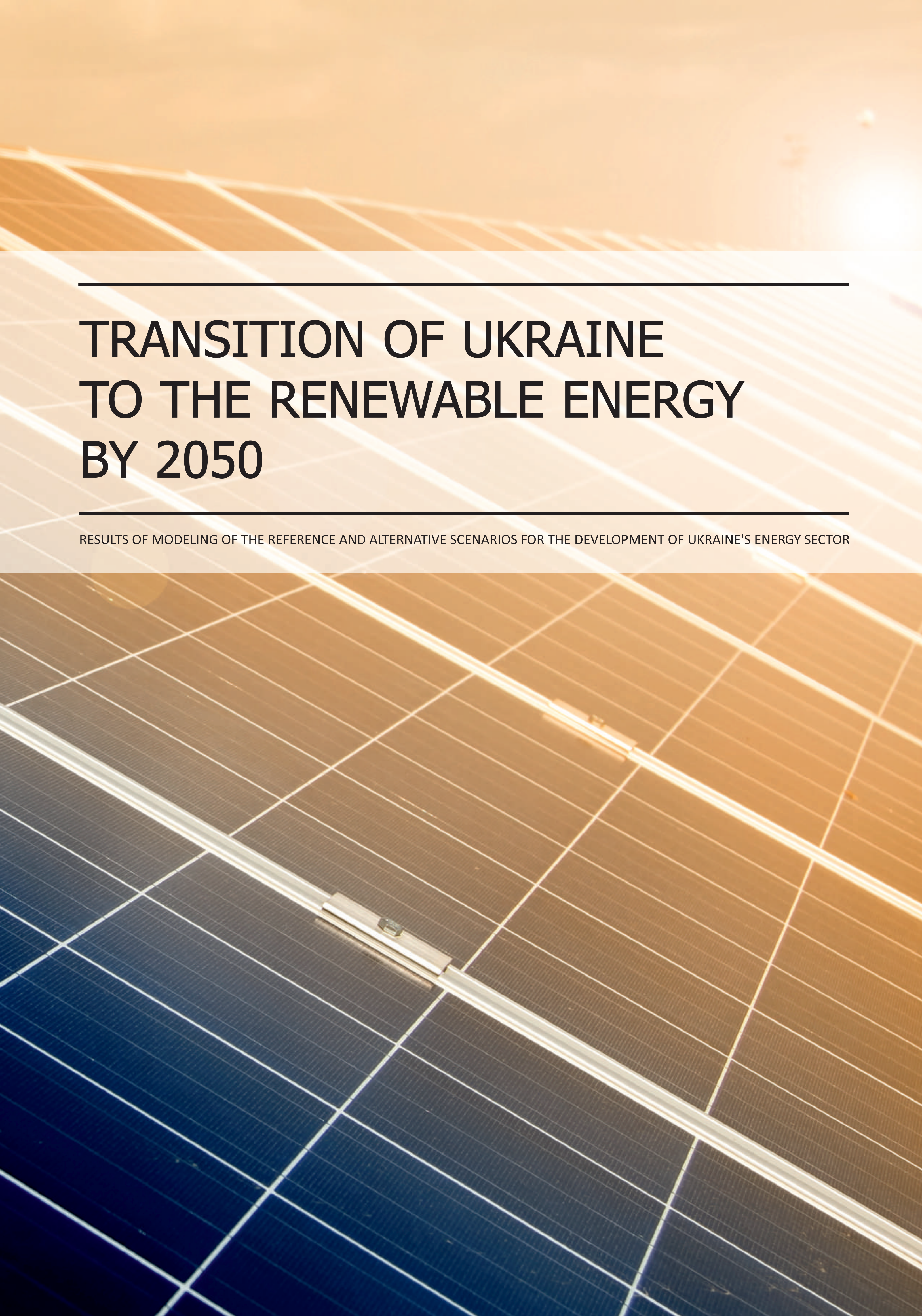

TRANSITION OF UKRAINE TO THE RENEWABLE ENERGY BY 2050

RESULTS OF MODELING OF THE REFERENCE AND ALTERNATIVE SCENARIOS FOR THE DEVELOPMENT OF UKRAINE'S ENERGY SECTOR

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HEINRICH BÖLL STIFTUNG KYIV

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П27

TRANSITION OF UKRAINE TO THE RENEWABLE ENERGY BY 2050

results of modeling of the reference and alternative scenarios for the development of energy sector

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The study "Transition of Ukraine to the Renewable Energy by 2050" was carried out in 2016-2017 by the State Organization "Institute for Economics and Forecasting" of the National Academy of Sciences of Ukraine with the support of the Heinrich Boell Foundation Regional Office in Ukraine and in cooperation with civil society organizations, public authorities, specialized in renewables business associations and independent experts. This study presents results of modeling of the reference and alternative scenarios for the development of Ukraine's energy sector by 2050 and demonstrates how the transition from fossil fuels to renewable energy can be achieved and what economic impacts it will have.

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FOREWORD

Just recently we believed that we have an undepletable source of almost free energy made of coal and gas. Today we painfully realise that the years of delays and disregard of the necessity for finding other ways to meet energy needs of Ukraine have caused the energy crisis.

The conflict in Donbas and the lack of access to our own deposits of coal, outdated units of Ukraine's nuclear power plants, the lack of investment in energy innovations and latest technologies, rising cost of energy resources make clear that there is no time to postpone the problem.

At the same time, rapid development of the renewable energy, the reduction in prices of solar and wind technologies, their higher environmental and social standards as well as the international consensus on the need of transition to renewable energy for reducing the emissions of greenhouse gases and counteracting climate change give us an insight about the necessary direction for modernization of the energy sector in Ukraine.

That is why we decided that the first step towards the energy transition in Ukraine should be a study, which will show that replacement of traditional energy sources with renewable ones is possible and most importantly will answer the question on what we can do for this.

Kind regards,
Head of the Heinrich Boell Foundation
Regional Office in Ukraine,
Sergej Sumlenny

Ukraine has chosen energy independence as one of the priority directions for development. Therefore, today we are confidently moving towards reduction and substitution of gas consumption, increasing energy efficiency in various aspects of life of the population and development of renewable energy.

There are many achievements in Ukraine. Over the past 3 years, about EUR 700 million have been invested in ''green'' projects in Ukraine thanks to the consistent action of the Government and the improvement of the legislative framework in the field of renewable energy. Almost EUR 400 million are invested in the development of 1,670 MW of new thermal capacities using alternative energy sources. About EUR 300 million were allocated by the business to set up 278 MW of renewable energy facilities.

All these examples prove effectiveness of legislation, which is the result of the fruitful cooperation between the Government, the Parliament, the State Agency on Energy Efficiency and Energy Saving and all market participants.

This is confirmed by the fact that Ukraine has begun a global energy transition for future economic growth. Renewable energy brings additional investments into Ukraine's economy and opens up new horizons of development.

We are aware that the potential of clean energy development is significant. According to the National Renewable Energy Action Plan by 2020, we should provide 11% of the energy needs of the state by renewable energy sources in 2020. In addition to this, the share of ''green'' energy in the total primary energy supply should be 25% in 2035. So, we continue to look for ways to accelerate the transition to sustainable energy not only to achieve energy independence, but also to provide a decent future for future generations. That's why this work is extremely important, as it demonstrates the opportunities that are now open to Ukraine under the condition of intensifying the efforts of all market players towards sustainable energy and economic growth.

Best regards,
Head of the State Agency on Energy Efficiency
and Energy Saving of Ukraine

A key feature of today's global economic processes is the rapid increase in the competitive struggle between countries for limited natural resources, the main ones being energy products and food. Almost no country in the world can be fully self-sufficient with such resources.

As the results of many scientific studies show, the use of traditional energy resources (coal, oil, gas) causes significant damage to the ecosystem of the planet and causes climate change, which in turn affects the health and living conditions of the population and, as a consequence, the world and national economies. To address this problem, the world community is actively developing technologies and means of using renewable and clean energy sources such as wind, solar radiation, renewable bioenergy resources, and other in the last decades.

Localization of these problems is not exclusive, therefore Ukraine should actively participate in low carbon economic development initiatives, taking full care of present and future generations. The task of scientists and experts in this context is to implement a comprehensive analysis of the interdependencies between the conditions of use of natural resources and the risks that it has for the environment.

The State Organization ''Institute for Economics and Forecasting'' of the National Academy of Sciences of Ukraine is grateful for the proposal and support to the Heinrich Boell Foundation Regional Office in Ukraine in conducting a scientific study on the possibilities of Ukraine to move to almost 100% use of renewable energy sources by 2050. Such a transformation of the energy sector can become an important factor in the socio-economic development of Ukraine, which will improve the living conditions of the population, increase competitiveness of the economy, resolving the problem of an energy dependence, etc. Of course, such an "energy transition" will require significant resources (human, financial, technological), and will require the implementation of appropriate structural changes in Ukraine's economy. Presented results are the first step in the "energy transition". Further research should be carried out considering that potential benefits of the long-term transformation of energy and the economy, as well as challenges and threats, are not fully defined and examined as of today. However, we are sure that this movement is in the right direction!

Regards,
Authors' Group of the State Organization
"Institute for Economics and Forecasting"
of the National Academy of Sciences of Ukraine

ORGANIZATIONS THAT SUPPORT THE TRANSITION OF UKRAINE TO THE RENEWABLE ENERGY BY 2050

Держенергоефективності

Асоціація енергоаудиторів

UYCA

UWEA UKRAINIAN WIND ENERGY ASSOCIATION

Ukrainian Climate Network

АВЕ

WOMEN'S ENERGY CLUB OF UKRAINE

UNIQUE PLANET UP ЄДИНА ПЛАНЕТА

BIOMASS

UABIO Bioenergy Association of Ukraine

екодія ecoaction.org.ua

RESOURCE EFFICIENT AND CLEANER PRODUCTION CENTRE

EUEA Європейсько-українське енергетичне агентство European-Ukrainian Energy Agency

Ecoclub

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Mykhailo Kordiukov

Member of the Parliament of Ukraine
Oleksii Riabchyn

National Ecological Centre of Ukraine
Oleksii Pasiuk
Yurii Urbanskyi

NPC "Ukrenergo"
Oleksandr Karpenko
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Rentechno Group
Dmytro Lukomskyi

Renewable Energy Agency
Oleksii Epik
Oleksandra Tryboi

Resource Efficient and Cleaner Production Centre
Ihor Shylovych
Oleksandra Kolmogortseva
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SEC "Biomass"
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WWF in Ukraine
Roman Volosianchuk

"Yedyna Planeta" NGO
Oleh Savytskyi

SUMMARY

The adoption of the Paris Climate Agreement has become a symbolic decision for the world community. It will have a significant impact on the development of world economy and energy as well as particular countries since it aims to keep the average temperature rise on the planet well below 2°C (compared to the pre-industrial levels). To make it happen it is necessary for the energy sector to become carbon neutral (greenhouse gases (GHG) emissions must not exceed the level of their absorption and / or capture on the planet). In other words, **a so-called ‘‘energy transition’’ from the fossil to renewable types of energy resources based on the principles of sustainable development is needed.** It will stimulate a significant increase in energy efficiency and rational use of energy resources.

Heinrich Boell Foundation Regional Office in Ukraine has initiated development of an ambitious study on the possibility of Ukraine’s energy sector transition to maximum share of renewable energy sources (RES) in final consumption by 2050. The State Organization “Institute for Economics and Forecasting” of the National Academy of Sciences of Ukraine that is the main partner of this research project has modeled three scenarios of the energy sector development. Modeling was carried out using well-known economic and mathematical models (TIMES-Ukraine model and Computable General Equilibrium Model of Ukraine) that are used on a permanent basis by the Institute.

The Conservative Scenario that in fact is the reference one implies ‘‘freezing’’ of technologies at the present level. The Liberal Scenario involves the development of energy sector under conditions of free competition, while the Revolutionary Scenario – the rapid development of RES. It should be noted that these scenarios on the Ukrainian energy sector development are just scenarios, and are not strategies, plans, programs, etc. However, they can be taken as a basis for further study of practical steps towards the ‘‘energy transition’’ of Ukraine to the RES.

The Conservative Scenario is considered to be a hypothetical scenario when characteristics of most energy technologies remain unchanged by 2050 compared to 2012 and hence there is almost no increase in efficiency of the use of energy resources and only a very small part of the potential of RES is used. The Conservative Scenario is used as a reference for comparing alternative scenarios (Liberal and Revolutionary), in particular the effectiveness of measures and policies that stimulate technological change in the energy sector and economy.

Conditions of *the Liberal Scenario* include perfect competition across the national energy market and its sectors. In the case of their implementation, it can be expected that by 2050 the **share of RES in the structure of the final energy consumption (FEC) may exceed 30% and the need for energy resources will decrease due to the introduction of energy efficiency measures while the economy will grow.** Results of this scenario demonstrate competitiveness potential of the renewable energy compared to the traditional one without the use of additional incentives for the development of RES.

In case target policy for the renewable energy development (condition of *the Revolutionary Scenario* of the ‘‘energy transition’’) is implemented, **it is quite feasible to increase the share of RES in the structure of FEC up to 91% in 2050 and to reduce the demand for energy resources by 42%** compared to the Conservative Scenario due to the implementation of energy efficiency and energy saving measures. In other words, **the results of modeling of the Revolutionary Scenario indicate that Ukraine has a sufficient renewable energy potential that can fully cover possible future demand for energy resources and services, even if a high share of energy-intensive industry will be maintained** (metallurgy, chemical industry, etc.). In case required technologies are fully or at least partially produced domestically, Ukraine can solve not only energy, environmental and climate problems, but also the socio-economic ones.

ACRONYMS AND ABBREVIATIONS

AEA – Association of the Energy Auditors

CGE model – Computable General Equilibrium Model

CHPP – Combined Heat and Power Plant

CP – Coefficient of Performance

CTEA – Classifier of Types of Economic Activity

DSTU – National Standard of Ukraine

EPR – European Pressurized Reactor

EU – European Union

FEC – Final Energy Consumption

GDP – Gross Domestic Product

GFCF – Gross Fixed Capital Formation

GHG – Greenhouse gases

GPP – Geothermal Power Plant

Gt – Gigaton (billion tons)

GW – Gigawatt

HEPP – Hydroelectric Power Plant

HPP – Hydro Power Plant

HUS – Housing and Utility Service

ICE – Internal Combustion Engine

ICUF – Installed Capacity Utilization Factor

IDSS NASU – Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine

IEA – International Energy Agency

IMF – International Monetary Fund

IOT – Input-output table

IPCC – Intergovernmental Panel on Climate Change

KhNPP – Khmelnytskyi Nuclear Power Plant

MBTU – Million British Thermal Units

MW – Megawatt

NECU – National Ecological Centre of Ukraine

NPP – Nuclear Power Plant

OECD – Organisation for Economic Co-operation and Development

PJ/a – Petajoule per year

PPP – Purchasing Power Parity

PSHP – Pumped Storage Hydropower plant

RECP – Resource Efficient and Clean Production

RES – Renewable energy sources

RNPP – Rivne Nuclear Power Plant

SAM – Social Accounting Matrix

SCP – Statistical Classification of Products

SNRIU – State Nuclear Regulatory Inspectorate of Ukraine

SPP – Solar Power Plant

SUNPP – South Ukraine Nuclear Power Plant

TFEC – Total Final Energy Consumption

TIMES-Ukraine – Economic-mathematical optimization model

TPES – Total Primary Energy Supply

TPP – Thermal Power Plant

TWh/a – Terawatt-hour per year

UN – United Nations

USAID – U.S. Agency for International Development

UWEA – Ukrainian Wind Energy Association

VAT – Value Added Tax

VVER – Water-Water Energetic Reactor

WASP – Wien Automatic System Planning Package

WB – World Bank

WPP – Wind Power Plant

ZNPP – Zaporizhzhia Nuclear Power Plant

LIST OF TABLES

LIST OF TABLES

continuation

LIST OF FIGURES

LIST OF FIGURES
continuation

TABLE OF CONTENTS

Depletion of traditional types of energy resources, agrravation of a negative environmental impact of energy sector and, consequently, strengthening of environmental standards, significant fluctuations in energy prices, objective to strengthen energy and economic security, the politicization of energy supplies and other factors have led to the urgent need to revise current state in the energy sector and look for opportunities for its modernisation and policy review.

Ukraine is one of many countries that are suffering from all of these problems. Its dependence on the import of expensive energy resources leads to considerable socio-economic problems. An extremely high degree of the infrastructure depreciation (in particular the one of energy sector) and consequently a very low efficiency of energy resources use are the factors explaining the position of Ukraine among the countries with high indexes of energy intensity of the economy. Thus, the energy intensity of Ukraine's GDP was 2.8 times higher than the corresponding indexes of OECD and Visegrad countries in 2014. A similar situation is observed with the GDP carbon intensity. Moreover, Ukraine has one of the highest mortality rates[1] due to the illnesses associated with air pollution as a result of the energy wastefulness and the lack of modern requirements for ecologically acceptable functioning of the energy system with a careful attitude towards the environment.

At the same time, Ukraine and the world have faced the problem of climate change that has been observed since the middle of the 20th century and is a consequence of human activity[2]. 195 countries of the world, including Ukraine, decided to approve the Paris Climate Agreement in 2015. It is aimed at strengthening of the global response to the threat of climate change in the context of sustainable development and efforts to eradicate poverty, in particular by limiting the growth of the global average temperature well below 2°C compared to the pre-industrial level and making efforts to limit the temperature growth to 1.5°C. However, in 2015-2016 the average global temperature exceeded the index of the 1850 by more than 1°C[3]. That is why the immediate actions are needed in order to achieve the goal of the Paris Agreement for the effective and proper respond to the problem of the GHG global emissions.

One of the most complex and realistic ways to solve these problems and to adapt to the climate change is the implementation of the complete ‘‘energy transition’’ from fossil fuels to renewables. It's really possible as today's development of high-tech and science-intensive technologies has already opened up real prospects for renewable energy

There is already seen a movement towards the decarbonisation of the energy sector. Thus, energy-generating facilities of the renewable energy are becoming more and more competitive in comparison with the ones that use fossil fuels, although the real environmental cost of the electricity from fossil fuels is not yet taken into account. Production of electric vehicles is continually growing and their models variety is developing. There are available technologies for the significant increase of the buildings' energy efficiency. The energy intensity of industrial products is significantly reduced due to the modernization and robotization of the production processes. The possibilities of electricity storage are increasing. There is a progress in the digitalization of all spheres of energy (IT technologies, smart grids, etc). Investments in the research and development of ‘‘clean’’ technologies and the construction of new renewable energy facilities are steadily increasing. For instance, the RES sector set a new record in 2015. It attracted USD 312.2 billion of investments that is two times more than the investments in the gas and coal sectors (USD 130 billion)[4].

Unfortunately, Ukraine lags behind not only the economically developed countries of the world (including the countries of the Visegrad Group) but also the global index in terms of the RES use. The share of RES in the global total final energy consumption was amounted to 20% in 2014, while in Ukraine this figure was only 4.2%[5].

However, Ukraine has a lot of prerequisites for the ‘‘energy transition’’ already. In particular, the level of investment in renewable energy is increasing. There are corresponding economic incentives (‘‘feed-in tariff’’, cost recovery programs for implementation of energy efficiency measures) and the State Agency on Energy Efficiency and Energy Saving of Ukraine promotes more active development of the renewable energy. Ukraine is a member of the European Energy Community. It signed and ratified the Association Agreement with the EU, undertaking the commitment to increase energy efficiency, to develop renewable energy, to reduce emissions of greenhouse gases and pollutants.

The Greenpeace in collaboration with the Institute of Engineering Thermodynamics, Systems Analysis and Technology Assessment (DLR), Global Wind Energy Council and SolarPower Europe has already developed a fully realistic long-term scenario for the complete energy supply based on the RES (Energy [R]evolution Scenario)[6] for some countries. The Heinrich Boell Foundation Regional Office in Ukraine initiated a similar research for Ukraine being inspired by their results. Scientists of the State Organization “Institute for Economics and Forecasting” of the National Academy of Sciences of Ukraine, that is the main partner of this study, has modeled three scenarios of the energy sector development. Obtained results are not the strategy for Ukraine's energy sector development, although they can be used for the formulation of relevant long-term strategic documents. Also these scenarios are not the predictions for the future of energy sector of Ukraine. This study only model pathways how Ukraine can implement the ‘‘energy transition’’ under the given conditions and if we set the goal to reach 90-100% of the energy supply of the country with RES in 2050. In this report readers can find out about the results of the research and see how the state's economy will change and what will be the consequences for reducing of social inequality, the environmental protection and the fulfillment of international obligations if Ukraine decides to perform ‘‘energy transition’’ to clean and safe energy.

1 https://www.theguardian.com/environment/2016/sep/27/more-than-million-died-due-air-pollution-china-one-yea

2 Climate Change 2013: The Physical Science Basis. Intergovernmental Panel on Climate Change. – Available at: http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf [in English].

3 2016 Climate Trends Continue to Break Records. – Available at: https://www.nasa.gov/feature/goddard/2016/climate-trends-continue-to-break-records

4 http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report.pdf

5 The calculations are made by authors on the base of the International Energy Agency's data

6 http://www.greenpeace.org/international/en/campaigns/climate-change/energyrevolution/

1 DEVELOPMENT OF THE ENERGY SECTOR IN THE WORLD AND IN UKRAINE

Climate Policy as the Driving Force of Energy Changes

Global Scenario of Transition to RES

Current State of Ukraine's Energy Sector

Photo: Shutterstock

1.1 Climate Policy as the Driving Force of Energy Changes

The adoption of the Paris Climate Agreement[7] in 2015 has become a landmark decision that has a significant impact on the development of both the world economy and energy and the economies and energy sectors of separate countries. First of all, the sector of electricity and heat production (e.g. the intensive development of the distributive generation of electricity and heat, the smart grids, etc.) as well as industry (the widespread use of robotics and technologies that use electricity for production) and transport (gradual phase-out of oil products and the use of electricity, hydrogen, biofuels, etc.) are undergoing the transformation that is aimed for decarbonisation. Private residential sector is moving towards energy self-sufficiency through wider use of RES, energy storage technologies and a significant reduction of energy needs without losing the comfort of buildings.

In its latest World Energy Outlook 2016[8] the International Energy Agency (IEA) states that if countries comply with their commitments undertaken during the preparation and ratification of the Paris Agreement (nationally determined contributions), then by 2040:

- electricity production from RES will reach 37% in the overall structure of electricity generation (compared to 23% now);
- almost 60% of all new capacities will be using RES and the majority of the renewable energy facilities will be competitive without any subsidies;
- the number of electric cars will be increased from 1.3 to 150 million units;
- the demand for gas will be increased by 50%, replacing the coal in the global energy balance.

In case of realization of these forecasts, CO_2 emissions from functioning of the global energy sector will annually increase by an average 0.5%, whereas since 2000 they grew by an average 2.4%. According to the IEA, even such **deceleration in the growth of CO_2 emissions is absolutely insufficient to achieve the main goal of the Paris Climate Agreement – to keep the average temperature increase on the planet well below 2°C compared to pre-industrial levels.** According to the Intergovernmental Panel on Climate Change (IPCC), the humanity still has a so-called "carbon budget" the volume of which is no more than 1 thousand Gt[9] CO_2 since today. In other words, the humanity must transit even more actively towards the carbon neutral development, in particular through the development of RES.

Investments play an important role in the development of RES. In 2015 global investments in RES set another record – USD 312.2 billion *(Figure 1.1)* and exceeded the investments in the gas and coal sectors more than twice (USD 130 billion). In 2016 investments dropped to USD 241.6 billion, however, they exceeded the level of 2013.

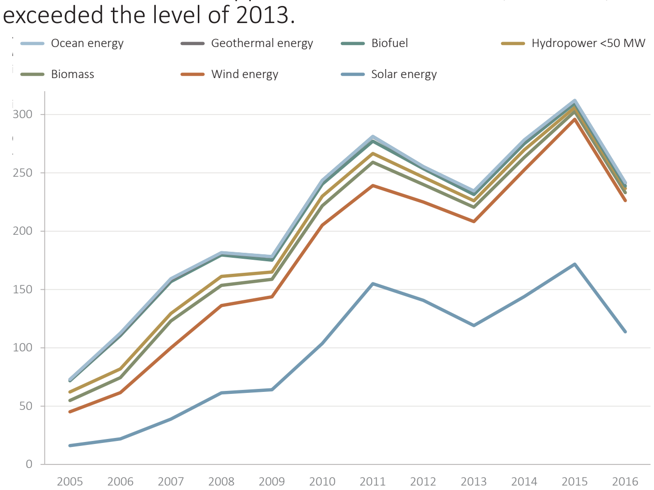


Figure 1.1 Global trends of investment in RES in 2005-2016

Units: USD billion. Source: prepared by the authors according to the data of REN21, http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf.

1.2 Global Scenario of Transition to RES

In September 2015 the Greenpeace[10], an international environmental organization, together with the Institute of Engineering Thermodynamics, Systems Analysis and Technology Assessment (DLR), the Global Wind Energy Council and SolarPowerEurope presented an updated study on modeling of the global energy transition scenarios[11]. These scenarios foresee a gradual transition from the fossil fuel consumption to the 100% use of RES by 2050. They are aimed to keep the global warming within 2°C.

A combination of forecasts about population and GDP growth and future energy intensity indexes that is used to model the Reference Scenario of the energy sector development indicates an increase in global demand for energy. According to the Reference Scenario, total final energy consumption is expected to increase by 65% from the current level (from 326,900 PJ/a in 2012 to 539,000 PJ/a in 2050). According to the Energy [R]evolution Scenario, final energy consumption will decrease by 12% *(Figure 1.2)* compared to the current consumption and will reach 289,000 PJ/a by 2050.

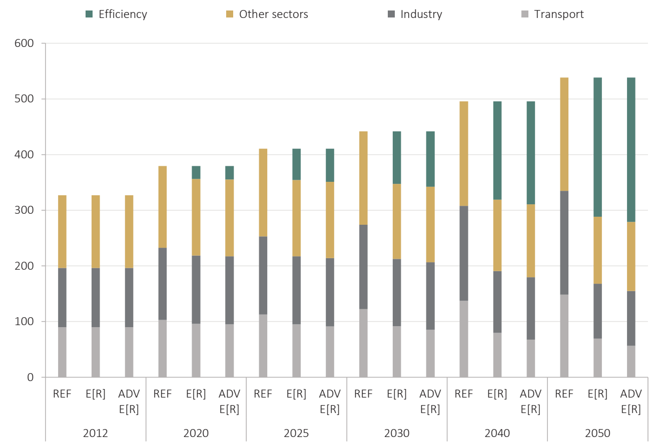


Figure 1.2 Forecast of the final energy consumption according to the three global scenarios of energy sector development

Note: REF- Reference Scenario, E[R]- Energy [R]evolution Scenario, ADV E[R]- Advanced Energy [R]evolution Scenario. Units: 1000 PJ/a. Source: Energy [R]evolution. A sustainable world Energy Outlook 2015. 100% renewable energy for all.

At the moment RES provide 21% of the world heat demand, mainly by biomass. The role of biomass can be diminished by the development of other technologies in the future. For example, the role of solar collectors, geothermal energy and hydrogen energy will increase in industry especially after 2030. According to the basic and advanced Energy [R]evolution Scenarios, RES will provide respectively 42% and 43% of the world demand for heat in 2030 and 86% / 94% in 2050. The energy efficiency measures will reduce demand for heat by 33% in 2050 according to the Reference Scenario. The estimated investment volume for the heat production based on the RES by 2050 will be USD 16.3 billion. According to the improved scenario, it will be necessary to invest a little bit more money for substitution of natural gas with synthetic fuels and / or hydrogen.

According to the Energy [R]evolution Scenario, the demand for electricity will increase despite the increasing efficiency in all sectors. Total demand for electricity will increase from 18,860 TWh/a in 2012 to 37,000 TWh/a in 2050. Thanks to the energy saving measures, the generation of 16,700 TWh/a could be avoided. The transition to the carbon-free energy system with 100% of RES in accordance with the Advanced Energy [R]evolution Scenario will lead to further increase of demand for electricity (up to 40,000 TWh/a in 2050) due to the electrification of industry, transport and part of the heat energy sector. About 8,100 TWh will be used by electric vehicles and by rail in 2050, 5,100 TWh – for hydrogen production and 3,600 TWh – for synthetic liquids production.

7 http://unfccc.int/paris_agreement/items/9485.php

8 World Energy Outlook 2016. Executive summary [Electronic resource] / Official website of the Internation Energy Agency – Available at: https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf

9 1 gigaton is 1 billion tons

10 http://www.greenpeace.org/international/en/

11 "Energy [R]evolution. A sustainable world Energy Outlook 2015. 100% renewable energy for all". Greenpeace International, Global wind energy Council, Solar PowerEurope September 2015

Energy efficiency in the heat supply sector is more important than in the power sector. According to the Energy [R]evolution Scenarios, due to the significant increase of energy efficiency compared to the Reference Scenario the consumption of 76,000 PJ/a by 2050 could be avoided. It will be possible due to the thermal renovation of existing buildings, the "passive climatisation" of new buildings and the use of highly efficient air conditioning systems.

Electricity generation from RES will provide more than just a compensation for phase out of electricity generation from fossil fuels and nuclear power. About 92% of the world's electricity will be produced with RES in terms of the Energy [R]evolution Scenario by 2050. In 2020 the share of electricity produced with RES will be 31%, in 2030 – 58%. The installed capacity of RES is 7,800 GW in 2030 and 17,000 GW by 2050. According to the Advanced Scenario, in order to ensure the generation of 100% of the electricity from RES in 2050 it is necessary to have 23,600 GW of installed capacity of RES objects. By 2020 the RES capacities will be mainly increased because of the wind and solar energy and after 2020 – because of the geothermal and ocean energy. The role of smart grids, demand side management and energy storage capacities will grow. The costs for electricity generation will slightly increase (compared to the Reference Scenario by 2030) according to the two scenarios of Energy [R]evolution, but the difference will be insignificant – about 0.002 USD/kWh (without taking into account the potential costs of joining, balancing and storage of energy). The electricity generation from RES will be cost efficient in all regions of the world beginning from 2030. The average world electricity generation cost will be 0.025 USD/kWh by 2050 (lower than in the Reference Scenario). According to the Advanced Scenario, it supposed that there will be larger reduction in costs due to the scale effect.

The world energy costs in the energy sector will amount to USD 48 trillion in accordance with the Energy [R]evolution Scenario. It is 50% more than planned in the Reference Scenario (USD 24.5 trillion) by 2050. In accordance with the Advanced Scenario, the investments by 2050 should be USD 64.6 billion. According to the Reference Scenario, half of the investments will be directed to conventional power plants and the other half to RES. According to both scenarios of the Energy [R]evolution, 95% of investments will be directed to RES and the rest to the natural gas power plants. In comparison with the fossil fuels, the RES power plants (except the biomass) don't need raw materials / fuel, that's why these savings may be directed to investments in RES, while the prices for fossil fuels will increase.

The RES sector is a potential source of many new jobs. The world's coal industry employs 10 million workers now. The photovoltaics can provide the same number of jobs in 15 years. By 2030 the wind energy sector can grow from the current 700 thousand jobs to 7.8 million jobs (twice as much as the global oil and gas industry has now) but the first changes should begin today. The number of people employed in the coal industry will significantly decrease by 2030. According to the Advanced Energy [R]evolution Scenario, the world energy sector will have 35.5 million jobs in 2020 and 29.6 million according to the Reference one. These figures can reach respectively 45.2 million and 29.1 million jobs in 2025. The number of jobs will be respectively 46.1 million and 27.3 million in 2030. By 2030 the 86% of jobs in the energy sector will be connected with RES.

1.3 Current State of Ukraine's Energy Sector

Fascinating prospects of the RES development that are presented in the global Energy [R]evolution Scenario inspire to investigate whether a similar scenario for Ukraine's energy sector development is actually possible, which in fact is the subject of this research (results are presented in the Section 5). However, before starting to model the scenarios of the long-term development of the Ukrainian energy sector, it is worth to analyze its current state. The results of such analysis are presented in this Section.

A comparison of Ukraine's and world energy balances as well as the energy balance of the OECD and the EU countries is given in the *Table 1.1*. It can be noted that in Ukraine the use of coal significantly exceeds the relative indicators of the OECD countries and the world. Instead, the use of oil and its products in Ukraine is much lower than the indicators in the world and especially in the OECD countries. This is explained by the fact that in Ukraine oil products are used mainly in the transport sector and almost unused in the electricity and heat generation as it happens in the OECD countries. On the other hand, in Ukraine the consumption of oil products in the transport sector is lower than the average indicators of the OECD countries.

The dynamics of the total primary energy supply (TPES) in Ukraine is shown in *Figure 1.3*. Ukraine significantly reduced the use of energy resources (first of all, the natural gas) over the past decade. TPES decreased by almost 20% compared to 2005 in 2013, and by more than a quarter in 2014. Of course, the decrease of TPES in 2014 is primarily explained by military and political conditions and hence the socio-economic situation in Ukraine.

Since 2007 the supply of oil was replaced with the import of oil products. This is due to the decline of domestic oil refinery.

The final energy consumption (FEC) in Ukraine *(Figure 1.4)* was characterized by a drop of the share of industry

Table 1.1 Main energy balance indicators of the world, OECD, EU and Ukraine in 2014

Total primary energy supply	World		OECD		EU		Ukraine	
	thousand toe	%	thousand toe	%	thousand toe	%	thousand toe	%
Coal	3,918,491	28.6%	1,012,463	19.2%	268,433	17.2%	35,576	33.7%
Crude oil	4,349,857	31.8%	2,061,714	39.1%	591,918	37.8%	3,043	2.9%
Oil products*	-64,557	-0.5%	-180,603	-3.4%	-82,930	-5.3%	7,645	7.2%
Gas	2,900,579	21.2%	1,343,845	25.5%	342,846	21.9%	33,412	31.6%
Nuclear energy	661,353	4.8%	516,273	9.8%	228,456	14.6%	23,191	21.9%
Hydroenergy	334,945	2.4%	120,471	2.3%	32,248	2.1%	729	0.7%
Geothermal, solar, etc.	181,072	1.3%	98,024	1.9%	40,069	2.6%	134	0.1%
Biofuel and waste	1,412,908	10.3%	299,787	5.7%	141,641	9.1%	1,934	1.8%
Electricity*	2,383	0.0%	395	0.0%	1,333	0.1%	-725	-0.7%
Heat energy	2,096	0.0%	899	0.0%	962	0.1%	745	0.7%
TOTAL	13,699,127	100%	5,273,268	100%	1,564,975	100%	105,684	100%

* Negative values mean that exports exceed the amount of imports and domestic production.
Source: prepared by authors on the base of the International Energy Agency's data.

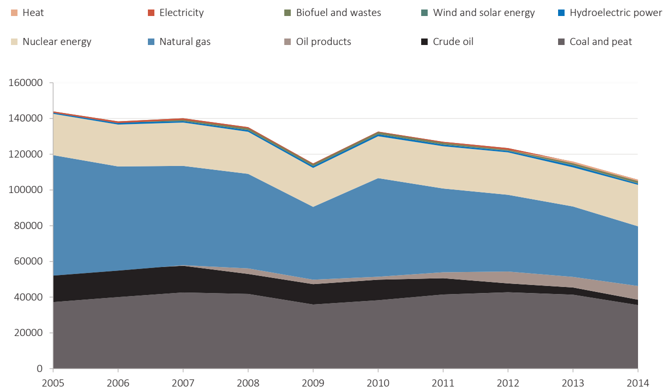


Figure 1.3 Dynamics of total primary energy supply in Ukraine

Units: thousand toe. Source: prepared by authors on the base of the International Energy Agency's data.

during 2005-2014 (from 45% in 2005 to 34-35% in 2013-2014), more or less stable share of population on the level of 35% (except for 2007-2008, when the share of population in the structure of FEC dropped to 29-30%). It is worth noting the steady growth of the service sector in the final energy consumption structure from 3% in 2005 to 8-9% in 2012-2014.

