S., Gomelya, M.D., Shablii, T.O.: Evaluation of the effectiveness of alkylimidazolines in reducing the corrosive aggressiveness of oil-containing waters. In: Bulletin of NTUU "KPI named after Ihor Sikorskyi". Chemical Engineering, Ecology and Resource Conservation, Issue no 2, pp. 60–71 (2022). https://doi.org/10.20535/2617-9741.2.2022.260350
21. Kulyk, M.M., Maliarenko, O.Y., Maistrenko, N.Y., Stanytsina, V.V., Kuts, H.O.: Energy Efficiency and Forecasting of Energy Consumption at Different Hierarchical Levels of the Economy: Methodology, Forecast Estimates until 2040 (Kyiv: Scientific Opinion) 234 p. (2021) ISBN 978-966-00-1739-9
22. Kulyk, M.M., Horbulin, V.P., Kyrylenko, O.V.: Conceptual approaches to the development of the energy industry of Ukraine (analytical materials) (Kyiv: General Institute of Energy of the National Academy of Sciences of Ukraine) 78 p. (2017)
23. Energy Strategy of Ukraine Until 2030, edition of 2013. http://www.energoatom.kiev.ua/ua/about/strategy_2030/
24. Shynkaruk, L.V., Baranovska, I.V., Bobukh, I.M., et al.: Structural transformations in the economy of Ukraine: dynamics, contradictions and impact on economic development scientific report; under the editorship L V Shinkaruk (Kyiv: Institute of Economics and Forecasting of the NAS of Ukraine) 304 p. (2015)
25. Skrypnychenko, M.I.: System of macro models in the program and analytical toolkit "Macroforecast of the economy of Ukraine". Economist **4**, 85–96 (2014)
26. Maliarenko, O.: Consumption forecast of petroleum products in ukraine by the main types of economic activity. Syst. Res. Energy **2**(71), 31–41 (2022). https://doi.org/10.15407/srenergy2022.02.031
27. Greenhouse Gas Inventory Guidance. Direct Emissions from Stationary Combustion Sources. U.S. EPA Center for Corporate Climate Leadership (2014). https://www.epa.gov/sites/default/files/2015-07/documents/emission-factors_2014.pdf
28. Greenhouse Gas Inventory Guidance. Direct Emissions from Stationary Combustion Sources. U.S. EPA Center for Corporate Climate Leadership. 21 p. (2020). https://www.epa.gov/sites/default/files/2020-12/documents/stationaryemissions.pdf
29. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC 2009 Off. J. Eur. Union L **140**, 16–61. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF
30. IEA.Emissionfactors2020DATABASEdocumentation43p.https://iea.blob.core.windows.net/assets/24422203-de22-4fe6-8d54-f51911addb8b/CO2KWH_Methodology.pdf
31. Michael Gillenwater 2005 Calculation tool for direct emissions from stationary combustion. WRI/WBCSD. GHG Protocol Stationary Combustion Guidance. 94 p. https://ghgprotocol.org/sites/default/files/Stationary_Combustion_Guidance_final_1.pdf
32. National strategy of approximation (approximation) of Ukrainian legislation to EU legislation in the field of environmental protection 2015 Kyiv 107 p. https://www.menr.gov.ua/docs/activity-adaptation/draft_NAS_FEB2015.pdf
33. Statistical Yearbook of Ukraine for 2015. Edited by Iryna M. Zhuk. State statistics service of Ukraine. Kyiv, 575 p. (2016). ISBN 978-966-8459-97-9. https://ukrstat.gov.ua/druk/publicat/Arhiv_u/01/Arch_zor_zb.htm
34. Statistical Yearbook of Ukraine for 2016. Edited by Ihor Yev. Verner. State statistics service of Ukraine. Kyiv, 611 p. (2017). ISBN 978-966-2224-90-0. https://ukrstat.gov.ua/druk/publicat/Arhiv_u/01/Arch
35. Statistical Yearbook of Ukraine for 2017. Edited by Ihor Yev. Verner. State statistics service of Ukraine. Kyiv, 541 p. (2018). ISBN 978-617-7551-15-6. https://ukrstat.gov.ua/druk/publicat/Arhiv_u/01/Arch_zor_zb.htm
36. Statistical Yearbook of Ukraine for 2018. Edited by Ihor Yev. Verner. State statistics service of Ukraine. Zhytomyr «Book-druk» LTD, 482 p. (2019). https://ukrstat.gov.ua/druk/publicat/Arhiv_u/01/Arch_zor_zb.htm
37. Statistical Yearbook of Ukraine for 2019 Edited by Ihor Yev. Verner. State statistics service of Ukraine. Kyiv, 465 p. (2020). ISBN 978-617-7551-24-8. https://ukrstat.gov.ua/druk/publicat/Arhiv_u/01/Arch_zor_zb.htm

38. Statistical Yearbook of Ukraine for 2020 Edited by Ihor Yev. Verner. State statistics service of Ukraine. Kyiv, 455 p. (2021). ISBN 978-617-7551-33-0. https://ukrstat.gov.ua/druk/publicat/Arhiv_u/01/Arch_zor_zb.htm
39. Oil fuel conversion coefficients from natural units to oil equivalent. https://uk.wikipedia.org/wiki/ton_ofoil_equivalent
40. Maliarenko, O.Y., Maistrenko, N.Y.: A methodical approach to forecasting the consumption of petroleum products by their main types. Energy Technol. Resour. Sav. **74**(1), 14–21 (2023). https://doi.org/10.33070/etars.1.2023.02
41. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2. Energy, 51 p. (2006). https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html
42. Maliarenko, O.Y., Maistrenko, N.Y., Horskyi, V.V.: Forecast of fuel and coal consumption in Ukraine until 2040 by a complex method of forecasting energy consumption. Probl. Gen. Energy **3**(66), 28–35 (2021). https://doi.org/10.15407/pge2021.03.028