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ORIGINAL ARTICLE

# Innovative energy policy to transform energy systems in Ukraine

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## Abstract

To enhance its national energy security, the government of Ukraine has adopted many energy polices since 1989. Unfortunately, most of these policies have proved to be unsuccessful. The country's energy supply is still highly dependent on fossil fuel imports. This paper provides a comprehensive review on Ukraine's challenges from economic, social, political, and environmental aspects that are related to energy and carbon emission policies. An empirical methodology is used to analyze the energy situation and project energy demand by 2050. A new roadmap of energy investments is made from 2035–2050 with an objective of decarbonizing the Ukrainian energy system by 2050. Such roadmap is in line with the global commitments to reducing greenhouse gas emissions by 45% over the next decade and to achieving net zero emissions by 2050. This article recommends 12 polices for the government ranging from stopping subsidy to fossil energy to accounting environment costs in fossil energy consumption, levying taxes on polluters, privatizing government–owned companies to adapt the Euopean Union (EU) energy systems, and terminating gas import from Russia. If these proposed energy policies are successfully implemented, the Ukrainian fossil fuel-based energy system will be transformed to a highly efficient energy system with zero-carbon emissions by 2050.

**Keywords** Energy independence policy · decarbonization technologies · Zero-carbon economy initiative

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## 1 Introduction

Ukraine continues to make the international headlines. The new administration of Ukraine provides opportunities to address the energy and climate change challenges; namely, Ukraine remains one of the least energy efficient countries and 24th largest emitter of greenhouse gasses globally.

Facing unprecedented energy and climate change challenges, Ukraine's energy policies are at a critical juncture. Compared with other European countries, independent Ukraine is still highly dependent on fossil energy and inefficient use of energy. In 2016, Ukraine's energy mix consisted of coal (28.7%), gas (27.4%), nuclear (25.1%), oil (3.7%), and renewables (4.4%) (SSSU 2018). As of 2017, Ukraine's energy intensity was 2.6 times as high as the average of OECD countries (SAEE 2018). High energy intensity has caused problems of high carbon intensity per capita and per unit of GDP output.

Greenhouse gas (GHG) emissions from fossil fuel combustion in Ukraine in 2017 amounted to 223.2 million tonnes of CO2eq, 65.8 % lower than in the base 1990 level, and 4.3 % lower than in 2016 (MENRU 2019) (see Fig. 1). According to the International Energy Agency (IEA 2018), global carbon emissions, however, driven by high energy demand, reached a historical high of 32.5 gigatonnes in 2017, rising for the first time since 2014. Based on the above data, in 2017, Ukraine contributed to 0.69% of total carbon emissions caused by fossil energy combustions.

Carbon emissions per capita in Ukraine are higher than the average of the world although the total carbon emissions of the country have been decreasing over the past few years. According to the World Bank (2019), in 2017, total population in Ukraine was 44.83 million, or 0.60% of the world's population (Table 1). The 0.6% of Ukrainians in the world emitted 0.69% of the world's total carbon emissions in 2017. The key factor causing higher carbon

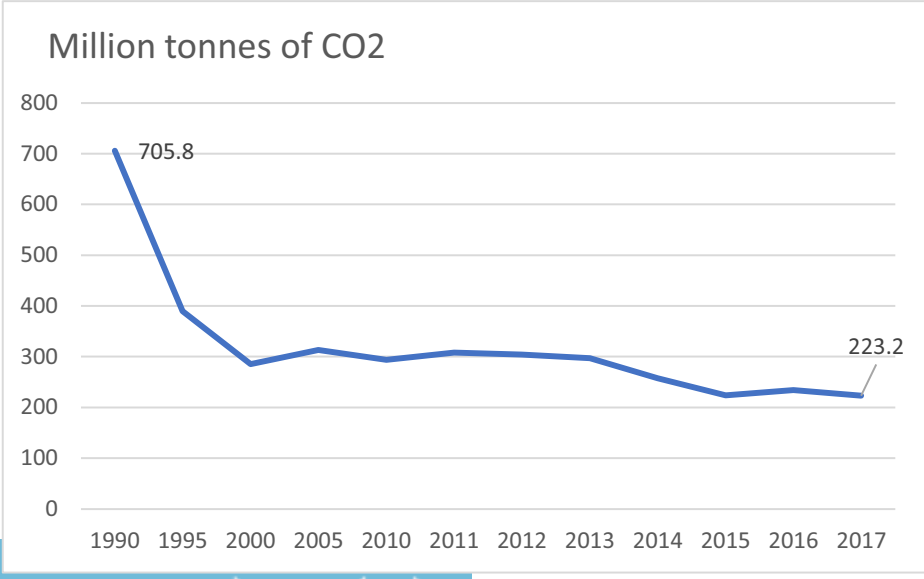


**Fig. 1** Carbon emissions from Ukraine (excluding from land use and land use changes)

**Table 1** Population of Ukraine in the World (million)

| | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Ukraine | 45.15 | 45 | 44.83 | 44.65 | 44.46 |
| World | 7358 | 7444 | 7530 | 7616 | 7702 |
| Share of Ukraine over world (%) | 0.61 | 0.60 | 0.60 | 0.59 | 0.58 |

Source: The World Bank (2019)

emissions per capita than the world is that the country depends on fossil energy supply and its energy system is not as efficient as the world's average.

If Ukraine keeps its business-as-usual scenario, it will likely continue to be heavily reliant on expensive fossil fuel imports, shortages of gas supplies, inefficient infrastructure, outdated building stocks and poor energy markets. However, if Ukraine embraces an innovative scenario, the country will likely undergo an energy revolution that will bring a range of benefits such as modernizing its energy sector with zero-carbon emission energy supply systems, reforming its energy markets, creating employment, and driving economic growth. The innovative scenario will require a swift transformational change in energy supply and demand, and zero-carbon emission policies.

The Climate Action Summit in New York, in September 2019, announced the commitment by 77 countries and more than 100 cities to reach net-zero carbon emissions by 2050 (IISD 2019). Germany and Slovakia were among those to join an alliance to halt the construction of coal plants. Companies and industry groups announced measures to reduce emissions from shipping, buildings, and more. For this reason, this paper will catalyze Eastern European countries to adapt new energy policies and proceed models of zero-carbon emission economies by 2050.

The authors of this paper used an empirical methodology to research and develop this paper. First, they comprehensively reviewed energy policies and strategies and analyzed how those policies and strategies impacted national economic development. Second, they collected the most recent economic, energy and environmental data. Third, they designed a unique analytic model for forecasting Ukraine's energy demand for the period of 2019–2050. Fourth, they developed an energy supply scenario to meet Ukraine's energy demand for the period of 2035–2050. The scenario uses the best and most economic zero-carbon emission technologies. Finally, they designed a road map that includes recommendations for innovative energy policies for the period of 2035–2050, for which the government does not yet have energy policies.

For energy demand, there is a huge potential for energy efficiency and energy savings, especially in the industrial and residential sectors. Ukraine's present energy policy framework insufficiently addresses this potential, leaving it largely untapped. By prioritizing energy efficiency policies from 2019 on, Ukraine could achieve a transformational change and will no longer have to rely on natural gas for space hearing in buildings. Doing so will require a framework and policies that progressively remove subsidies for gas consumption in households and district heating systems and attract private and public investments in energy efficient technologies to make energy efficiency as the first fuel in energy demand.

For energy supply, this paper estimates that by developing the country's bioenergy, solar, and wind energy potentials, and by maximizing the energy efficiency in power generation, Ukraine can eliminate its dependence on natural gas imports in the foreseeable future. The paper also estimates that the new policies and strategies will attract investors to the modernization of Ukraine's electricity and heat generation systems.

In short, this paper presents the results of a comprehensive review of economic development, energy supply, energy demand, GHG emissions, energy and climate policies, and energy technologies for Ukraine. With intensive literature reviews, in country collected data and an empirical methodology, the paper analyzes key policy issues and barriers that would otherwise prevent Ukraine from achieving a transformational change in energy systems from 2019 to 2050. The objective of this paper is to provide the national government of Ukraine with innovative policy recommendations. By implementing these policy recommendations, the government of Ukraine will be able to transform its existing fossil fuel-based energy system to a new zero-carbon emission energy system by 2050.

## 2 Conceptual framework of methodology of the study

Multiple research approaches have been used in the study, and they can be aligned into four steps: literature review, data collection, analyses, energy demand and supply road map design, and recommendations (see Fig. 2).