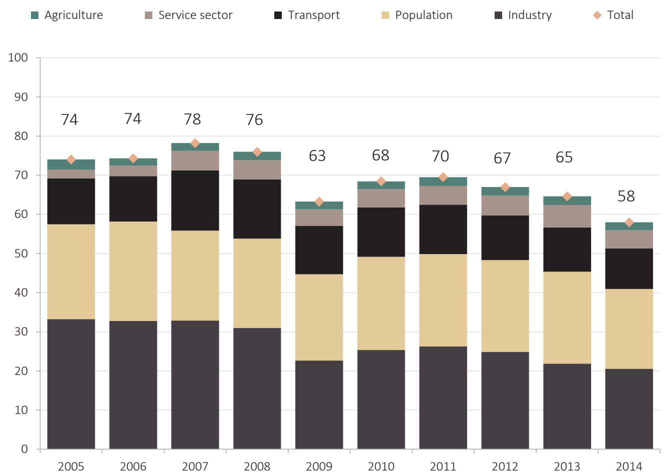


Figure 1.4 Final energy consumption in Ukraine by sectors

Units: thousand toe. Source: prepared by authors on the base of the International Energy Agency's data.

A decrease in the share of gas from 38-39% in 2005-2008 to 32% in 2012-2014 and an increase in the share of electricity from 14% in 2005 to 19% in 2014 can be noted *(Figure 1.5)* in the structure of FEC by the types of energy resources.

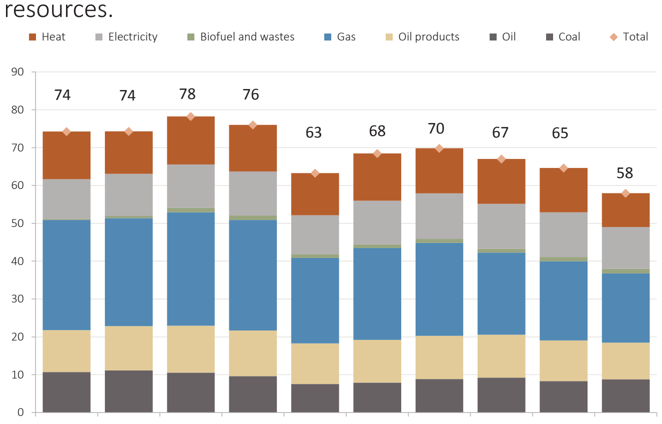


Figure 1.5 Final energy consumption in Ukraine by types

Units: thousand toe. Source: prepared by authors on the base of the International Energy Agency's data.

As can be seen in the *Table 1.1* and *Figure 1.5*, **Ukraine lags behind not only economically developed countries of the world with its level of RES use** (including the countries of the Visegrad Group), **but also the global indicator** *(Figure 1.6)*. The share of RES in the global total final energy consumption (TFEC)[12] amounted to 20% in 2014, while in Ukraine this figure was only 4.2%.

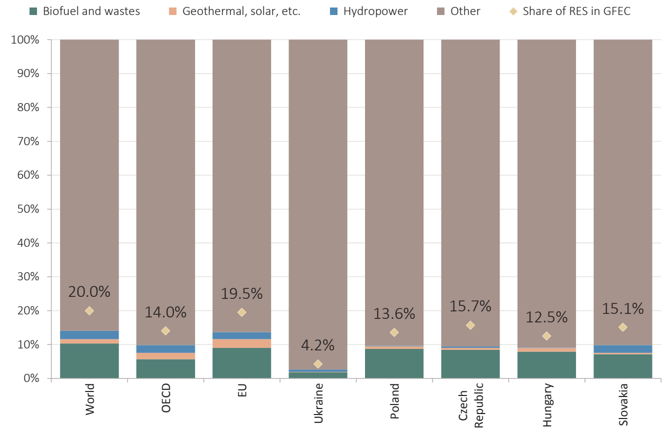


Figure 1.6 RES in the total final energy consumption in 2014

Source: calculated by authors on the base of the International Energy Agency's data.

Despite decrease of energy intensity of GDP and specific GHG emissions, Ukraine's economy remains to be extremely energy-intensive in comparison not only with the developed countries, but also with its European neighbors, in particular, the countries of the Visegrad Four *(Figure 1.7)*.

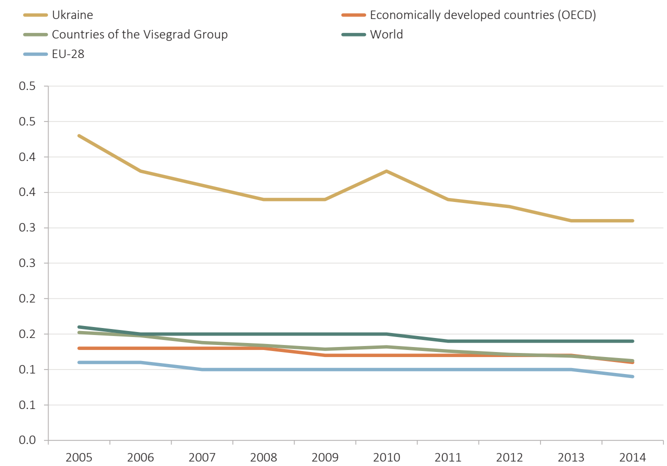


Figure 1.7 Energy intensity of GDP (PPP)

Units: thousand toe / USD 1,000 (2010). Source: prepared by authors on the base of International Energy Agency's data http://energyatlas.iea.org/?subject=1378539487.

Despite the fact that the level of energy intensity of Ukraine's GDP decreased almost by one half from 2000 to 2014, it is still 2.8 times higher than corresponding indicators of countries of the OECD and the Visegrad Group. A similar situation is observed with the level of carbon intensity of GDP (PPP). According to data of 2014 it is 2.4 and 2.6 times higher than the indicators of the OECD and the Visegrad countries and 3.8 times higher than in the EU *(Figure 1.8)*.

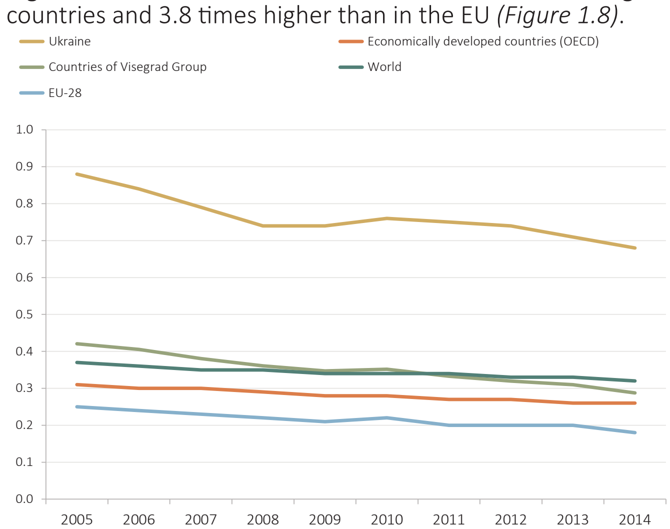


Figure 1.8 Carbon intensity of GDP (PPP)

Units: tons of CO_2 / USD 1,000 (2010). Source: prepared by authors on the base of International Energy Agency's data http://energyatlas.iea.org/?subject=1378539487.

12 Total final energy consumption (TFEC) is the amount of final energy consumption, own energy consumption and losses during transportation and distribution with the exception of non-energy use of energy resources.

2 METHODOLOGY

- General Methodological Approach
- Definition and Conditions of Energy Sector Development Scenarios
- Macroeconomic Conditions and Assumptions
- Demographic Conditions and Assumptions
- Forecast of Energy Resources' Prices
- Assumptions on Nuclear Energy

Photo: Shutterstock

2.1 General Methodological Approach

A combination of economic and mathematical models was used to model scenarios of the energy sector development in Ukraine. This includes dynamic optimization TIMES-Ukraine[13] model and a dynamic computable general equilibrium model (CGE model). The algorithm for studying the economic and energy scenarios is presented in *Figure 2.1*.

To develop the scenarios of the energy sector development *(Section 2.2)* the macroeconomic scenario *(Section 2.3)* has been used, which determines dynamic changes of the principal drivers (control parameters) of the demand for energy services: GDP, value added, industrial production, number of population and household income, housing stock, energy resource prices, other macroeconomic and demographic indicators, the primary forecasts of which

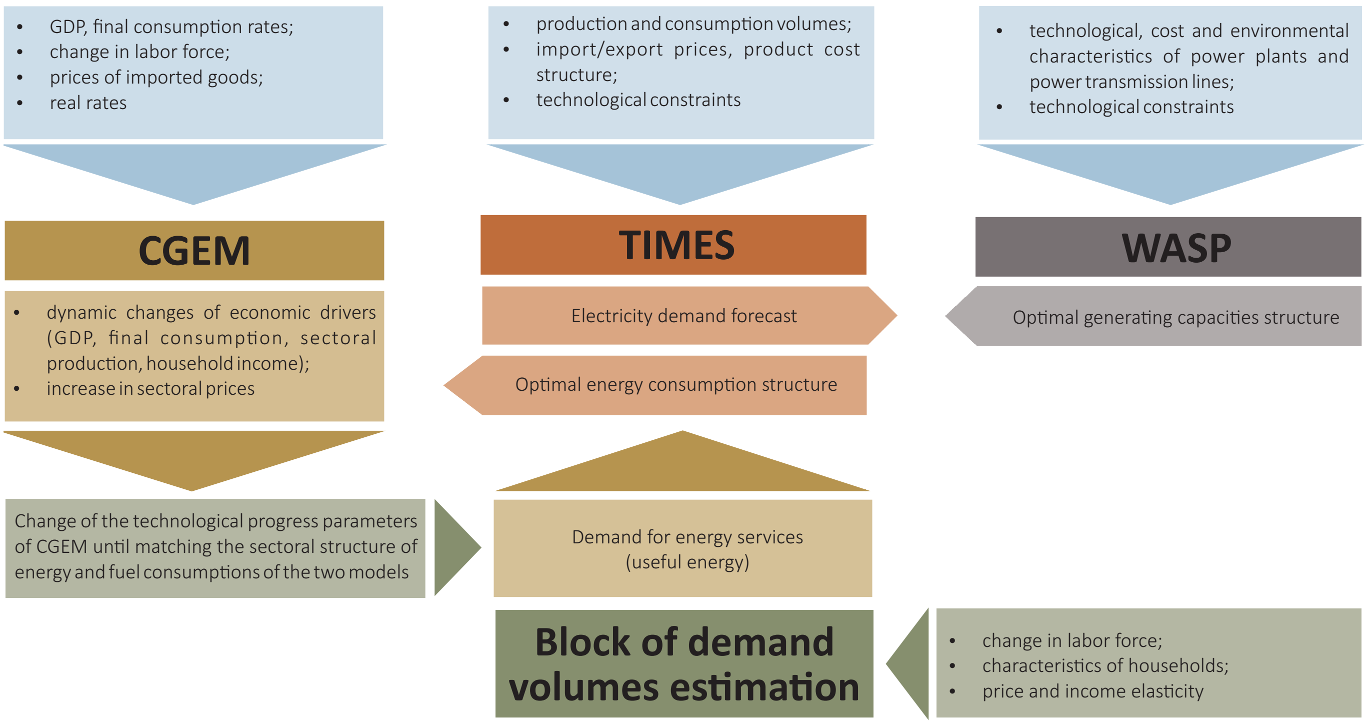


Figure 2.1 Combination of economic and mathematical models to forecast the energy sector development

Note: no additional models to assess the optimization of the power sector (such as WASP Wien Automatic System Planning Package) to verify the structure of generating capacities for imposed technical and economic scenario constraints have been used in this work.
Source: prepared by the authors.

consistant with each other and are used to calibrate and parameterize the CGE model.

Estimated forecasted volumes of demand for energy services (needs), expressed in terms of work or useful energy (production, transportation, heating of buildings, etc.), are presented in *Annex A.1*. For example, the need for heating was calculated by the categories of residential buildings in cities and rural areas, taking into account the dynamics of the population at the place of residence and composition of households, the growth rate of the space per resident, the volumes of housing construction with centralized and autonomous heating systems. Similarly, the need for transportation services was calculated by the type of transport based on the rate of renewal of the fleet of vehicles (rolling stock) and the forecast of production and international trade in goods that are the main types of cargo (agricultural, extractive industry, metal rolling products), which, in turn, depends on the general economic scenario assumptions.

The possibility of meeting the demand for energy services in accordance with the conditions of the macroeconomic scenario is estimated at the next stage with the help of the TIMES-Ukraine energy system model[14]. The model takes into account the imposed budgetary and technological constraints, calculates the optimal combination of energy technologies throughout the chain of the use of energy resources, i.e. explicitly defines the forecasted energy balance of the country. Calculation of other associated important parameters of the forecast, such as marginal prices or emission of pollutants from the use of the estimated set of energy resources is carried out simultaneously.

First, the Reference (Conservative) Scenario has been developed, which assumes no fundamental change in the conditions of the energy system functioning (see the definition in *Section 2.2*). The purpose of the calculations under this scenario is to establish a reference for comparison with the alternative (target) energy scenarios, the development of which is the next step of the analysis algorithm. The lowest total costs (or maximum usefulness) are calculated for all the scenarios within the defined path of system development, and respective assessments of the structure of supply and use of energy by sectors and types of fuel, GHG emissions by categories of consumers, optimal technological structure of producers and consumers of energy, etc. are qualified.

The TIMES-Ukraine model[15] is an optimization model of the energy flows in Ukraine. The energy system of Ukraine (see *Annex A.2*) is represented in the TIMES-Ukraine model as a single region and consists of seven sectors: the energy supply sector (production, import, export, international bunkers, stock changes, and the production of secondary energy resources – petroleum products, briquettes and other); electricity and heat production; industry; transport; household sector (population); trade and services; agriculture (including fishing). That is, the structure of the model corresponds to the structure of the energy balance of Ukraine[16] in line with the methodology of the International Energy Agency. Today the TIMES-Ukraine model takes into account over 1.6 thousand technologies, the model database has been updated based on the data of 2012 and calibrated for the same year. More detailed information on the structure and logic of the TIMES-Ukraine model design is provided in the articles by O. Diachuk and R. Podolets.

13 Podolets, R.Z., Diachuk, O.A. Strategic Planning in Fuel and Energy Complex Based on TIMES-Ukraine Model: Scientific Report/NAS of Ukraine; Institute for Economics and Forecasting. – Kyiv, 2011. – 150 pages.

14 The term ''energy system'' means the whole complex of economic relations related to the production and use of energy resources, therefore this term is wider than the generally used terms «energy industry» or ''fuel and energy complex''.

15 The model is developed by the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine for the study of energy and ecological policy and scenarios of the national energy system development.

16 Energy balances of Ukraine in 2007-2014 / State Statistics Service of Ukraine. – Available at: http://ukrstat.gov.ua/

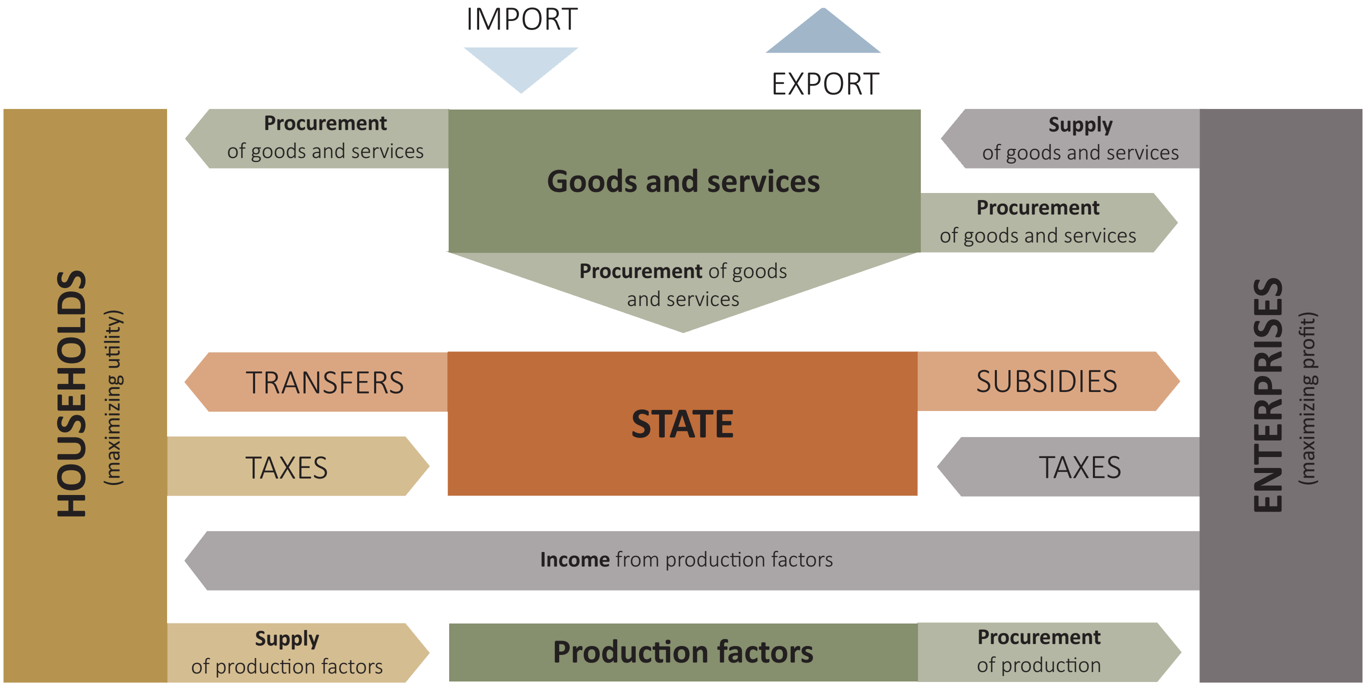


Figure 2.2 Circulation of CGE model flows of Ukraine

Source: prepared by the authors.

The CGE model of Ukraine[17] has been used to assess the socio-economic implications of the implementation of the Liberal and Revolutionary Scenarios of the energy sector development in Ukraine. This model describes the principal inter-industry relationships, takes into account the behavior of such economic agents as enterprises, general government sector and households. The export and import of products are represented as separate units in the model *(Figure 2.2)*.

Producers are divided by 40 types of economic activities in the model; enterprises determine the volume of production and sales to maximize their own profits. Products manufactured by enterprises are consumed by households, general government sector, used for gross capital accumulation as raw materials and materials in the production process, i.e. intermediate consumption, and exported. Money received by enterprises from the sale of goods and services are used to purchase raw materials and production factors – labor and capital. An enterprise can purchase raw materials and materials from national manufacturers or import them. The payment for the use of production factors serves as a source of income of households. Households spend their income to purchase goods and services while trying to maximize their own utility of consumption. The state receives tax revenues, makes transfers, pays subsidies, and purchases products under government orders.

The basic statistical information used in the process of model calibration is grouped in the so-called Social Accounting Matrix (SAM) – that is an extended version of the IO table[18], which in this case differs from the latter by availability of additional information on transfers between economic agents, including the disaggregated structure of tax revenues, data on the sectoral distribution of investments, detailed structure of final household consumption depending on the per capita income level, data on transfers to the Pension Fund and social insurance funds.

Today CGE model of Ukraine is based on the data of IO table for 2012 and updated to 2016 indicators based on the national accounts data using the RAS method procedure[19].

2.2 Definition and Conditions of Energy Sector Development Scenarios

The Reference (Conservative) Scenario is considered as a hypothetical scenario when the characteristics of the most technologies remain unchanged up to 2050, such as they were in 2012. Gradual replacement of technologies takes place only when the life time of certain existing capacities comes to its end. The cost and efficiency of technologies that replace the old ones reflects current trends: the cost decreases with time and the efficiency increases. At the same time, most of the existing technologies still can be used during the modeling period (2012-2050). This approach is useful to assess the implications of the implementation of two alternative scenarios, namely the effectiveness of measures and policies stimulating the technological change in the economy[20].

The first, *Liberal Scenario* (or "Perfect Competitive Market") implies the existence of a perfect competition across the national energy market and its sectors, the availability of economic incentives for the development of renewable energy and implementation of energy efficiency and energy saving measures, implementation of the basic environmental requirements for energy sector installations, application of a low CO_2 emission tax, etc. This scenario makes it possible to assess the competitiveness of renewable energy as compared to the conventional one under equal macroeconomic conditions.

The *Revolutionary Scenario* **of the national energy sector transformation by 2050 has a single comprehensive target to guarantee that energy needs (demand) in the final energy consumption sectors are met exclusively by RES**, which will greatly strengthen energy independence and climate policy of Ukraine. At the same time, the welfare of Ukrainian citizens, reliable energy supply and energy sufficiency, economic, energy, environmental, food and other security must be ensured.

Table 2.1 summarizes key conditions and assumptions of the Reference (Conservative) and alternative scenarios. The macroeconomic indicators, projections of energy prices and dynamics of the population of Ukraine are detailed in the *Section 2.3* and are similar input data for the three scenarios.

Base year for this study is the year of 2012, since it was the last year for Ukraine when the national economy was balanced, there was an economic growth and, most importantly, there was no military and political crisis prompted by the actions of the Russian Federation, and the unity of Ukraine was ensured.

17 Chepeliev, M.H. Modeling and assessment of economic consequences of subsidizing household consumers of energy resources: dissertation of PhD in Economic Sciences: 08.00.11 / Chepeliev Maksym Hryhorovych. – Kyiv, 2015. – 266 pages. – References: Pages 195-230

18 Input-output table (in consumer prices) [Electronic resource] // State Statistics Service of Ukraine. – Available at: http://www.ukrstat.gov.ua/

19 Trinh B. A Short Note on RAS Method [Electronic resource] / B. Trinh and N.V. Phong // Advances in Management & Applied Economics. – 2013. – Vol. 3, no. 4. – P. 133-137. – Available at: http://www.scienpress.com/Upload/AMAE/Vol%203_4_12.pdf

20 https://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch2s2-7-1-1.html

Table 2.1 Matrix of modeled scenarios

CONDITIONS	**SCENARIOS**		
	Reference (Conservative) Scenario	Liberal Scenario	Revolutionary Scenario
GDP[21]	• Average annual GDP growth in the period of 2016-2050 – 4.0%. • By 2050 GDP will grow fourfold.		
Prices of the main energy resources[22]	• The import price of oil will increase from \$96 to \$129 per barrel in the period of 2014-2050. Growth – 35%. • After the decrease in 2015-2016, the import price of coal will fluctuate at \$55-70 (2014)/ton in the period of 2014-2050. Growth in 2050 – 0%. • The price of natural gas will increase from \$10 to \$16 per MBTU in the period of 2014-2050. Growth – 60%.		
Population of Ukraine[23]	• The population of Ukraine will decrease from 45.2 million people in 2014 to 38.9 million people in 2050.		
Cost of technology[24]	• The assumptions about the cost of technology (capital investment and operating costs) using fossil fuels, nuclear energy and RES are primarily based on estimates of the International Energy Agency, data of Lappeenranta University of Technology (Finland) and, of course, data of national experts in energy efficiency and renewable energy.		
Energy efficiency	• There are no measures to increase energy efficiency and energy saving, even economically attractive ones. • Efficiency of technologies in the final energy consumption sectors at the level of 2012. • Implementation of advanced technologies is not planned. • Insignificant influence of external (global) factors on the cost and efficiency of technology. • Energy intensity of GDP decreases as a result of changes in the structure of the economy in line with the macroeconomic scenario and limited changes in the technological structure.	• Possibility of introduction of any measures to increase energy efficiency and energy saving. • Implementation of economically attractive energy efficient measures. • Perfect competition at the national energy market and its sectors.	• The conditions of the Liberal Scenario are in place. • The implementation of any energy efficiency and energy saving measures are stimulated to reduce the use of RES.
Renewable energy sources	• The feed-in-tariff is effective in line with the schedule established by the legislation up to 2030, but there are no environmental, climate or other restrictions on the use of any fuel.	• The feed-in-tariff is effective in line with the schedule established by the legislation up to 2030. There are no institutional barriers and interventions envisioned in the legislation. • There is only an economic incentive for the renewable energy development.	• Achievement of 90-100% RES in the final energy energy consumption. • The feed-in-tariff is effective in line with the schedule established by the legislation up to 2030.
Nuclear power	• No barriers to development. • Possibility of prolonging the operation of the existing power units for a maximum of 20 years. • The cost of new power units corresponds to European indicators.	• No barriers to development. • Possibility of prolonging the operation of the existing power units for a maximum of 20 years. • The cost of new power units in line with European experience.	• Decommissioning of all NPPs by 2050. • Possibility of prolonging the operation of the existing power units of nuclear power plants for a maximum of 20 years by 2049. • No construction of new NPPs.
Environmental requirements	• N/A	• Compliance with the requirements of Directive 2010/75/EU on the limitation of emissions of certain pollutants into the air from large combustion plants (> 50 MW). • Compliance with the requirements of Directive 2015/2193/EU on the limitation of emissions of certain pollutants into the air from medium combustion plants (1-50 MW) has not been approved by Ukraine yet and has not been included in the model.	• Compliance with the requirements of Directive 2010/75/EU on the limitation of emissions of certain pollutants into the air from large combustion plants (> 50 MW). • Compliance with the requirements of Directive 2015/2193/EU on the limitation of emissions of certain pollutants into the air from medium combustion plants (1-50 MW) has not been approved by Ukraine yet and has not been included in the model.

Source: prepared by the authors.

21 See Table 2.2.
22 See Figure 2.3.
23 See Table 2.3.
24 See Annex 2.

2.3 Macroeconomic Conditions and Assumptions

For the purposes of the Reference macroeconomic scenario[25], it was assumed that the military and political conflict in the East of Ukraine would be settled not earlier than in 2018-2019. Under such conditions, the Ukrainian economy is not likely to fully recover from the crisis during the period of 2016-2018. The size of the aggregate GDP is not likely to reach the pre-crisis level of 2012-2013, although there will be a minor economic growth. There is a probability of significant exchange rate fluctuations, and further devaluation of the hryvnia will pose a high risk for the recovery of the economic growth. There will be a slight increase in nominal wages, while the real wages will only increase starting from 2019.

Nevertheless, the economic growth will be driven by the food, light and pharmaceutical industries. Recovery of positive trends coud be also expected in the production of building materials. There will be a positive dynamics in the production of computers, electronic and optical products in machine-building industry.

A gradual recovery of production in the real sector is expected in the short and medium term, but the growth rate will be lower than in the agricultural sector. In the period up to 2020, a decline in output may be observed in certain extractive industries, in particular, in black and brown coal mining. A more active recovery of production will be observed in the gas sector, in particular as a result of the latest gas market reforms and increase of the selling prices for gas extraction companies. Overall, processing industries will grow at a slightly higher rate than mining leading to a decline in the share of the latter in GDP.

The recovery of the overall positive dynamics in the Ukrainian economy can be expected starting from 2017. In 2020-2025, the economy will grow at a rather high rate *(Table 2.2)*. Extractive industries will have a lower growth rate than the processing ones. The mining and metallurgical complex will gradually decrease its share in GDP. This trend is likely to continue in the long term.

The recovery of pre-crisis production volumes in the absolute majority of industries will take place during 2020-2025. However, several sectors will grow quite slowly and will reach pre-crisis production volumes only in the long term, i.e. after 2030. These industries, in particular, include "Extraction of black and brown coal" and "Manufacture of chemicals and chemical products".

The highest growth rates among the sectors of the processing industry in the long-term will be observed in machine-building industries, in particular, "Manufacture of computers, electronic and optical products" and "Manufacture of electrical equipment", as well as in food and pharmaceutical industries.

In the long-term period (2026-2050), no significant structural shifts are expected in the Ukrainian economy at the aggregated level, and the growth rates of the service sector will be comparable to the growth rates of manufacturing industries. The highest growth rates in the tertiary sector are expected in "Telecommunications" and "Computer programming, consulting and provision of information services". In general, annual average growth rate of GDP projected under reference macroeconomic scenario would be at the level of 4% *(Table 2.2)*.

Overall, the presented above GDP forecast for Ukraine is in line with the expectations of the IMF and the World Bank. Thus, the IMF forecasts annual average growth rate of the GDP at 2.9%[26] in 2016-2020. According to the World Bank[27], the annual average growth rate of UGDP will be 2.0% in the period of 2016-2018, and it will be accelerated in the medium term (1% in 2016, 2% in 2017, and 3% in 2018).

The structure of Ukraine's GDP by sectors for the period 2015-2050 is presented in *Annex A.4*.

Table 2.2 Annual average Ukraine's GDP growth rate in the period of 2016-2050, %

Sectors/Years	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Agriculture, forestry and fishing	1.4	5.7	4.9	5.1	5.1	5.1	5.1
Mining and quarrying	3.0	3.4	2.3	2.0	2.0	2.0	2.0
Processing industry	6.5	5.6	4.1	3.3	3.3	3.3	3.3
Supply of electricity, gas, steam and conditioned air	4.4	4.9	4.8	4.5	4.5	4.5	4.5
Construction	8.0	6.4	5.1	5.1	5.1	5.1	5.1
Manufacturing – total	4.2	5.3	4.3	4.0	4.0	4.0	4.0
Services– total	2.5	5.0	4.2	4.0	4.0	4.0	4.0
GDP	2.8	5.0	4.2	4.0	4.0	4.0	4.0

Source: prepared by the specialists of the Institute for Economics and Forecasting of the NAS of Ukraine in 2016 within the USAID Municipal Energy Reform Project in Ukraine.

Table 2.3 Forecast of the population of Ukraine up to 2050, million people[28]

Scenarios	2012	2014	2015*	2020	2025	2030	2035	2040	2045	2050
IDSS- AAA scenario	45.3	45.2	42.7	44.4	43.6	42.8	41.8	40.8	39.9	38.9
IDSS- HHH scenario				45.1	45.1	45.1	45.1	45.2	45.4	45.6
IDSS- LLL scenario				43.4	41.6	39.7	37.8	35.8	33.9	32.0
IDSS- Stable scenario				44.1	42.7	41.1	39.5	37.8	36.1	34.3
IDSS- AAZ scenario				44.3	43.3	42.1	40.8	39.5	38.3	37.1
IDSS- HLH scenario				44.3	43.5	42.7	41.8	41.1	40.7	40.3
IDSS- LHL scenario				44.2	43.2	42.1	41.0	39.8	38.5	37.0
Scenario of the United Nations Department of Economic and Social Affairs				43.7	42.4	40.9	39.3	37.8	36.4	35.1

* Excluding the temporarily occupied territory of the Autonomous Republic of Crimea and the city of Sevastopol.
Source: prepared by the authors based on the data of the Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine.

25 The reference macroeconomic scenario was prepared by the specialists of the Institute for Economics and Forecasting of the NAS of Ukraine in 2016 within the USAID Municipal Energy Reform Project in Ukraine.

26 World Economic Outlook Database. International Monetary Fund. Available from: https://www.imf.org/external/pubs/ft/weo/2016/01/weodata/index.aspx

27 Global Economic Prospects. Europe and Central Asia. The World Bank. Available from: http://pubdocs.worldbank.org/en/484281463605616745/Global-Economic-Prospects-June–2016-Europe-and-Central-Asia-analysis.pdf

28 Abbreviated names of the scenarios mean: AAA – Average birth rate, Average life expectancy, Average net migration; HHH – High birth rate, High life expectancy, High net migration; LLL – Low birth rate, Low life expectancy, Low net migration; AAZ – Average birth rate, Average life expectancy, Zero net migration; HLH – High birth rate, Low life expectancy, High net migration; LHL – Low birth rate, High life expectancy, Low net migration; the Stable scenario assumes that all components are fixed at the level of 2011.

2.4 Demographic Conditions and Assumptions

Modeling of scenarios of the Ukraine's energy sector development is based on the use of population projections of the Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine (IDSS of the NAS of Ukraine)[29], which are in line with projections of the United Nations Department of Economic and Social Affairs[30]. Demographic forecasts of national scientists can be considered as more reliable, as they better take into account the current conditions in Ukraine.

This study uses one demographic scenario of the IDSS of the NAS of Ukraine (AAA scenario, *Table 2.3*), which predicts average birth rates, average life expectancy and average net migration in Ukraine.

Table 2.3 shows that the population of Ukraine decreased sharply in 2015 due to the temporary occupation of the territory of the Autonomous Republic of Crimea and the city of Sevastopol. Since all the scenarios suggest that temporary occupation will not last longer than 2020, population of Ukraine will return to its trajectory and will continue to move in line with the previously developed demographic scenarios.

2.5 Forecast of Energy Resources' Prices

The energy prices forecast by 2050 for Ukraine is based on the forecast prices for the world market by 2030[31] published by a team of researchers of the World Bank in the latest Commodities Market Overview (January 2017)[32]. A forecast of prices for 2035-2050 is obtained by a simple extrapolation of data provided in the January 2017 Commodities Market Overview (*Figure 2.3*).

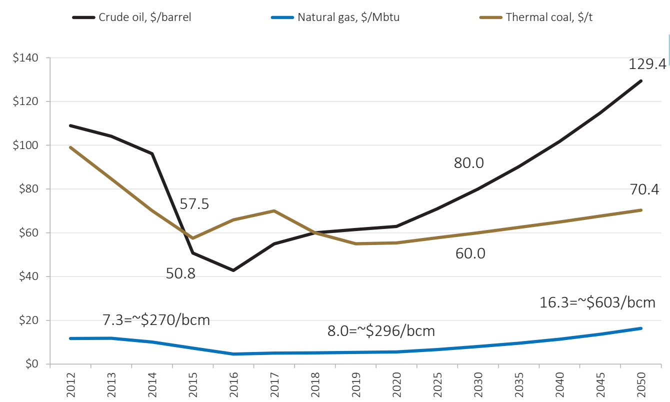


Figure 2.3 Price forecast for main energy resources (nominal prices)

Units: USD $. Source: prepared by the authors based on the data of the World Bank (prices for 2014-2030), and own calculations of prices for the period of 2035-2050.

2.6 Assumptions on Nuclear Energy

State company NNEGC "Energoatom" is responsible for operating of all NPPs in Ukraine (Zaporizhzhia, Rivne, Khmelnytskyi and South Ukraine NPPs). There are 15 power units at the operating NPPs: 13 with the VVER-1,000 type reactor units and 2 with the VVER-440 type reactor units.

As can be seen in *Table 2.4*, the construction of power units No. 3 and No. 4 at Khmelnytskyi NPP started in the 80s of 20th century and has not been completed yet. It was suspended by the moratorium on the construction of the new nuclear units in 1990. As of the beginning of April 2017, there is no decision on the construction (completion) of these power units approved in accordance in line with all procedures.

The Verkhovna Rada of Ukraine adopted laws in September 2015 that denounced the Agreement between the Cabinet of Ministers of Ukraine and the Government of the Russian Federation on the cooperation in the construction of KhNPPs No. 3 and No. 4 and declared invalid the Law of Ukraine "On Placement, Designing and Construction of Power Units No. 3 and No. 4 of the Khmelnytskyi NPP" No. 5217-VI

Table 2.4 Summary information on operating NPPs in Ukraine

NPP name	Power unit No.	Reactor unit type	Installed power capacity (MW)	Start of construction	Connection to the grid	Validity of the operation license
Zaporizhzhia (ZNPP)	1*	VVER-1000/320	1,000	04/1980	10/12/1984	23/12/2025
	2*	VVER-1000/320	1,000	04/1981	22/07/1985	19/02/2026
	3	VVER-1000/320	1,000	04/1982	10/12/1986	05/03/2017
	4	VVER-1000/320	1,000	01/1984	18/12/1987	04/04/2018
	5	VVER-1000/320	1,000	07/1985	14/08/1989	27/05/2020
	6	VVER-1000/320	1,000	06/1986	19/10/1995	21/10/2026
South Ukraine (SUNPP)	1*	VVER-1000/302	1,000	03/1977	31/12/1982	20/12/2023
	2*	VVER-1000/338	1,000	10/1979	06/01/1985	31/12/2025
	3	VVER-1000/320	1,000	02/1985	20/09/1989	10/02/2020
Rivne (RNPP)	1**	VVER-440/213	415	08/1976	22/12/1980	22/12/2030
	2**	VVER-440/213	420	10/1977	22/12/1981	22/12/2031
	3	VVER-1000/320	1,000	02/1981	21/12/1986	11/12/2017
	4	VVER-1000/320	1,000	1986	10/10/2004	07/06/2035
Khmelnytskyi (KhNPP)	1	VVER-1000/320	1,000	11/1981	22/12/1987	13/12/2018
	2	VVER-1000/320	1,000	1983	07/08/2004	07/09/2035
	3***	VVER-1000		09/1985		
	4***	VVER-1000		06/1986		

* The life time of power units No. 1 and No. 2 of South Ukraine NPP, No. 1 and No. 2 of Zaporizhzhia NPP has been extended for 10 years.
** The life time of power units No. 1 and No. 2 of Rivne NPP has been extended for 20 years.
*** The construction of the power units has not been completed.
Source: prepared by the authors [33, 34]

29 http://www.idss.org.ua/monografii/popforecast2014.rar

30 http://esa.un.org/unpd/wpp/unpp/panel_population.htm

31 Consodering that the energy prices in Ukraine are largelyliberalized, it is reasonable to assume that the prices in the national market will correspond to the world market prices.

32 Commodities Market Overview. Investment Weakness in Commodity Exporters / World Bank Group, January 2017. Available at: http://pubdocs.worldbank.org/en/820161485188875433/CMO-January-2017-Full-Report.pdf

33 Order of the Ministry of Energy and Coal Industry of Ukraine No. 798 dated 10/12/2015 "Decommissioning Conception of the operating NPPs in Ukraine". – Page 11.

34 Presentation of SE NNEGC "Energoatom": current state, development perspectives and problematic issues. – Kyiv, 2017. – Available at: http: //www.xaec.org.ua/pdf/pres201701261048.pdf

dated September 6, 2012. Currently, there is no new formal construction agreement with other suppliers of nuclear technology and no corresponding funding has been confirmed.

However, NNEGC "Energoatom" estimates the construction readiness of new power units at KhNPP: power unit No. 3 – 75%, power unit No. 4 – 28%, the total approved construction cost – EUR 3.7 billion.

According to experts of the National Ecological Center of Ukraine (NECU), given the long process of preparation of project documentation and construction of NPPs in Europe[35], **it is not likely that all stages of the process will be completed by 2030 including selecting technology supplier and securing funding, approval of the project documenttion and the construction of power units.** An additional factor that will significantly influence the increase of the construction period and the cost of the design, is the unreliability of using existing structures and the probability of their partial or complete dismantling recognized by the State Nuclear Regulatory Inspectorate of Ukraine[36]. These structures stayed unconservated for more than 30 years (from 1985 and 1986) and partly flooded with water. Thus, the possibility of their use and reliability is questionable.

According to the NNEGC "Energoatom", the cost of power units construction at new sites is USD 7,000 (~ EUR 6,514) million per GW[37]. According to 2016 report of the European Commission[38] the cost of new nuclear power plants construction is growing every year. For example, the construction of new NPP power units of the EPR type (European Pressurized Reactor) with a capacity of 1,670 MW in Flamanville (France) is estimated at EUR 6,287 (~ USD 6,756) per kW, and in Hanhikivi (Finland) the cost of construction of new NPP power units of 1,200 MW is estimated at EUR 6-7 billion or EUR 5,000-5,800 (~ USD 5,373-6,233) per kW. The joint study of the International Energy Agency (IEA) and the Nuclear Energy Agency at the Organization for Economic Cooperation and Development (OECD) indicates that the cost of construction of new NPP power units in European countries is from USD 4,986 (EUR 4,640) per kW in Slovakia to USD 7,535 (EUR 7,012) per kW in Hungary[39]. Thus, the cost of construction in Hungary is compareable to the estimates of the NNEGC "Energoatom".

Taking into account discussed above data and the fact that construction costs are constantly growing due to the increased safety requirements for operation of NPPs, data of the NNEGC "Energoatom" was taken into account for the long-term forecasting of the energy sector development in Ukraine. In particular, it was estimated that the price of construction of new NPP power units could amount to USD 7.0 or EUR 6.5 billion per 1,000 MW of installed capacity.

The life time of 6 out of 15 operating power units at NPPs was extended for:

- RNPP No. 1, 2 – operational lifetime was extended on December 10, 2010 till 2030 and 2031, respectively;
- SUNPP No. 1 – operational lifetime was extended on November 28, 2013 till December 02, 2023;
- ZNPP No. 1 – operational lifetime was extended on September 14, 2016 till December 23, 2025;
- ZNPP No. 2 – operational lifetime was extended on October 04, 2016 till February 19, 2026.

Work is carried out at 4 power units: RNPP No. 3; ZNPP No. 3, 4; KhNPP No. 1. Operational lifetime of SUNPP No. 3 and the ZNPP No. 5 will expire in 2020, and of RNPP No. 4; ZNPP No. 6; KhNPP No. 2 after 2020.

According to the NNEGC "Energoatom"[40], the specific cost of a unit of installed capacity for the extension of the life time of power units No. 1, 2 of RNPP amounted to USD 358 per 1 kW[41] (taking into account implemented reconstruction and modernization measures). In April 2016, the Head of the NNEGC "Energoatom" noted in his presentation at the Hearings at the Verkhovna Rada Committee on Fuel and Energy Complex, Nuclear Policy and Nuclear Safety, that according to the latest estimates, the cost of extending the life time of power units of Ukraine's NPPs is about USD 300 million per GW (or USD 300 per 1 kW), while the construction of a new power unit costs USD 7,000 (~ EUR 6,514) million per GW. However, the costs of implementing the Comprehensive (consolidated) program for increasing the level of safety at Ukraine's NPPs, approved by the Regulation of the Cabinet of Ministers of Ukraine No. 1270[42] as of December 7, 2011, should be added to the cost of extending the life time of Ukrainian NPPs. According to the estimates of the NNEGC "Energoatom", this amount was UAH 30.1 billion (excluding VAT) or USD 1.31 billion (~ EUR 1.22)[43].

In order to determine the cost of extending the life time of power units at NPP used for modelling of the long-term development of Ukraine's energy sector, the actual costs incurred in extending the life time of power units No. 1, 2 of RNPP (USD 358 per 1 kW or EUR 333 million per 1,000 MW) were taken into an account. The average costs of the Comprehensive programme implementation for NPP power units (9 units) were added for NPPs for which lifetime has not been extended yet. Consequently, the cost of extending the life time of operating NPP units for 20 years will be USD 358 + USD 1,310/9 = USD 504 (~ EUR 467) million per 1,000 MW of installed capacity.

35 The Flamanville 3 reactor in France is scheduled to be completed in 11 years, and in Finland, the preparation process for the construction of Olkiluoto 3 began in 2000 and is scheduled to be completed in 2018 with a 9 year delay. Find more at https://www.carbonbrief.org/new-nuclear-finlands-cautionary-tale-for-the-uk and https://www.theguardian.com/environment/2016/jul/27/flamanville-france-edf-nuclear-reactor-hinkley-point-c

36 Letter of the State Nuclear Regulatory Inspectorate of Ukraine No. 15-55/1439-60 dated March 01, 2013 regarding requirements for the construction design of power units No.3, 4 of Khmelnytskyi NPP. – Available at: http://necu.org.ua/wp-content/uploads/novi_vymogy_khaes_vidpovid.pdf

37 Presentation ''Strategic development of the nuclear industry. Problematic Issues'' made by SE NNEGC ''Energoatom'' at the Hearings at the Verkhovna Rada Committee on Fuel and Energy Complex, Nuclear Policy and Nuclear Safety Issues on April 15, 2016- Page 34.- Available at: https://yadi.sk/i/td-Gtgo6r7XBQ

38 Communication from the Commission ‹‹Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for the opinion of the European Economic and Social Committee››, Brussels, 4.4.2016, SWD(2016) 102 final. – Available at: https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf

39 Projected Costs of Generating Electricity // International Energy Agency, Nuclear energy agency under the Organisation for Economic Co-operation and Development, 2015. Available at: https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

40 Response to the request of the National Ecological Center of Ukraine, letter No. 11673 dated August 16, 2013

41 Letter from NNEGC ''Energoatom'' ''On provision of information'' No. 11673 dated August 16, 2013 – Available at: http://necu.org.ua/wp-content/uploads/2017/04/vidpovid-ea-2013.pdf

42 Regulation of the Cabinet of Ministers of Ukraine No. 1270 as of December 07, 2011 ''On approval of the Comprehensive (consolidated) program for increasing the level of safety at Ukraine's NPP s''. – Available at: http://zakon0.rada.gov.ua/laws/show/1270-2011-%D0%BF

43 Official exchange rate established by the National Bank of Ukraine as of January 6, 2016 – Available at: https://bank.gov.ua/control/uk/curmetal/currency/search?formType=searchFormDate&time_step=daily&date= 06.01.2016&&execute=%D0%92%D0%B8%D0%BA%D0%BE%D0%BD%D0%B0%D1%82%D0%B8&outer=xls

3 POTENTIAL OF RENEWABLE ENERGY SOURCES IN UKRAINE

| Wind Energy | Solar Power | Bio-energy | Hydro-power | Balancing WPP and SPP |

3.1 Wind Energy

Ukraine has a significant natural potential for the implementation of wind energy projects, which determines government's interest in the development of this industry and also attracts a large number of potential national and foreign investors.

According to the latest estimates of the Ukrainian Wind Energy Association (UWEA), 16 GW of WPP is a real potential of the wind energy sector of Ukraine. If capacity utilization rate is at least 40%, which is confirmed in practice for currently operating WPPs in Zaporizhzhia, Kherson and Mykolaiv regions, the annual power generation capacity of WPPs can amount to 56 billion kWh. This is equivalent to 29% of the total electricity production in Ukraine before the occupation of the Autonomous Republic of Crimea, city of Sevastopol by the Russian Federation and its military aggression on the territory of defined areas of Donetsk and Luhansk regions. Based on 2016 figures, 56 billion kWh equals to 34% of the total electricity production.

Table 3.1 Estimation of perspective technical characteristics of on-shore WPPs

		2015	2020	2025	2030	2035	2040	2045	2050
Cost of installed capacity (overnight cost[44]), EUR/kW	Minimum	1,600	1,500	1,500	1,440	1,350	1,300	1,250	1,250
	Average	1,665	1,590	1,590	1,505	1,440	1,365	1,325	1,300
	Maximum	1,730	1,680	1,680	1,570	1,530	1,430	1,400	1,350
Operating expenses (opex), EUR/kW	Minimum	20	23	26	29	32	35	35	35
	Average	25	28	31	34	37	40	40	40
	Maximum	30	33	36	39	42	45	45	45
Average ICUF for all WPPs in Ukraine		36%	36%	36%	36%	37%	38%	39%	40%

Source: prepared by the authors based on the data of the Ukrainian Wind Energy Association, 2016.

Full cost of construction of wind power plants is in the range from USD 1,400 to 1,700 per 1 kW. According to UWEA forecasts, this cost could decrease by more than 20% by 2050 (*Table 3.1*).

Taking into account study by Child et al. (2016)[45], more optimistic potential of wind power (25 GW in 2030 and 60 GW in 2050) was considered to model the Liberal and Revolutionary Scenarios.

In order to avoid the negative impact of the rapid development of wind energy on the populations of birds it is necessary to take into account at the project planning stage the distance to the protected areas and / or areas of mass seasonal concentrations and migratory routes of birds. This should be done when environmental impact assessment of the project is carried out. Reasonable planning of wind farms will avoid or significantly reduce the potential risks of wind power affecting the population of birds.

3.2 Solar Power

According to the State Agency on Energy Efficiency and Energy Saving of Ukraine, the theoretically possible potential of solar energy at the territory of Ukraine is over 730 billion kWh per year[46], but the technically possible potential is only 34.2 billion kWh per year. One of the main obstacles to the intensive development of renewable power is a poorly developed grid and outdated centralized approach. According to Rentechno experts[47], renewable energy technologies in Ukraine can cover up to 80% of electricity demand taking into an account current level of technology development.

The number of households installing rooftop PV systems can reach 40-50% by 2050. In addition, solar collectors for heating water will become more and more cost-effective. These technologies will allow meeting the demand for hot water in private households by 70-100% during the summer and by 15% in winter. In the services sector, the potential for solar energy use is smaller, but it is also promising.

To model the Liberal and Revolutionary Scenarios, the following assumptions regarding the potential (*Table 3.2*) and the cost (*Table 3.3*) of solar power in Ukraine were used, taking into account study of Child et. al (2016)[48], and consultations with national experts.

Table 3.2 Potential of Solar Power, GW

	2030	2050
For ground-mounted power plants	16	90
For roof-mounted power plants	5	36

Source: prepared by the authors based on the data presented in the study by M. Child, D. Bogdanov and C. Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016, and consultations with national experts.

Table 3.3 Cost of solar power plants, EUR/kW

	2015	2020	2030	2050
Ground	1,300	750	700	475
Roof	1,700	800	750	510

Source: prepared by the authors based on the data presented in the study by of M. Child, D. Bogdanov and C. Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016, and consultations with national experts.

3.3 Bioenergy

According to the Bioenergy Association of Ukraine, the economically feasible current bioenergy potential is about 20 million toe, and it could reach 42 million toe in 2050 (*Table 3.4*). This is possible due to increased use of corn for biogas production, energy crops cultivation and use of biogas. Currently available energy potential of wood and agricultural residues and wastes is almost not used. To enable its use, logistical networks for collecting, delivering and storage of biomass should be developed, since the transportation of wood with a low bulk density over long distances is not cost-effective. In order to enable the use of biomass in the utilities sector, long-term wood supply contracts are required in addition to addressing a number of technical issues.

Cogeneration technologies allow receiving both heat and electric power. Renewable "raw materials" for such technologies can be biogas, methane of coal deposits, etc. New (not used) cogeneration units of the leading world manufacturers, as well as those that were in use, are available on Ukraine's market. Main technical characteristics of cogeneration technologies used to model the long-term scenarios of the energy sector development are provided in *Table 3.5.*

In case co-firing of biomass with coal is used the investment is USD 50-250 kW, the cost of electricity is USD 20/MWh (if own raw materials are available and the transport costs are minimal). The cost of raw materials

44 Overnight cost includes pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).

45 M.Child, D.Bogdanov and C.Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016: https://www.researchgate.net/publication/315117520_The_role_of_storage_technologies_for_the_transition_to_a_100_renewable_energy_system_in_Ukraine.

46 http://saee.gov.ua/uk/pressroom/1133

47 According to the result of consultations with the experts in the field of RES conducted in preparation of this report in March 2017.

48 M.Child, D.Bogdanov and C.Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016

Table 3.4 Bioenergy potential of Ukraine

Biomass type	2015			2050
	Theoretical potential, mln t	Share available for energy sector, %	Economic potential, mln tce[49]	Economic potential, mln tce
Cereals straw	35.14	30	5.22	7.83
Rape straw	3.10	40	0.62	0.93
Corn grain production wastes (stems, cores)	30.3	40	3.31	4.97
Sunflower seed production wastes	21.2	40	1.74	1.74
Secondary agricultural wastes (sunflower husks)	1.9	41	0.39	0.39
Total agricultural potential	91.64		11.28	15.86
Wood biomass (firewood, logging wastes and residues, splinters)	8.8	41	1.47	2.97
Wood biomass (maintenance logging of forest bands, dead-wood)	11.0	58	2.57	1.47
Total wood	14.80		3.45	4.44
Biodiesel	-	-	0.27	0.27
Bioethanol	-	-	0.77	0.77
Total biofuel	-	-	1.04	1.04
Biogas from by-products of the agri-food sector (manure + food industry)	1.6 bln m^3 CH_4	50	0.97	3.40
Biogas from solid waste landfills	0.6 bln m^3 CH_4	34	0.26	0.85
Biogas from wastewater	1.0 bln m^3 CH_4	23	0.27	0.56
Total biogas	3.2 bln m^3 CH_4		1.5	4.81
Poplar, miscanthus, acacia, alder, willow	11.5	90	6.28	18.84
Corn (biogas)	3.3 bln m^3 CH_4	90	3.68	14.72
Total energy crops			9.96	33.56
Peat			0.4	0.4
TOTAL, million tce			27.63	60.10
TOTAL, million toe			19.34	42.07

Source: data provided by the Bioenergy Association of Ukraine.
Note: considering the significant environmental impacts of peat extraction, this study does not include energy potential of peat for designing scenarios for the energy sector development.

Table 3.5 Basic costs of cogeneration technologies based on biomass

	New	Used
Capital expenditure, EUR/kW$_{electr.}$	532	250
Operating expenses, EUR/kW$_{electr.}$	20	20
CP, %	87.2	87.2

Source: prepared by the authors based on data at http://m-energo.biz/goods/al/Belgium_JMC412_biogas_2010_11000.

(biomass) is USD 3-3.5/GJ, so the cost of electricity can exceed USD 30-50/MWh. Power plants using only biomass are more expensive and require the investment of USD 1,500-3,000/kW. In this case, the cost of electricity can be USD 40-90/MWh[50].

To model the long-term development of the energy sector, it has been assumed that the share of hot water supply provided by biomass boilers will correspond to the share of the population using biomass boilers for heating by 2050. Cooking with biomass as a fuel is not expected in the future. According to the Bioenergy Association of Ukraine, today the production of thermal energy from biomass is cost-effective at current prices for natural gas and will remain so in the future. The payback period for biomass power plants is 8 years subject to the current feed-in-tariff, while the biomass CHPP has a payback period of 4.5 years, which is attractive result for business.

The main technical characteristics of biomass TPPs, CHPPs, biomass boilers and biogas technologies used to model the long-term scenarios of the energy sector development are developed based on data of the Bioenergy Association of Ukraine, taking into consideration studies of Child et al. (2016)[51] and presented in *Table 3.6-3.9*. In addition, it was taken into account that the reduction of capital costs could be achieved due to domestic production of equipment.

3.4 Hydropower

Large hydropower development is limited for all scenarios, as this type of generation is recognized as unsustainable renewable energy source. Thus, only the completion of the Kakhovka HPP-2 on the basis of the existing dam is potentially considered, since serious environmental impacts are not expected in this case. Based on these assumptions, the capacity of large hydropower (HPP and PSPP) will be 6,033 MW (2015) + 250 MW (Kakhovka HPP-2), which will amount to 6,283 MW in total.

According to environmental NGOs there is no small HPP in Ukraine that meets environmental criteria, and they bring much more environmental damage than potential benefits can be obtained (for example, a reduction of greenhouse gas emissions). At the same time, there are examples of HPPs in Austria and Norway that are completely safe for the environment. Therefore, a compromise option was chosen in this study: the use of 50% of the available potential of small HPP provided that the most stringent environmental criteria are met. As of 2016, installed capacity of small HPPs is 90 MW[52].

According to the Institute of Renewable Energy of the National Academy of Sciences of Ukraine, the maximum capacity of small HPPs, which could be achieved by 2030,

49 tce stands for tons of coal equivalent

50 https://www.iea.org/publications/freepublications/publication/essentials3.pdf

51 M.Child, D.Bogdanov and C.Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016

52 Report "Development of Renewable Energy Sources in Ukraine", http://www.minregion.gov.ua/wp-content/uploads/2017/03/Rozvitok-VDE-v-Ukrai--ni.pdf

Table 3.6 Basic costs of biomass TPPs

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW$_{electr.}$	2,800	2,800	2,800	2,600	2,500	2,400	2,200	2,000
Operating expenses, EUR/kW$_{electr.}$	30							
CP, %	24	24	25	26	28	29	30	31
ICUF, %	50							
Life time, years	30							
Biomass from waste of agri-food complex, etc.								
Capital expenditure, EUR/kW$_{electr.}$	3,500	2,900	2,800	2,700	2,600	2,500	2,300	2,100
Operating expenses, EUR/kW$_{electr.}$	30							
CP, %	23	23	24	24	25	27	28	29
ICUF, %	50							
Life time, years	30							
Biogas								
Capital expenditure, EUR/kW$_{electr.}$	4,500	4,400	4,300	4,200	4,100	4,000	3,900	3,800
Operating expenses, EUR/kW$_{electr.}$	30							
CP, %	42	42	42	43	43	43	44	44
ICUF, %	90							
Life time, years	30							

Source: prepared by the authors based on the data of the Bioenergy Association of Ukraine and study by M. Child, D. Bogdanov and C. Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016.

Table 3.7 Basic costs of biomass CHPPs

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW$_{electr.}$	3,500	3,400	3,300	3,200	3,100	3,000	2,900	2,800
Operating expenses, EUR/kW$_{electr.}$	50							
CP, %	20	20	20	20	20	20	21	21
ICUF, %	50							
Life time, years	35							
Biomass from waste of agro-industrial complex								
Capital expenditure, EUR/kW$_{electr.}$	3,500	3,400	3,200	3,100	2,900	2,900	2,800	2,800
Operating expenses, EUR/kW$_{electr.}$	55							
CP, %	19	19	19	19	19	19	20	20
ICUF, %	50							
Life time, years	35							
Household waste								
Capital expenditure, EUR/kW$_{electr.}$	5,500	5,400	5,200	5,100	5,000	4,800	4,500	4,500
Operating expenses, EUR/kW$_{electr.}$	55							
CP, %	25	25	25	25	25	25	26	26
ICUF, %	50							
Life time, years	35							
Energy crops								
Capital expenditure, EUR/kW$_{electr.}$	3,500	3,400	3,300	3,200	3,100	3,000	3,000	3,000
Operating expenses, EUR/kW$_{electr.}$	50							
CP, %	20	20	20	20	20	20	21	21
ICUF, %	50							
Life time, years	35							

Source: prepared by the authors based on the data of the Bioenergy Association of Ukraine and study by M. Child, D. Bogdanov and C. Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016.

is 250 MW[53]. That is, the additional potential to existing capacities will be 250-90 = 180 MW. Assuming that 50% of the new small HPPs meet all environmental criteria, the additional increase will be 90 MW. It is assumed that a significant part of this potential should be implemented as a result of modernization and increase of efficiency of the existing small HPPs. New mini-HPPs can only be constructed subject to stringent environmental criteria that need to be introduced at

53 Report "Development of Renewable Energy Sources in Ukraine", http://www.minregion.gov.ua/wp-content/uploads/2017/03/Rozvitok-VDE-v-Ukrai--ni.pdf

Table 3.8 Basic costs of biomass boiler houses

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW$_{electr.}$	150	145	142	140	138	136	136	136
Operating expenses, EUR/kW$_{electr.}$	7							
CP, %	64	64	64	64	64	65	65	65
ICUF, %	50							
Life time, years	35							
Waste of the agri-food complex, etc.								
Capital expenditure, EUR/kW$_{electr.}$	400	350	320	300	280	270	260	250
Operating expenses, EUR/kW$_{electr.}$	7							
CP, %	62	62	62	62	63	63	63	64
ICUF, %	50							
Life time, years	35							

Source: prepared by the authors based on the data of the Bioenergy Association of Ukraine.

Table 3.9 Basic costs of industrial biomass boilers

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW$_{electr.}$	145	142	140	138	136	134	134	145
Operating expenses, EUR/kW$_{electr.}$	7							
CP, %	83							
ICUF, %	60							
Life time, years	40							
Waste of the agri-industrial complex, etc.								
Capital expenditure, EUR/kW$_{electr.}$	270	260	250	240	230	220	220	270
Operating expenses, EUR/kW$_{electr.}$	7							
CP, %	80							
ICUF, %	60							
Life time, years	40							

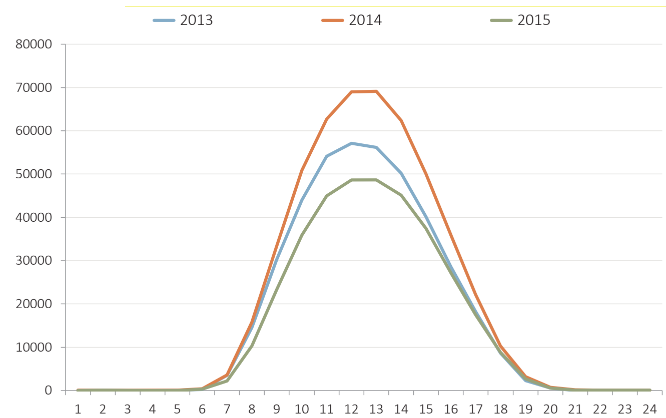
Source: prepared by the authors based on data of the Bioenergy Association of Ukraine.

the legislative level (such as those used by the International Rivers Network[54], WWF[55], Greenpeace, Bankwatch[56]). In addition, after 2030 the feed-in-tariff will be abolished, so the construction of new mini-HPPs after 2030 is very questionable, as the latter will not be competative with the cost of WPP and SPP that are getting cheaper rapidly.

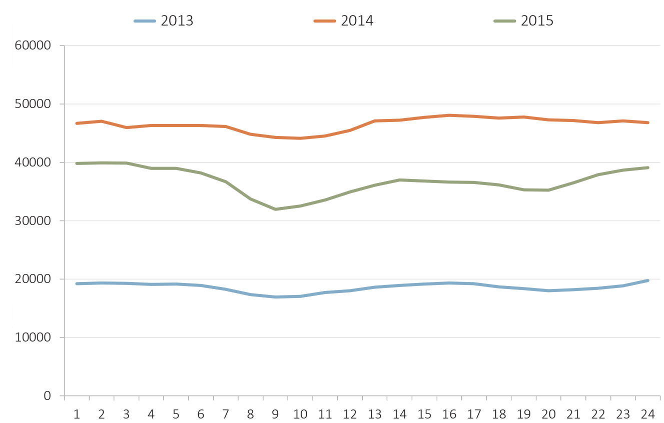
3.5 Balancing WPP and SPP

Transition of the electricity sector to the use of RES (mainly wind and solar energy) by 90-100% will require the necessary amount of balancing capacity. Hydropower will not be able to meet the demand for balancing capacity, so development of solar and wind energy should be accompanied by the development of energy storage technologies (batteries) to ensure the stability and predictability of these types of generation.

Figure 3.1 presents the diagrams of the distribution of average daily electricity production by solar and wind power plants in Ukraine for the period of 2013-2015. At first glance, these diagrams (in annual terms) look rather smooth and can be easily predicted, and, consequently, the calculation of required balancing capacity promises to be simple.



a. SPPs



b. WPPs

Figure 3.1 Distribution of annual average daily electricity production by SPPs (a) and WPPs (b) in Ukraine in 2013-2015

Units: vertical axis – thousand kWh, horizontal axis – hours. Source: prepared by the authors based on the data of NEC "Ukrenergo".

If distribution of electricity production by SPPs and WPPs in Ukraine is presented as monthly average (*Figures 3.2-3.3*), balancing problem looks more complicated, but equally acceptable for choosing the algorithm (method) for calculating required balancing capacity.

However, it is necessary to examine daily electricity production by SPPs and WPPs. *Figures 3.4-3.5* illustrate a significant fluctuation throughout the year.

In order to calculate the volume of balancing capacities in the form of batteries, an assumption (without taking into account balancing potential of hydropower and bioenergy) was made that they should ensure constant power production by SPPs and WPPs during the day. In such case the amount of electricity accumulated by batteries should be equal to its production. To provide theoretical explanation of the proposed approach, *Figure 3.6* shows the normalized schedule of SPPs electricity generation in Ukraine in 2015. It is assumed that at the time when the production of a SPP exceeds the weighted average value, the battery will be charging, and the battery will supply electricity to the grid if electricity production is

54 https://www.internationalrivers.org/

55 http://wwf.panda.org/uk/?285130/hydropower-Ukraine

56 https://bankwatch.org/publications/sustainability-criteria-hydropower-development

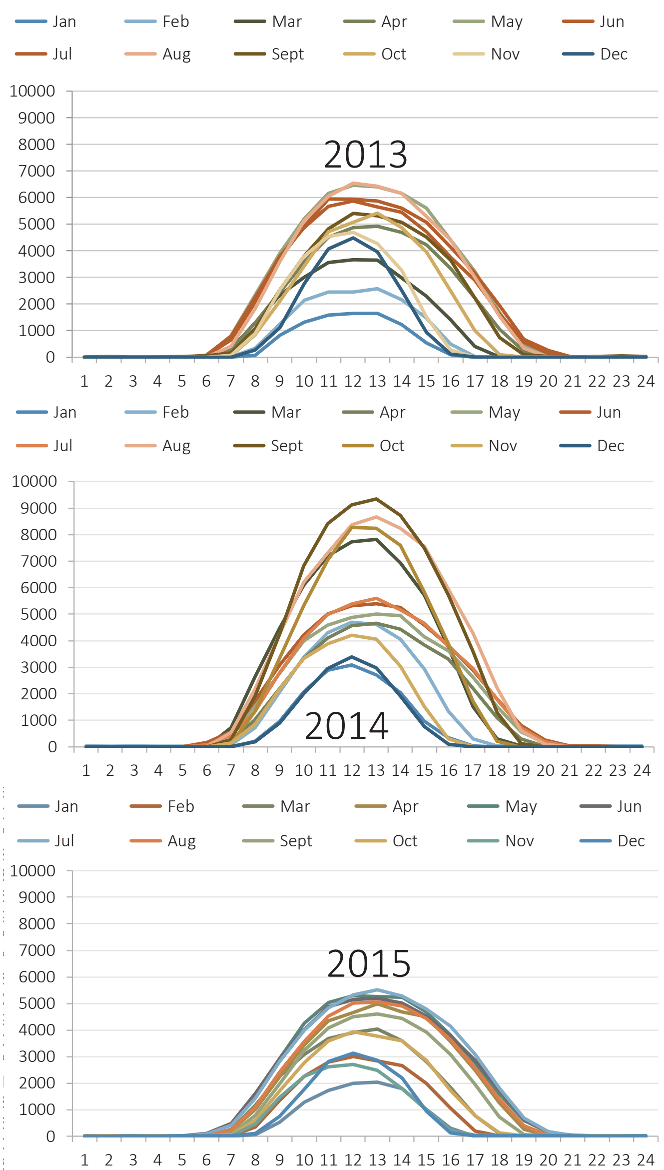


Figure 3.2. Distribution of monthly average daily electricity production by SPPs in Ukraine in 2013-2015

Units: vertical axis – thousand kWh, horizontal axis – hours. Source: prepared by the authors based on the data of NEC "Ukrenergo".

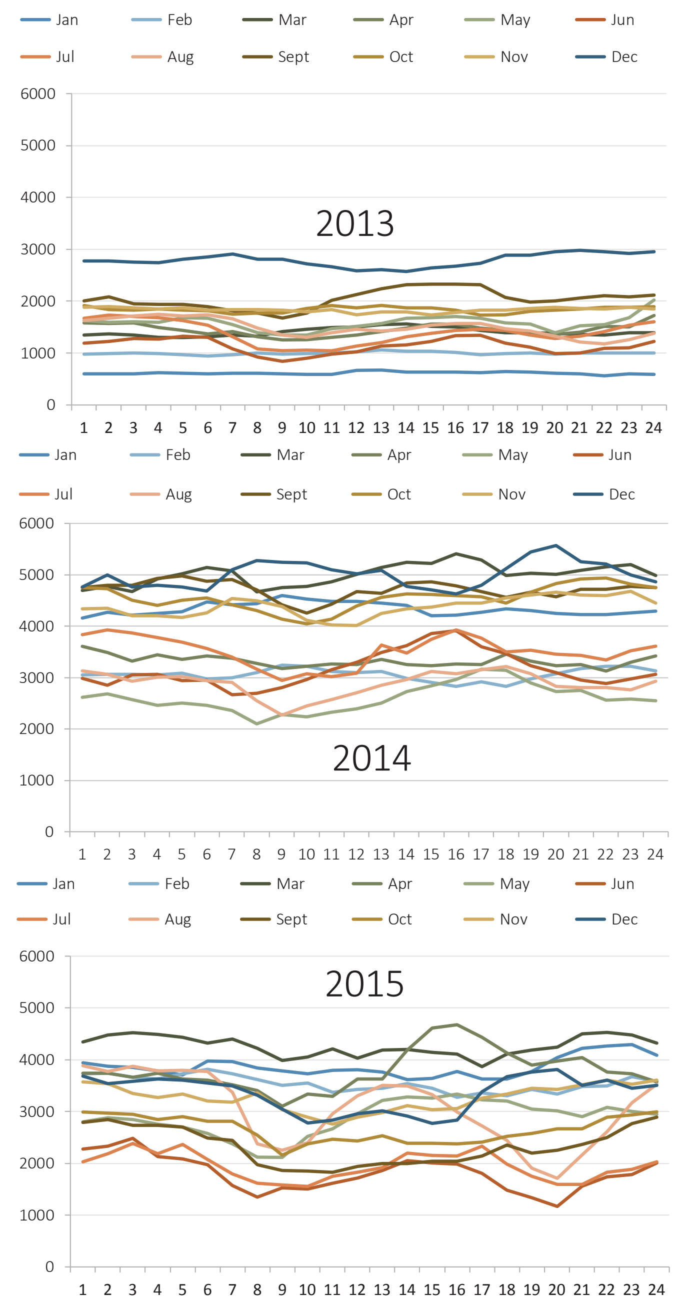


Figure 3.3 Distribution of monthly average daily electricity production by WPPs in Ukraine in 2013-2015

Units: vertical axis – thousand kWh, horizontal axis – hours. Source: prepared by the authors based on the data of NEC "Ukrenergo".

below average. Thus, the area of the figure A is equal to the sum of areas of figures B and C. *Figure 3.6* shows that storage capacity should be about 70% of the SPP capacity at the time of maximum power production.

Actual data show (*Table 3.10*) that the ratio of storage capacities to the capacity of a SPP could vary from 63% to 91% if the batteries are used according to the proposed principle. The average value of this ratio is 75-77% for 2013-2015.

The situation with WPPs is a similar. *Figure 3.7* shows the normalized electricity production schedule for WPPs in Ukraine in 2015. It is assumed that at the time when the production of a WPP exceeds the weighted average value, the battery will be charging, and the battery will supply electricity to the grid if electricity production is below average. Thus, the area of the figures A and B is equal to the sum of areas of figures C and D. It is calculated that at the time of maximum power generation, storage capacity should be about 40% of the WPP capacity.

Actual data of the operation of WPPs in Ukraine in 2013-2015 (*Table 3.11*) show that the ratio of capacity of accumulators to capacity of the WPP could fluctuate from 9% to 94% if accumulators are used according to the proposed principle. The average value of this ratio is 47-54% for 2013-2015.

Taking into account results of the analysis presented above, it is assumed for modeling of the long-term energy development scenarios for Ukraine by 2050 that the storage capacities of 0.74 kW for solar power plants, and 0.42 kW for wind power plants should be reserved for every 1 kW. Obviously, the need for implementation of storage technologies is not limited to RES balancing. Batteries can also be used to ensure the reliability and security of the energy system even at the current, rather low share of RES in the energy balance (a pilot project is being carried out in Odesa region**[57]**). However, the rapid growth of WPPs and SPPs itself will be the greatest challenge for the energy system, so the balancing of wind and solar energy is considered as a priority in this study. A comprehensive solution to the problem of energy storage needs requires further research, taking into account the technical and economic characteristics of a wide range of storage technologies.