First, extensive literature was carried out in economic development, energy consumption and supply, energy development and investment policies, and climate change policies in Ukraine. The review results were used as input data for the analyses of the government energy and climate policies.

Then, analyses were undertaken for energy supply and demand for the period of 2019–2035 based on the existing national energy policy and strategies. The analyses derived the value of a quantitative indicator: elasticity of energy demand versus GDP, which was further used in energy demand forecasting for the period of 2035–2050. In addition, the analysis in the second step also covered energy balance showing how energy demand was met by the energy supply under multiple constraints from geographic politics, domestic resources, and the international energy market.

Afterwards, energy demand is projected by using economic growth rate that was preferred by the national government and the elasticity of energy demand growth versus GDP growth; road maps for the development of energy supply systems and energy resources from 2035–2050 were designed in this step. During the research on the road map, the authors visited many cities of Ukraine and interviewed several policy makers including the city mayor of Zhytomyr

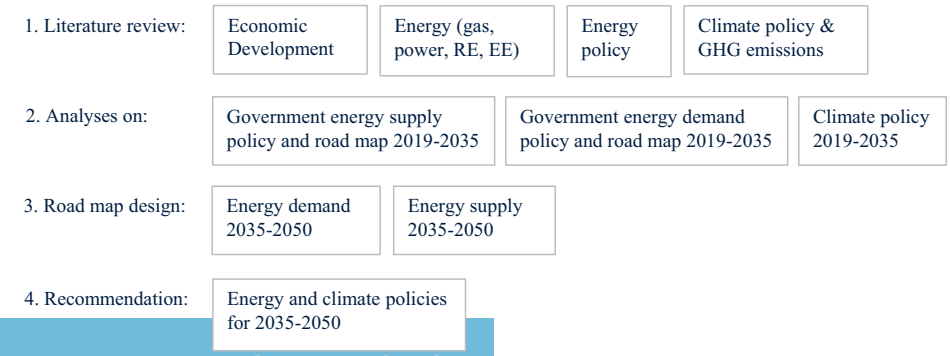


**Fig. 2** Conceptual framework of methodology

and the head of the State Agency on Energy Efficiency of Ukraine[1]. The outstanding components of the road maps included (1) a time-bound road map for energy demand and energy supply from 2035–2050, which was not available yet for Ukraine, and (2) an initiative of zero-carbon emission energy strategy in the whole energy system for the country by 2050.

Finally, energy and climate policies are recommended to the national and municipal governments for their actions to attract capital investments from the private sector in zero carbon emission technologies, and to achieve the long-term goals of national energy security and climate change mitigation.

## 3 Literature review

### 3.1 Review of the economy

Ukraine has a great potential to become a major European economy. Being one of the largest countries in Europe by land area, the country has fertile farmlands, a well-developed industrial base, highly trained labor, and a good education system. Over the past decades, Ukraine evolved from an agricultural to an industrialized and then to a service-oriented country. Major industries include coal, electric power, machinery, chemicals, food processing, woodworking and tourism.

Despite the pains, Ukraine has continued to make strides and progress in reforms, increasing its ranking in the Humanitarian Development Index from 90th to 88th place (out of 189 countries and territories), according to the 2018 Human Development Report. The Human Development Report's assessment of decent living standards reflected a 10 percent increase in the GNI per capita over 2015 levels (from $7375 to $8130 in 2018). Nevertheless, problems persist. Insufficient job creation keeps unemployment high, particularly in eastern Ukraine. This combined with job losses due to corporate downsizing and closings, weak economy, and labor-related migration has resulted in significant "brain drain" and damage to social capital. Young women and men with higher education are leaving to countries abroad in search of better opportunities. Moreover, foreign investment has been hampered, primarily in eastern Ukraine where the business environment is volatile and companies have pulled out.

Anti-corruption has been the core agenda of President Zelensky. There have been some breakthroughs in public procurement, new anti-corruption laws, the establishment of anti-corruption bodies, and the introduction of an electronic asset declaration register. These important strides in tackling graft slightly increased Ukraine's ranking in the Corruption Perceptions Index; however, there is still a lot of room for improvement. Corruption, which remains one of the core priorities in the country and of the President, lingers and hinders many of the reform efforts in Ukraine. Anti-corruption is recognized as one of the key remedies to the lack of foreign investment the country is experiencing.

Overall, the national economy of Ukraine is not in a good condition due to several factors. The first is the historic economic relationship with Russia. Ukraine's gross domestic product (GDP) fell sharply for 10 years following the collapse of the former Soviet Union in 1991. The economic recession of the early 1990s included hyperinflation and a fall in economic output to less than half of GDP levels before 1991. The economy began growing in 1992 and continued until 2000, largely due to low energy prices in the international market.

[1] Authors' interview with Mr. Sergiy Sukhomlyn and Mr. Sergiy Savchuk in November, 2018, in Ukraine.

The growth of Ukrainian GDP was hampered by the second major negative factor, the 2008 global financial crisis. Owing to its exposure to foreign markets, Ukraine's economy fell into a deep recession in 2009, with real GDP down by 15% and industrial output falling almost 22% (IMF 2010). With international capital inflow, including approximately US$14.4 billion in loans released by the IMF under the Stand-by Arrangement in mid-2010, Ukraine's real GDP recovered by 4.2% during 2010 and a further 5.2% in 2011 (IMF 2014).

The third set of factors, beginning in mid-2012, included insufficient capital investment, lower international steel demand, high energy import prices, lack of structural reforms, corruption, month-long street protests in Kyiv, and a change in government in March 2014. The GDP growth rate of the county fell to 0.0% in 2013 and contracted by 6.8% in 2014 and 9.9% in 2015. As a result, the national economy has never recovered from the 2009 crisis (IMF 2017).

The fourth factor was the loss of control of Crimea and the beginning of military conflict in the Ukraine's eastern region that resulted in casualties, significant infrastructure damage and considerable economic loss. This has provoked strong depreciation of the domestic currency, the hryvnia (UAH). The exchange rate fell from UAH8 to US$1 in December 2013 to UAH27 to US$1 in February 2017.

These four negative factors impacted the social and economic sectors, causing total natural gas consumption to drop from 100.45 billion cubic meters (bcm) in 1992 to 29.77 billion in 2017 (YCharts 2018). In 2016, the economy showed tentative signs of recovery; industrial production increased by 2.4% according to the State Statistical Service of Ukraine. The World Bank reported that Ukraine's economy grew by 2.5% in 2017. Growth in manufacturing, services and construction was robust, but weaknesses in the agriculture and mining sectors, combined with delays in key reforms to strengthen investor confidence, contributed to modest overall growth performance (World Bank 2018). In 2018, Ukraine became the poorest country in Europe with $2963 per capita GDP (IMF 2019). Table 2 shows the economic development data of Ukraine over the past 5 years. Ukraine's GDP growth is expected to be 2.7% in 2019 and 3.4% in 2020 (Ukraine Interface Agency 2018).

### 3.2 Review of energy and carbon emissions

Primarily due to economic recessions, final energy consumption in Ukraine decreased by 42% from 86 million tonnes of oil equivalent (Mtoe) in 2007 to 50 Mtoe in 2017 (Table 3 in thousand tonnes of oil equivalent of Ktoe). The industrial sector, residential, public services,

**Table 2** National profile data of Ukraine 2013–2017

| | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| Population (million) | 45.2 | 42.8 | 42.6 | 42.4 | 42.3 |
| GDP per capita (US$) | 3974 | 3058 | 2055 | 2175 | 2678 |
| GDP (US$ billion) | 180 | 131 | 87.5 | 92.3 | 112 |
| Economic growth (GDP, annual variation in %) | 0.0 | − 6.6 | − 9.8 | 2.4 | 2.5 |
| Unemployment rate | 7.2 | 9.3 | 9.1 | 9.4 | 9.5 |
| Public debt (% of GDP) | 39.9 | 69.4 | 79.1 | 80.9 | 71.8 |
| Inflation rate (CPI, annual variation in%, eop) | 0.5 | 24.9 | 43.3 | 12.4 | 13.7 |
| Exchange rate (US$/UAH) | 8.24 | 15.82 | 24.03 | 27.10 | 28.16 |
| External debt (% of GDP) | 79.0 | 96.4 | 136 | 124 | 103 |

Source: FocusEconomics (2018)

agriculture, forestry, and fishing are the major sectors in final energy consumption reduction. Energy consumption in the transportation sector was also significantly reduced from 15.4 Mtoe equivalent in 2007 to 9.77 Mtoe in 2017.