To model the Liberal and Revolutionary Scenarios, the following assumptions (*Table 3.12*) on the cost of storage technologies (stationary lithium-ion batteries) was used in this study, taking into account study by Child et al. (2016)**[58]**.

57 http://itc.ua/news/mask-v-ochered-koreyskaya-kompaniya-kokam-obsudila-s-minenergouglya-i-gosenergoeffektivnosti-voprosyi-stroitelstva-rezervnyih-hranilishh-energii-v-ukraine/

58 M.Child, D.Bogdanov and C.Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016

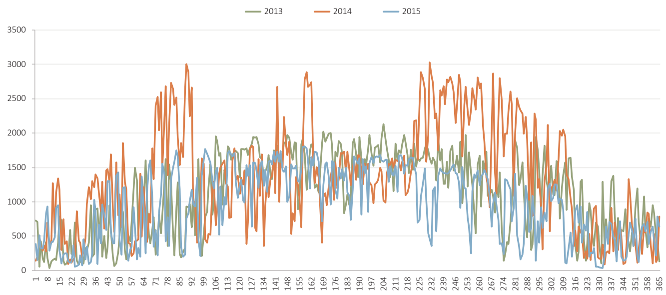


Figure 3.4 Daily electricity production by SPPs in Ukraine in 2013-2015

Units: vertical axis – thousand kWh, horizontal axis – days of the year. Source: prepared by the authors based on the data of NEC "Ukrenergo".

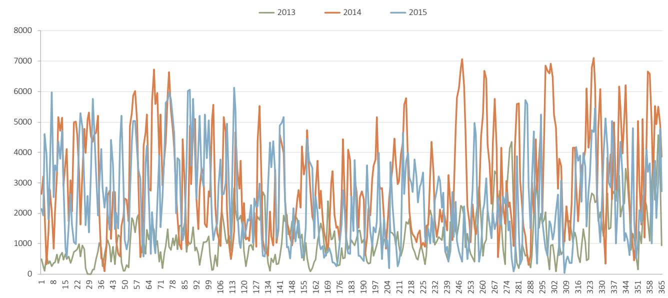


Figure 3.5 Daily electricity production by WPPs in Ukraine in 2013-2015

Units: vertical axis – thousand kWh, horizontal axis – days of the year. Source: prepared by the authors based on the data of NEC "Ukrenergo".

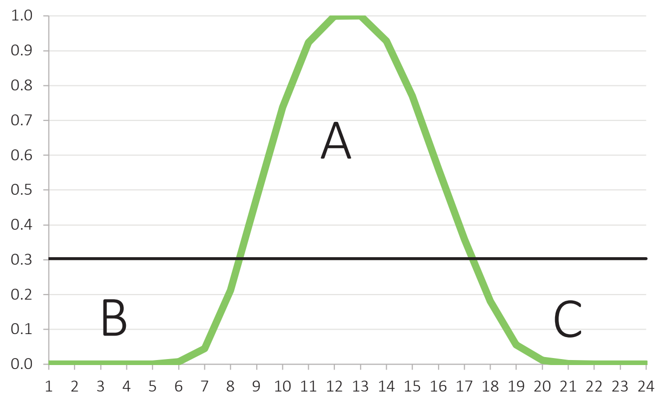


Figure 3.6 Normalized schedule of power generation by SPPs in Ukraine in 2015

Units: vertical axis – units, horizontal axis – hours. Source: prepared by the authors based on the data of NEC "Ukrenergo".

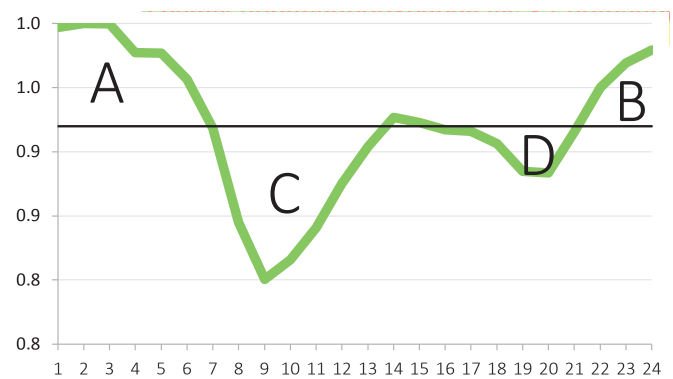


Figure 3.7 Normalized schedule of power generation by WPPs in Ukraine in 2015

Units: vertical axis – units, horizontal axis – hours. Source: prepared by the authors based on the data of NEC "Ukrenergo".

Table 3.10 Ratio of capacity of accumulators to capacity of SPP, %

	2013	2014	2015	Average value
Maximum value	93%	88%	88%	90%
Minimum value	64%	63%	64%	64%
Average value	75%	74%	74%	74%

Source: calculations of the authors based on the data of NEC "Ukrenergo".

Table 3.11 Ratio of capacity of accumulators to capacity of WPP, %

	2013	2014	2015	Average value
Maximum value	94%	73%	85%	84%
Minimum value	5%	3%	4%	4%
Average value	41%	38%	47%	42%

Source: calculations of the authors based on the data of NEC "Ukrenergo".

Table 3.12 Cost of storage technologies, EUR/kW

	2015	2020	2030	2050
Storage technologies	600	300	150	75

Source: prepared based on the data published in the study by M. Child, D. Bogdanov and C. Breyer "Transition towards a 100% renewable energy system by 2050 for Ukraine", 2016.

4 NATIONAL TECHNOLOGY PROSPECTS

Transport Sector

Buildings Sector

Industry

Agriculture

Photo: Shutterstock

4.1 Transport Sector

There were 3,360 electric cars registered in Ukraine as of April 2017 according to the Ministry of Infrastructure of Ukraine. Market growth rate exceeded 500% in 2016. The Ministry of Infrastructure of Ukraine and the Ministry of Energy and Coal Industry of Ukraine have the goal to achieve a 15% share of electric vehicles among all cars sold in 2020[59]. According to Oxygen Group there will be 7,000-10,000 passenger electric cars in Ukraine by the end of 2017. Charging devices for freight transport are not available yet, but they are expected to be available in 2018. There is a number of projects in the country on the development of infrastructure (charging stations) in large cities and on the Kyiv-Odesa highway.

Ukraine is the 5th in the world by the growth rate of electric cars, but most of these electric cars are used. The price of a used electric car at the national market is about EUR 10,000-12,000, the price of a new one begins from EUR 28,000[60]. According to Oxygen Group, the price of an electric vehicle with a hydrogen fuel cell is EUR 50,000-60,000, but they are not present in Ukraine yet. Therefore, electric cars are more promising not only for private ownership, but also for the use in taxi services, mail and delivery services, small cargo transportation, small businesses, etc.

There are currently several draft laws registered in Ukraine that offer tax and other preferences for potential owners of electric cars. These incentives will improve affordability of this type of transport. In particular, the following tax benefits are envisioned: abolishment of VAT on the import and supply of components and charging stations for electric cars; a zero VAT for electric cars and charging stations manufactured in Ukraine; a zero VAT for transportation by e-transport and for renting e-transport; a tax discount of up to 18% of the cost of an electric car that can be returned; a zero payment to the Pension Fund at the first registration of an electric car[61].

Electric cars can be supplied with electricity from RES. In addition, increase of electric mobility could also reduce the energy demand as a whole as electric cars are more energy efficient than cars with internal combustion engines (ICEs). The CP of electric motors can be 90-98%, while the CP of ICEs is 30-45%[62]. In addition, a number of studies have shown that the energy efficiency of electric cars increases if the latter are couples with other technological solutions, for example, energy storage devices[63]. Main characteristics of electric cars used in the TIMES-Ukraine model are presented in *Table 4.1.*

Table 4.1 Main characteristics of electric vehicles used in the TIMES-Ukraine model

Mode of transport	Cost, EUR thousand		Life time, years	Efficiency, Km/GJ		Annual mileage, thousand km
	2015	2050		2015	2050	
Intercity buses	400	180	20	185	220	27.5
City buses	400	190	20	180	215	27.5
Cars	27	20	20	855	885	17.2
Trucks	670	125	20	355	425	22.0
Motorcycles	13	13	20	777	854	4.8

Source: calculations of the authors.

Bioethanol in Ukraine is produced in small amounts (*Table 4.2*). According to the Energy Balance of Ukraine, biofuels accounted for 0.5% of energy consumption by cars (or 53 thousand tons) in 2015, while in 2014 this figure was 0.6%.

Table 4.2 Amount of bioethanol production in Ukraine, thousand tons

2011	2012	2013	2014	2015
55	52	66	51	53

Source: Energy Balance of Ukraine (product) http://www.ukrstat.gov.ua

According to the Ukrainian Association of Alternative Transport Fuels Producers "Ukrbiopalyvo", no more than six producers currently produce ethanol. The profitability of the production depends on the price of oil: production is expedient if oil prices are above USD 55/barrel. Bioethanol is made of molasses, the production volume of which decreases each year due to the reduction of sugar production. SE "Ukrspyrt" could produce 160 thousand tons using available capacities. Among existing producers, Biokhim Group is located on the temporarily uncontrolled territory (Donetsk). KoronArgo (Zolotonosha, Cherkasy region) is constructing a plant with a production capacity of 100 thousand tons of ethanol per year[64]. A plant with a capacity of 100 thousand tons of ethanol per year will be built in Zhytomyr region[65] in 2018. Zaplazskyi Factory with a production capacity of 50 thousand tons per year will be converted for the production of bioethanol[66]. Thus, potential production of bioethanol could amount to 510 thousand tons.

Bioethanol price was UAH 12 thousand per ton in 2013, while high-octane petrol was UAH 13 thousand per ton. The profitability of production remains questionable depending on the technology and the amount of energy used (4 times more electricity is used per unit of bioethanol production in Ukraine than in the EU)[67]. Distilling plants in Ukraine spend 9-12 tons of steam per ton of bioethanol produced, while plants in the USA and Canada spend 2-3 tons[68].

Construction of mixing capacities for one petroleum products retailer costs USD 3-4 million, which is equivalent to the construction of two new gas stations[69]. In Ukraine, construction of new bioethanol production plant requires investments at EUR 1.1/kg, or EUR 110 million/64,000 toe, or EUR 1,718/toe. Investments required for conversion of a sugar plant for bioethanol production amount to EUR 0.44/liter, or EUR 86/toe[70]. For comparison, in the EU investments in lignocellulosic bioethanol plants were EUR 6-12/kg bioethanol as of 2013[71].

Cars using exclusively motor biofuel (biodiesel, bioethanol) are not common in Ukraine. Vehicles on methane, propane-butane and engines designed for a small share of motor biofuel in petroleum cost about the same – from USD 5 to 24 thousand (depending on class, equipment, etc.). Main characteristics of biofuel vehicles used in the TIMES-Ukraine model are presented in *Table 4.3*.

4.2 Buildings Sector

Despite proclaiming energy efficiency as one of the main priorities of state policy and the gradual expantion of government initiatives to stimulate consumers to use energy in an efficient manner in their everyday life, the technical condition of most existing residential and non-residential buildings and related energy systems does not ensure required level of energy characteristics of buildings. Specific costs of the energy use considerably exceed similar indicators in most European countries (*Figure 4.1*).

59 Concept of the reform to stimulate the development of the electric transport market in Ukraine. #ELECTROTODAY. http://www.mtu.gov.ua/files/EV%20Reform%2013.04%20FINAL.pdf

60 http://nissan-elektro.com.ua

61 Concept of the reform to stimulate the development of the electric transport market in Ukraine. #ELECTROTODAY. http://www.mtu.gov.ua/files/EV%20Reform%2013.04%20FINAL.pdf

62 Wilson, Lindsay Shades of Green: Electric Cars' Carbon Emissions Around the Globe. Shrink That Footprint 2013 http://shrinkthatfootprint.com/wp-content/uploads/2013/02/Shades-of-Green-Full-Report.pdf

63 Crist, Philippe. Electric Vehicles Revisited – Costs, Subsidies and Prospects. Discussion Paper 2012. International Transport Forum. OECD, Paris http://www.itf-oecd.org/sites/default/files/docs/dp201203.pdf

64 Plant for production of bioethanol to be constructed in Poltava region 27/02/2007 http://www.proagro.com.ua/news/ukr/45866.html?t=3

65 http://news.finance.ua/ru/news/-/395944/avstrijtsy-postroyat-v-ukraine-zavod-po-proizvodstvu-bioetanola

66 http://oleg-leusenko.livejournal.com/tag/биотопливо

67 Finnish biofuel: experience for Ukrainians:13/05/2013 http://oil-gas-energy.com.ua/finske-biopalivo-dosvid-dlya-ukrainciv.html

68 Trypolska, H.S. Agro-bioenergy market of Ukraine / Monograph. NAS of Ukraine; Institute for Economics and Forecasting. – Kyiv, 2011. – 264 pages. ISBN 978-966-02-6077-1

69 Slynko, D. Biofuel. What is the risk of transfer of cars to vegetable fuel 08/07/2012 http://news.finance.ua/ua/news/~/282810

70 Calculated based on the data: Kuiun, S. Spirit finds the way to petrol. January 17, 2014 http://gazeta.zn.ua/energy_market/spirt-ischet-put-k-benzinu-_.html

71 Lignocellulosic Ethanol. Process and Demonstration. A Handbook Part I. 2013 by WIP Renewable Energies, Munich, Germany. David Chiaramonti, Arianna Giovannini, Rainer Janssen, Rita Mergner

Table 4.3 Main characteristics of biofuel vehicles used in the TIMES-Ukraine model

Mode of transport	Share of biofuel, %	Cost, EUR thousand		Life time, years	Efficiency, Km/GJ		Annual mileage, thousand km
		2015	2050		2015	2050	
Intercity buses							
Diesel + biodiesel	up to 20	210	190	20	93	112	27.5
Gasoline + ethanol	up to 20	200	180	20	92	111	27.5
Biodiesel	up to 100	225	205	20	93	112	27.5
Ethanol	up to 100	240	215	20	92	111	27.5
City buses							
Diesel + biodiesel	up to 20	210	190	20	106	127	27.5
Gasoline + ethanol	up to 20	200	180	20	108	130	27.5
Biodiesel	up to 100	250	205	20	106	127	27.5
Ethanol	up to 100	240	215	20	108	180	27.5
Cars							
Diesel + biodiesel	up to 20	20	18	20	308	370	14.3
Diesel + biodiesel	up to 70	20	19	20	293	352	14.3
Biodiesel	up to 100	21	20	20	280	335	14.3
Gasoline + ethanol	up to 20	21	18	20	318	382	11.5
Gasoline + ethanol	up to 70	21	19	20	302	362	11.5
Ethanol	up to 100	22	21	20	285	340	11.5
Trucks							
Diesel + biodiesel	up to 20	126	122	20	118	142	25.1
Gasoline + ethanol	up to 20	130	125	20	122	146	25.1
Biodiesel	up to 100	140	134	20	118	142	21.7
Ethanol	up to 100	147	141	20	122	146	21.7

Source: calculations of the authors.

Energy costs for heating amount to 250-400 kWh per m² per year in Ukraine (*Figure 4.2*), while it is 180 in Germany, 150 in Scandinavia, and 60-80 kWh per m² per year in buildings constructed using heat-saving technologies[72].

The energy consumption for heating of buildings in Ukraine can be reduced substantially, primarily by insulating enclosing structures (windows, walls, roofs) of buildings. Thermal insulation can significantly reduce the weight and thickness of the enclosing structures in addition to reducing the heat loss, and, accordingly, the cost of materials and their transportation. Various types of insulation materials of both foreign and domestic manufacturers are widely represented on the Ukrainian market today. Main requirements for insulation materials are determined by the state standard DSTU B GOST 16381:2011. The choice of particular insulation material is determined by results of the technical and economic analysis, taking into account the availability of raw materials, their cost, physical and mechanical parameters (density, thermal conductivity, strength, water absorption, water resistance), durability, compliance with sanitary norms (toxicity) and fire safety (combustibility).

However, thermal insulation is only one of the instruments for thermal modernization of a building. It is also necessary to upgrade the engineering equipment for heating,

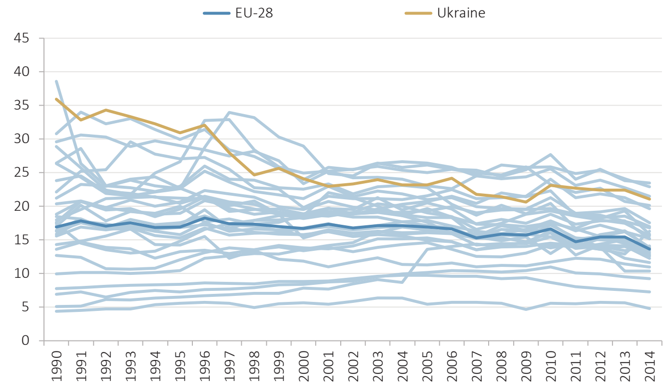


Figure 4.1 Specific energy consumption by household consumers, kg oe/m² per usable floor area per year

Note: light blue color shows specific energy consumption by household consumers for each EU country, and the dark blue shows the average value for the EU.
Units: kg oe/m². Source: calculated by the authors based on the data of the International Energy Agency.

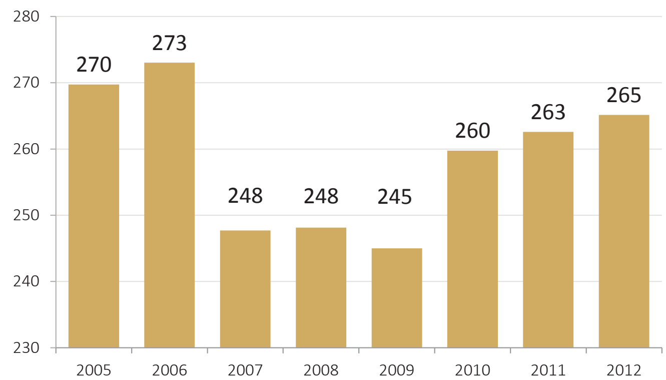


Figure 4.2 Specific energy consumption by household consumers for heating in Ukraine, kWh/m² per usable floor area per year

Units: kWh/m² per year. Source: calculated by the authors based on the data of the State Statistics Service of Ukraine.

ventilation, air conditioning, hot water supply systems, etc., to install metering equipment, to use renewable and / or alternative sources of energy and / or fuels, to organize the regulation of energy consumption to ensure effectiveness of implemented energy efficiency measures. At the same time, it is important to carry out a large-scale implementation of automated heating substations, which allow for a flexible distribution of thermal energy to respond to changes in weather conditions. Modernization of energy supply systems of utilities sector is also connected with the development and implementation of hybrid systems for electric heating of multi-apartment buildings. Such objects can act as regulator consumers of the United Energy System of Ukraine.

The energy saving potential of thermal insulation of buildings in Ukraine is quite large, but investment costs for its use are estimated at over UAH 500 billion[73]. At the same time, the lack of objective information on the structure of the housing stock and the energy efficiency of buildings makes impossible direct calculation of necessary investments, payback period of the projects and the corresponding energy savings. Therefore, expert estimates are used for modeling the long-term scenarios of the energy sector development.

Data of the Association of the Energy Auditors of Ukraine[74] (*Tables 4.4-4.6*) and SEVEn Energy[75] company were used to estimate the average cost of buildings repair and the amount of energy savings by the type of measures. According to the estimates of national experts, the average effect of low-cost short-term measures can make up to 14% energy savings. These measures include modernization of building enclosing structures and heating systems: isolation of heating and hot water supply pipelines laid out in unheated sections of a

72 Ukraine on the way to independence. Achievements and perspectives // State Agency on Energy Efficiency and Energy Saving of Ukraine. – Kyiv, 2016. – 45 pages.

73 Ladyhin, S. Legal aspects of Draft Law of Ukraine No. 4947 // Utilities Sector. – 2016 – No. 6. – Pages 11-12.

74 http://aea.org.ua/

75 http://www.svn.cz

Table 4.4 Fast-payback measures in multi-apartment buildings

No.	Floor	Heated area	Investments for 1 building	Investments per m²	Basic consumption	Savings / building			
		m²	UAH	UAH	kWh/m² year	kWh/m² year	%	kWh/m² year	kWh/m² year
1	2-4	1,359	200,000	147	200	36	18%	48,924	58,894
2	5-8	3,740	320,000	86	163	30	18%	112,200	135,064
3	9-10	8,323	527,000	63	156	20	13%	166,460	200,382
4	>10	10,141	600,000	59	140	15	11%	152,115	183,113
Weighted average values		6,094	424,800	70	156	22	14%	134,733	162,188

Source: Association of the Energy Auditors of Ukraine.

Table 4.5 Comprehensive rehabilitation of buildings (without replacement of in-apartment systems)

No.	Floor	Heated area	Investments for 1 building	Investments per m²	Basic consumption	Savings / building			
		m²	UAH	UAH	kWh/m² year	kWh/m² year	%	kWh/m² year	kWh/m² year
1	2-4	1,359	2,050,000	1,508	200	125	63%	169,875	204,493
2	5-8	3,740	4,200,000	1,123	163	100	61%	374,000	450,215
3	9-10	8,323	7,000,000	841	156	60	38%	499,380	601,145
4	>10	10,141	8,500,000	838	140	54	38%	545,036	656,105
Weighted average values		5,655	5,320,000	941	158	73	46%	412,291	496,309

Source: Association of the Energy Auditors of Ukraine.

Table 4.6 Comprehensive rehabilitation of private houses

No.	Floor	Heated area	Investments for 1 building	Investments per m²	Basic consumption	Savings / building			
		m²	UAH	UAH	kWh/m² year	kWh/m² year	%	kWh/m² year	kWh/m² year
1	1-2	80	120,000	1,500	240	125	52%	10,000	8,872

Source: Association of the Energy Auditors of Ukraine.

building, glazing and sealing of windows and doors, installation of thermostats and prevention of buildings overheating in the autumn and spring periods, washing of in-house systems, sealing of inter-panel joints of residential buildings, etc.

Specific costs per square meter for comprehensive rehabilitation of buildings (thermal modernization of exterior walls, floor slabs and buildings' roofs, replacement of windows and doors, modernization of the existing utility systems, heating and hot water supply systems) are higher. At the same time the specific costs per unit of saved energy are lower due to a greater energy saving effect (*Table 4.7*).

Similar assessments of investments and energy savings for comprehensive rehabilitation were made by SEVEn Energy in the study of the possibilities for implementation Directive 2012/27/EU by countries of the Energy Community[76]. Research was done based on the analysis and synthesis of a large array of actual cost data for the implementation of the four categories of energy saving measures. Specific costs per unit of saved energy presented in *Table 4.7* are higher than the AEA estimates, but lower than similar costs in the EU. This can be explained by a high current energy consumption level in the utilities sector in the countries of the Energy Community, in particular in Ukraine (about 250 kWh/m² compared to 100-150 kWh/m²) and availability of unrealized potential for relatively low cost technical solutions for energy saving in buildings.

Category of measures focused at reducing heat losses also include a large list of technical solutions, including thermal insulation of walls and ceilings, windows replacement, etc. using the best available materials and technologies. It is the most expensive option for energy saving per unit of energy saved. However, these measures can still be attractive to consumers due to the long service life and the low maintanence cost for new materials or equipment. It is estimated in the study mentioned above that a complete renovation of building would save up to 75% of energy consumption for heating (*Table 4.8*).

Taking into account discussed above estimates, assumptions were made on the investment costs and the effectiveness of the measures for the modernization of buildings for modeling of the long-term development scenarios of the energy sector (*Table 4.9*).

An analysis of the prospective needs for heating and the use of energy resources for other household needs has been carried out. It takes into account the assumptions of the demographic scenario, in particular living conditions of households, as well as the forecasted growth rates and structure of the service sector. Despite the forecast for

Table 4.7 Specific costs for implementation of energy saving measures in buildings, EUR million/PJ

Category	Thermal modernisation and other measures to reduce heat loss	Automatic regulation of heating system	Installation of heat recovery systems	Complete modernization of building
Private house	170	80	100	140
Multi-apartment building	210	70	140	180
Office buildings, in particular:	250	70	160	210
- educational institutions	210	50	150	180
- health care institutions	250	100	200	220

Source: SEVEn Energy.

76 Impact Assessment of the Energy Efficiency Directive (2012/27/EU) for the Energy Community, https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/3304025/0633975ADB617B9CE053C92FA8C06338.PDF

Table 4.8 Energy savings for heating depending on type of measures and category of buildings, %

Category	Thermal modernisation and other measures to reduce heat loss	Automatic regulation of heating system	Installation of heat recovery systems
Private house	50	7	17
Multi-apartment building	50	8	
Office buildings, in particular:	40	9	
- educational institutions	45	9	
- health care institutions	50	8	

Source: SEVEn Energy.

Table 4.9 Assumptions on investment needs and efficiency of measures for thermal modernization of buildings

	Private residential buildings			Multi-apartment buildings			Non-residential buildings		
	investments		savings	investments		savings	investments		savings
	UAH/kWh/m²	EUR mln/PJ	%	UAH/kWh/m²	EUR mln/PJ	%	UAH/kWh/m²	EUR mln/PJ	%
Simple rehabilitation	3.0	28.9	14	3.2	31.0	14	4.0	38.8	10
Complete rehabilitation	12.0	117.0	52	12.9	125.6	46	16.9	165.0	55
Additional modernization	14.4	140.0	74	18.5	180.0	75	22.6	220.0	75

Source: prepared by the authors based on the data of the Association of the Energy Auditors of Ukraine and SEVEn Energy.

further gradual reduction of the population, the growth rate of the living space in the household sector will outweigh this negative trend: the total area of residential buildings will increase by 14.5% till 2050 as compared to 2015. The average area for households living in multi-apartment buildings will be about 60 m^2, and 90-100 m^2 in private houses.

4.3 Industry

An increased use of renewable energy and alternative fuel by industrial enterprises in Ukraine is important to reduce the use of traditional fuel and energy resources and associated negative environmental impacts.

An important part of this process is the introduction of new promising technologies suitable for the transition of the national industry to the use of alternative types of energy.

The development of the electric furnace steel production method (Electric Furnace)[77] is promising for the implementation of the Revolutionary Scenario in the metallurgical industry of Ukraine. At the same time, electricity consumption for the production of a ton of electrical steel depends on a number of factors, in particular, on the capacity of the electric furnace, duration of melting, etc. It can range from 325 to 735 kWh/t[78]. Data in columns 4 and 5 of *Table 4.10* was used in this study for modeling.

Over 70% of all final energy[79] consumed in the chemical industry is used for production of petroleum and inorganic chemicals, in particular, for the production of ammonia[80]. Thus, the average energy cost of ammonia production amounts to 35-38 GJ/t. The introduction of new promising technologies into the above production will contribute to their reduction by at least 20%.

The average consumption of traditional energy in the pulp and paper industry ranges from 29 to 32 GJ/t of products. At the same time, international experience shows that there is a potential for replacement of traditional energy resources with renewable ones in pulp and paper production, in particular, with biomass (up to 60% of total energy consumption). Such replacement can reduce the energy intensity of the production to 17.1 GJ/t of paper[81].

Average energy consumption per ton of portland cement produced in industrialized countries is about 3.0-4.0 GJ[82].

According to national experts[83], the minimum energy consumption theoretically could be 1.76 GJ per ton of cement

Table 4.10 Energy consumption subject to introduction of new technologies in industry

Sector	Current average energy consumption per ton of product*	Data of Resource Efficient and Cleaner Production Centre**	Perspective energy consumption / t products***,****	Cost of technology, $/t products*****
1	2	3	4	5
Metallurgy	13-14 GJ/t of cast iron	from 0.7 to 6.5 GJ/t	from 750 to 325 kWh/t of steel (1.2-2.7 GJ)	$540-600/t of steel
Production of ammonia	35-38 GJ/t	7,500 kWh/t (27 GJ/t)	27 GJ/t	$30-50/t
Pulp and paper	29-32 GJ/t	–	from 18.7 to 17.1 GJ/t	$600-800/t
Cement	Wet technology: 5.3-7.1 GJ/t; Dry technology: 3-4 GJ/t	1,800 kWh/t (6.5 GJ/t)	from 3.0 to 2.5 GJ/t of cement	$90-130/t
Production of glass		3,000 kWh/t (10.8 GJ/t)	10.8 GJ/t	$250-300/t

Source: compiled based on the data of: * Perspectives of energy technologies. In support of the G-8 Action Plan. Scenarios and Strategies up to 2050. OECD/IEA, WWF of Russia (translation into Russian, Part 1 edited by A. Kokorin, Part 2 edited by T. Muratova. – Moscow: 2007 – 586 pages. – Pages. 485; 499; 505; 519. Nordic Energy Technology Perspectives 2016 (NETP 2016) is a Nordic edition of the International Energy Agency's (IEA) global Energy Technology Perspectives 2016. – 211 pages. – Page 87. Available at: http://www.nordicenergy.org/project/nordic-energy-technology-perspectives.

** Data provided by the Resource Efficient and Cleaner Production Centre, http://www.recpc.kpi.ua/en/.

*** Kudrin, B. Electricity in electrometallurgy / B.I. Kudrin // Electricity. – 2003. – Pages. 35-45; Prospects for energy technologies In support of the G-8 Action Plan. Scenarios and Strategies up to 2050. OECD/IEA, WWF of Russia (translation into Russian, Part 1 edited by A. Kokorin, Part 2 edited by T. Muratova. – Moscow: 2007 – 586 pages. – Page 514; Nordic Energy Technology Perspectives 2016 (NETP 2016) is a Nordic edition of the International Energy Agency's (IEA) global Energy Technology Perspectives 2016. – 211 pages. – Page 87. Available at: http://www.nordicenergy.org/project/nordic-energy-technology-perspectives; Mykoliuk O.; Kovalchuk I. Practice of Implementation of Energy Efficient Technologies at Cement Industry Enterprises in Ukraine / O. Mykoliuk, I. Kovalchuk // Bulletin of the Khmelnytskyi National University – 2014. – No. 1. – Pages 227-230

**** Calculations of the authors.

77 According to the WSA, over 25% of world steel output was produced in electric furnaces in 2015.

78 Kudrin, B. Electricity in electrometallurgy / B.I. Kudrin // Electricity. – 2003. – Pages 35-45.

79 According to the IEA, only a few manufacturing processes from among over 50 promising technologies in the chemical industry are significant in terms of energy consumption.

80 Prospects for energy technologies. In support of the G-8 Action Plan. Scenarios and Strategies up to 2050. OECD/IEA, WWF of Russia (translation into Russian, Part 1 edited by A. Kokorin, Part 2 edited by T. Muratova. – Moscow: 2007 – 586 pages. – Page 505.

81 Nordic Energy Technology Perspectives 2016 (NETP 2016) is a Nordic edition of the International Energy Agency's (IEA) global Energy Technology Perspectives 2016. – 211 p. – P. 87. Available at: http://www.nordicenergy.org/project/nordic-energy-technology-perspectives

82 Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide / [Electronic resource]. – Available at: eippcb.jrc.ec.europa.eu/reference/BREF/CLM_30042013_DEF.pdf

83 Mykoliuk, O.; Kovalchuk, I. Practice of Implementation of Energy Efficient Technologies at Cement Industry Enterprises in Ukraine / O. Mykoliuk, I. Kovalchuk // Bulletin of the Khmelnitsky National University – 2014. – No. 1. – Pages 227-230

clinker. At the same time, the energy efficiency of existing furnaces with heaters and pre-burning is 3.06 GJ of energy per ton of clinker, while wet technology consumes from 5.3 to 7.1 GJ per ton of clinker.

Thus, **there are new promising technologies for various industrial processes in the world today, which make possible transition from consumption of traditional fuel and energy resources to the use of energy from renewable sources (in particular, electricity and thermal energy produced from RES). Such transition will lead to reduction of the energy consumption and negative impacts on environment.**

4.4 Agriculture

Agriculture is represented in a simplified form in the TIMES-Ukraine model. Five sub-sectors are identified in this sector: crop growing, livestock breeding, local transport, non-energy consumption and other needs. In addition, energy consumption for the autonomous production of electricity and heat is included not in this but in the energy sector. The model assumes that each demand in agriculture can be met with the technologies using RES. Information provided below is not used in the TIMES-Ukraine model directly, but it is intended to give an idea of the prospects for the transition of this sector to renewable energy sources.

Agriculture and forestry sector use no more than 5% of the final energy demand and are not significant emitters of CO_2[84] in Ukraine. At the same time, the sector faces challenges of reducing greenhouse gas emissions (first of all, methane), ensuring food security in conditions of climate change and population growth and urbanization, cultivating new types of energy crops, and mastering new technologies that will be used by agricultural machines and equipment.

Agricultural machines and equipment on biogas are currently at the testing stage before industrial production will commence (for example, the New Holland Methane Power Tractor model). Conversion of existing tractors and other equipment with internal combustion engines to use of electric drives is more common. Electric tractors are only entering the market with a price of USD 8,000-10,000 (produced in China) and a load capacity of 300 kg. There are also available trucks (used ones on methane at a price of USD 5,000, the price in Ukraine), tractors (used ones on methane at a price of USD 1,000, the price in Ukraine), milk delivery trucks (used ones on methane at a price of USD 4,000-5,000, the price in Ukraine), pump trucks (used ones on methane at a price of 9,000 USD, the price in Ukraine, with a load capacity about 2,000 kg). Electric tractors (used) cost on average USD 13,000-15,000 in Ukraine[85].

Biodiesel in Ukraine is produced in small amounts (up to 20 thousand tons per year), largely to meet the technical needs of agricultural firms. As of 2016, investments required for construction of a biodiesel installation in Ukraine are as follows: EUR 95 thousand/2 million liters = EUR 95 thousand/1,513 toe = EUR 62/toe[86]. Operating expenses are EUR 360/1 toe[87].

Biodiesel Bessarabia company opened a plant for the production of biodiesel with a capacity of 7 thousand tons per year in Odesa region in 2007. Lieber company opened a plant with capacity of 10 thousand tons of biodiesel per year in Kherson region in 2007.

In 2014, the largest producers of biodiesel were Oriana-Galev (Kalush; raw materials – rape), Liber (Kherson; raw materials – rape), Styrol (Horlivka; raw materials – sunflower seeds). 300 installations for the production of biodiesel with a total capacity of about 500 thousand tons per year were built at farms. They produced biodiesel for their own needs[88]. There is no industrial biodiesel production in Ukraine due to lack of raw materials and demand for it. The only excemption is a plant with a capacity of 28 thousand liters of biodiesel per day in Sambir district of Lviv region, which was launched in 2014.

Research projects on the production of biodiesel from microalgae was conducted in Ukraine for about 10 years. Domestic company Biodiesel-Dnipro was the first in Ukraine to begin operating of a plant for cultivation of microalgae and producing oil[89]. Reactors can be installed both vertically and horizontally, which allows saving space considerably. In addition, closed automatic control systems and self-cleaning systems can be used. Algae grow faster by 30% when they consume CO_2[90]. A technology for obtaining biogas from poisonous algae that pollute rivers was developed in the Kremenchuk National University named after M. Ostrohradskyi. 200 liters of biogas were made from 50 liters of algae. In the future, the technology will become waste free[91]. These technologies are not yet used on an industrial scale in Ukraine[92].

84 Ukraine's Greenhouse Gas Inventory 1990-2015. Annual National Inventory Report for Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. – Available at: http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/ukr-2017-nir-24may17.zip

85 https://ecoelectro.com.ua/electric-vehicles/electric-cars/

86 http://www.advantageaustria.org/mx/events/BEFA_Plantas_Biodiesel.pdf

87 http://www.eubia.org/cms/wiki-biomass/biofuels-for-transport/biodiesel/

88 Ukraine could export biofuel instead of rape. 27.11.2009: http://www.biofuels.ru/bioethanol/news/ukraine_could_export_biofuel_instead_of_rape

89 Installations for growing algae. [Electronic resource]. – Available at: http://biodiesel.dp.ua/.

90 Hryniuk, I. Biofuel from algae // Agrosector – 2009 – No. 6(36)

91 Scientists of the Kremenchuk University created a technology for extraction of biogas from poisonous algae 27/05/2010 [Electronic resource]. – Available at: http://fuelalternative.com.ua/

92 Trypolska, H.S. Agro-bioenergy market of Ukraine / Monograph. NAS of Ukraine; Institute for Economics and Forecasting. – Kyiv, 2011. – 264 pages. ISBN 978-966-02-6077-1

5 DEVELOPMENT OF ENERGY SECTOR IN UKRAINE UNDER DIFFERENT SCENARIOS UP TO 2050

- Final Energy Consumption
- Electricity Generation
- Heat Generation
- Total Primary Energy Supply
- Relative Indicators of Energy Sector Development
- Greenhouse Gas Emissions
- Total Costs and Investments


Photo: Shutterstock

This Section presents the results of economic and mathematical modeling under three scenarios (Conservative[93], Liberal and Revolutionary), which are based on the conditions and assumptions (macroeconomic, demographic, energy use, prices, etc.) specified in the previous sections of the report. Detailed results of modeling under three scenarios are provided in tables in *Annex A.6*.

5.1 Final Energy Consumption

The results of modeling show that the final energy consumption in Ukraine will increase from 67.0 mln toe in 2012 to 85.1 mln toe in 2050 (increase of 27%) under the Conservative Scenario. It will be lower by 27% in 2050 compared to the base year of 2012 under the Revolutionary Scenario. As *Figure 5.1* shows, the implementation of the energy efficiency and energy saving (EE) potential is very important. **It is the cheapest "resource" and investments in energy efficiency are more economically feasible than investments in electricity or heat generation.**

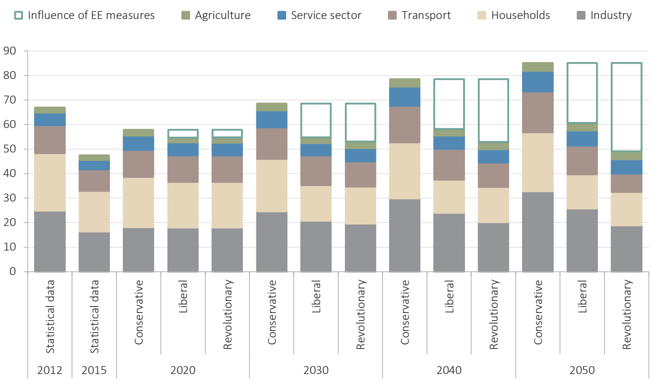


Figure 5.1 Final energy consumption

Units: mln toe.

According to the Liberal Scenario, the share of RES in the structure of FEC could exceed 30% by 2050. Implementation of the energy efficiency measures results in reduction of FEC by 9% to 60.7 mln toe compared to the base year of 2012. *Figure 5.2* shows the influence of the energy efficiency measures and RES compared to the Conservative Scenario.

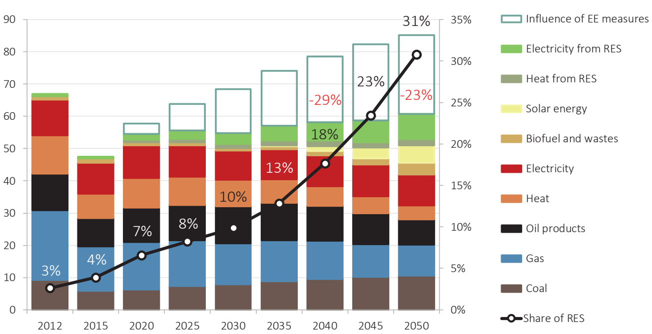


Figure 5.2 Final energy consumption under the Liberal Scenario

Units: mln toe.

The main role in increasing the share of RES under the Liberal Scenario will belong to electricity generated from RES, biofuel and wastes, and solar energy used for hot water and heating, as well as heat generated from RES directly by households and supplied to consumers in the centralized way (*Figure 5.3*).

At the same time, consumption of natural gas and certain petroleum products will decrease considerably. The share of coal in FEC could increase due to the growth of industrial production (first of all, metallurgy).

Implementation of the Revolutionary Scenario will allow increasing the share of RES in the structure of FEC up to 91% in 2050. At the same time, final energy consumption may be reduced by 42% (compared to the base year of 2012) due to the implementation of energy efficiency and energy saving measures (*Figure 5.4*).

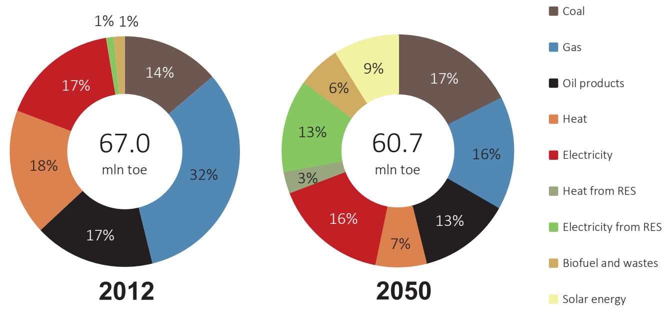


Figure 5.3 Structure of the final energy consumption under the Liberal Scenario

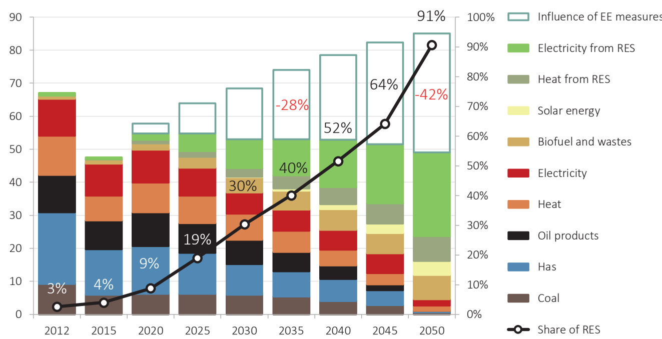


Figure 5.4 Final energy consumption under the Revolutionary Scenario

Units: mln toe.

Energy transition under the Revolutionary Scenario will require rapid electrification of households and economy (Electrification 2.0). This could lead to increase of the electricity share in FEC from 17% in 2012 to 56%, 52% out of which should be generated from RES (*Figure 5.5*). In addition, biofuel and wastes, centralized heating based on RES and solar energy will play an important role in satisfaction of demand for heating and hot water.

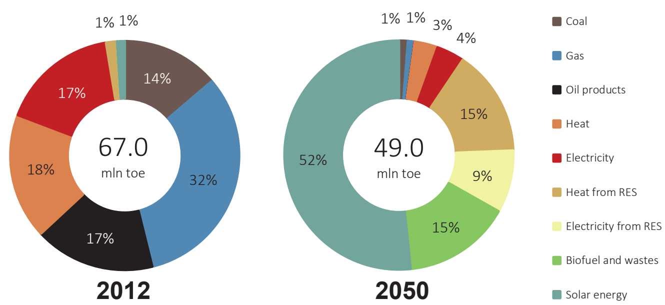


Figure 5.5 Structure of the final energy consumption under the Revolutionary Scenario

Industry will remain the largest end consumer of energy resources. The shares of the service sector and agriculture will be increased and the share of households as well as the share of transport could be decreased considerably due to the energy efficiency measures (*Figure 5.6, 5.7*).

93 It should be reminded that the Conservative Scenario is considered as a hypothetical scenario when characteristics of most technologies remain unchanged up to 2050 as they were in 2012. Gradual replacement of technologies takes place only when the life time of certain existing capacities comes to its end. The cost and efficiency of technologies that replace the old ones reflects current trends: the cost decreases with time and the efficiency increases. At the same time, most of the existing technologies can be used during the modeling period (2012-2050). Conservative Scenario is used as reference for comparison of results obtained for Liberal and Revolutionary Scenarios. However, authors believe that Conservative Scenario is not realistic because Ukraine will not be able to resist to technological progress.

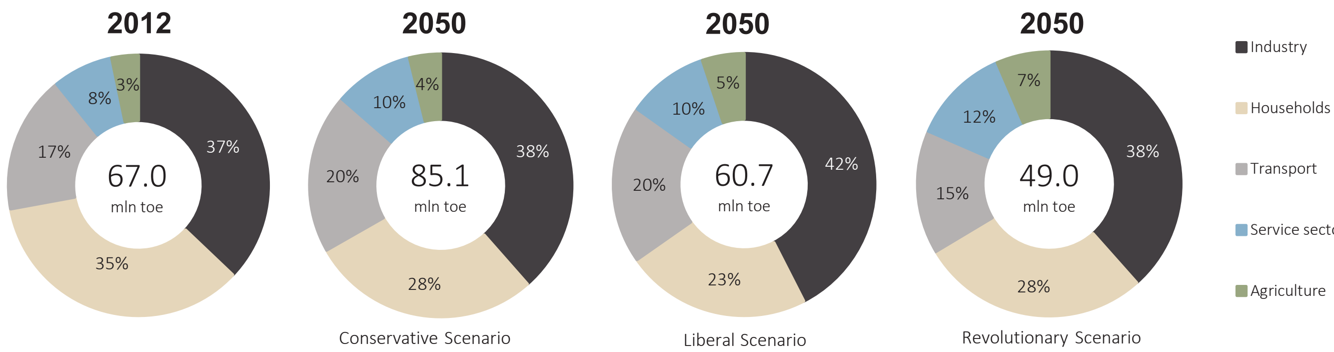


Figure 5.6 Structure of the final energy consumption by sectors

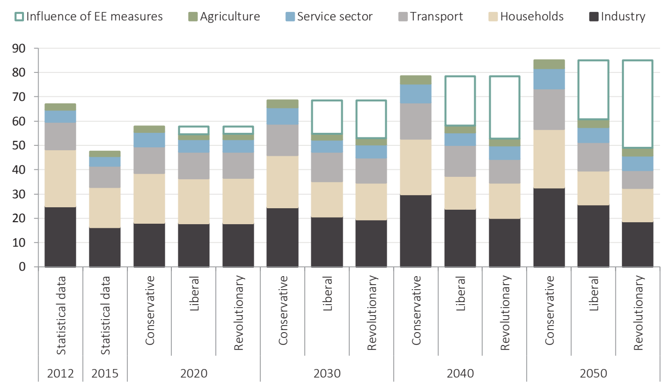


Figure 5.7 Final energy consumption by sectors according to different scenarios

Units: mln toe.

5.1.1 Industry

Industry is and will remain the largest consumer of energy resources. Under the Liberal Scenario energy needs of industry will be a little bit higher in 2040-2050 than in 2012 (*Figure 5.8*). Energy efficiency measures will play an important role in reducing industrial FEC. However, the use of fossil fuels and energy produced from them will decrease by 14% in 2050 compared to the baseline year of 2012.

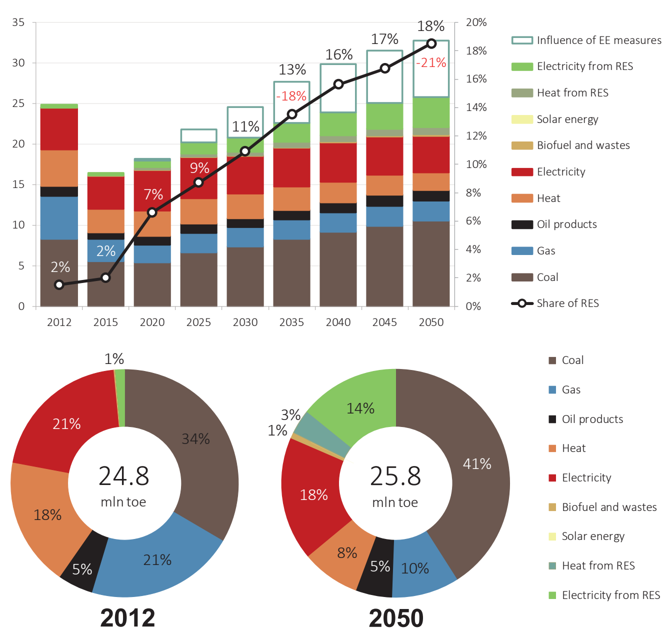


Figure 5.8 Final energy consumption by industry under the Liberal Scenario

Units: mln toe.

At the same time, final energy consumption of industrial sector will not exceed the value of the base year under the Revolutionary Scenario (*Figure 5.9*). FEC will increase within the period of 2020-2040 and decrease after 2040. Moreover, results of modeling show that the consumption of the fossil energy resources could be reduced starting from 2025. Growing energy demand could be replaced with electricity and heat generated from renewable sources. Total share of RES can reach 88% in the industrial sector by 2050.

Electrification of the industry is a significant challenge for the implementation of the Revolutionary Scenario because it will require the replacement of almost all existing energy intensive industrial equipment with a new one that will only use electricity and heat. *The use of energy resources as raw materials (for example, coke in metallurgy, gas in chemistry) is not taken into account as it is considered to be a non-energy consumption, which is not considered for modeling of the long-term scenarios of the energy sector development.*

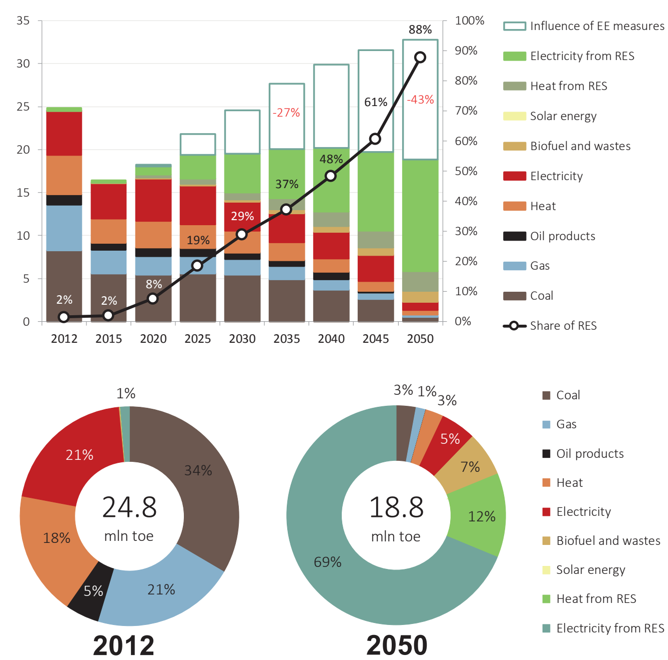


Figure 5.9 Final energy consumption by industry under the Revolutionary Scenario

Units: mln toe.

5.1.2 Households

Residential sector has significant potential for increasing energy efficiency and energy saving as well as the industry. In addition, there is also the largest potential for use of renewable energy sources.

Under the conditions of the Liberal Scenario, which does not define target energy efficiency indicators, economic feasibility of energy saving and use of the modern efficient household equipment is extremely high (*Figure 5.10*). Energy demand could be reduced by 36% in 2035 and by 42% in 2050 compared to similar years of the Conservative Scenario. Energy efficiency improvements, as well as the use of RES will allow reducing the share of fossil fuels (gas, coal and oil products) in the final consumption from 62% in 2012 to 36% in 2050. It is expected that the share of RES in the household

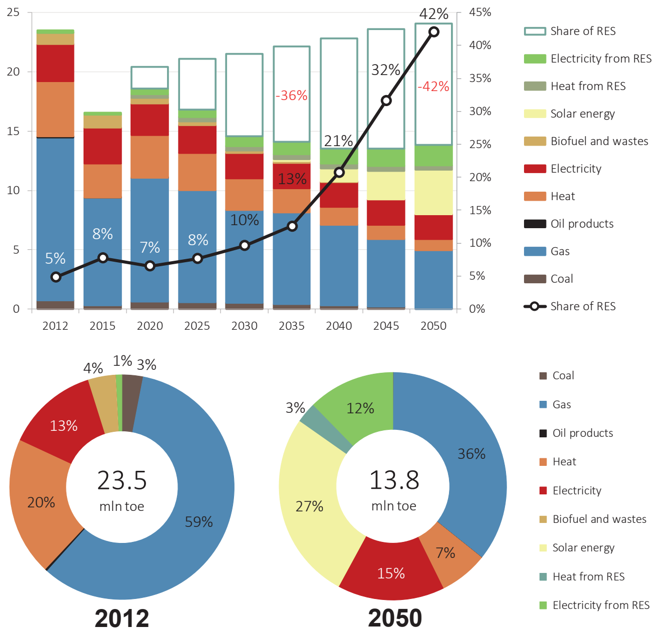


Figure 5.10 Final energy consumption by households under the Liberal Scenario

Units: mln toe.

energy consumption will increase significantly after 2035 and could reach 42% in 2050.

Households could completely abandon direct use of fossil fuels if appropriate state policies are used for the implementation of the Revolutionary Scenario. In this case RES will grow rapidly starting from 2020 and will reach 32% in 2035[94] (*Figure 5.11*).

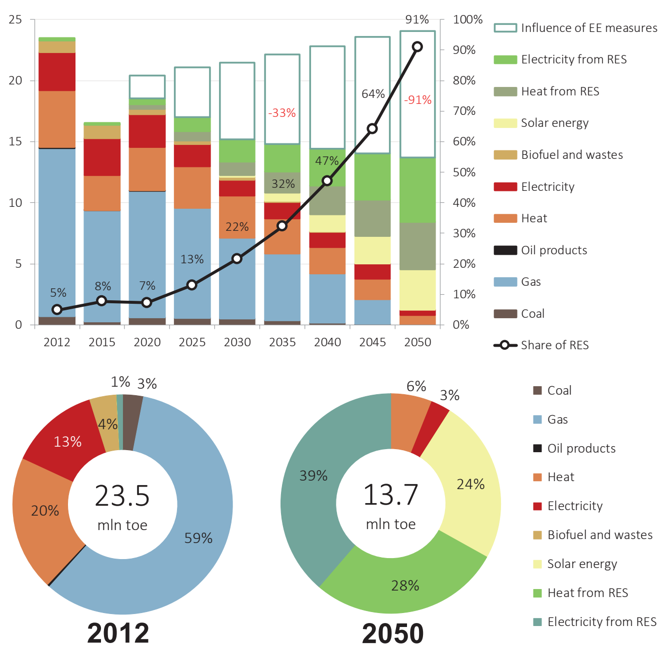


Figure 5.11 Final energy consumption by households under the Revolutionary Scenario

Units: mln toe.

5.1.3 Transport

Final energy consumption by the transport sector is falling after 2015 but could grow quite intensively to 2035 under the conditions of the Liberal Scenario. This is explained by the forecasted increase in household incomes and associated growth of the number of motor vehicles. However, the energy consumption in the transport sector will not exceed the indicators of 2012 by 2050 due to the use of more efficient motor vehicles. Though the share of RES will increase significantly after 2035, oil products will remain the main energy resource up to 2050 and will make 54% in FEC of this sector (*Figure 5.12*).

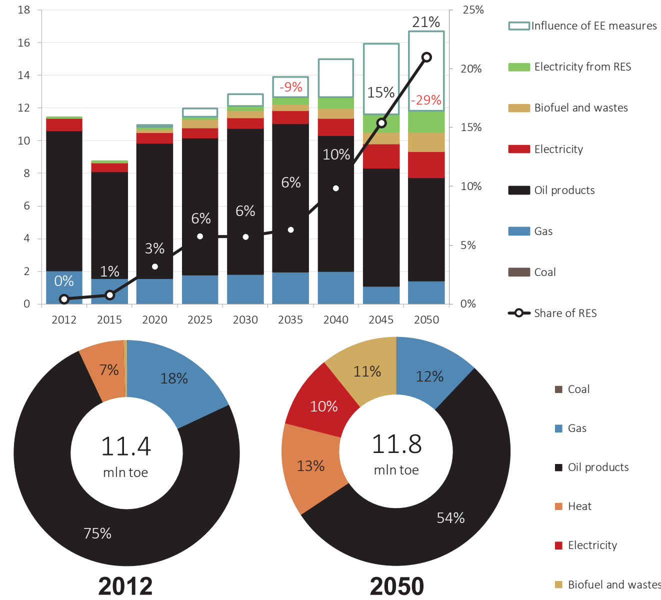


Figure 5.12 Final energy consumption by transport under the Liberal Scenario

Units: mln toe.

Consumption by the road freight transport will make up to 60% in the structure of the oil products while buses and cars will make 16% and 17% respectively in 2050. For comparison, shares of these transport means were 31%, 17% and 44% respectively in 2012. Electric vehicles could constitute up to 40% of the private motor vehicles in 2050.

The air and water transport could switch to biofuel. The share of biofuel will make up 82% in the structure of their consumption.

To fulfill the conditions of the Revolutionary Scenario, it is necessary to start using RES (electricity and biofuel) in the transport sector (*Figure 5.13*). The total final energy consumption by transport sector can be reduced by more than a half, compared to the Conservative Scenario, due to the increased used of electricity.

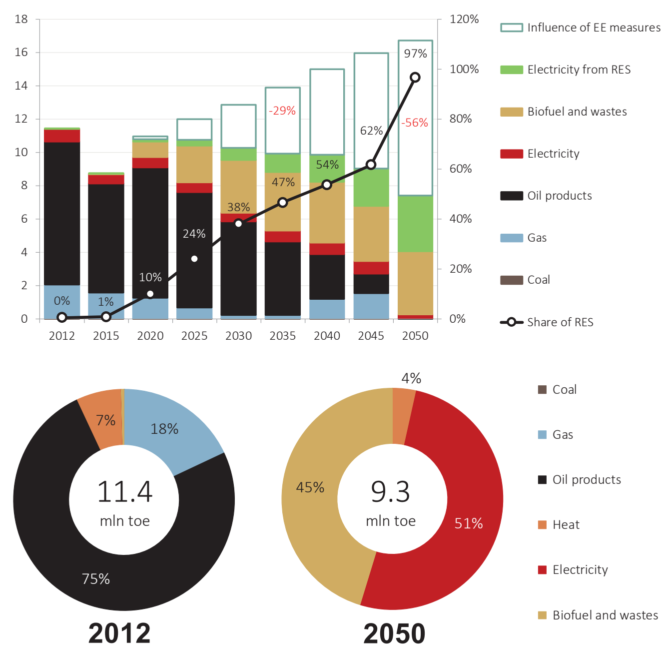


Figure 5.13 Final energy consumption by transport under the Revolutionary Scenario

Units: mln toe.

94 It should be noted that electricity generation by the solar panels in private households which are connected to the general electricity grid is included in the transformation sector. Thus, figures on the final energy consumption show only solar energy, which is directly consumed by households (mainly, for hot water by solar collectors), as well as electricity generation by autonomous households.

The number of the private electric vehicles can be more than 90% in 2050. The remaining vehicles will use biofuel. The full electrification is advantageous for the bus and railway transport as well.

The air and water transport should completely switch to biofuel. The road freight transport may completely switch to biofuel taking into account the available technologies in the Ukrainian market for today. Though the electrification of this transport could also take place.

5.1.4 Service Sector

The final energy consumption in the service sector (commercial and budget sectors) will increase under the every scenario. However, growth rate will be negligible under the Liberal Scenario (*Figure 5.14*).

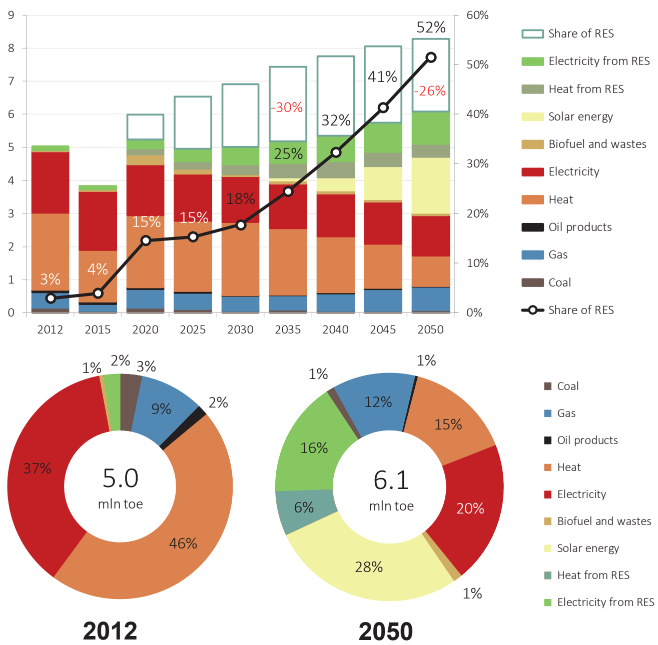


Figure 5.14 Final energy consumption by service sector under the Liberal Scenario

Units: mln toe.

Electricity and heat made about 83% (37% and 46% respectively) in the FEC structure of the service sector in 2012. The total share of electricity (generated from RES and fossil fuels) will remain at the same level in 2050, but the share of heat supplied in the centralized way may fall to 21%. The replacement will take place by solar energy and heat generated from RES. The share of gas will possibly slightly increase. The small share of biofuel and wastes is due to the preference given to the district heating supply in the service sector (from boiler houses, cogeneration plants) instead of direct burning in boilers[95].

The Revolutionary Scenario shows that the use of RES in the service sector could grow very fast and reach 88% in 2050. Increasing energy efficiency and energy saving will play a significant role as well as allow saving about 30% of resources compared to the Conservative Scenario (*Figure 5.15*). Thermal

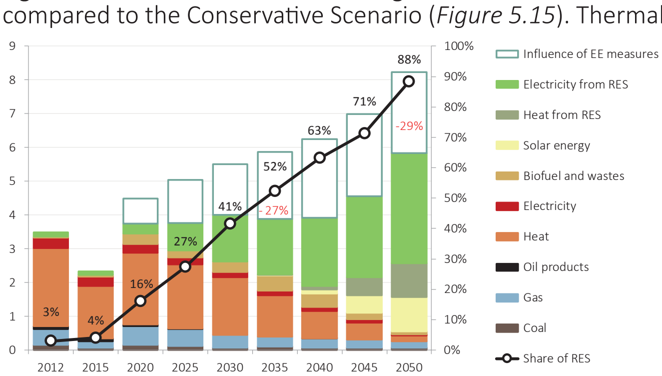


Figure 5.15 (part 1) Final energy consumption by service sector under the Revolutionary Scenario

Units: mln toe.

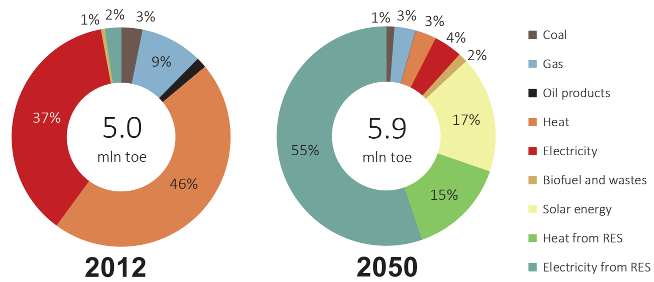


Figure 5.15 (part 2) Final energy consumption by service sector under the Revolutionary Scenario

Units: mln toe.

insulation of buildings and the use of high-efficient electric equipment will also play an important role.

On the one hand, district heating and hot water supply will use the biomass, on the other hand, to meet these demands, direct use of solar energy, biofuel and wastes will increase significantly. In addition, the electric heating technologies and electric boilers for hot water will be actively developing.

5.1.5 Agriculture

Ukraine has a high agricultural potential, thus the use of biofuel and wastes in agriculture is also significant. The share of biofuel and wastes could reach almost 80% under the Liberal Scenario (*Figure 5.16*). The results of modeling show that rapid implementation rates of this potential will gain momentum after 2030. This can happen earlier in case of more intensive development of agricultural technologies for the use of biodiesel, bioethanol, biomass and agricultural wastes.

There is a significant potential in agriculture for the direct use of solar, wind, geothermal and bioenergy for the generation of electricity and heat. At the same time, the production process itself belongs to the transformation sector. FEC of this sector inludes only electricity and heat, which are consumed in the centralized way but generated from RES.

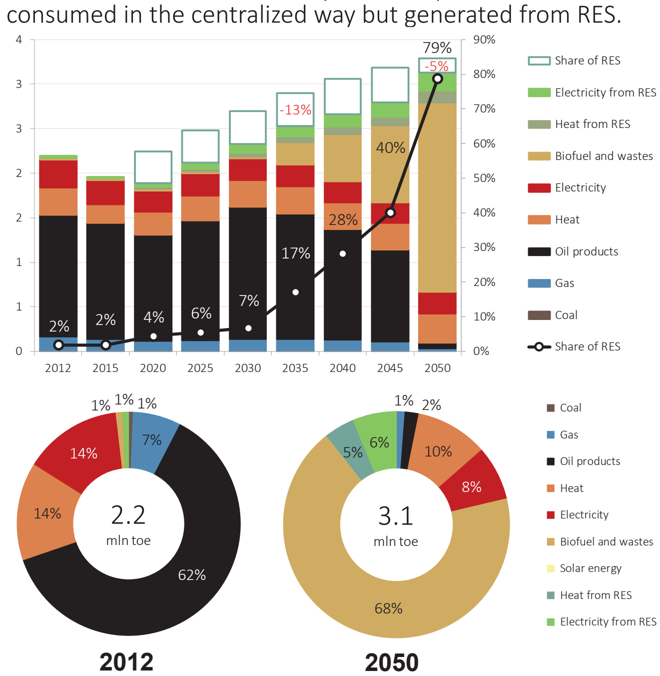


Figure 5.16 Final energy consumption by agriculture under the Liberal Scenario

Units: mln toe.

Agriculture can switch to RES up to 96% in FEC under the Revolutionary Scenario, where biofuel and wastes will make up to 70% (*Figure 5.17*). In fact, the results do not show any significant technological breakthrough in this sector. It is enough to change motor vehicles and agricultural machines to biofuel (biodiesel, bioethanol) and maximize the share of "green" electricity and heat in Ukraine.

95 The use of biofuel and wastes by boiler houses and cogeneration plants belongs to the energy transformation sector rather then to the final energy consumption.

As the figure below shows, the use of the energy efficiency and energy saving potential in the agricultural sector is negligible. This is explained not only by the absence of the economic feasibility of energy saving and the implementation of energy-efficient technologies, but also by the computational complexity of this potential and its representation in the mathematical model. In fact, agriculture has much more opportunities for reduction of the final energy consumption, but this requires further research.

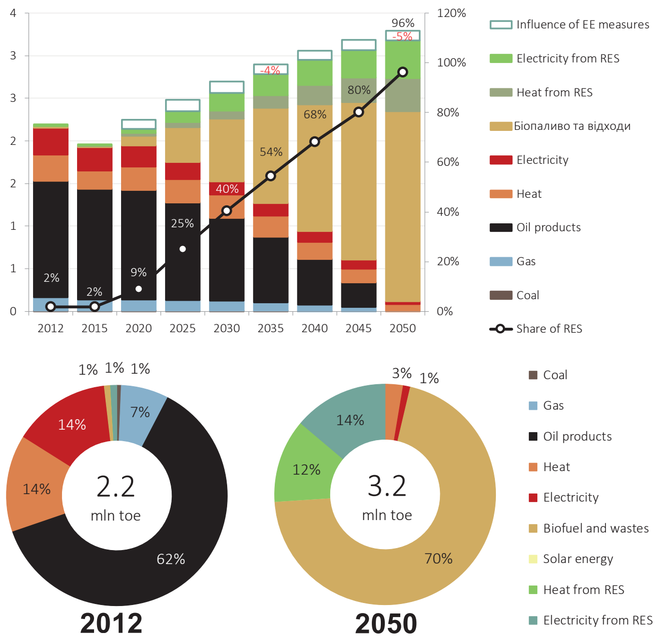


Figure 5.17 Final energy consumption by agriculture under the Revolutionary Scenario

Units: mln toe.

5.2 Electricity Generation

Modeling results for the hypothetical Conservative Scenario of energy development in Ukraine show that coal power plants can considerably expand their share in the structure of electricity generation (*Figure 5.18*). Conditions of this scenario envisage that the characteristics of the most technologies remain unchanged by 2050, modern requirements for decarbonization and ecologization of the energy sector are not included, as well as incentives for increasing energy efficiency and RES.

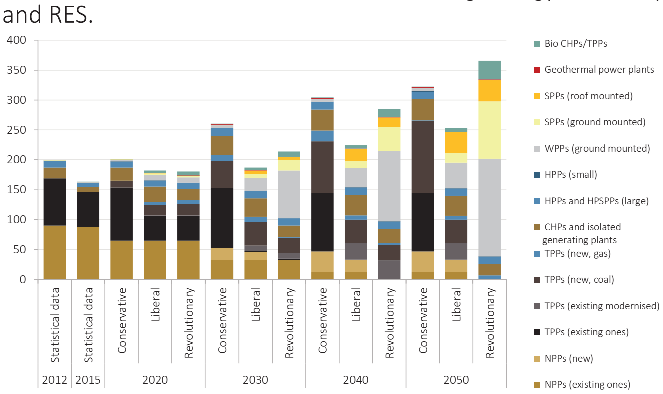


Figure 5.18 Electricity generation

Units: bln kWh.

However, results of modeling under the Liberal Scenario by 2050 (free development of all technologies is assumed) make it clear that electricity will be generated by all currently available technologies in Ukraine. Their structure will change considerably as the share of RES by 2050 will expand significantly compared to 2012. This is the case due to the rapid improvement and decreasing costs of RES technologies.

The demand for electricity will be significantly reduced compared to the Conservative Scenario due to the implementation of economically feasible energy efficiency potential in the final energy consumption. Electricity generation will be reduced by 28% in 2035 and 22% in 2050 compared to the similar years of the Conservative Scenario (*Figure 5.19*). The demand for the electricity generation may slightly exceed the indicator of 2012 in 2035, and it will make about 253 bln kWh in 2050, which is 27% higher that the indicator of 2012.

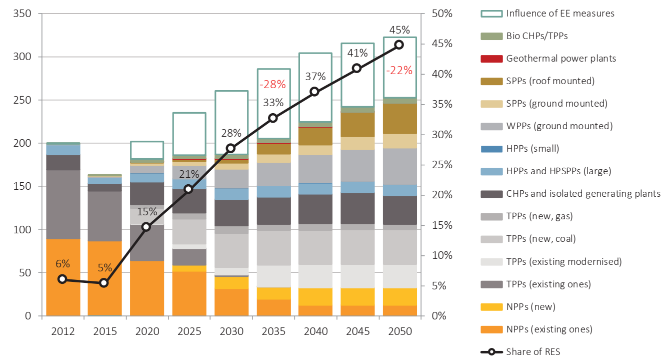


Figure 5.19 Electricity generation under the Liberal Scenario

Units: bln kWh.

Electricity generation by coal-based TPPs will slightly reduce, though the share in the total electricity generation structure will decline from 40% in 2012 to 27% in 2050 (*Figure 5.20*). It is necessary to modernize existing and / or construct new coal units that should meet modern European environmental requirements to maintan coal-based generation at the same level.

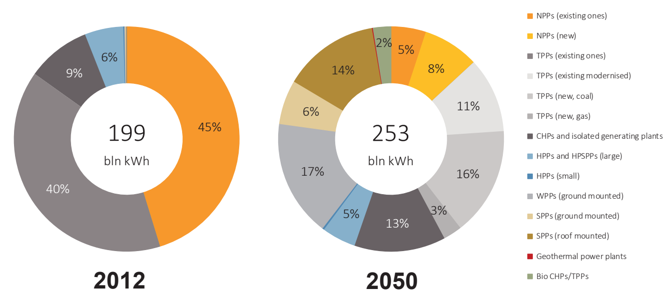


Figure 5.20 Electricity generation structure in 2012 and 2050 under the Liberal Scenario

Respective share of NPPs could decline significantly from 45% in 2012 to 13% in 2050. This reduction is associated with high capital expenses for the plant lifetime extension and especially for the construction of new nuclear units. Innovative types of reactors and small module units are not investigated in this work, but only reactors which are similar by the technical and economic characteristics to those currently used in Ukraine.