Total primary energy supply declined by 36% (from 139.3 Mtoe in 2007 to 89.6 Mtoe in 2017, including 28 Mtoe reduced domestic production) and 29.2 Mtoe of less imports. Fossil fuel reductions were significant with coal by 17.0 Mtoe (− 40%), oil by 11.6 Mtoe (− 78%), and natural gas by 30.0 Mtoe (− 56%). Conventional non-fossil energy was also reduced with nuclear energy by 2 Mtoe (− 7%) and large hydro by 0.1 Mtoe (− 12%).

Two kinds of energy (oil products and renewable energy), increased in supply. Oil products increased 32-fold, from 0.29 Mtoe in 2007 to 9.51 Mtoe in 2017. New renewable energy, with wind power and solar, increased 37 times (from 4 Ktoe in 2006 to 149 Ktoe) in 2017; biofuels and wastes increased 102% (from 1.58 Mtoe in 2006 to 3.05 Mtoe) in 2017. Table 4 presents detailed information on energy supplies in Ukraine from 2007 to 2017.

### 3.3 The natural gas sector

Natural gas supply and transit have dominated Ukraine's energy system over the past decade. Natural gas played a particularly prominent role in heat generation as of 2017. About 55% of the gas was consumed by district heating companies and by households with private heating systems, while only 3% was used for electricity generation. Natural gas supply attracted more public attention because it served marginal energy supply, and the supply was not controlled by the national government. Reducing natural gas consumption has become one of the top energy policy priorities in Ukraine as uncertain natural gas import endangers national energy security. As a result, in 2017, natural gas consumption was reduced by 56% from 2007.

### 3.4 The transport sector

Transportation, storage, mailing and delivery services comprised approximately 6.7% of GDP and 6% of the total employed population (MIU 2018). Many sectors of Ukrainian economy are highly dependent on the transport system, including agriculture, metallurgy, coal industry, mining and smelting, chemical and food industries, construction, retail trade, communications and postal services, and defense. On May 30, 2018, the Cabinet of Ministers of Ukraine approved "Drive Ukraine 2030—the National Transport Strategy—2030." The strategy is about Ukraine's transformation into a high-tech, low carbon and innovative country with modern transport infrastructure and new technologies. Under the "Drive Ukraine 2030," digital infrastructure, e-mobility, transport safety, self-driving cars, transport corridors, and transport infrastructure network unified with the European Union will be the major directions of development. Electrical vehicles with renewable energy supply will become the dominant fleet in road transport towards 2030 and beyond.

### 3.5 The power sector

Ukraine remains one of the largest electricity producers in Europe, even after an economic contraction caused by the conflict in the country's East. As of the end of 2016, the country's total installed capacity amounted to 59.18 gigawatts (GW). Fossil fuel–fired thermal power plants still constitute most of the total installed capacity (27.5 GW), followed by nuclear power plants (13.8 GW), hydro (6.2 GW), and renewables (1 GW). With the exceptions of hydro,

**Table 3** Total final energy consumption in Ukraine 2007–2017 (Ktoe)

| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017[a] | Growth 2007–2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | 32,852 | 30,942 | 22,629 | 25,327 | 26,253 | 24,845 | 21,864 | 20,570 | 16,409 | 14,955 | 15,103 | − 54% |
| Transport | 15,417 | 15,141 | 12,396 | 12,627 | 12,611 | 11,448 | 11,280 | 10,327 | 8750 | 9165 | 9768 | − 37% |
| Others* | 29,975 | 29,904 | 28,261 | 30,502 | 30,980 | 30,698 | 31,482 | 17,062 | 22,353 | 24,618 | 22,701 | − 24% |
| Non-energy use | 7712 | 7295 | 4269 | 5547 | 6008 | 6116 | 4932 | 3500 | 3318 | 2910 | 2515 | − 67% |
| Total | 85,956 | 83,282 | 67,555 | 74,003 | 75,852 | 73,107 | 69,558 | 51,459 | 50,830 | 51,648 | 50,087 | − 42% |

*Others include the following sectors: residential, communal and public services, agriculture, forestry, fishing

Source: SSSU (2017)

2014–2016 excluding temporarily occupied territories of Autonomous Republic of Crimea and Sebastopol and part of the anti-terrorist operation zone.

[a] Operative data

**Table 4** Energy supply mix in Ukraine 2007–2017

| | Unit | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017[a] | Growth 2007–2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy production | Ktoe | 84,998 | 84,260 | 79,339 | 78,712 | 85,485 | 85,247 | 85,914 | 76,928 | 61,614 | 66,323 | 58,851 | − 31% |
| Imports of energy | Ktoe | 64,975 | 65,263 | 48,506 | 51,260 | 58,055 | 46,520 | 39,722 | 34,437 | 31,575 | 29,152 | 35,261 | − 46% |
| Exports of energy | Ktoe | 7901 | 7984 | 7081 | 9278 | 10,303 | 8007 | 8213 | 6967 | 1447 | 1427 | 1944 | − 75% |
| International marine and aviation bunkers | Ktoe | 283 | 262 | 241 | 274 | 246 | 306 | 126 | 131 | 124 | 157 | 251 | − 11% |
| Stocks changes | Ktoe | − 2460 | − 6715 | − 6102 | 11,888 | − 6552 | − 966 | − 1356 | 1417 | − 1529 | 492 | − 2291 | − 7% |
| TPES (row 1 + row 2 − row 3 − row 4 + row 5) | Ktoe | 139,330 | 134,562 | 114,420 | 132,308 | 126,438 | 122,488 | 115,940 | 105,683 | 90,090 | 94,383 | 89,625 | − 36% |
| of which | | | | | | | | | | | | | |
| Coal and peat | Ktoe | 42,657 | 41,798 | 35,870 | 38,251 | 41,490 | 42,718 | 41,427 | 35,576 | 27,344 | 32,450 | 25,696 | − 40% |
| | % of total | 30.6% | 31.1% | 31.3% | 28.9% | 32.8% | 34.9% | 35.7% | 33.7% | 30.4% | 32.4% | 28.7% | |
| Crude oil | Ktoe | 14,926 | 11,166 | 11,384 | 11,497 | 9100 | 5050 | 3978 | 3043 | 2851 | 2806 | 3351 | − 78% |
| | % of total | 10.7% | 8.3% | 9.9% | 8.7% | 7.2% | 4.1% | 3.4% | 2.9% | 3.2% | 3.0% | 3.7% | |
| Oil products | Ktoe | 291 | 3202 | 2518 | 1682 | 3360 | 6559 | 5928 | 7645 | 7700 | 8387 | 9507 | 3167% |
| | % of total | 0.2% | 2.4% | 2.2% | 1.3% | 2.7% | 5.4% | 5.1% | 7.2% | 8.5% | 8.9% | 10.6% | |
| Natural gas | Ktoe | 55,586 | 52,805 | 40,789 | 55,229 | 46,841 | 43,018 | 39,444 | 33,412 | 26,055 | 25,603 | 24,554 | − 56% |
| | % of total | 39.9% | 39.2% | 35.6% | 41.7% | 37.0% | 35.1% | 34.0% | 31.6% | 28.9% | 27.1% | 27.4% | |
| Nuclear | Ktoe | 24,273 | 23,566 | 21,764 | 23,387 | 23,672 | 23,653 | 21,848 | 23,191 | 22,985 | 21,244 | 22,453 | − 7% |
| | % of total | 17.4% | 17.5% | 19.0% | 17.7% | 18.7% | 19.3% | 18.8% | 21.9% | 25.5% | 22.5% | 25.1% | |
| Hydro energy | Ktoe | 872 | 990 | 1026 | 1131 | 941 | 901 | 1187 | 729 | 464 | 660 | 769 | − 12% |
| | % of total | 0.6% | 0.7% | 0.9% | 0.9% | 0.7% | 0.7% | 1.0% | 0.7% | 0.5% | 0.7% | 0.9% | |
| Wind and solar energy etc. | Ktoe | 4 | 4 | 4 | 4 | 10 | 53 | 104 | 134 | 134 | 124 | 149 | 3625% |
| | % of total | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.1% | 0.1% | 0.1% | 0.2% | |
| Biofuels and wastes | Ktoe | 1508 | 1610 | 1433 | 1476 | 1563 | 1522 | 1875 | 1934 | 2102 | 2832 | 3046 | 102% |
| | % of total | 1.1% | 1.2% | 1.3% | 1.1% | 1.2% | 1.2% | 1.6% | 1.8% | 2.3% | 3.0% | 3.4% | |
| Electricity | Ktoe | − 789 | − 579 | − 367 | − 349 | − 541 | − 987 | − 851 | − 725 | − 116 | − 323 | − 445 | − 44% |
| | % of total | − 0.6% | − 0.4% | − 0.3% | − 0.3% | − 0.4% | − 0.8% | − 0.7% | − 0.7% | − 0.1% | − 0.3% | − 0.5% | |
| Heat energy | Ktoe | … | … | … | … | … | … | 1000 | 745 | 571 | 599 | 546 | − 45%[b] |
| | % of total | n/a | n/a | n/a | n/a | n/a | n/a | 0.9% | 0.7% | 0.6% | 0.6% | 0.6% | |