Moreover, traditional cogeneration (CHP and isolated generating plants) could increase. Its share in the total structure of electricity generation could increase from 9% in 2012 to 13% in 2050. In addition, CHP and isolated generating plants using biomass can generate up to 2.5% of electricity in the country.

Considerable development of hydropower is not expected, because the potential of small rivers is small, while the potential of large rivers is almost completely exhausted. In addition, construction of new big hydroelectric power plants (HPP) or hydroelectric pumped-storage power plants (HPSPP) has serious environmental consequences.

Solar and wind energy show the highest growth rates of the electricity generation due to considerable decrease of their cost. The share of the solar (SPP) and wind (WPP) power plants in the structure of electricity generation is expected at the level of 20% and 17% respectively. And the share of the households' SPP (roof mounted) could exceed more than two times the share of industrial SPP (ground mounted).

The total installed capacity of the power plants can increase by almost 2.7 times from 53 GW to 143 GW (*Figure 5.21*).

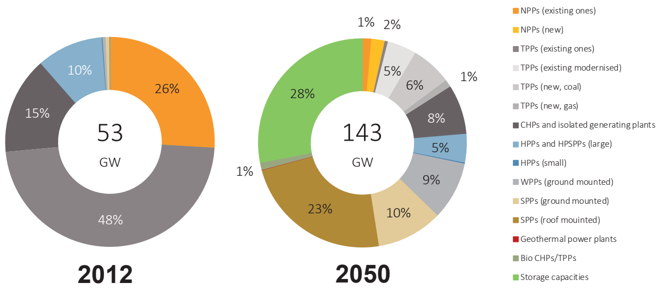


Figure 5.21 Structure of installed capacity of power plants under the Liberal Scenario

The use of the storage capacity is considered to ensure planned and reliable operation of SPP and WPP. It is assumed that it is necessary to reserve 0.74 kW and 0.42 kW of the storage capacity for every 1 kW of power produced by SPP and WPP, respectively (see detailed explanation in *Section 3.5*). Taking into account this information and possible rapid development of solar and wind energy, the share of the installed capacity of storage technologies in the total installed capacity in the energy sector is the highest and will make up 28% (about 40 GW). The capacity of roof mounted SPPs owned by households will make up 23% and the one of industrial SPPs will constitute 10%. The share of WPP will grow to 9%.

Only storage capacities is taken into account in the model to ensure predictability and reliability of SPPs and WPPs. The actual demand for the storage capacities could be lower, because gas-based generation and hydropower facilities could also be used for balancing and ensuring reliability of the power system.

Moreover, possibilities for intensive development of "smart" grids and demand-side management systems are not taken into account. At the same time, they can significantly reduce the needs for the storage capacities and significantly improve the quality of energy services. The balancing potential of the interstate flow of electricity was not taken into account intentionally, because it was important to estimate the national self-sufficiency for implementation of scenarios with high share of RES. However, this instrument can significantly reduce the cost of the "energy transition".

If condition on conservative ("frozen") techologies in the power sector is applied, the demand for investments for construction of the new power plants, support and modernization of the existing power plants could be even greater than in the case of the Liberal Scenario (*Figure 5.22*). This confirms once again that "unused" energy due to improvements in energy efficiency and energy saving is "cheaper" than additional power generation for satisfying growing demand.

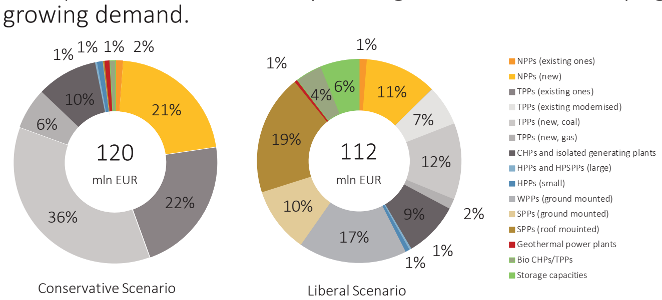


Figure 5.22 Structure of investments in power sector under Conservative and Liberal Scenarios up to 2050

Results of modeling under the Revolutionary Scenario show that available RES potential is sufficient to satisfy the demand for electricity generation by 91% from RES (*Figure 5.23*). This is definitely a big challenge for the United Energy System and institutions responsible for implementation of such "greening" policy in the power sector. Thus, practical institutional, technical, economic, etc. dimensions of this "energy transition" should be examined in more detail involving a number of competent experts in the field.

To achieve objectives of the Revolutionary Scenario it is necessary to electrify the energy sector of Ukraine as much as possible. Thus, electricity demand in 2050 will be greater than it was under the Conservative Scenario, even if implementation of energy efficiency policies is taken into an account. However, calculations show that electricity generation will be only by 14% higher in 2050 compared to baseline year of 2012.

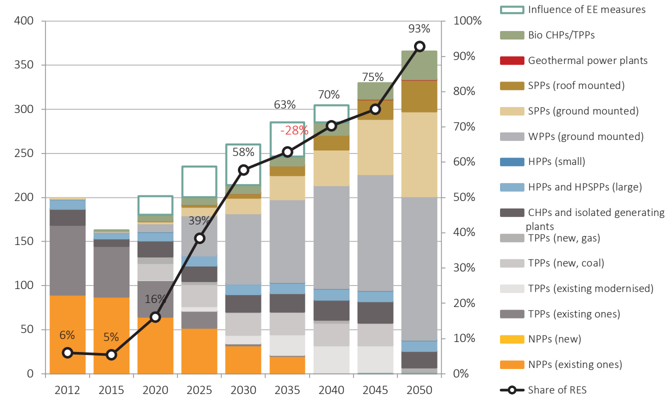


Figure 5.23 Electricity generation under the Revolutionary Scenario

Units: bln kWh.

One of the conditions of the Revolutionary Scenario is phase out of nuclear power by 2050. Thus, construction of new units is not envisioned under this scenario, and existing units will be operating until the end of their extended life time (see *Section 2.6* on explanation of assumptions on NPP). RES-based technologies also replace coal power plants as envisioned under conditions of this scenario.

Thus, the structure of electricity generation will change considerably by 2050 compared to 2012 (*Figure 5.24*). Wind and solar power plants will provide the largest share of electricity production. In total, they will count for more than 80% of the generated electricity.

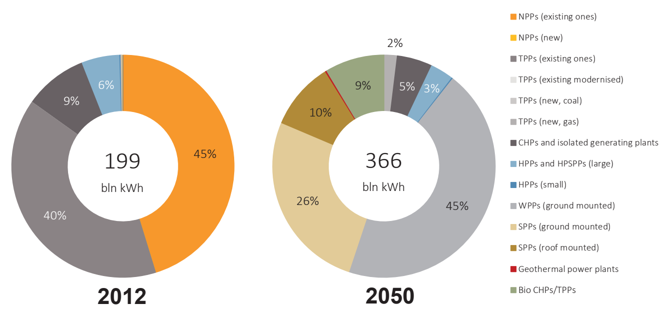


Figure 5.24 Electricity generation structure in 2012 and 2050 under the Revolutionary Scenario

In contrast to the Liberal Scenario, in the Revolutionary Scenario the share of industrial SPP in the total structure of the electricity generation exceeds the share of the SPP owned by households.

Electricity generation under the Revolutionary Scenario in 2050 will be only by 14% higher than in the Conservative Scenario though installed capacity of the electricity generation objects will be 3.6 times higher in the Revolutinary Scenario (*Figure 5.25*). This is explained by the fact that ICUFs of WPPs and SPPs are significantly lower than ICUF of coal TPPs and NPPs. Moreover, considerable amount of storage capacities

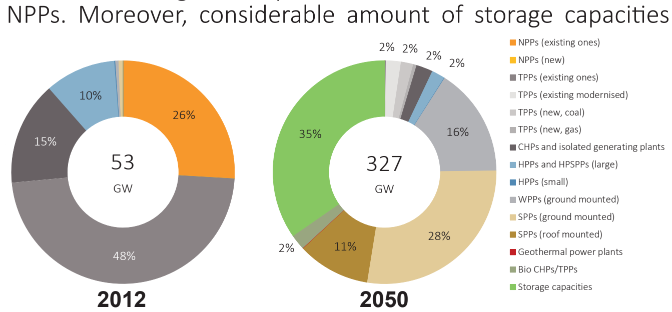


Figure 5.25 Structure of installed capacity of power plants under the Revolutionary Scenario

will be required, which could constitute up to 35% of the total capacity regardless of the potential of other technologies. It should be noted that this scenario does not take into an account introduction of “smart” grids, demand-side management, advanced technologies such as”power-to-gas”, etc., wich can be used for balancing and ensuring reliability of electricity grid.

As mentioned above total investments required for power sector under the Liberal Scenario are lower compared to the Conservative Scenario. At the same time, implementation of the Revolutionary Scenario would require much more investments than for two other scenarios (*Figure 5.26, 5.27*).

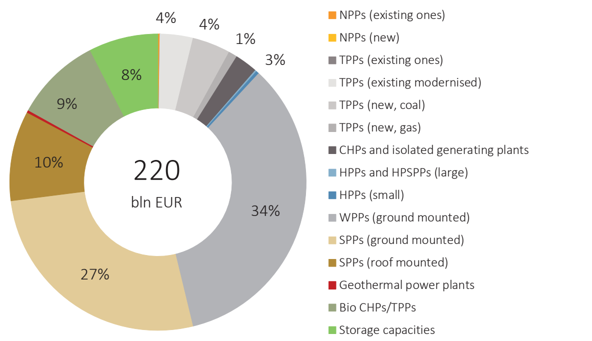


Figure 5.26 Structure of investments in the power sector under the Revolutionary Scenario up to 2050

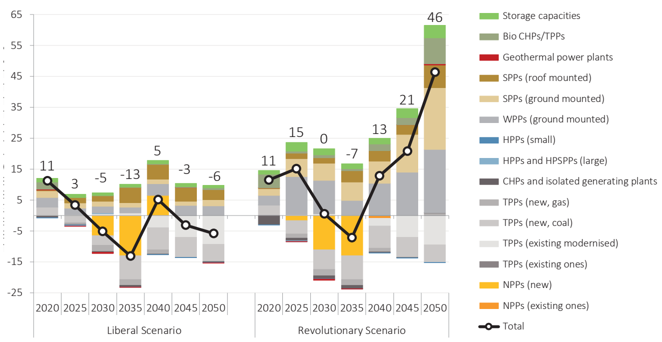


Figure 5.27 Difference in investment demands in the power sector between the alternative and Conservative Scenarios

Units: EUR bln.

Clearly, if a decision is taken on the “energy transition” to RES, it will be necessary to carry out more detailed and comprehensive analysis on potential development of the energy system of Ukraine. In particular, development of the advanced technologies should be taken into account. It is likely that new technologies will be available at the market in the next 10-15 years, which will allow significantly reduce the cost of “energy transition” and more equal distribution of the investments over time. In addition, it is necessary to examine possibility to use interstate flow of electricity to achieve targets of the Revolutionary Scenario.

5.3 Heat Generation

Under conditions of the Conservative and Liberal Scenarios, the share of coal generation in the district heating supply increases greatly (*Figure 5.28*). This is due to the fact that gas prices grow considerably compared to coal prices in the long run (see *Section 2.5* on price forecasts in the energy market). It should also be noted that logistical issues on coal supply to boiler houses have not been considered, which could influence the results. Moreover, Ukraine approved strict environmental liabilities on the limitation of emissions from large combustion plants (Directive 2010/75/EU), but the implementation of Directive 2015/2193/EU for the medium-sized combustion plants (1-50 MW) is not planned yet. Therefore, the latter was not taken into account under conditions of scenarios. However, the implementation of Directive 2015/2193/EU is mandatory for all EU countries. Thus, it can be expected that Ukraine will also be obliged to comply with requirements of this Directive following further integration of Ukraine’s energy sector to the EU market. Hence, it is likely that medium-sized combustion

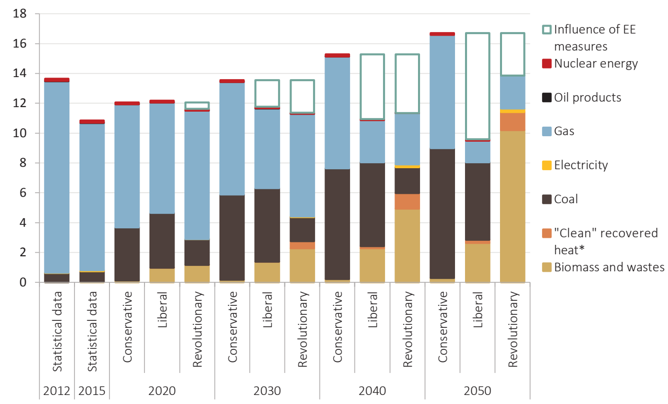


Figure 5.28 Heat generation

Units: mln toe.

* “Clean” recovered heat is thermal energy obtained from recovery boilers, cooling installations, water heaters, etc. which function based on the following energy resources: a) heat dissemination from cooling systems of production units (blast furnaces and open-hearth furnaces, pyrite furnaces, gas generators, heating furnaces, etc.); b) physical heat of production products including collected heat at the intermediate stages of the technological process (heat of hot coke, heated metal, refined products, chemical products); c) waste-gas heat from industrial furnaces and boiler units, waste slag heat, etc.; d) heat of exhausted steam from the heat installations such as presses, steam drives of pumps and compensators, etc.

plants will be also obliged to meet strict environmental criteria in the long run up to 2050. This will significantly reduce competitiveness of coal generation compared to biomass based CHPs or other RES-based technologies, which will be available at the market by that time. Thus, conditions of the energy sector development will change significantly. The results would differ considerably from those presented in this Section if requirements of Directive 2015/2193/EU are taken into an account for scenario modeling.

Establishment of conditions for unimpeded development of technologies in the heating sector will first of all significantly reduce consumption and, thus, production of heat. *Figure 5.29-5.30* shows that demand for heat in 2050 will be 30% lower than under the Conservative Scenario. Moreover, heat generation from biomass will grow rapidly, up to 2.6 mln toe in 2050.

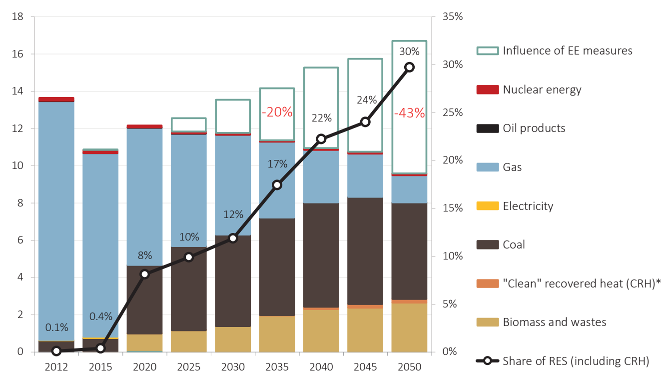


Figure 5.29 Heat generation under the Liberal Scenario

* See explanation under the previous figure

Units: mln toe.

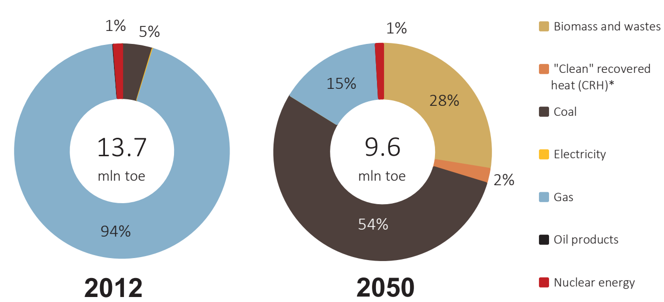


Figure 5.30 Structure of heat generation under the Liberal Scenario

* See explanation under the Figure 5.28

According to results of modeling under the Revolutionary Scenario, the use of biomass and wastes should become a high-priority in the heat supply sector and coal use should be phased out completely to achieve the set targets (*Figure 5.31*). It may also be feasible to develop district electric heating.

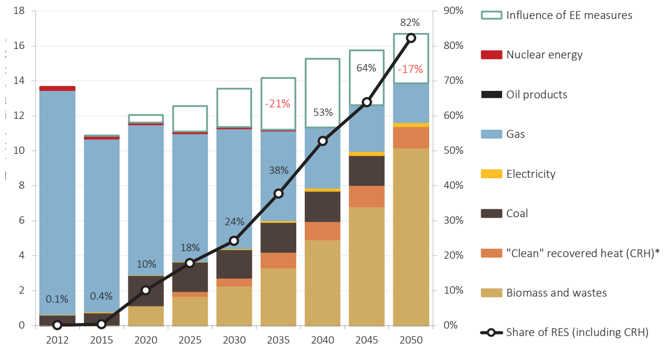


Figure 5.31 Heat generation under the Revolutionary Scenario

* See explanation under the Figure 5.28
Units: mln toe.

Heat generated from biomass and wastes could account for about 73% in total heat generation including centralized heating and industrial needs. At the same time, the share of heat generated from gas will decrease from 94% in 2012 to 16% in 2050 (*Figure 5.32*).

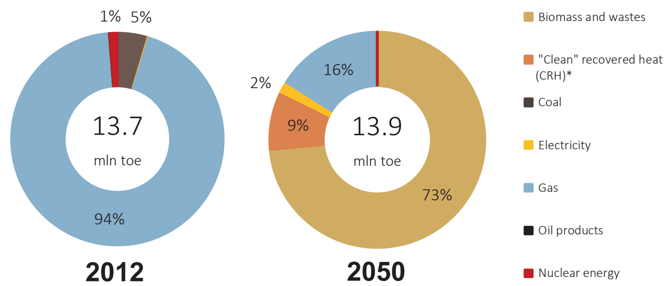


Figure 5.32 Structure of heat generation under the Revolutionary Scenario

* See explanation under Figure 5.28

It should be noted that a range of currently available techhologies were considered for modeling of heat sector development under the Liberal and Revolutionary Scenarios including biomass-based technologies, heat recovery from technological processes and electric heating technologies. In the long run, new RES-based technologies can be developed, in particular, heat storage technologies which will significantly change heating sector future.

5.4 Total Primary Energy Supply

Total primary energy supply (TPES) under the Conservative Scenario will be constantly increasing after 2015. In contrast, it can stabilize at the level of 80-85% compared to 2012 levels, namely 10 mln toe under the Liberal Scenario (*Figure 5.33*). According to model estimates, TPES will be by 57% lower under the Revolutionary Scenario compared to Conservative Scenario in 2050. The share of RES under the Revolutionary Scenario can reach 30% in 2035 and 76% in 2050. Domestic production of energy resources could be more than 90% of TPES, which will considerably improve economic and energy security.

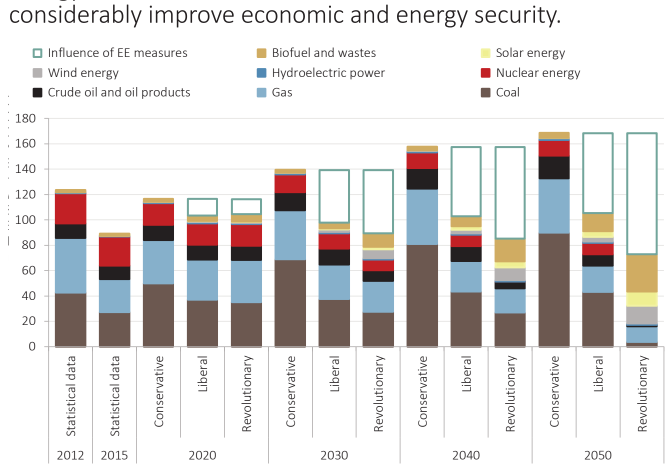


Figure 5.33 Total primary energy supply

Units: mln toe.

Moreover, it is important that "energy transition" to RES will be implemented based on maximum possible domestically produced technologies. To ensure development of advanced technologies in Ukraine, it is important to successfully complete all reforms in the energy and banking sectors, as well as considerably simplify all administrative and tax procedures for doing business.

Thus, results of modeling of the energy sector development scenarios indicate that **Ukraine has absolutely sufficient renewable energy potential, which is required for implementation of the Revolutionary Scenario and meeting potential demand for energy resources and services even in the case of maintaining a high share of the energy-intensive industry (metallurgy, chemical industry, etc.)** in the country. It should be noted that only those RES-based technologies for implementation of the renewable potential and meeting energy demand of society were analysed, which are already available at the Ukrainian market. What is most important their production can be either partially or fully located in Ukraine.

At the same time, the Liberal Scenario, which envisions perfect competition at national energy market demonstates competitiveness potential of renewable energy compared to traditional energy, even without target policy for RES development.

5.5 Relative Indicators of Energy Sector Sevelopment

Taking into account macroeconomic assumptions provided in previous sections, particularly, on annual average GDP growth rates during 2016-2050 (4% per year), as well as calculated indicators of the total primary energy supply under the Liberal Scenario, it can be expected that the primary energy intensity of GDP in Ukraine will reach the level of countries of Organisation for Economic Co-operation and Development only in 2050. However, integrated indicator for 28 countries of the European Union will not be reached by 2050 (*Figure 5.34*).

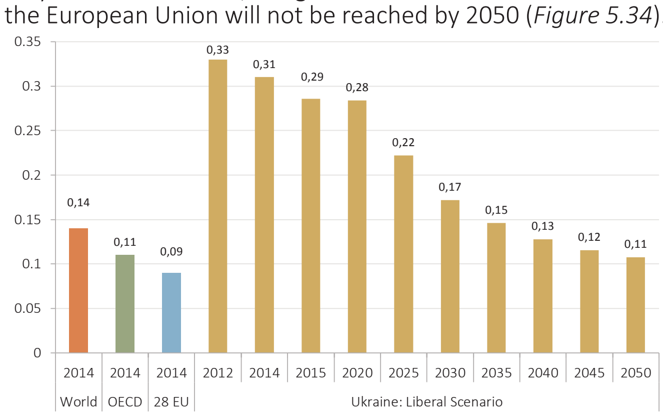


Figure 5.34 Primary energy intensity of GDP under the Liberal Scenario

Source: prepared by authors based on the results of modeling and IEA data (Key World Energy Statistics).
Units: toe/$1000 (2010) GDP(PPP).

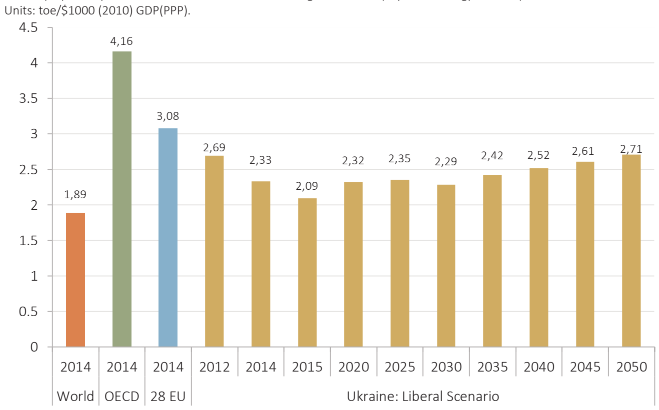


Figure 5.35 Primary energy intensity per person under the Liberal Scenario

Source: prepared by authors based on the results of modeling and IEA data (Key World Energy Statistics).
Units: toe/person.

The indicator of total primary energy supply per person in Ukraine is higher than average one for the world but much lower than in the countries of Organisation for Economic

Co-operation and Development and slightly lower than for the European Union countries (*Figure 5.35*).

At the same time, primary energy intensity of GDP in Ukraine can reach current level of energy intensity of the countries of Organisation for Economic Co-operation and Development in 2040, and the level of the countries of the European Union in 2045 under the Revolutionary Scenario (*Figure 5.36*).

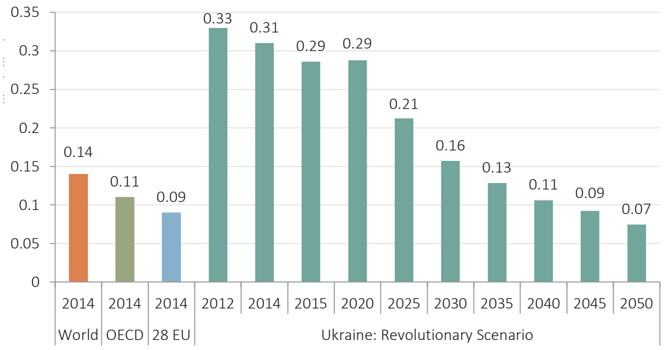


Figure 5.36 Primary energy intensity of GDP under the Revolutionary Scenario

Source: prepared by authors based on the results of modeling and IEA data (Key World Energy Statistics).
Units: toe/$1000 (2010) GDP (PPP).

The indicator of the total primary energy supply per person in Ukraine is expected to be quite stable under the Revolutionary Scenario (*Figure 5.37*).

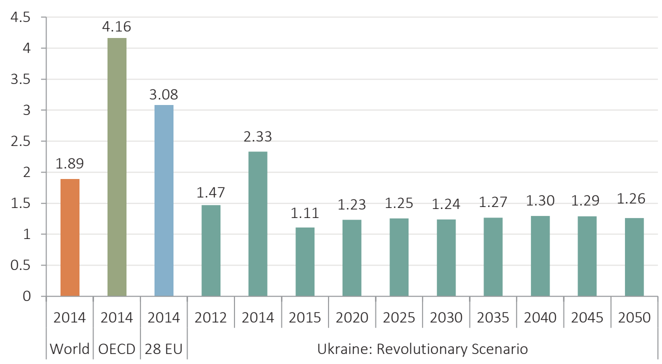


Figure 5.37 Primary energy intensity per person under the Revolutionary Scenario

Source: prepared by authors based on the results of modeling and IEA data (Key World Energy Statistics).
Units: toe/person.

The gap between specified indicators of primary energy intensity in Ukraine and economically developed countries demonstrates that this problem lays not only in energy dimension (inefficient and wasteful use of energy resources), but also in economic dimension. It is necessary not only to carry more in-depth research on "energy transition" of Ukraine to the renewable energy sources, but also study possible transformation pathways of the modern socio-economic model of Ukraine into the one, which will promote greening of the energy sector and welfare improvement of the population in Ukraine.

5.6 Greenhouse Gas Emissions

Under the Conservative Scenario, GHG emissions[96] will be constantly increasing and in 2050 they can reach 73% of the level observed in 1990 (*Figure 5.38*). At the same time, in 2030 they will amount approximately to 56% of the level observed in 1990, which is lower than the targeted indicator specified in the Nationally Determined Contribution (NDC) of Ukraine to the Paris Agreement. This confirms once again that the selected target for NDC of Ukraine is not ambitious and should be revised.

Implementation of the Liberal Scenario will allow stabilizing greenhouse gas emissions (GHG) at the level of 35-38% compared to the level observed in 1990 (*Figure 5.39*).

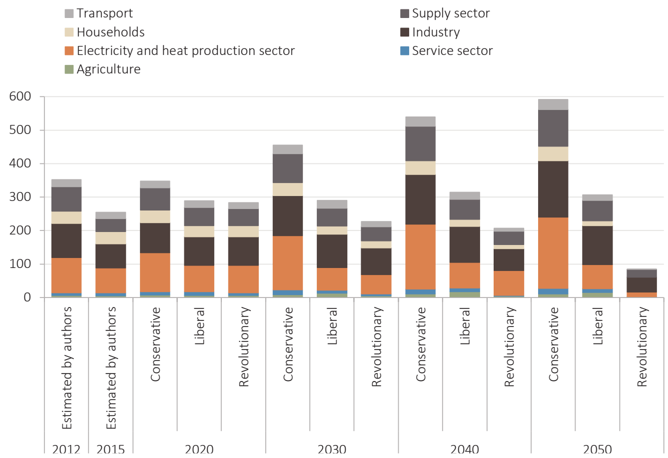


Figure 5.38 Greenhouse gas emissions

Units: mln t CO_2-equivalent.

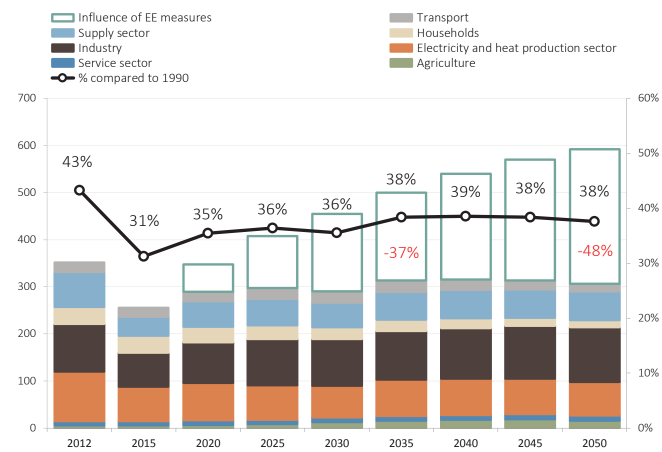


Figure 5.39 Greenhouse gas emissions under the Liberal Scenario

Units: mln t CO_2-equivalent

The structure of GHG emissions under the Liberal Scenario (*Figure 5.40*) will undergo changes in 2050. Considering that this scenario envisions significant development of renewable energy, amount of GHG emissions from power and heat generation sectors will significantly decrease. At the same time, due to the low level of RES in industry, the share of GHG emissions from industrial sector will increase.

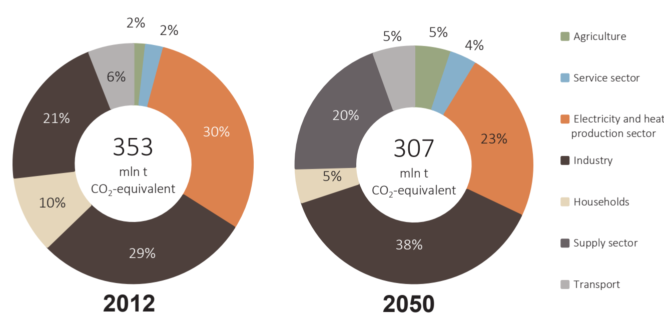


Figure 5.40 Structure of greenhouse gas emissions under the Liberal Scenario

Results of modeling show that the achievement of targets under the Revolutionary Scenario will result in significant reduction of GHG emissions, which in 2050 can make up only 10% of the level observed in 1990 (*Figure 5.41*).

Under this scenario, GHG emissions from industrial sector will account for over half and households will not be responsible for any GHG emissions. The shares of agriculture, service and transport sectors will be within the range of 0.5-1.5% (*Figure 5.42*).

96 GHG emissions include emissions from the "Energy sector" and "Industrial Processes Sector" according to the classification by the Intergovernmental Panel on Climate Change.

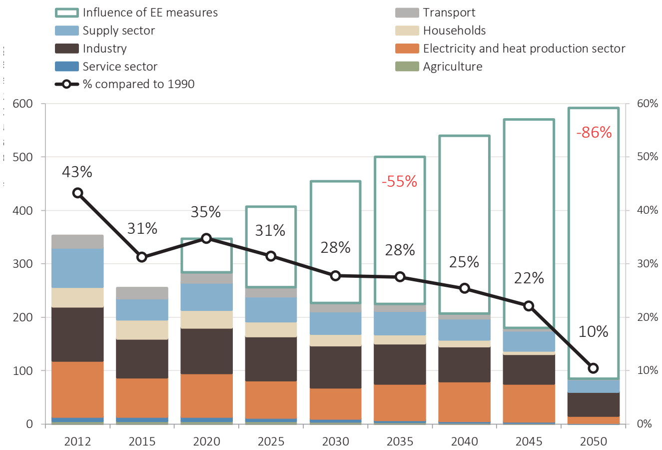


Figure 5.41 Greenhouse gas emissions under the Revolutionary Scenario

Units: mln t CO_2-equivalent.

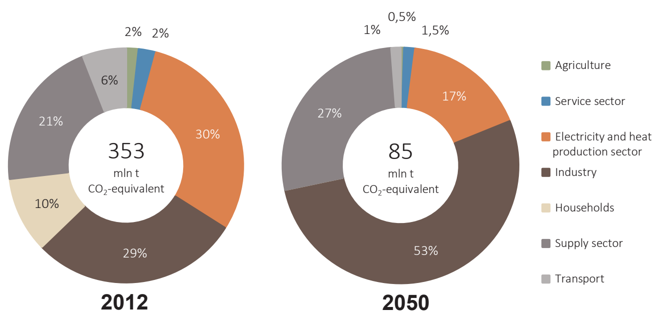


Figure 5.42 Structure of greenhouse gas emissions under the Revolutionary Scenario

5.7 Total Costs and Investments

Figure 5.43 shows that total annual costs for operating of the energy system, which include investments in technologies (modernization, purchasing of new ones), maintenance expenses, costs of purchasing, transportation and supply of fuel, etc., can grow rapidly after 2020. Investments in technologies of the final energy consumption (for example, household appliances, different transport vehicles, lighting fixtures, etc.) will account for significant share in investment structure because they have a significantly lower life time compared to, for example, electricity and heat generation technologies, and their number is large.

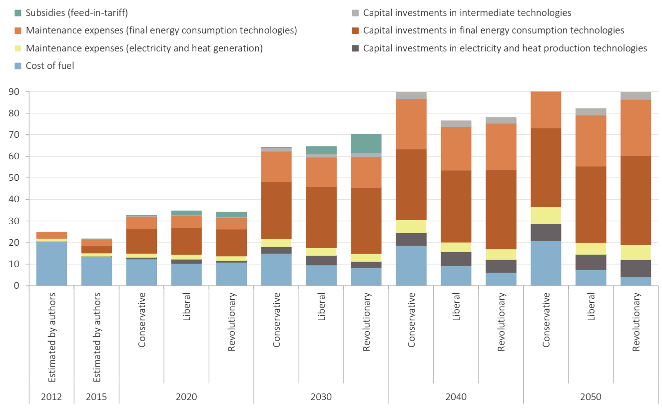


Figure 5.43 Annual costs for functioning of the energy system[97]

Units: bln EUR.

In the long run, transition from the current energy supply system with high shares of costs for fuel and maintenance expenses to the system which will be characterized by the high capital investments and a relatively lower share of costs for fuel is expected, as technical life time of the majority of existing energy capacities is either exhausted or already comes to its end.

However, annual costs for functioning of the energy system under alternative scenarios will be lower, than under the Conservative Scenario according to modeling results. Thus, it seems that cost savings for fuel purchasing cover the costs to be invested in new technologies (*Figure 5.44*).

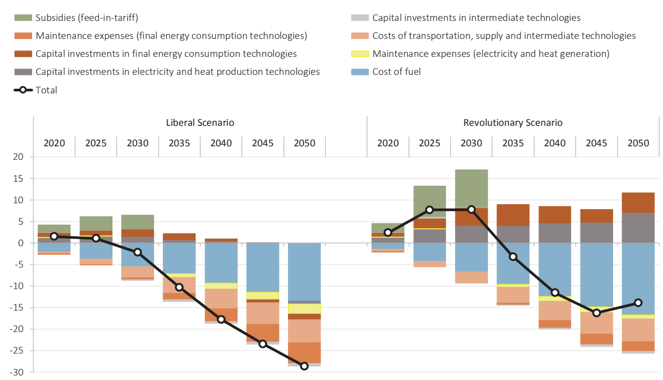


Figure 5.44 Difference between the annual costs for functioning of the energy system under the alternative and Conservative scenarios

Units: bln EUR.

97 For the most energy technologies (thermal power plants, final consumption appliances, etc.), capital expenditures accrue over the entire period of their operation, and annual cash flow is calculated taking into account the period of use of a technology and the cost of capital. These annual payments combined with relevant maintenance expenses make up total costs of the energy system. Annual investment costs of technologies put into operation in the previous periods are not calculated and, thus, are not included in the target function.