Source: SSSU (2018)

2014–2016 excluding temporarily occupied territories of Autonomous Republic of Crimea and Sebastopol and part of the anti-terrorist operation zone. TPES, Total Primary Energy Supply

[a] Operative data

[b] For the period of 2013–2016 only energy

solar, and wind power, many power plants use cogeneration technologies to produce both electricity and heat. Table 5 illustrates the distribution of power generation capacity amounts by different technologies.

Ukraine's electricity sector struggles with the challenges of supply security and operational security, pricing and the need for modernization. In the past, all nuclear fuel for power plants was supplied from TVEL, a Russian company. Currently, the country uses 56% of its nuclear fuel supplies from TVEL and 44% from Westinghouse, a US company. Ukraine aims to continue diversifying its nuclear fuel supplies, thereby making its fuel cycle and nuclear waste management less dependent on Russia. According to the national strategy of Ukraine, generation of nuclear power plants will remain at 22.5 Mtoe by 2035.

Another great challenge to sustainable and secured power generation is coal supply. The availability of A-grade coal (anthracite) which is used as a primary energy supply for power generation has been ruled out, since the start of the conflict in eastern Ukraine. Anthracite has historically been sourced from mines in the Donetsk and Luhansk provinces, which are currently controlled by separatist forces. Anthracite shipments from the east were increasingly obstructed by blockades and were fully suspended in mid-March 2017. Ukraine has been forced to import anthracite coal from abroad to make up for the loss of supply from the eastern provinces. This increased government costs and exacerbated energy insecurity. In the first half of 2017, 91% of Ukraine's 826,000 tons of imported anthracite came from Russia. In November 2017, the government of Ukraine announced its intent to have all Ukrainian thermal power plants operate without anthracite coal from 2019 and rely instead on lower-quality bituminous coal.

Nuclear power plants are running with very high utilization factor (or capacity factor) to meet base demand of the country. Combined heat and power plants (CHP) and thermal power plants generally have high utilization factors between 50–80%. But due to insecure primary energy supply, these power plants were significantly affected in operations in 2016. Low utilization factors for hydro, wind, and solar are due to seasonal character of the river runoff, daily variation of solar intensity and wind speed. Biomass is mostly used for heating, mostly during the heating season of the year. Nevertheless, new renewable power plants have high utilization factors only after nuclear power plants and large hydro power plants. This justifies the feasibility of new energy policy scenario that favors new renewables to replace imported natural gas and coal for power generation.

**Table 5** Installed capacity of generating power plants by type in 2017

| Type of generating facility | Capacity, MW | Capacity, Gcal/h | Annual generation in 2017, GWh | Utilization factor (for power generation only)[a], % |
|---|---|---|---|---|
| Thermal power plants | 27,489 | 5130 | 44,960 | 19 |
| Combined heat and power plants (CHP) | 10,569 | 32,331 | 10,881 | 12 |
| Nuclear power plants | 13,835 | 2596 | 85,576 | 71 |
| Hydro power plants | 6167 | - | 10,568 | 22 |
| Boiler houses | - | 229,367 | | |
| Utilization units | 39 | 6404 | 1531 | |
| New renewables including wind, solar, and biomass- and biogas-fired | 1077 | 1752 | 1898 | 20 |
| Total | 59,176 | 277,580 | 155,414 | |

Source: SSSU (2018)

[a] Ratio of an actual annual electricity output to the maximum possible output. Data in this column are calculated as generation (in GWh/yr)/[(Capacity (MW)/1000(GW/MW conversion factor)*8760(h/yr)]

Most power generation assets will reach the end of their lifetime during the next decade and will need to be decommissioned or upgraded. Almost all of Ukraine's power plants were deployed in the Soviet time, and around half of them are over 40-years old. Approximately 14 GW will be decommissioned by 2030 per the government plan of power sector development (see Table 6). From 2020 to 2035, the use of new renewable energy resources in the final energy supply will double and the share of total renewables in the gross final energy supply mix will increase from 11% in 2020 to 20.4% in 2035.

Electricity tariffs for households in Ukraine are regulated by the national government to benefit the poor and the rich. Per the data on electricity tariffs for consumers released by the government for the first half of 2018, a poor household with consumption less than 1000 kWh per year pays electricity at US$0.036/kWh, which is the cheapest tariff in the country. The number of these households amounted to 6,192,188 in 2018, representing more than 40% of total households. A rich household with consumption of 70,255 kWh per year pays electricity at US$0.041/kWh. Rich households comprise 0.45% of total household customers. Other households pay tariffs between US$0.042/kWh and US$0.047/kWh. Non-household customers pay their electricity bills at US$0.069/kWh to US$0.089/kWh, with cheaper prices applicable to those who consume more electricity. Table 7 shows more information on the tariffs of Ukraine. The National Commission for State Regulation in Energy and Utilities (NKREKP) which is responsible for pricing and tariff policy for energy and utilities established the differentiated tariffs for residential and non-residential consumers (Table 8).

### 3.6 Review of renewable energy

Renewable energy development will have the fastest growth rate in Ukraine's energy mix over the upcoming years. Renewable energy sources were accounted for around 6.4% of the total

**Table 6** Government planned energy balance by 2035

| Primary energy consumption (Mtoe) | 2013 | 2020 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|
| Coal | 41.4 | 37.69 | 38.37 | 37.27 | 33.78 |
| Natural gas | 39.5 | 37.33 | 33.57 | 33.2 | 34.17 |
| Oil | 9.85 | 13.97 | 14.86 | 15.74 | 16.48 |
| Nuclear power | 21.9 | 25.31 | 25.38 | 27.39 | 32.86 |
| Biomass, biofuel, and waste | 1.56 | 6.38 | 8.91 | 11.85 | 13.1 |
| Solar energy | 0.07 | 0.37 | 0.56 | 0.7 | 0.84 |
| Wind energy | 0.08 | 0.21 | 0.32 | 0.43 | 0.54 |
| Hydro power | 1.14 | 0.93 | 1.02 | 1.21 | 1.25 |
| Ambient power | 0.05 | 0.78 | 1.42 | 1.86 | 2.4 |
| Net export | | − 1.03 | − 1.29 | − 2.15 | − 2.58 |
| Energy efficiency as a fuel | | | | | |
| Total | 115.55 | 121.94 | 123.12 | 127.5 | 132.84 |
| Non-electric power consumption | 4.93 | 4.72 | 4.96 | 5.16 | 5.31 |
| Electric power consumption | 110.62 | 117.2 | 118.17 | 122.33 | 127.53 |
| Including renewable energy (REN) | 3.13 | 8.66 | 12.23 | 16.05 | 18.12 |
| GDP, US$ billion (ppp 2005) | 391 | 457 | 540 | 638 | 761 |
| Energy intensity (Ktoe/US$1000) | 0.33 | 0.27 | 0.23 | 0.2 | 0.17 |
| Final energy consumption | 69.56 | 78.89 | 80.84 | 85.13 | 88.91 |
| The share of renewables in the total final energy consumption | 4.5 | 11 | 15.1 | 18.9 | 20.4 |

Source: GOU (2014)

**Table 7** Electricity tariffs for consumers in the first half of 2018[1]

| | Number of consumers | Volume of delivered electricity[2], GWh | Average electricity tariff, without VAT[3], UAH/kWh | Average electricity tariff, with VAT[3], UAH/kWh | Average electricity tariff, with VAT, US$/kWh |
|---|---|---|---|---|---|
| Electricity supply to household consumers total | 15,283,623 | 14,958,480 | 1.01 | 1.21 | 0.044 |
| Including in bands with annual consumption, kWh | | | | | |
| < 1000 | 6,192,188 | 1,770,225 | 0.84 | 1.00 | 0.036 |
| ≥ 1000 < 2500 | 5,742,566 | 5,083,510 | 0.96 | 1.16 | 0.042 |
| ≥ 2500 < 5000 | 2,628,560 | 4,671,367 | 1.11 | 1.33 | 0.048 |
| ≥ 5000 < 15,000 | 650,054 | 2,467,557 | 1.08 | 1.29 | 0.047 |
| ≥ 15,000 | 70,255 | 965,822 | 0.95 | 1.14 | 0.041 |
| Electricity supply to non-household consumers total | 487,406 | 32,508,523 | 1.83 | 2.19 | 0.079 |
| Including in bands with annual consumption, MWh | | | | | |
| < 20 | 350,246 | 1,351,452 | 2.05 | 2.46 | 0.089 |
| ≥ 20 < 500 | 120,132 | 5,868,051 | 2.03 | 2.44 | 0.088 |
| ≥ 500 < 2000 | 9794 | 4,240,761 | 1.93 | 2.32 | 0.084 |
| ≥ 2000 < 20,000 | 5727 | 7,195,351 | 1.88 | 2.26 | 0.082 |
| ≥ 20,000 < 70,000 | 1008 | 3,289,020 | 1.75 | 2.10 | 0.076 |
| ≥ 70,000 < 150,000 | 229 | 1,951,429 | 1.72 | 2.06 | 0.074 |
| ≥ 150,000 | 270 | 8,612,459 | 1.60 | 1.92 | 0.069 |

[1] Data exclude the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol, and the part of temporarily occupied territories in the Donetsk and Luhansk regions

[2] Data exclude volumes of electricity produced and consumed by electric power plants and CHP

[3] Data for households are given including transmission and distribution costs and trade margin; for non-household consumers—including transmission and distribution costs

electricity generation mix, or 4.5% of the total primary energy supply in 2017. The country has made policy efforts to ensure that by 2020 the share of renewable energy in overall energy consumption mix will reach 11%, with a marginal growth of 7.5%.[2] These policy efforts include both green tariffs and tax incentives.

In 2015, the government of Ukraine started legal reforms in the power sector and introduced feed-in tariff or green tariff regulations. Due to the green tariffs policy, many new renewable energy projects were commissioned from 2016 to 2018, using wind, solar, and biomass energy technologies. Most of these projects were invested directly by foreign firms.

Fig. 3 illustrates the growth of new renewable power generation between 2014 and 2017. From 2014 to 2015, the growth was only 3%. From 2015 to 2016, and from 2016 to 2017, this figure reached to 12% and 23%, respectively. In 2018, total capacity increased by 54% over 2017 and reached 2117 MW, including 1389 MW solar power plants.[3]

Source: SAEE (2018)

[2] This target, 11 % share of renewable energy sources in total final consumption (or 8 % in total primary energy supply) by 2020, is different from another target: 11 % share of renewable energy sources in total primary energy supply by 2035

[3] https://www.fryday.net/blog/post/ukraines-installed-renewable-energy-capacity-jumped-by-54-%-2018-hitting-2117-mw-ukraine-renew/

**Table 8** Feed-in tariff for different types of renewable energy sources (US$/kWh)

| Type | Capacity, kW | Commission date | | | | |
|---|---|---|---|---|---|---|
| | | 01.07–31.12.2015 | 2016 | 2017–2019 | 2020–2024 | 2025–2029 |
| Ground-mounted solar power plant | | 0.1881 | 0.1771 | 0.1775 | 0.1598 | 0.1419 |
| Rooftop solar power plant | | 0.2001 | 0.1908 | 0.1934 | 0.1743 | 0.1547 |
| Wind turbine | < 600 | 0.0646 | 0.0644 | 0.0688 | 0.0611 | 0.0534 |
| | 600–2000 | 0.0753 | 0.0752 | 0.0802 | 0.0713 | 0.0624 |
| | > 2000 | 0.1129 | 0.1127 | 0.1203 | 0.1069 | 0.0936 |
| Biomass | | 0.1374 | 0.1372 | 0.1464 | 0.1318 | 0.1171 |
| Biogas | | 0.1374 | 0.1372 | 0.1464 | 0.1318 | 0.1171 |
| Hydro plant | < 200 | 0.1935 | 0.1932 | 0.2062 | 0.1858 | 0.1648 |
| | 200–1000 | 0.1547 | 0.1545 | 0.1648 | 0.1483 | 0.1318 |
| | 1000–10,000 | 0.1159 | 0.1157 | 0.1235 | 0.1113 | 0.0987 |
| Geothermal energy | | 0.1666 | 0.1663 | 0.1775 | 0.1598 | 0.1419 |
| Solar power for private household | < 30 | 0.2222 | 0.2105 | 0.2138 | 0.1921 | 0.1712 |
| Wind turbine for private household | < 30 | 0.1290 | 0.1288 | 0.1374 | 0.1235 | 0.1101 |

Source: DLF (2018)

Tax benefit policy is another instrument to incentivize investments in renewables. Although amendments to the tax code of Ukraine in 2014 canceled many tax privileges for producers of electricity from alternative energy sources, some tax benefits are still available for renewable energy producers. These include exemption of import and export duties for renewable energy and energy efficient equipment, and materials for production of alternative fuels or electricity from renewable energy sources. Unfortunately, this tax benefit policy could not be implemented, because of the Cabinet of Ministers of Ukraine failed to approve the list of such clean energy equipment and materials with specification of codes under the Ukrainian classification of foreign economic activity products. Four years later, the government of Ukraine debated another policy to facilitate renewable energy investments.

On 20 December 2018, the Ukrainian parliament approved a draft law:"*On Introduction of Certain Changes to Laws of Ukraine regarding Ensuring Competitive Conditions for Generation of Electricity from Alternative Energy Sources*." If adopted, the law will have substantial positive impacts on the renewable energy market in Ukraine.[4] The draft law calls for establishment and implementation of a quota auction system for the country. The auctioning system will be in operation from January 1, 2020. Under the system, private investors will bid for renewable power development with their technologies, capacities, and expected tariffs once the government is calling for auctions. Successful bidders will be granted with a quota of renewable energy production in a fixed timeframe. The government will guarantee the purchase of the renewable energy generated from the bidders at agreed tariffs. Per the draft law, by 2020, it is mandatory to go through an auction process before giving a contract to a private investor if the project capacity is above 20 MW for wind power technologies by 2020, or above 10 MW for other renewable energy technologies by 2022. The draft law also supports the feed-in tariff policy for already commissioned projects to last until January 1, 2030.

[4] http://www.usubc.org/site/recent-news/ukraine%2D%2Ddraft-law-proposing-the-new-renewables-generation-support-scheme-approved-in-the-first-reading-by-ukrainian-parliament

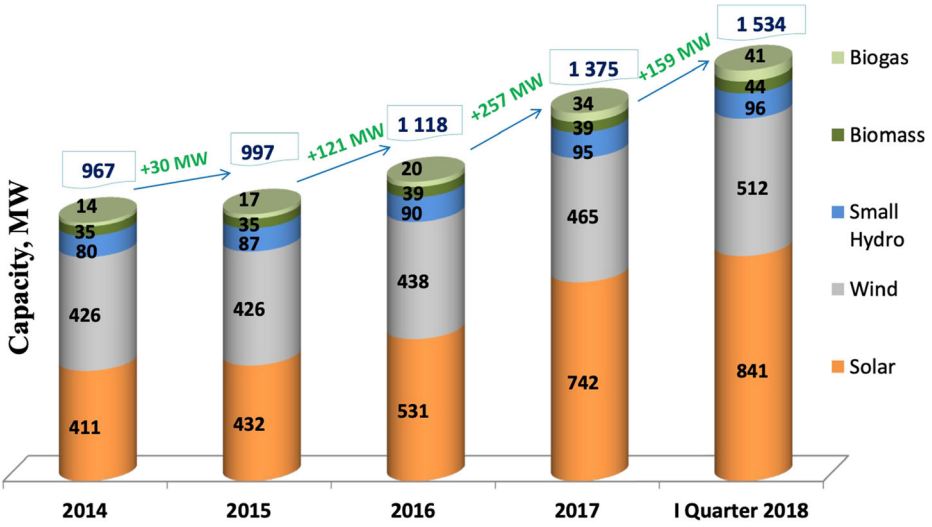


**Fig. 3** Installed capacity of renewable energy capacities under the feed-in tariffs

While undertaking the literature review, the authors discovered the following main challenges for renewable energy development and investment:

1) Lack of secondary legislations at state and city levels for implementing nationally adopted strategies and action plans;
2) Unclear financial incentives for investments in renewable energy sources, including access to loan financing at reasonable terms and conditions, which causes high interest rates (above 20%) in the loans;
3) Shortage of local capacities to develop, implement, and operate bankable renewable energy projects;
4) Lack of power storages in the national power grid. According to Ukrenergo, the Ukrainian national power company, the power grid of the country can only accept up to 3.5 GW of solar and wind power generation capacity. Battery storage or electrical vehicle technologies must be developed and invested together with additional massive investments of solar and wind power plants.