6 ECONOMIC CONSEQUENCES OF UKRAINE'S ENERGY SECTOR DEVELOPMENT SCENARIOS UNTIL 2050

Macroeconomic Impacts

Impacts for Households

Sectoral Impacts

Photo: Shutterstock

6.1 Macroeconomic Impacts

This Section presents an assessment of social and economic impacts of the Ukraine's energy sector development under Liberal and Revolutionary Scenarios, which are discussed in previous Sections of this study.

Energy policy measures are studied under the reference macroeconomic scenario, with 4% average GDP growth rate until 2050 (see *Section 2.3*). Energy policies are imposed on the reference scenario and their impact on macroeconomic and sectoral indicators is examined.

To provide an assessment of economic impacts for these two scenarios a dynamic Ukrainian CGE model with extended energy block is used. TIMES-Ukraine and Ukrainian CGE models are unified using the same assumptions on aggregate GDP growth rates. TIMES-Ukraine model estimates the additional investments and changes in energy consumption by sectors used to define energy scenarios in the Ukrainian CGE model.

All estimates presented in this Section are provided relatively to the Conservative scenario. That is, any changes in macroeconomic, sectoral, or other indicators should be interpreted as deviations from the Reference (Conservative) Scenario in the corresponding year. Reference Scenario is based on the baseline GDP growth rates, but does not include implementation of energy policies defined in the Liberal or Revolutionary Scenarios. Therefore, this Section provides an impact assessment of energy efficiency, energy saving, renewable energy development and other measures on macroeconomic, sectoral and social indicators, all other conditions being equal (current fiscal and monetary policy remains the same, no additional sectoral reforms, etc.).

Considering relative nature of impacts for both scenarios, negative values of reported indicators do not necessarily imply a decrease in their absolute values under the analyzed energy policies, and in most cases reflect the slowdown in the growth rates of the corresponding indicators.

Modeling results show that **implementation of the Liberal and Revolutionary Scenarios is characterized by positive macroeconomic impacts.** This is especially the case in the medium term and long term, starting from 2019-2020 (*Figure 6.1*). Such effects could be explained by dynamics of investment processes. In particular, GFCF increases substantially during the first years, but the level of energy efficiency is growing at a much slower pace, especially in case of energy intensive sectors. At the same time, in the medium term positive contribution of energy efficiency improvements and substitution exceeds investment costs of the energy policy scenarios.

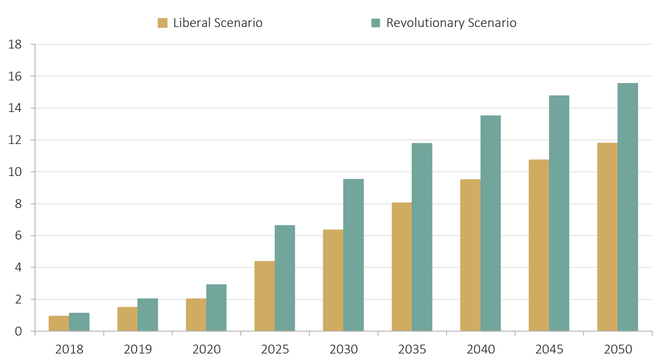


Figure 6.1 Impact of the energy policies on GDP

Units: % to the Reference (Conservative) Scenario.

Considering the dynamics of investments and technological changes, macroeconomic impacts have a cumulative nature, i.e. additional growth relative to the reference scenario increases over time. While in 2025 additional GDP increase is 4-6%, by 2050 it can reach 12-15%.

Under the current approach it is assumed that own funds of enterprises and households are key investment sources. Therefore, the nature of the observed economic effects is also determined by a more rapid increase in production costs during the first years of policies implemenation comparing to subsequent periods when increased expenditures on energy efficiency, energy saving, energy substitution and renewable energy development are compensated by energy consumption savings.

On the one hand, an assumption of own funds use reduces aggregate expenses on the implementation of energy policies, as it eliminates the need to attract external funds and pay interest. On the other hand, it implies a more stringent commodity price increase and a change in the final and intermediate consumption structures.

In general, **implementation of the Revolutionary Scenario has higher GDP and output growth rates compared to the Liberal Scenario** (*Figure 6.1, 6.2*). This is explained by the significantly higher gross fixed capital formation (GFCF) level within the Revolutionary Scenario (*Figure 6.3*).

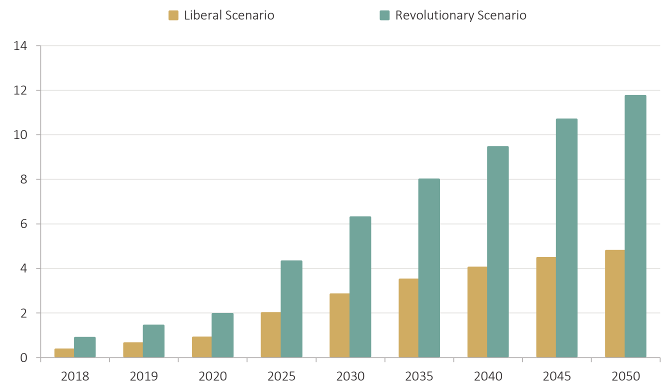


Figure 6.2 Impact of the energy policies on the output

Units: % to the Reference (Conservative) Scenario.

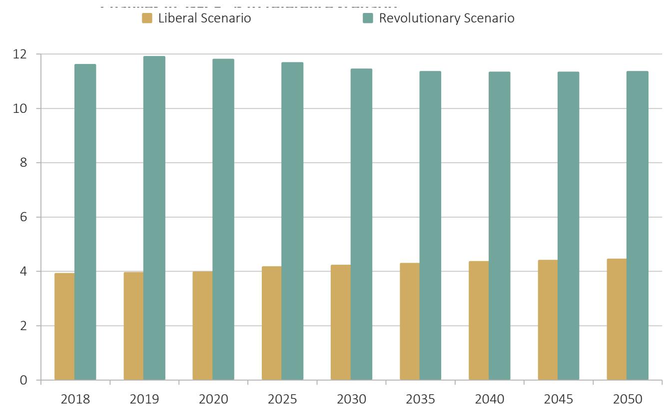


Figure 6.3 Impact of the energy policies on the gross fixed capital formation (GFCF)

Units: % to the Reference (Conservative) Scenario.

The need to accumulate additional investments serves as a key success factor and, at the same time, as a significant risk for the effective implementation of energy policies. It is the ever-increasing level of GFCF, combined with efficiency improvements of fixed assets, which is a prerequisite for successful implementation of energy policy measures.

Regarding sources of investments, a key role is played by households, which should provide more than half of the additional funding for energy policy measures under the Liberal Scenario. At the same time, a significantly higher amount of investments should be provided by industrial producers, in particular in the power sector, within the Revolutionary Scenario (*Figure 6.4*). The amount of additional investment expenses of households is practically the same in both energy scenarios, while additional investments in the electric power sector take place only in the Revolutionary Scenario.

It should be noted that in terms of aggregate investments category (GFCF), households share is relatively small as of 2015 (less than 3% or UAH 4.5 billion in 2011 prices). However, in the context of analyzed energy policies, the category of financial expenses of households becomes much broader and includes not only investments (under the National accounts

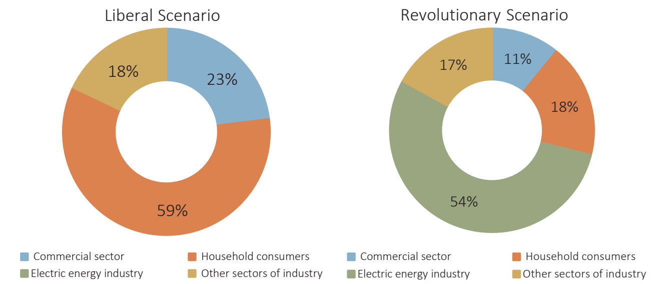


Figure 6.4 Distribution of additional investments by source

Units: % of total additional investments during 2017-2050.

definition) but also final consumer expenses, i.e. expenditures on large and small household appliances, electrical appliances, cars, etc., thus reaching significant amounts (in 2014, over UAH 100 billion)[98]. In this context, **additional investment expenditures of households estimated at USD 169 billion (in 2011 prices) for the implementation of the Revolutionary Scenario for 2017-2050 seem to be a relatively minor additional resource representing less than 0.3% of the total final consumer expenditures of households over the same period (2017-2050).**

6.2 Impacts for Households

Should the Liberal Scenario be implemented, there are minor positive economic impacts for residential consumers in the short term (until 2019), while in the case of the Revolutionary Scenario, there might be even moderate negative effects (*Table 6.1, 6.2*). However, in the medium term (2020-2025), an additional households' income growth will amount to 4-6% with a further increase to 11-15% in 2050.

Table 6.1 Impact of the energy policies implementation on the households' income within Liberal Scenario (changes of the real income relative to the Conservative Scenario, %)

Indicator/ Scenario	Liberal Scenario of energy sector development							
	2018	2020	2025	2030	2035	2040	2045	2050
Aggregate income	0.3	1.4	3.8	5.8	7.6	9.0	10.3	11.4
I decile group[99]	0.4	1.7	4.6	7.1	9.2	11.1	12.8	14.2
II	0.4	1.7	4.6	7.1	9.2	11.1	12.7	14.1
III	0.4	1.7	4.6	7.1	9.3	11.1	12.7	14.1
IV	0.4	1.7	4.5	6.9	9.0	10.8	12.4	13.7
V	0.4	1.7	4.5	6.9	8.9	10.7	12.2	13.6
VI	0.4	1.6	4.3	6.6	8.6	10.2	11.7	12.9
VII	0.4	1.5	4.1	6.3	8.2	9.7	11.1	12.2
VIII	0.4	1.5	3.9	6.0	7.7	9.2	10.5	11.6
IX	0.3	1.3	3.4	5.1	6.5	7.6	8.6	9.5
X (the highest one)	0.2	0.8	2.1	3.2	4.1	4.8	5.4	5.9

The main driver of households' real income change is the growth in wages due to increase in the total output of goods and services. Thus, considering changes in the sectoral output structure (see *Section 2.3*), there will be changes in the employment distribution by sectors, with a decrease in the number of employees in the extractive industries and an increase in employment in the service sector, agriculture and some processing industries.

Higher investments and more rapid output growth within the Revolutionary Scenario lead to faster growth in households' real income in the long term compared to the Liberal Scenario (*Table 6.1, 6.2*).

As real income of lower decile households will grow faster than of higher ones, analyzed energy policy measures can be considered effective also in the context of reducing income differentiation.

Table 6.2 Impact of the energy policies implementation on the households' income within Revolutionary Scenario (changes of the real income relative to the Conservative Scenario, %)

Indicator/ Scenario	Revolutionary Scenario of energy sector development							
	2018	2020	2025	2030	2035	2040	2045	2050
Aggregate income	-0.1	1.7	5.6	8.5	10.8	12.6	13.8	14.6
I decile group	-0.1	2.1	6.6	10.3	13.2	15.4	17.1	18.1
II	-0.3	1.9	6.6	10.3	13.2	15.5	17.2	18.2
III	-0.2	2.0	6.7	10.4	13.3	15.6	17.2	18.2
IV	-0.1	2.0	6.5	10.1	12.9	15.0	16.6	17.6
V	-0.2	1.9	6.5	10.0	12.9	15.0	16.6	17.7
FVI	-0.1	2.0	6.3	9.7	12.3	14.3	15.7	16.6
VII	-0.3	1.8	6.1	9.4	12.0	13.9	15.4	16.3
VIII	-0.1	1.8	5.7	8.7	11.0	12.7	13.9	14.7
IX	0.0	1.7	5.1	7.5	9.4	10.7	11.7	12.2
X (the highest one)	-0.1	0.9	3.0	4.5	5.6	6.4	7.0	7.4

In general, results show that **successful implementation of Ukraine's energy sector development policy within both studied scenarios is characterized by positive socio-economic effects for all groups of households**. Even though there might be moderate negative impacts in the short term (2019-2020), implementation of energy efficiency measures and development of RES will lead to an increase in real income of households, and by 2050 these trends will strengthen significantly.

6.3 Sectoral Impacts

In addition to increase in aggregate output, there are also significant shifts at the sectoral level. In most cases these changes are related to energy sector and energy-intensive industries. The following factors are the main determinants of such changes.

Firstly, it is a productivity change. As has already been mentioned, it is assumed that intensification of investment processes leads not only to quantitative (increase in volumes of fixed assets), but also to qualitative (increased efficiency of production processes) changes. Thus, increased production efficiency leads to a decrease in the specific energy consumption and changes in the consumption structure (fuel substitution).

Secondly, additional investments. The increase in productivity is defined mainly by additional investments. In this context, the balance between volumes of additional investments and changes in the output efficiency is also important.

Thirdly, the change in the intermediate consumption prices, primarily for energy resources. If intermediate consumption prices increase more than the corresponding energy use efficiency, there may be negative sectoral effects.

Finally, changes in sectoral demand, which include both domestic and foreign markets, also provide an important contribution. In general, a combination of these factors defines sectoral effects (*Figure 6.5*).

Following the relative increase in electricity consumption and reduction in the coal and oil products use, there are corresponding changes in the sectoral output. Several industries, in particular metallurgical production, chemical industry and some sectors of mechanical engineering are growing due to improvements in intermediate energy

98 National Accounts of Ukraine for 2014 [Text]: Statistical compendium / State Statistics Service of Ukraine (Under the editorship of I. M. Nikitina). – Kyiv. – 2016. – 172 p.

99 Households divided into decile groups by the level of per capita income.

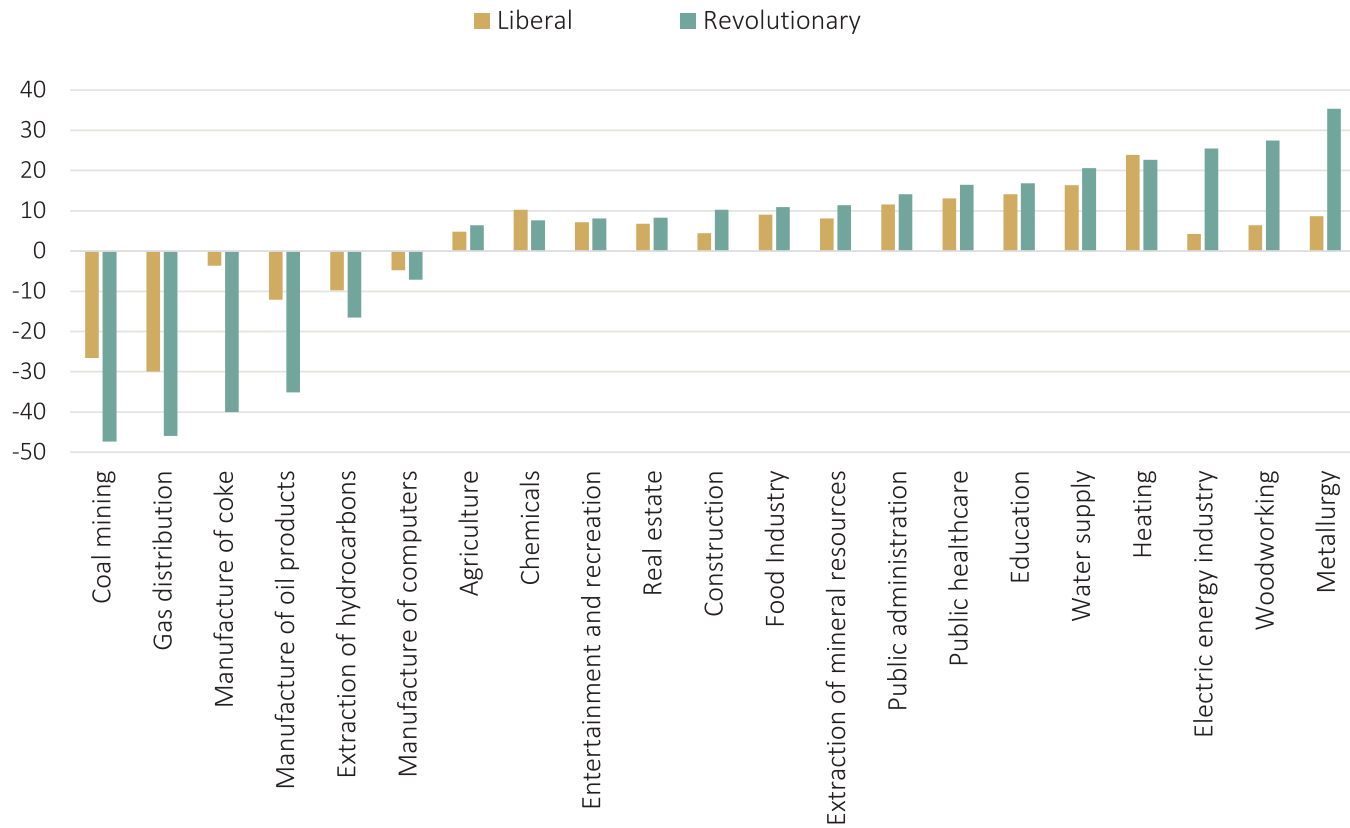


Figure 6.5 Impact of the energy policies on the sectoral output in 2050

Units: % to the Reference (Conservative) Scenario.

consumption, as well as coal and natural gas price reduction due to the decrease in demand. There is also a moderate growth, relative to the Reference (Conservative) Scenario, in most service sector industries. These trends are presented in more detail in *Annexes A.7-A.8*.

As a result of a significant increase in the share of biomass in the final consumption relative to the Reference (Conservative) Scenario, especially within the Revolutionary Scenario, there is an additional output growth in the woodworking industry and agriculture.

Considering the scale of structural shifts, another important aspect of sectoral effects includes impacts on the labor market. Although labor market is not explicitly modeled in this study, as the aggregate supply of labor is set exogenously and does not change between scenarios, it is possible to analyze labor redistribution and employment changes by sectors. It should be noted that such approach has significant limitations, since employment is not linked directly to specific technologies (e.g. the number of jobs created following the setup of new SPP) and it does not estimate changes in the total level of unemployment. However, such approach can provide important insights into the possible structural shifts on the labor market.

Sectoral redistribution of labor force is defined by several factors and is not always proportional to the changes in output volumes. In the long run, the composition of the sectoral value added may change due to capital-labor substitution. Therefore, sectoral employment may decrease under growing output (e.g. if the share and / or the efficiency of fixed assets increases), and, vice versa, grow in case of output reduction (e.g. if the share of fixed assets decreases).

The number of employees by type of economic activities in the reference year (2015) is based on the State Statistics Service of Ukraine[100] data. Redistribution of the number of employees in the case of industrial subsectors was carried out proportionally to the number of permanent employees[101]. The change in the total number of employees on the national level until 2050 is based on the reference demographic scenario of the Institute for Demography and Social Studies[102] and is assumed to be proportional to the change in the number of people aged 15-64.

In general, results show that changes in employment qualitatively correspond to the sectoral output shifts, however, quantitative effects differ significantly (*Figure 6.6*). In particular, relative decrease in the number of people employed in the coal-mining industry is significantly higher than the decrease in output (*Annex A.9*), reflecting the improvement of fixed assets' technological efficiency in the long term.

As in the case of output, the scale of structural shifts on the labor market under the Revolutionary Scenario substantially exceeds the impacts of the Liberal Scenario. The largest relative decrease in the number of employees can be seen in the extractive industry, oil refining, gas distribution, and manufacture of coke products (*Annex A.9*). At the same time, in the context of absolute changes, the most significant growth is observed in the service sector, in particular, for public healthcare, public administration and education (*Figure 6.6*), although, in relative terms, the increase in the number of people employed in these sectors does not exceed 10-17% in 2050.

Considering a significant development of the renewable energy sources, especially within the Revolutionary Scenario, small changes in the number of people employed in the electric power industry may seem somewhat unexpected *(Figure 6.6)*. This could be explained by several factors, mainly associated with methodological approach. In particular, the change in the number of employees is estimated in the context of the labor redistribution between sectors and does not explicitly estimates a number of newly created jobs. In addition, electric power sector in the Ukrainian CGE model is aggregated (unlike in the TIMES-Ukraine model), and therefore change in the number of employees is assessed for the power industry in general, rather than for individual sub-sectors (wind power, solar power, etc.). Finally, due to the significant intensification

100 Economic activity of the population of Ukraine 2015 // State Statistics Service of Ukraine. Statistical compendium. Kyiv, 2016. – 201 p.

101 Labor of Ukraine in 2015 // State Statistics Service of Ukraine. Statistical compendium. Kyiv, 2016. – 312 p.

102 Demographic forecast for Ukraine for 2014-2061 // Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine. – Available at: http://www.idss.org.ua/monografii/popforecast2012.zip

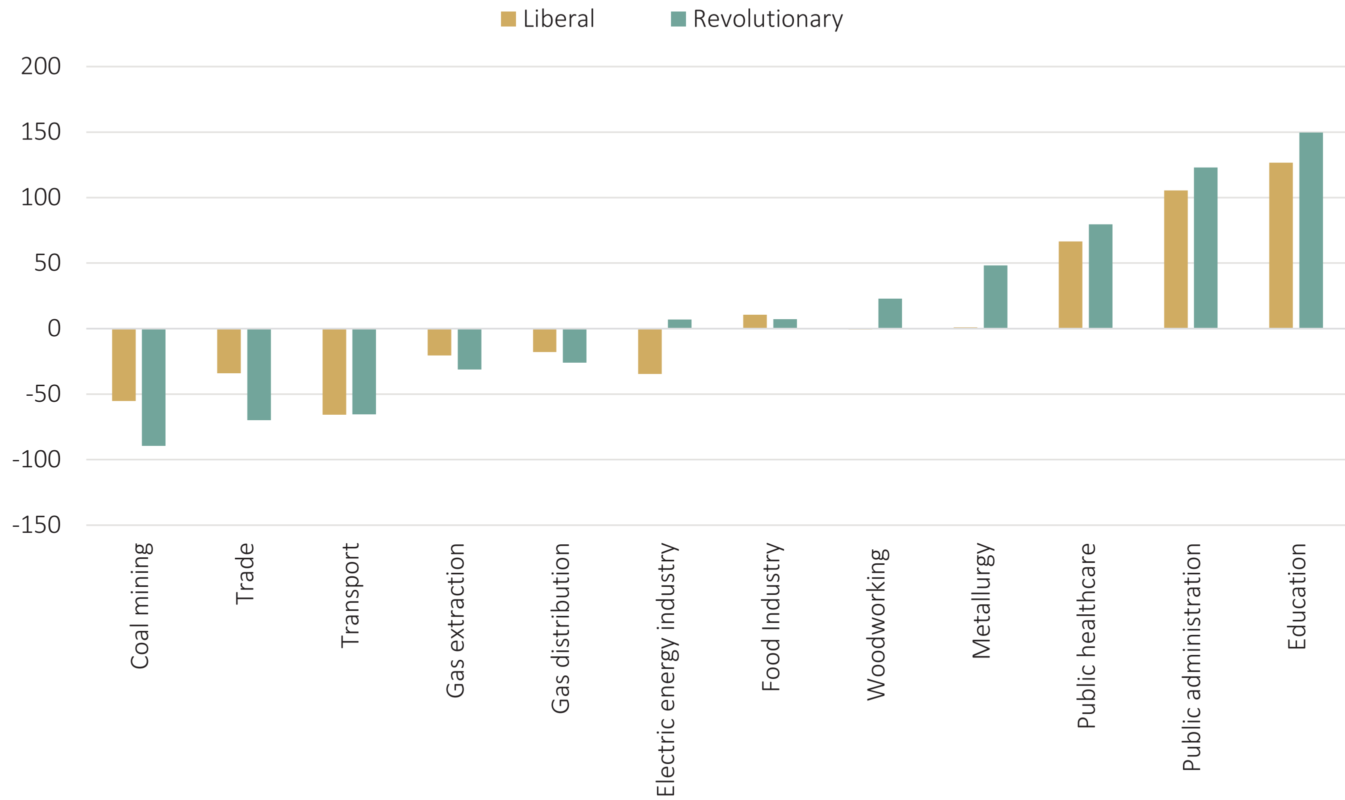


Figure 6.6 Impact of the energy policies on the change in the number of employees by sector in 2050

Units: thousand of people to the Reference (Conservative) Scenario.

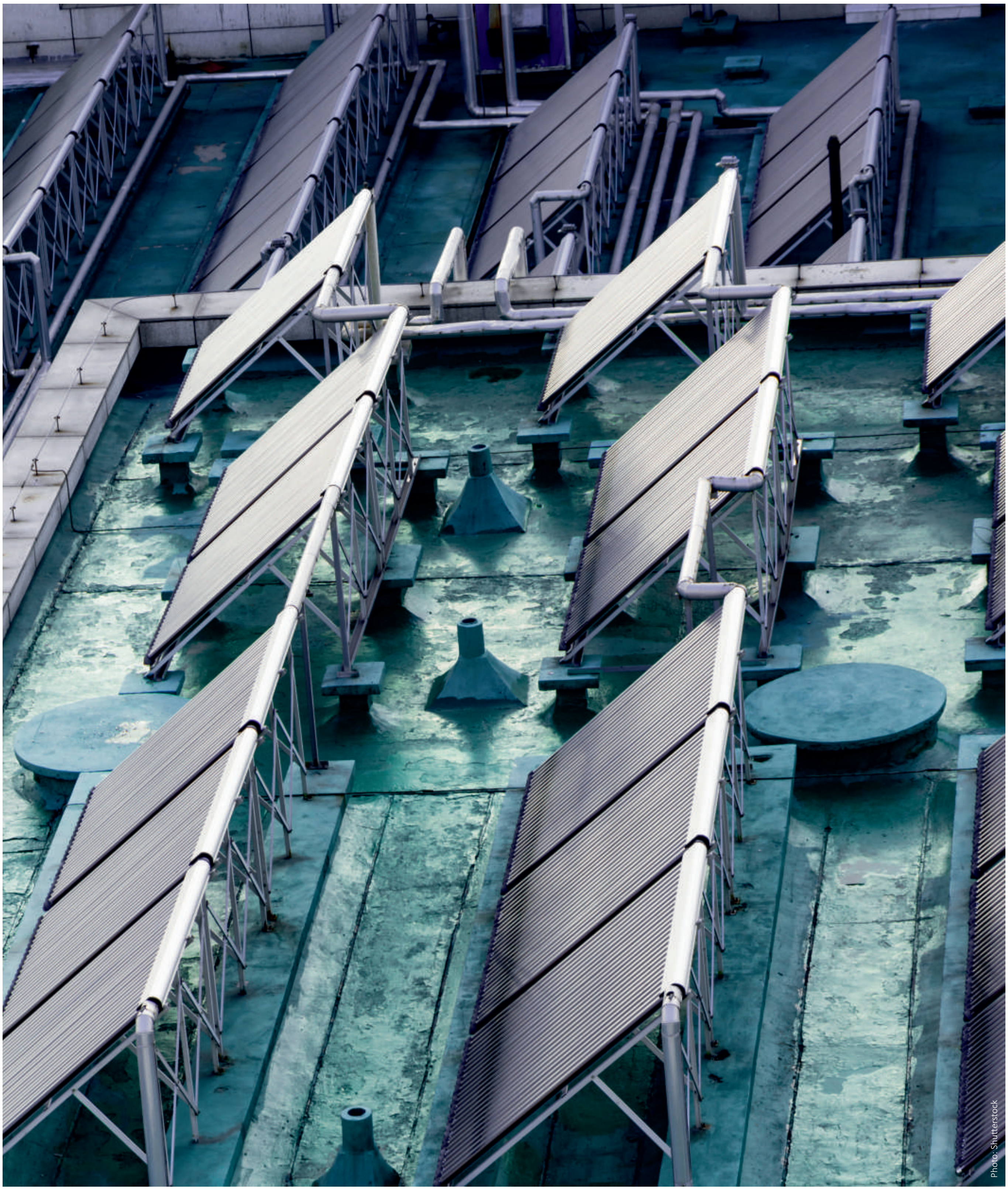
of investment processes in the electric power industry, both capital stock and production efficiency increase, which results in substitution away from labor towards capital.

Similar effects, associated with the intensification of GFCF, are also observed, for example, in the metallurgical industry, where output increases by more than 35% under the Revolutionary Scenario (*Figure 6.5*), while the number of employees is growing at a significantly lower rate.

In general, assessment of labor force sectoral redistribution shows that there are some preconditions for emergence of structural unemployment, primarily as a result of reduction of output by extractive industries and sectors related to processing of fossil fuels. However, the size of the labor force in 2050 may decrease by 25-30% relative to the 2015 level according to available demographic forecasts, which is a prerequisite of labor shortage rather than additional unemployment. Therefore, further increase in labor productivity and shift towards more capital-intensive economic activities may be a relevant policy in the long run.

In the context of output structural changes, there is another group of risks that can occur during implementation of studied energy policies, which is related to the increase in the level of import dependence. In particular, this can be the case for precision engineering and power machine building (solar panels, wind-powered generators, electric cars, etc.), components and maintenance services for relevant equipment (post-warranty service, batteries for electric cars, etc.), and some categories of biomass / biofuel. If most of the demand for these categories of goods / services is secured through imports, there may be significant risks of negative macroeconomic effects and related monetary imbalances. Therefore, it is extremely important to create favorable environment for the development of entrepreneurship and attract investments for the development of advanced technologies in Ukraine.

CONCLUSIONS



CONCLUSIONS

The possibility of the extensive use of renewable energy sources (RES) in meeting the demand for energy services and resources in Ukraine until 2050 was assessed using economic and mathematical models (the TIMES-Ukraine model and the computable general equilibrium model of Ukraine) based on the existing potential of RES and technologies available on the domestic market (or those that may be available in the coming years). In particular, three scenarios that foresee "Conservative", "Liberal" and "Revolutionary" development of energy technologies in all sectors of economy and energy use by the population were modeled.

The main results of the modeling of three scenarios for Ukraine's energy sector development until 2050:

- In the absence of effective policy aimed at promotion of energy efficiency measures and RES development (Conservative Scenario), final energy consumption (FEC) in 2050 will be 27% higher than in 2012. **In case of the implementation of the ambitious Revolutionary Scenario involving a significant reduction in energy consumption and intensive development of RES, FEC will decrease by 27%, and the share of energy received from RES will be 91%.** This shows that saved energy resource is the cheapest "resource", and investments in saving are more feasible than those needed to produce additional electricity and heat to meet the needs of the population and economy as a whole.
- According to the Liberal Scenario, which involves ensuring perfect technological competition in energy markets, FEC in 2050 will not exceed the corresponding figure of 2012, while the share of RES will be 31%.
- The need for electricity production in case of the Liberal Scenario will decrease by 22%, while in case of the Revolutionary Scenario it will increase by 13% compared to the Conservative Scenario. In the first case, the decrease will be due to the implementation of energy efficiency measures and RES development, and in the second, the increase is due to the need to abandon fossil fuels in favor of RES, which can be achieved through the increased use of electricity and heat.
- The electricity will be produced by all RES technologies that are now available in Ukraine until 2050, since they rapidly develop and become cheaper. The most promising among them are wind and solar energy technologies, and bioenergy technologies can become leaders in heat generation. According to the **Revolutionary Scenario, the share of WPP in the structure of the electricity production can reach 45%, SPP – 36%, and the share of biomass and waste in the structure of the thermal energy production can reach up to 73%.**
- **Annual costs of energy system operation under alternative scenarios will be lower by 6-10% compared to the Conservative Scenario.** That is, savings on costs of purchasing fuel will cover the costs associated with investing in new technologies, meaning that targets for increasing energy efficiency and RES development proposed in this paper are economically feasible.
- Nuclear power industry in Ukraine, according to the results of the Liberal Scenario modeling, is unpromising in case of absence of innovative approaches of its development (for example, implementation of innovative reactor types and small module units). This is reasoned by high capital costs especially for construction of new nuclear power units. Considering this fact, the share of NPPs in the structure of electric power generation can decrease drastically from 45% in 2012 and 54% in 2015 to 13% in 2050. For economic reasons only, modeling estimates show the feasibility of completing the 3rd and 4th units of the Khmelnitsky NPP and building one new unit, replacing those planned to be decommissioned.
- Under the Revolutionary scenario, NPPs will not be represented in the structure of electric power generation, as one of the conditions of this scenario is a complete phase out of nuclear power. Lifiteme is extended only for two units of NPPs during the period 2024-2026 provided that all safety requirements are fully met. No new investments are foreseen.
- Coal-fired thermal power generation can maintain its output levels in the Liberal Scenario, but at the condition of its complete modernization (including new construction) in accordance with modern European environmental requirements. This is a rather expensive measure and can have a significant impact on the competitiveness of coal generation. In addition, this paper did not explore the issue of a significant increase in the CO_2 emission tax, which could further reduce the competitiveness of coal generation.
- While according to the Revolutionary Scenario electricity production in 2050 is only 14% more compared to the Conservative Scenario, installed capacity of the power generation facilities should increase by 3.6 times (from 53 GW in 2012 to 327 GW in 2050). This is explained by the fact that the efficiency of the use of the capacities of WPPs and SPPs is much lower than that of coal-fired TPPs and NPPs. In addition, transition to RES will require significant volumes of storage capacities (up to 35% of the total capacity), which are proposed to be used to ensure predictability and reliability of SPP and WPP operation. However, this paper did not explore the possibility of using gas generation, hydropower facilities, smart grids, demand management systems, and interstate power flows for these purposes, which can significantly reduce the need for storage capacities and considerably improve the quality of energy service delivery.
- The investment resources needed for the transformation of the electric power sector in the Liberal Scenario will be lower (€112 billion for the entire period) than corresponding needs in the Conservative Scenario (€120 billion for the entire period) due to wide implementation of economically feasible energy efficiency and RES development measures. However, the implementation of the Revolutionary Scenario requires 83% more of these investments (€220 billion for the entire period), especially after 2035.
- Changes in the structure of heat production will depend on the implementation of environmental standards for the emission of pollutants into the air. So far, Ukraine has not assumed obligations to fulfill the requirements of the Directive 2015/2193/EU which regulates limitation of emissions of certain pollutants into the air from medium combustion plants (1-50 MW). At the same time, the process of European integration of Ukraine will involve its future fulfillment, and hence the use of biomass and waste will have advantages and should be a priority in heat supply. According to calculations under the Revolutionary Scenario, **existing potential of the biomass and waste can satisfy almost 75% of the needs for centralized heat supply.**
- When integrating the above indicators of energy sector development until 2050 into the indicator of total primary energy supply (TPES), it can be stated that there will be a significant decrease in TPES (by 57% less compared to the Conservative Scenario according to the Revolutionary Scenario). Thus, **the needs of Ukraine can be covered by domestic supply of energy resources by more than 90%**, which significantly strengthens energy and economic security.
- **"Energy transition" to RES will result in radical reduction in greenhouse gas (GHG) emissions which in 2050 might amount only to 10% of the 1990 level** (or 85 mln t CO_2-equivalent), which corresponds to required efforts at the global level to achieve the goal of the Paris Agreement. This will draw Ukraine nearer to a country with carbon-neutral energy sector.
- As the calculations show, **implementation of both Liberal and Revolutionary Scenarios is generally characterized by positive macroeconomic impacts** that become fully apparent in the medium term and long term starting from 2020.
- Considering the dynamics of investment processes and technological changes, macroeconomic impacts have a cumulative character: an additional growth relative to the reference scenario increases over time. While in 2025 additional GDP growth is 4-6%, by 2050 it can reach 12-15%.