### 3.7 Review of energy efficiency in buildings

Being the most energy intensive, buildings consume a very large share of final energy in Ukraine. In 2017, residential buildings used 16.4 Mtoe, or 33% of the total final energy in Ukraine (50.1 Mtoe). By the end of 2018, there were a total of 6,680,000 buildings in Ukraine; most of them private-owned houses. Public buildings and multi-apartment residential buildings only counted for 80,000 and 100,000, respectively. Energy saving potentials are mainly in private-owned houses and multi-apartment buildings. Table 9 shows the statistics of buildings and energy consumption of the buildings in 2018.

Two innovative mechanisms accelerated energy efficiency for buildings in Ukraine. The first was the government-supported "warm loan program" that has been implemented in

**Table 9** Energy saving potentials in Ukrainian buildings

| Type of buildings | Number of buildings | Investments needed, US$ billion | Annual saving potential, million $m^3$ of natural gas equivalent |
|---|---|---|---|
| Multi-apartment residential buildings | ≈ 80,000 | from 50 to 85* | 8000 |
| Private (individual) | ≈ 6.5 million | | |
| Public buildings | ≈ 100,000 | from 4 to 8* | 800 |

*Depending on the thermal modernization level

Source: SAEE (2018)

Ukraine since 2014. The program subsidizes 35% of investment costs for individual households and 40% for multi-apartment residents if they invest in energy efficiency for their properties. About US$82 million have been reimbursed from the national budget since October 2018. The Cabinet of Ministers decided to allocate an additional US$3.57 million for the warm loans program.

The second mechanism was to introduce energy efficiency retrofits for buildings by Energy Service Companies (ESCOs) under the Energy Performance Contracts (EPCs) in 2016. Currently, EPCs are applicable for public buildings only; additional incentives are needed for ESCOs to retrofit residential buildings. In 2016, the first 20 EPCs were concluded in five regions of Ukraine. From 2017 to 2018, more than 350 tender procedures have been started; about 200 EPCs have been signed.

While undertaking broad literature review, the authors discovered the following main challenges for energy efficiency investment in buildings:

1) Lack of secondary legislation at the state and city levels for implementing energy efficiency policies and strategies;
2) Lack of financial incentives for investments in energy efficiency retrofits by ESCOs, including access to loan financing at reasonable terms and conditions. At present, the problem is not only in high interest rates in the loans, but also in high risks related to currency exchange rate variations. Unlike green tariffs for renewable energy sources which are linked to the US dollar, EPCs are in the local currency. Even if the loan is in EUR/US$ at a reasonable rate, ESCOs have to convert UAHs into Euros or US dollars at unstable and unpredictable exchange rates;
3) Uncorrected baseline scenario for EPCs. Currently, many residential buildings might be under-heated due to lack of financial resources. With this baseline, energy savings from either better energy performance or improved energy management might be used to increase heat-use to meet basic heating standards. In this case, the actual energy savings calculated as a difference of energy consumption before and after the retrofit might not be enough to cover the capital investment and operation costs. To mitigate these risks, ESCOs prefer retrofit buildings that can save significant amount of energy and require modest capital investment. In such cases, not all potential energy savings can be achieved. To resolve this issue, a new methodology for baseline energy consumption calculation must be developed and adopted for feasibility studies of energy efficiency projects;
4) Lack of local capacities to develop, implement, and operate bankable energy efficiency projects.

### 3.8 Review of energy policy and strategies

Ukraine elaborated its main energy policy priorities in four sets of strategic documents in 2006, 2013, and 2017. These priorities were different with focuses and targets. Practice showed that the designed targets were not always achievable and the determined policy measures and economic and financial incentives were not adequate.

The first energy strategy of Ukraine, adopted in March 2006, focused on intensive development of the national nuclear energy sector from 2007 to 2030. The main argument was the "alternativeness" of nuclear power to fossil fuel technologies and thus the potential for strengthening the country's energy independence. However, crucial problems, such as the environmental safety of reprocessing and storing nuclear fuel and radioactive wastes, have not been addressed adequately. As such, the policy did not have any significant impact on mainstreaming nuclear energy development.

The second energy strategy of Ukraine, approved in July 2013, focused on two goals. The first was to develop domestic coal for electrical power generation. However, due to the public concern over high GHG emissions from coal and political uncertainty (most of the coal mines are in the temporarily uncontrolled territories), the first goal of the 2013 energy strategy turned out to be unachievable. The second goal was to increase the use of renewable energy and alternative fuels and to improve energy efficiency. It was understood that conserving traditional energy and mitigating environmental impacts could be achieved only through the investment and development of renewable energy and energy efficiency. As a result, the National Renewable Energy Action Plan was adopted in 2014, and the National Energy Efficiency Action Plan until 2020 was also adopted by the national government in 2015. Several quantitative renewable energy and energy efficiency targets were designed in these two action plans.

The planned renewable energy targets by 2020 include the following:

1) 11% of renewable energy in gross final energy consumption;
2) 12% of renewable energy in total energy demand for heating and cooling;
3) 11% of electricity to be generated from renewable energy sources; and
4) 10% of energy demand in transport to be met by renewable energy.

Planned energy efficiency targets by 2020 include the following:

1) 9% of energy savings to be achieved from the average final energy consumption between 2005 and 2009; and
2) 44% of gas consumption to be saved from 18 billion in 2017 to 10 billion cubic meters in the residential sector (Zubko 2018).

In 2017, the government adopted the third National Energy Strategy "The Energy Security Strengthening Plan (ESSP) for Ukraine until 2020." The document included overviews of the energy supply situation, energy security provisions, and the national policy implementation system. With the objective of strengthening the country's energy security, the document presents steps and efforts to be undertaken along with the dynamic international energy market development and fundamental domestic energy supply-side management principles.

The fourth important Ukrainian national energy document is the Energy Strategy of Ukraine (ESU) until 2035, adopted by the Cabinet of Ministers of Ukraine on August 18, 2017. The ESU determines the main energy policy goals and tasks, sets out measures for Ukraine's energy

security, and outlines major directions, priorities, and the future development of the country's energy sector. The main goals declared in the ESU include liberalizing markets, establishing effective regulation, and attracting investors to the energy sector. The important measures to mitigate GHGs include the promotion of both renewable energy and energy efficiency.

The ESU is to be implemented in three stages: finalizing energy sector reform by 2020; optimizing/developing an innovative infrastructure by 2025; and ensuring the long-term sustainable development of the energy sector. Detailed targets of the ESU for the period of 2018–2035 include:

- Reducing GDP energy intensity by 2035 to the level of 0.17 kg of oil equivalent per US dollars of GDP (at PPP) or 0.17 kgoe/US$;
- Optimizing the structure of the country's energy balance and increasing the share of renewable energy in primary energy supply to 25%;
- Capping energy imports from any single country or any company, by 2020, not exceeding 30% of total national primary energy imports;
- Capping energy imports from any single country, by 2035, not exceeding 30% of total consumption of all types of energy; and
- Integrating Ukrainian and European electricity and gas markets and making sure at least 15% of Ukraine's domestic energy market volume is integrated to the European energy market by 2025.

### 3.9 Review of carbon emissions

Ukraine is one of the most carbon-intensive countries in Europe, with carbon intensity (carbon emissions per unit of GDP) as 2.6 times as the average level of OECD member countries. The absolute amount of Ukraine's GHG emissions fluctuated around 430 MtCO2 per year between 2000 and 2013. A substantial dip in emissions occurred in 2014–2015. Fig. 1 follows the trend of the economic development in Ukraine in the same period. The substantial dip in emissions since the 2010 was attributable to the ongoing economic recession experienced in the country, with GDP declining by 30% between 2010 and 2015. The country's inventory data on GHG emissions to the UNFCCC report in 2015 was about 300 MtCO2, approximately 27% lower than the 2000 level. As Ukraine's economy recovers, restoration and growth of industrial output under the business-as-usual scenario are projected to drive up GHG emissions in the energy and industrial sectors to around 50% of the 1990 baseline level by 2030.[5] Adding emissions from other sectors will leave little room for the country to meet the goal expressed in Ukraine's Nationally Determined Contribution of staying below 60% of 1990 levels. Given this situation, the government of Ukraine should address key factors that drive high fossil fuel consumption and high carbon emissions in its long-term energy planning and climate policy development.

## 4 Energy demand and forecasting with the existing energy strategies for 2019–2035

In 2014, the government of Ukraine published its long-term energy policy up to 2035 (GOU 2014). The policy book illustrated an energy road map for Ukraine to move

[5] Ukraine 2050 Low Emission Development Strategy

towards clean energy development. By 2035, Ukraine's electricity will be provided from different primary energy resources including 50% from nuclear power, 25% from new renewable sources, 13% from large hydropower, and 12% from coal and gas power stations. The ultimate goals of the policy are to (1) meet energy demand in both normal and emergency conditions; (2) ensure the technically reliable and safe operation of the power supply system; (3) ensure high efficiency in energy use for the national economy; (4) find an environmentally sound solution to the environmental and climate impact of the energy sector; and (5) ensure national energy security under any potential internal and external threats. The quantitative and qualitative targets of the policy are to (1) reduce GDP energy intensity by 2035 to the level of 0.17 kgoe per US$1 of Ukrainian GDP (PPP), which is close to that of countries with similar climatic, geographic, and economic conditions; (2) optimize the structure of the country's energy balance based on energy security requirements and to renewable energy development requirement (20%); (3) achieve by 2020 the level of dependence on energy supplies from a single country (company) not exceeding 30% of total imports; (4) achieve by 2035 the level of dependence on supplies from a single country not exceeding 30% of the total consumption of all types of energy; (4) ensure by 2025 the technical integration of Ukrainian and European electricity and gas markets amounting to at least 15% of Ukraine's domestic market volume; (6) form by 2035 a system of guaranteed power supplies to meet the total electricity demand of the country during an emergency period equivalent to 90 days of consumption; and (7) launch renewable energy investment auctions in January 2020. It will take place twice in April and October each year until 2029. The auctions will be mandatory for wind power plants with total capacity exceeding 20 MW and for solar power plants with total capacity more than 10 MW. The auctions will be optional for power plants with smaller installed capacities, which can opt for either the feed-in tariff or auctions. Auction winners will be awarded 20-year power purchase agreements with a guaranteed buyer and will be required to complete their projects over a period of 3 years. For other types of renewable energy technologies, auctions are not mandatory.

## 5 Energy road map towards clean energy

### 5.1 Energy demand projection and energy supply analysis for 2035–2050

Based on the government planned energy balance from 2020 to 2035 (Table 6), the authors projected total primary energy demand of Ukraine from 2035 to 2050. The government data show that the growth rates of primary energy demand from 2020 to 2025 and from 2025 to 2030 are all 4% in each of the two periods. The authors used the same growth rate to project primary energy demand for each of the three periods of 2035–2040, 2040–2045, and 2045–2050. By 2050, Ukraine will need approximately 150 million tonnes of oil equivalent primary energy. The last row in Table 10 presents the calculated results.

### 5.2 Energy supply map with security and zero carbon emission scenario

Table 10 also maps the energy supply roads for Ukraine. The following scenario assumptions were made for the mapping based on the intensive literature review and best knowledge of the authors:

**Table 10** Primary energy demand and supply analysis 2035–2050

| Primary energy consumption (M toe) | 2013 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Coal | 41.4 | 37.69 | 38.37 | 37.27 | 33.78 | 22.52 | 11.26 | 0.00 |
| Natural gas | 39.5 | 37.33 | 33.57 | 33.2 | 34.17 | 22.78 | 11.39 | 0.00 |
| Oil | 9.85 | 13.97 | 14.86 | 15.74 | 16.48 | 10.99 | 5.49 | 0.00 |
| Nuclear power | 21.9 | 25.31 | 25.38 | 27.39 | 32.86 | 27.39 | 25.38 | 25.31 |
| Biomass, biofuel, and waste | 1.56 | 6.38 | 8.91 | 11.85 | 13.1 | 23.58 | 42.44 | 76.399 |
| Solar energy | 0.07 | 0.37 | 0.56 | 0.7 | 0.84 | 1.68 | 3.36 | 6.72 |
| Wind energy | 0.08 | 0.21 | 0.32 | 0.43 | 0.54 | 0.972 | 1.75 | 3.1493 |
| Hydro power | 1.14 | 0.93 | 1.02 | 1.21 | 1.25 | 1.25 | 1.25 | 1.25 |
| Ambient power | 0.05 | 0.78 | 1.42 | 1.86 | 2.4 | 3.10 | 4.00 | 5.16 |
| Net export | | − 1.03 | − 1.29 | − 2.15 | − 2.58 | − 1.72 | − 0.86 | 0.00 |
| Energy efficiency as a fuel | | | | | | 25.86 | 38.74 | 32.26 |
| Total | 115.55 | 121.94 | 123.12 | 127.5 | 132.84 | 138.40 | 144.20 | 150.24 |

1. Supply of fossil energy sources including coal, oil, and gas will all be linearly diminishing from the government-projected amounts in 2030 to zero in 2050.
2. Energy supply from nuclear power/heat plants will reach peak in 2035, namely 32.86 Mtoe. Then, it will be decreasing from 2035–2040 to the level of 2030, from 2040–2045 to the level of 2025, and from 2045–2050 to the level of 2020.
3. Biomass energy and wind energy will grow at a rate of 80% in each of the three periods of 2035–2040, 2040–2045, and 2045–2050.
4. Solar energy will increase at a rate of 100% in each of the three periods of 2035–2040, 2040–2045, and 2045–2050.
5. Hydropower plants will be fully harnessed by 2035 and will continue to provide full capacity from 2035–2050.
6. In the whole period of 2035–2050, ambient power will steadily increase at the rate which the Ukrainian government projected for the period of 2030–2035.
7. The net amount of energy export will change from negative 2.58 Mtoe in 2025 to zero in 2050. With that, Ukraine will become 100% independent in energy supply.
8. Energy efficiency as the first fuel in primary energy supply will offset 19% of primary energy supply in the period of 2035–2040, 27% in 2040–2045, and 21% in 2045–2050.

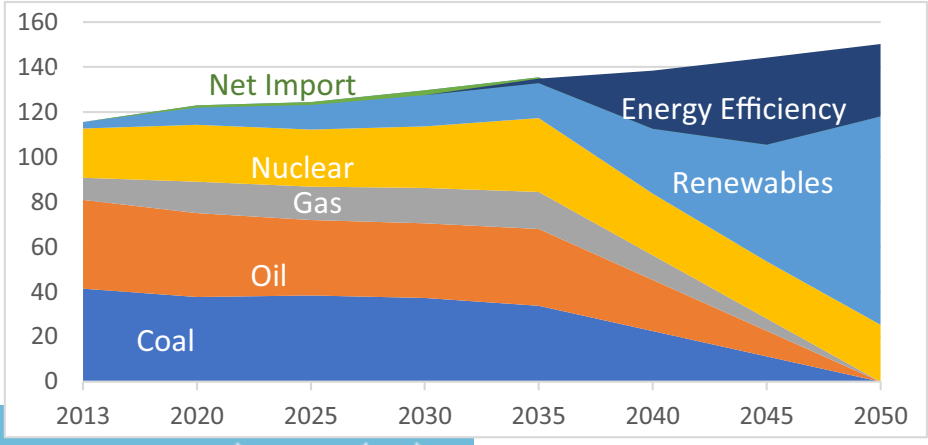


**Fig. 4** Energy supply map of Ukraine 2035–2050 (Mtoe)

Figure 4 shows the historical energy supply data of Ukraine from 2013 to 2019, the government projected supply energy mix from 2019 to 2035, and the authors projected scenario from 2035 to 2050. In the chart, renewables, which include solar, hydro, wind, biomass, biofuel, waste to energy, and ambient power, will steadily grow from 2019 to 2035 as the government projected. They will scale up at an increasing rate of approximately 100% per year from 2035 to 2045. Renewable energy will be dominant in marginal energy growth to substitute fossil fuels from 2045 to 2050. Energy efficiency as the first fuel starting in 2030 will play a more and more important role in transforming the country's energy system from 2030 to 2045. The mapped energy supply path will enhance Ukraine's energy security, increase energy efficiency and renewable energy, and catalyse Ukraine's economic development.

## 6 Conclusions and policy recommendations

Ukraine, similarly to other former Union of Soviet Socialist Republics (USSR) countries in Eastern Europe and Central Asia (e.g., Belarus and Kazakhstan), faces energy security and carbon emission challenges. The study results, methods, conclusions, and recommendations can be widely applicable to other countries in the region and around the world. The country remains behind the EU and other OECD countries in improving energy efficiency.

The energy challenges in Ukraine are compounded by many other ongoing challenges. Over the past few decades, Ukraine's economy has undergone several downturns and the major causes of these downturns were related to geographic politics with Russia and energy. In the early years of this period, the government has tried several energy policies and strategies with a focus on nuclear and coal to get sufficient domestic energy supply with cheap costs. However, these options were risky due to the following facts: (1) primary nuclear fuel depended on a Russian company, and (2) the country's coal resources are in the disputable area between Russia and Ukraine. The most recent energy policy or strategy is the ESU that covers a period of 18 years from 2017 to 2035. The main goals declared in the ESU include liberalizing markets, establishing effective regulation, and attracting investors to the energy sector. The important measures to mitigate GHGs include the promotion of both renewable energy and energy efficiency. The ESU will be implemented in three stages: (1) finalizing energy sector reform by 2020; (2) optimizing/developing an innovative infrastructure by 2025; and (3) ensuring the long-term sustainable development of the energy sector by 2025.

Due to economic recessions, final energy consumption in Ukraine decreased from 86 Mtoe in 2007 to 50 Mtoe in 2017, by more than 40%. Reduced energy activities in turns have significantly affected economic development of the country. The country's economic development has not decoupled from energy use. As Ukraine's economy recovers, restoration and growth of industrial output under the business-as-usual scenario are projected to drive up GHG emissions in the energy and industrial sectors. Given this situation, the government of Ukraine should address key factors that drive high fossil fuel consumption and high carbon emissions in its long-term energy planning and climate policy development.

Ukraine is one of the most carbon intensive countries in Europe and carbon emission per capita has been increasing. A major reason is that fossil energy is dominant in energy mix and energy resources are not efficiently used. The Ukrainian housing and communal sectors are highly inefficient in terms of energy consuming around 44 percent of all energy resources for the country. To reduce carbon emissions per capita, a new and transformed energy system must

be developed with the development of the country's economy in the next two or three decades, which will use domestic zero-carbon energy resources, and harness energy efficiency as the first fuel from 2020 to 2050. Ukraine's outdated energy infrastructure is in dire need of major upgrades. The country's thermal power stations are on average 40-years old and the majority have not been rehabilitated since they were built.

According to the government's 2014 policy, from 2015 to 2035, Ukraine will move towards clean energy development and the use of renewable energy will increase. By 2035, Ukraine's electricity will be generated from different primary energy resources. The government aims at reducing GDP energy intensity by 2035 to the level of 0.17 kgoe per US dollar by 2035. The government continues to undertake policy measures. For example, the government adopted the bill on energy efficiency fund which is expected to work with over 6000 home-owners associations around the country to help with promoting energy efficient multi-family houses.

In addition to the above government-planned road map, this article extended the energy road map from 2035 to 2050 with an aim to get rid of fossil fuel import from any foreign countries and to achieve zero-carbon emission for country. With this road map, energy efficiency will become the first fuel in the country's primary energy supply. It will gradually substitute coal, oil, and natural gas from 2035 to 2050. As shown in Fig. 4, renewable energy will steadily grow from 2019 to 2035 as the government has projected. Then, it will scale up at an increasing rate of approximately 100 percent per year from 2035 to 2045, and it will be dominant in marginal energy growth to substitute fossil fuels from 2045 to 2050. With the development and investment in energy efficiency and renewable energy, by 2050, Ukraine will become an economy with energy independent and zero-carbon emissions. To achieve such a goal, the government needs to commit effective energy policies.

This article recommended 12 policies for the government. These policies include: stopping subsidy to fossil energy and treat energy as a commodity in the energy market, enhancing government institutional reform to regulate the energy market rather than control the market and to scale up renewable energy deployment and energy efficiency investments, accounting environment costs in fossil energy consumption and levying taxes on polluters, privatizing government owned companies to adapt the EU energy systems, and terminating gas import at earliest possible time frame to increase national energy security. If these recommended new energy policies are successfully implemented, the Ukrainian energy system will be transformed from a fossil fuel–based system to a highly efficient and zero-carbon-based system by 2050.

The following policy measures and instruments are recommended to facilitate Ukraine's energy road map shown in Fig. 4:

1. Insall meters for measuring heat consumption. So far, many heat consumers in Ukraine do not pay their energy bills according to meters' measurements. They pay lump sum fees for a period regardless of actual heat consumption. A meter must be installed for each heat consumer in the residential and commercial sectors.
2. Reform energy price and electricity tariffs. Energy should become a commodity in Ukraine and consumers should pay energy at market prices. Practice has proven that the rising gap between the fixed household tariffs and rising energy import costs cannot be filled sustainably. Consumers must pay the energy at market prices. It will catalyse domestic investment in energy production, encourage necessary savings, and cut down energy imports.
3. Establish an independent energy regulator. The scope of energy regulation should cover all energy-related natural monopolies including natural gas, electricity, pipeline companies, the

electrical grid, district heating, and the railways. The regulator should serve as an honest broker in weighing the interests among producers, consumers, and the government.

4. Ensure full transparency. To avoid corruptions in the energy sector, a fully transparent system must be established in bidding and in implementing any energy projects or programs. The public should get information on any on-going or forthcoming energy projects and programs from the government and regulatory organizations' websites. Transparency will stimulate energy savings and thus contribute to greater efficiency.
5. Levy reasonable and stable taxation on fossil fuel productions and consumptions. A more detailed study is needed to calculate the threshold taxation rate beyond which energy production companies are willing to switch from fossil energy investments to non-fossil energy investments.
6. Privatize state-owned enterprises (SOEs). The reform of SOEs has remained largely conceptual with few practical steps taken to improve governance or financial accountability. For example, unbundling Naftogaz, which is the national oil and gas company of Ukraine, is a long process. Naftogaz's business covers extraction, transportation, and refinement of natural gas and crude oil. It should be broken up into independent subsidiaries for production and transportation to increase competition and efficiency. Following international successful experiences in government reform in the energy sector, such as in China, Nafrogaz's gas and oil production sub-companies should be privatized. The company should only keep its gas and oil transportation sub-companies. Consequently, competition and higher efficiency will take place in the energy market.
7. Terminate gas purchasing from Russia in short run. Russia can frequently switch back and forth between offering very cheap gas and very expensive gas. Natural gas supply and demand should be built on a long-term and stable contract. Ukraine should have such stable contract with the EU, and not fall for the temptations of temporarily lower prices from Russia.
8. Use regulatory policy to scale up renewable energy deployment. Investments in renewable energy should be firstly driven by regulatory policies such as quotas and obligations and pricing instruments, supported by fiscal and financial incentives. To ensure the effectiveness of quotas and certificates, a robust framework to monitor and penalize non-compliance is needed.
9. Use incentive pricing policies to scale up renewable energy investments. Dynamic and adjustable feed-in tariffs and premiums need to continuously adapt to changing market conditions. The setting of the feed-in tariffs should consider the falling costs of renewable energy technologies and make sure consumers will not overpay for their future energy consumptions.
10. Use auctions to boom renewable energy investments. Auctions with ability for real-price discovery have constantly reduced electricity prices from solar PV and wind power over the past 10 years. In Ukraine, auctions are suitable for large-scale projects and feed-in tariffs and premiums for small-scale installations.
11. Encourage distributed renewable energy generation with integration of information technologies (IT). Net metering, net billing and charging for the use of power distribution network are increasingly important in transforming the energy system. They are often complemented by information awareness campaigns highlighting the benefits of renewable energy. Development and education of IT for the public should be in the Ukraine's energy road map of 2050.

It is important to align and integrate the Ukrainian energy market with the EU energy market. The negotiation of the integration should be proceeded without delay. By 2050, the Ukrainian energy market should be a part of the whole EU energy market to enhance efficiency and security of the country's energy sector.

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