- As to sources of investments, if the Liberal Scenario is implemented, a key role will be played by households which should provide more than half of the additional funding for energy policy measures. At the same time, within the Revolutionary Scenario a significantly higher amount of investments should be provided by industrial producers, in particular, in the electric power industry.
- Should the Liberal Scenario be implemented, there are minor positive economic impacts for households in the short term. **However, in the medium term (2020-2025), an additional growth in aggregate income of households may reach 4-6% with a further increase to 11-15% in 2050.**
- Due to possible emergence of structural unemployment as a result of the decrease in the output of the sectors related to fossil energy sources, there is a need to implement effective re-training programs for employees. It is expected that **market demand for labor force additionally released as a result of structural changes will be significantly higher than the supply,** so there will be no increase in the general level of unemployment due to energy policies implementation.
- According to the model assessments of implementing the Liberal Scenario, primary energy intensity of Ukraine's GDP will reach the level of OECD countries only in 2050, and corresponding indicator for EU 28 countries will not be reached during the studied period. At the same time, according to the Revolutionary Scenario, primary energy intensity of Ukraine's GDP could reach current level of energy intensity of the GDP of OECD countries in 2040, and the same of EU 28 countries in 2045. This suggests that it is extremely important to transform modern socio-economic model of Ukraine into the one that would promote "greening" of the energy sector and increase well-being of the population of Ukraine.
- The above results of the modeling of three development scenarios show that **the most ambitious energy and environmental goals, such as transition to 90-100% of RES in the final consumption by 2050, can have significant benefits for both the economy and society as a whole,** which should be taken into account when developing strategies or action plans for energy sector development or climate policy.

ANNEXES

Annex A.1 Assessments of the main forecasted demand for energy services (drivers) in the TIMES-Ukraine model

Table A.1.1 Assessments of the main forecasted demand for energy services (drivers) in the TIMES-Ukraine model

DRIVER	Measurement units	Reference value, 2012	Change indices from 2012								
			2012	2015	2020	2025	2030	2035	2040	2045	2050
GDP	billion USD	143.8	1.00	0.84	0.98	1.25	1.53	1.87	2.17	2.43	2.64
Population	million people	45.5	1.00	0.94	0.93	0.91	0.90	0.88	0.86	0.84	0.82
INDUSTRY											
Production of steel	mln t	17.1	1.00	0.66	0.85	1.07	1.21	1.38	1.52	1.63	1.72
Production of aluminum	thousand tons	47.0	1.00	0.54	0.70	0.89	1.00	1.14	1.26	1.35	1.36
Index of industrial products, ferrous metallurgy	%	100	1.00	1.00	1.00	1.12	1.27	1.37	1.44	1.48	1.51
Index of industrial products, non-ferrous metallurgy	%	100	1.00	0.68	0.92	1.22	1.45	1.73	1.91	1.95	1.96
Production of ammonia	thousand tons	3.8	1.00	0.54	0.69	0.76	0.86	1.02	1.16	1.25	1.31
Production of cement	mln t	9.8	1.00	0.86	1.23	1.66	2.09	2.67	3.21	3.69	4.10
Production of lime	mln t	2.0	1.00	0.58	0.81	1.09	1.34	1.67	1.98	2.24	2.46
Production of glass	mln t	0.9	1.00	0.58	0.87	1.15	1.43	1.69	1.93	2.14	2.31
Production of paper	mln t	0.7	1.00	0.49	0.49	0.66	0.86	1.10	1.21	1.30	1.34
AGRICULTURE											
Production index, crop cultivation	%	100	1.00	1.00	1.08	1.17	1.27	1.36	1.43	1.49	1.55
Production index, livestock breeding	%	100	1.00	0.96	1.03	1.16	1.26	1.35	1.42	1.46	1.50
Production index, other sectors	%	100	1.00	0.95	0.99	1.08	1.16	1.20	1.23	1.24	1.24
TRANSPORT											
Passenger transportation – electric road transport	mln pas. per km	7.8	1.00	0.95	0.79	0.82	0.85	0.95	1.07	1.19	1.32
Passenger transportation – subway	mln pas. per km	5.9	1.00	0.91	0.91	0.97	1.03	1.11	1.20	1.29	1.39
Passenger transportation – urban transport	mln pas. per km	11.0	1.00	0.69	0.68	0.76	0.85	0.98	1.12	1.27	1.42
Passenger transportation – intercity transport	mln pas. per km	39.3	1.00	0.69	0.96	1.14	1.40	1.45	1.52	1.58	1.65
Passenger transportation – railway transport	mln pas. per km	49.3	1.00	0.71	0.81	0.90	1.01	1.13	1.24	1.32	1.38
Freight transport – road transport	mln t per km	57.4	1.00	0.88	0.99	1.12	1.20	1.29	1.35	1.40	1.42
Freight transport – railway transport	mln t per km	237.7	1.00	0.82	1.04	1.15	1.21	1.30	1.41	1.46	1.47
Transportation by cars	mln pas. per km	132.6	1.00	1.02	1.04	1.06	1.08	1.10	1.13	1.15	1.17
SERVICE SECTOR											
Value added	%	100	1.00	1.15	1.38	1.66	1.99	2.39	2.87	3.44	4.13
Heating – small buildings	PJ*	36.2	1.00	1.01	1.10	1.22	1.31	1.40	1.48	1.55	1.60
Heating – large buildings	PJ*	66.3	1.00	1.01	1.11	1.20	1.26	1.33	1.39	1.44	1.48
Air conditioning – small buildings	PJ*	10.6	1.00	1.06	1.21	1.35	1.46	1.57	1.67	1.74	1.80
Air conditioning – large buildings	PJ*	9.7	1.00	1.04	1.15	1.27	1.37	1.47	1.54	1.59	1.63
Water heating – small buildings	PJ*	8.8	1.00	1.06	1.20	1.35	1.46	1.57	1.68	1.74	1.80
Water heating – large buildings	PJ*	17.6	1.00	1.04	1.14	1.26	1.37	1.45	1.51	1.57	1.60
Lighting	PJ*	11.4	1.00	1.06	1.23	1.37	1.48	1.59	1.66	1.71	1.75
Food storage	PJ*	9.2	1.00	1.04	1.15	1.27	1.37	1.47	1.53	1.59	1.65
Cooking	PJ*	7.0	1.00	1.04	1.15	1.27	1.35	1.42	1.49	1.53	1.57
Street lighting	PJ*	17.4	1.00	1.04	1.15	1.30	1.43	1.57	1.66	1.72	1.78
Water supply	PJ*	7.3	1.00	1.00	1.04	1.10	1.16	1.22	1.28	1.33	1.37
Other electrical appliances	PJ*	1.4	1.00	1.06	1.23	1.39	1.56	1.75	1.94	2.15	2.37
Other energy needs	PJ*	15.9	1.00	1.09	1.21	1.37	1.50	1.61	1.68	1.74	1.78
POPULATION (HOUSEHOLDS)											
Heating – private rural houses	PJ*	134.7	1.00	0.96	0.95	0.95	0.94	0.96	0.97	0.98	0.99
Heating – private town houses	PJ*	123.9	1.00	0.90	0.95	0.97	0.98	1.00	1.03	1.05	1.08
Heating – private apartment houses	PJ*	193.2	1.00	0.89	0.93	0.96	0.97	1.01	1.05	1.09	1.14
Air conditioning – private rural houses	PJ*	2.8	1.00	1.23	1.36	1.52	1.69	1.88	2.09	2.32	2.58
Air conditioning – private town houses	PJ*	7.5	1.00	1.23	1.36	1.52	1.69	1.88	2.09	2.32	2.58
Air conditioning – private apartment houses	PJ*	27.4	1.00	1.23	1.36	1.52	1.69	1.88	2.09	2.32	2.58
Water heating – private rural houses	PJ*	65.5	1.00	0.99	0.99	1.00	1.00	1.01	1.01	1.02	1.02
Water heating – private town houses	PJ*	50.8	1.00	0.96	1.00	1.05	1.11	1.16	1.22	1.28	1.34

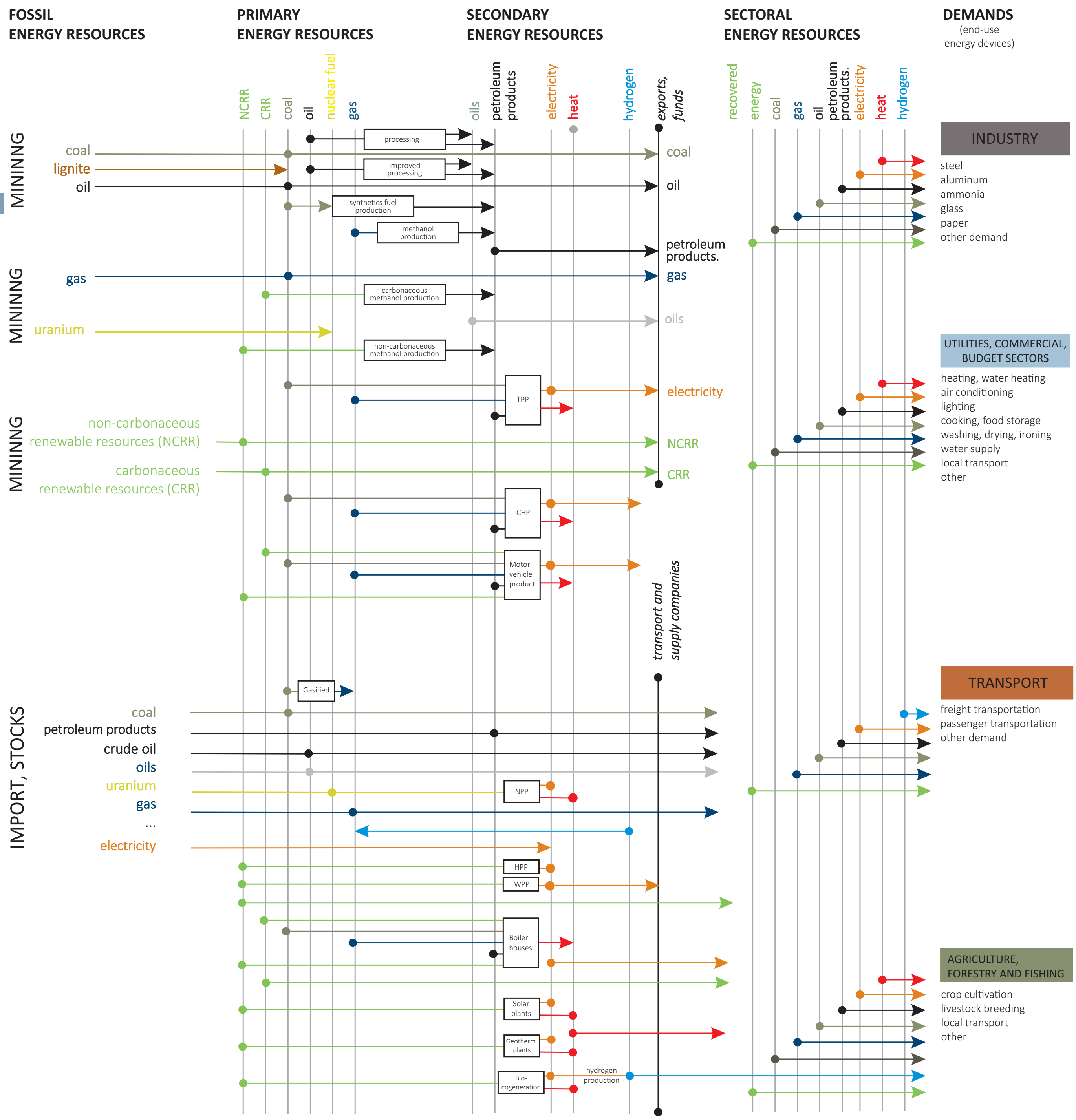
Continuation of the table A.1.1

DRIVER	Measurement units	Reference value, 2012	Change indices from 2012								
			2012	2015	2020	2025	2030	2035	2040	2045	2050
Water heating – private apartment houses	PJ*	94.8	1.00	1.03	1.09	1.16	1.23	1.30	1.38	1.46	1.55
Lighting	PJ*	18.1	1.00	1.01	1.03	1.06	1.08	1.11	1.14	1.17	1.20
Cooking	PJ*	82.8	1.00	1.00	1.01	1.02	1.02	1.03	1.03	1.04	1.05
Food storage	PJ*	11.7	1.00	1.01	1.06	1.12	1.17	1.23	1.29	1.36	1.43
Washing clothes	PJ*	6.3	1.00	1.01	1.01	1.02	1.03	1.03	1.04	1.05	1.05
Ironing/drying clothes	PJ*	2.7	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.04	1.04
Dishwashing	PJ*	0.6	1.00	1.23	1.29	1.49	1.71	1.97	2.26	2.60	2.99
Other electrical appliances	PJ*	13.5	1.00	1.06	1.17	1.31	1.45	1.61	1.79	1.98	2.20

* The demand for energy services (drivers) in the service sector and households is measured in so-called "useful demand" and in energy units, in this case in PJ.

Annex A.2 Basic structure of energy system in the TIMES-Ukraine model

Figure A.2.1 Basic structure of energy system in the TIMES-Ukraine model



Annex A.3 Database of the TIMES-Ukraine model

Database of the TIMES-Ukraine model includes reported data of statistical observations of the State Statistics Service of Ukraine, in particular:

Forms:

- 1P-NPP "Report on the production of industrial products";
- 4-mtp "Report on the use of energy materials and oil processing products";
- 11-mtp "The results of using fuel, heat energy and electricity";
- No.4-TZ "Report on the number and technical condition of cars, buses, motorcycles and trailers (semitrailers)";
- No.51-avto "Report on the volumes of freight and passenger transportation by public railway transport";
- No.2-tr "Report on the operation of motor transport";
- No.2-etr "Report on the operation of urban electric transport";
- No.51-TsA "Report on the main performance indicators of an air transport enterprise";
- No.31-vod "Report on the transportation of cargoes and passengers by water transport";
- No.1-torh (oil products) "Report on the sale of light oil products and gas";
- "Export and import of certain types of goods by countries of the world".

Compendiums:

- "Production and consumption of electricity and separate technical and economic performance indicators of thermal power plants in Ukraine";
- "On the main performance indicators of heating boiler houses and heat networks of Ukraine";
- "Transport and communications in Ukraine";
- "Housing Stock of Ukraine";
- "Availability of durable goods in households";
- "Socio-demographic characteristics of households in Ukraine";
- "Hotels and other places for temporary accommodation";
- "Preschool education of Ukraine";
- "General educational institutions of Ukraine";
- "Main performance indicators of higher education institutions of Ukraine";
- "Cultural, arts, physical culture and sport establishments of Ukraine";
- "Health care institutions and disease incidence of the population of Ukraine";
- "Network of retail and restaurant enterprises";
- "Availability and use of a trading network in markets";
- "On the main performance indicators of the water-supply facilities of Ukraine";
- "On the main performance indicators of the gas-supply facilities of Ukraine".

Database of the TIMES-Ukraine model also includes information of the Ministry of Energy and Coal Industry of Ukraine, in particular:

Report forms:

- "Production and supply of electricity by energy companies and thermal power plants";
- "Supply of thermal energy by energy companies and thermal power plants";
- "Operation of power-generating units 150, 200, 300 and 800 MW";
- "Fuel flow at energy enterprises";
- "Specific equivalent fuel consumption for supply of electricity by energy companies and thermal power plants of Ukraine";
- "Technological electricity consumption for transmission by power supply networks";
- "Consumption (losses) of thermal energy for its transportation in heat networks";
- "Cost price of electric and thermal energy";
- "Daily power consumption patterns of UES (United Energy System) of Ukraine".

In order to verify existing and promising technologies, data from the State Agency on Energy Efficiency and Energy Saving of Ukraine, domestic energy generating, energy and gas supply companies, as well as companies producing oil, gas and coal, are used.

In order to identify promising energy technologies and their technical and economic characteristics, data from the International Energy Agency contained in recurrent publications, in particular, in Energy Technology Perspectives[103], and E-TechDS[104], information and analytical database of energy technologies, created within the Energy Technology Systems Analysis Program (ETSAP), were used. Data from DIW Berlin were also used, in particular, the study on Current and Prospective Costs of Electricity Generation until 2050[105]. Particular attention should be given to the study (report) on Projected Costs of Generating Electricity[106] drawn up by such leading and credible institutions as the International Energy Agency and the Nuclear Energy Agency (NEA) within the Organisation for Economic Co-operation and Development.

Information on the efficient technologies for the use of energy resources is also available on the websites of domestic producer companies or supplier companies, but mainly it does not contain all the necessary data. More systematized data can be found on the information resources of specialized associations (Bioenergy Association of Ukraine[107], Ukrainian Wind Energy Association[108], Ukrainian Association of Renewable Energy[109]), SE NNEGC "Energoatom"[110] etc.

To determine indicators of a long-term economic development of Ukraine, data from the State Organization "Institute for Economics and Forecasting" of the National Academy of Sciences of Ukraine, international financial, rating agencies and other organizations are used (for example, International Monetary Fund, World Bank, Standard & Poor's, etc.), as well as data from the Ministry of Economic Development and Trade of Ukraine.

Price forecast for main energy resources is based on the World Bank's data, namely on the report Commodity Markets Outlook[111].

The forecasts of demographic dynamics in Ukraine are based on the data from the Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine[112] and United Nations Department of Economic and Social Affairs[113].

Coefficients for CO_2, CH_4 and N_2O emissions from combustion of fuel in stationary plants in different sectors are based on the data from the National cadastre of anthropogenic emissions and absorbing of greenhouse gas emissions in Ukraine for 1990-2014[114].

103 Energy Technology Perspectives / IEA. — Available at: http://www.iea.org/etp/

104 E-TechDS – Energy Technology Data Source / The Energy Technology Systems Analysis Program (ETSAP) — Available at: http://iea-etsap.org/index.php/energy-technology-data

105 Current and Prospective Costsof Electricity Generation until 2050 // Deutsches Institut für Wirtschafts forschung. Available at: http://www.diw.de/documents/publikationen/73/ diw_01.c.424566.de/diw_datadoc_2013-068.pdf

106 Projected Costs of Generating Electricity // International Energy Agency, Nuclear energy agency under the Organisation for Economic Co-operation and Development, 2015. Available at: https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

107 http://www.uabio.org/

108 http://www.uwea.com.ua/

109 http://uare.com.ua/

110 Strategic development of the nuclear sector of Ukraine / NNEGC "Energoatom", 2016. – Available at: http://www.atom.gov.ua/ua/press/nngc/45256-strategchniyi_rozvitok_yaderno_galuz_ukrani__sluhannya_komtetu_vr_z_pitan_pek_yaderno_poltiki_ta_yaderno_bezpeki/

111 Available at: http://pubdocs.worldbank.org/en/174381493046968144/CMO-April-2017-Full-Report.pdf

112 Demographic forecast for Ukraine for 2014-2061 // Institute for Demography and Social Studies of the National Academy of Sciences of Ukraine. — Available at: http://www.idss.org.ua/monografii/popforecast2012.zip

113 World Population Prospects: The 2012 Revision // Population Division of the United Nations Department of Economic and Social Affairs of the United Nations Secretariat. — Available at: http://esa.un.org/unpd/wpp/unpp/panel_population.htm

114 National Inventory Submissions 2016 / United Nation Framework Convention on Climate Change. — Available at: http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_ submissions/application/zip/ukr-2016-nir-18jul16.zip

Annex A.4 Sectoral structure of Ukraine's GDP for the period 2015-2050

Table A.4.1 Sectoral structure of Ukraine's GDP for the period 2015-2050, %[115]

Sectors/Years	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture, forestry and fishing	11.9	11.1	11.5	11.9	12.5	13.2	13.9	14.7
Extractive industries and quarrying	4.8	4.8	4.5	4.1	3.7	3.4	3.1	2.8
Processing industry	12.1	14.4	14.8	14.8	14.3	13.8	13.3	12.9
Supply of electricity, gas, steam and conditioned air	2.7	3.0	2.9	3.0	3.1	3.2	3.3	3.3
Construction	2.3	2.9	3.1	3.2	3.4	3.6	3.8	4.0
Commodity production sector – total	31.0	33.2	33.7	33.9	33.9	33.9	33.9	33.9
Service sector – total	53.9	53.1	53.1	53.1	53.1	53.1	53.1	53.1

Annex A.5 Main characteristics of energy technologies presented in the TIMES-Ukraine model

A.5.1 Electricity and heat production

Table A.5.1.1 Basic cost performance of heat plants

	2015	2020	2025	2030	2035	2040	2045	
Wood biomass								
Capital expenditure, EUR/$kW_{electr.}$	2,800	2,800	2,800	2,600	2,500	2,400	2,200	2,000
Operating expenses, EUR/$kW_{electr.}$	30							
CP, %	24	24	25	26	28	29	30	31
ICUF, %	50							
Life time, years	30							
Biomass from waste of agro-industrial complex, etc.								
Capital expenditure, EUR/$kW_{electr.}$	3,500	2,900	2,800	2,700	2,600	2,500	2,300	2,100
Operating expenses, EUR/$kW_{electr.}$	30							
CP, %	23	23	24	24	25	27	28	29
ICUF, %	50							
Life time, years	30							
Biogas								
Capital expenditure, EUR/$kW_{electr.}$	4,500	4,400	4,300	4,200	4,100	4,000	3,900	3,800
Operating expenses, EUR/$kW_{electr.}$	50							
CP, %	42	42	42	43	43	43	44	44
ICUF, %	50							
Life time, years	30							
Gas (combined cycle)								
Capital expenditure, EUR/$kW_{electr.}$	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Operating expenses, EUR/$kW_{electr.}$	20							
CP, %	60	60	60	60	61	61	62	62
ICUF, %	50							
Life time, years	35							
Gas (gas turbine)								
Capital expenditure, EUR/$kW_{electr.}$	600	600	600	600	600	600	600	600
Operating expenses, EUR/$kW_{electr.}$	20							
CP, %	51	51	51	52	52	52	53	53
ICUF, %	50							
Life time, years	35							
Gas (steam turbine)								
Capital expenditure, EUR/$kW_{electr.}$	920	920	920	920	920	920	920	920
Operating expenses, EUR/$kW_{electr.}$	12							
CP, %	34	34	34	34	34	35	35	35
ICUF, %	50							
Life time, years	30							

115 The sum of shares of the services sector and commodity production sector represents less than 100%, since GDP also includes taxes and subsidies for products that, within the national accounts system, are presented separately from sectors.

Continuation of the table A.5.1.1

	2015	2020	2025	2030	2035	2040	2045	
Coal (combustion in a circulating boiling layer)								
Capital expenditure, EUR/kW$_{electr.}$	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700
Operating expenses, EUR/kW$_{electr.}$	28							
CP, %	43	43	43	43	43	43	43	43
ICUF, %	50							
Life time, years	35							
Coal (integrated gasification combined cycle)								
Capital expenditure, EUR/kW$_{electr.}$	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Operating expenses, EUR/kW$_{electr.}$	63							
CP, %	46	46	46	46	46	47	47	48
ICUF, %	50							
Life time, years	35							
Coal (combustion on undercritical parameters)								
Capital expenditure, EUR/kW$_{electr.}$	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Operating expenses, EUR/kW$_{electr.}$	30							
CP, %	39	39	39	39	39	40	40	41
ICUF, %	50							
Life time, years	35							
Joint combustion of coal and biomass (on undercritical parameters)								
Capital expenditure, EUR/kW$_{electr.}$	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
Operating expenses, EUR/kW$_{electr.}$	30							
CP, %	33	33	33	33	33	34	34	34
ICUF, %	50							
Life time, years	35							
Coal (combustion on above-critical parameters)								
Capital expenditure, EUR/kW$_{electr.}$	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300
Operating expenses, EUR/kW$_{electr.}$	43							
CP, %	43	43	43	43	43	44	44	45
ICUF, %	50							
Life time, years	35							

Table A.5.1.2 Basic cost performance of heat and power plants

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW$_{electr.}$	3,500	3,400	3,300	3,200	3,100	3,000	2,900	2,800
Operating expenses, EUR/kW$_{electr.}$	50							
CP, %	20	20	20	20	20	20	21	21
ICUF, %	50							
Life time, years	35							
Biomass from waste of agro-industrial complex								
Capital expenditure, EUR/kW$_{electr.}$	3,500	3,400	3,200	3,100	2,900	2,900	2,800	2,800
Operating expenses, EUR/kW$_{electr.}$	55							
CP, %	19	19	19	19	19	19	20	20
ICUF, %	50							
Life time, years	35							
Household waste								
Capital expenditure, EUR/kW$_{electr.}$	5,500	5,400	5,200	5,100	5,000	4,800	4,500	4,500
Operating expenses, EUR/kW$_{electr.}$	55							
CP, %	25	25	25	25	25	25	26	26
ICUF, %	50							
Life time, years	35							

Continuation of the table A.5.1.2

	2015	2020	2025	2030	2035	2040	2045	2050
Energy crops								
Capital expenditure, EUR/$kW_{electr.}$	3,500	3,400	3,300	3,200	3,100	3,000	3,000	3,000
Operating expenses, EUR/$kW_{electr.}$	50							
CP, %	20	20	20	20	20	20	21	21
ICUF, %	50							
Life time, years	35							
Gas (combined cycle)								
Capital expenditure, EUR/$kW_{electr.}$	800	800	800	800	800	800	800	800
Operating expenses, EUR/$kW_{electr.}$	42							
CP, %	50	50	50	50	51	51	52	52
ICUF, %	50							
Life time, years	35							
Gas (steam turbine)								
Capital expenditure, EUR/$kW_{electr.}$	920	920	920	920	920	920	920	920
Operating expenses, EUR/$kW_{electr.}$	12							
CP, %	45	45	45	45	45	46	46	47
ICUF, %	42							
Life time, years	35							
Coal (combined cycle)								
Capital expenditure, EUR/$kW_{electr.}$	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Operating expenses, EUR/$kW_{electr.}$	52							
CP, %	36	36	36	36	36	37	37	37
ICUF, %	50							
Life time, years	35							
Coal (steam turbine)								
Capital expenditure, EUR/$kW_{electr.}$	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Operating expenses, EUR/$kW_{electr.}$	52							
CP, %	33	33	33	33	33	34	34	34
ICUF, %	50							
Life time, years	35							

Table A.5.1.3 Basic cost performance of boiler houses

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW	150	145	142	140	138	136	136	136
Operating expenses, EUR/kW	7							
CP, %	64	64	64	64	64	65	65	65
ICUF, %	50							
Life time, years	35							
Biomass from waste of agro-industrial complex, etc.								
Capital expenditure, EUR/$kW_{electr.}$	400	350	320	300	280	270	260	250
Operating expenses, EUR/$kW_{electr.}$	7							
CP, %	62	62	62	62	63	63	63	64
ICUF, %	50							
Life time, years	35							
Gas								
Capital expenditure, EUR/$kW_{electr.}$	300	300	300	300	300	300	300	300
Operating expenses, EUR/$kW_{electr.}$	2,5							
CP, %	71	71	71	71	71	71	72	72
ICUF, %	50							
Life time, years	40							

Continuation of the table A.5.1.3

	2015	2020	2025	2030	2035	2040	2045	2050
Coal								
Capital expenditure, EUR/$kW_{electr.}$	400	400	400	400	400	400	400	400
Operating expenses, EUR/$kW_{electr.}$	10							
CP, %	40	40	40	40	40	40	41	41
ICUF, %	50							
Life time, years	35							
Electricity								
Capital expenditure, EUR/$kW_{electr.}$	350	350	350	350	350	350	350	350
Operating expenses, EUR/$kW_{electr.}$	1,2							
CP, %	75	75	75	75	75	76	76	77
ICUF, %	50							
Life time, years	40							

Table A.5.1.4 Basic cost performance of industrial boilers

	2015	2020	2025	2030	2035	2040	2045	2050
Wood biomass								
Capital expenditure, EUR/kW	145	142	140	138	136	134	134	145
Operating expenses, EUR/kW	7							
CP, %	83							
ICUF, %	60							
Life time, years	40							
Biomass from waste of agro-industrial complex, etc.								
Capital expenditure, EUR/$kW_{electr.}$	270	260	250	240	230	220	220	270
Operating expenses, EUR/$kW_{electr.}$	7							
CP, %	80							
ICUF, %	60							
Life time, years	40							
Gas								
Capital expenditure, EUR/$kW_{electr.}$	60	60	60	60	60	60	60	60
Operating expenses, EUR/$kW_{electr.}$	2							
CP, %	90							
ICUF, %	60							
Life time, years	40							
Coal								
Capital expenditure, EUR/$kW_{electr.}$	90	90	90	90	90	90	90	90
Operating expenses, EUR/$kW_{electr.}$	8							
CP, %	80							
ICUF, %	60							
Life time, years	40							

A.5.2 Heating, hot water supply and improvement of energy efficiency of buildings

Table A.5.2.1 Basic cost performance of technologies (including boilers) for heating of buildings

	Capital expenditure, EUR/kW		CP, %	Life time, years
	2015	2050		
Biomass and waste	25-45	25-45	75-85	15
Gas	25-38	25-38	75-90	20
Coal	8-50	8-50	60-75	15
Solar energy + Electricity	63	31	97	30
Solar energy + Gas	88	44	94	30
Geothermal energy + Electricity	415	208	90	30
Electricity	14-21	14-21	94	15

Table A.5.2.2 Basic cost performance of technologies (including boilers) for hot water supply

	Capital expenditure, EUR/kW		CP, %	Life time, years
	2015	2050		
Biomass and waste	13-38	13-38	70	20
Gas	7-13	7-13	92	15
Coal	9-14	9-14	70	20
Solar energy + Electricity	45	23	97	20
Solar energy + Gas	65	33	94	20
Electricity	8-11	8-11	96	15

Table A.5.2.3 Assumptions regarding investment needs and efficiency of measures for thermal modernization of buildings

	Private residential buildings			Apartment buildings			Non-residential buildings		
	investments		savings	investments		savings	investments		savings
	UAH/ kWh/ m²	mln EUR/ PJ	%	UAH/ kWh/ m²	mln EUR/ PJ	%	UAH/ kWh/ m²	mln EUR/ PJ	%
Simple insulation	3.0	28.9	14	3.2	31.0	14	4.0	38.8	10
Complete insulation	12.0	117.0	52	12.9	125.6	46	16.9	165.0	55
Additional modernization	14.4	140.0	74	18.5	180.0	75	22.6	220.0	75

A.5.3 Transport

Table A.5.3.1 Basic cost performance of transport technologies

Mode of transport	Share of biofuel, %	Cost, thousand EUR		Life time, years	Efficiency, km/GJ		Annual mileage, thousand km
		2015	2050		2015	2050	
Intercity buses							
Diesel + biodiesel	up to 20	210	190	20	93	112	27.5
Gasoline + ethanol	up to 20	200	180	20	92	111	27.5
Biodiesel	up to 100	225	205	20	93	112	27.5
Ethanol	up to 100	240	215	20	92	111	27.5
Electricity	0	400	180	20	185	220	27.5
Gas	0	220	210	20	95	95	27.5
City buses							
Diesel + biodiesel	up to 20	210	190	20	106	127	27.5
Gasoline + ethanol	up to 20	200	180	20	108	130	27.5
Biodiesel	up to 100	250	205	20	106	127	27.5
Ethanol	up to 100	240	215	20	108	180	27.5
Electricity	0	400	190	20	180	215	27.5
Gas	0	220	210	20	111	111	27.5
Motor cars							
Diesel + biodiesel	up to 20	20	18	20	308	370	14.3
Diesel + biodiesel	up to 70	20	19	20	293	352	14.3
Biodiesel	up to 100	21	20	20	280	335	14.3
Gasoline + ethanol	up to 20	21	18	20	318	382	11.5
Gasoline + ethanol	up to 70	21	19	20	302	362	11.5
Ethanol	up to 100	22	21	20	285	340	11.5
Electricity	0	27	20	20	855	885	17.2
Gas	0	20	19	20	328	328	14.3
Trucks							
Diesel + biodiesel	up to 20	126	122	20	118	142	25.1
Gasoline + ethanol	up to 20	130	125	20	122	146	25.1
Biodiesel	up to 100	140	134	20	118	142	21.7
Ethanol	up to 100	147	141	20	122	146	21.7
Electricity	0	670	125	20	355	425	22.0

Continuation of the table A.5.3.1

Mode of transport	Share of biofuel, %	Cost, thousand EUR		Life time, years	Efficiency, km/GJ		Annual mileage, thousand km
		2015	2050		2015	2050	
Gas	0	126	126	20	115	115	25.1
Motorcycles							
Electricity	0	13	13	20	777	854	4.8
Gasoline	0	3	3	20	1555	1865	5.1

A.5.4 Industry

Table A.5.4.1 Basic cost performance of industrial technologies

Sector	Specific energy consumption per 1 ton of products	Cost of technology, $/t of products
Metallurgy	from 750 to 325 kWh/t of steel (1.2-2.7 GJ)	$540-600/t of steel
Production of ammonia	27 GJ/t	$30-50/t
Pulp and paper	from 18.7 to 17.1 GJ/t	$600-800/t
Cement	from 3.0 to 2.5 GJ/t of cement	$90-130/t
Production of glass	10.8 GJ/t	$250-300/t

Annex A.6 Detailed results of modeling Ukraine's energy sector development scenarios until 2050

A.6.1 Reference (Conservative) Scenario

Table A.6.1.1 Total primary energy supply, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	42,718	27,344	50,042	60,980	68,974	75,464	80,993	86,010	90,027
Gas	43,018	26,055	33,944	36,513	38,546	41,036	43,660	43,810	42,761
Crude oil and oil products	11,609	10,551	12,252	13,126	14,229	15,340	16,078	16,837	17,753
Nuclear energy	23,653	22,985	16,951	15,544	13,989	14,429	12,537	12,554	12,554
Electricity	-987	-116	-253	-299	-354	-391	-431	-418	-405
Hydroelectric power	901	464	907	1,030	1,117	1,123	1,130	1,133	1,140
Wind energy	25	94	258	370	378	387	396	396	430
Solar energy	28	40	24	48	72	82	42	42	42
Biofuel and waste	1,522	1,465	2,112	2,205	2,221	2,520	2,828	3,399	3,944
Total	122,487	89,519**	116,238	129,515	139,172	149,989	157,233	163,762	168,245
Share of RES	2.0%	2.3%	2.8%	2.8%	2.7%	2.7%	2.8%	3.0%	3.3%

* Statistical data. Here and in other tables, statistical data for 2015 are given without taking into account temporarily occupied territory of the Autonomous Republic of Crimea, City of Sevastopol and part of the area of anti-terrorist operation (ATO). In 2012, territorial integrity was not violated, and this particular year was taken as a reference one. Therefore, modeling results from 2020 actually include the Crimea and Donbas territory under ATO, which explains a significant leap between statistical data for 2015 and modeling results from 2020.
** Thermal energy was not taken into account as primary energy.

Table A.6.1.2 Domestic extraction (production) of energy resources, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	40,256	17,423	42,081	51,260	58,294	62,706	66,335	70,060	70,496
Gas	15,403	14,814	16,247	16,736	17,219	18,552	19,196	19,887	20,626
Crude oil	3,414	2,618	3,232	3,879	3,807	4,454	4,354	3,395	1,469
Uranium ore**	7,884	7,662	10,931	15,544	13,989	14,429	12,537	12,554	12,554
Hydroelectric power	901	464	907	1,030	1,117	1,123	1,130	1,133	1,140
Wind energy	25	94	258	370	378	387	396	396	430
Solar energy	28	40	24	48	72	82	42	42	42
Biofuel and waste	1,565	2,606	2,658	2,421	2,377	2,668	2,985	3,555	4,135
Total	69,477	45,721	76,338	91,287	97,252	104,400	106,974	111,022	110,891
Share in the structure of TPES	56.7%	51.1%	65.7%	70.5%	69.9%	69.6%	68.0%	67.8%	65.9%

* Statistical data
** Here and in other scenarios, the discrepancy with the data from energy balances (EB) is explained by the fact that in EB the value of nuclear energy corresponds to its production at NPP, but here and in the table on the import of energy resources, conditional indices of uranium ore production, which in Ukraine covers about a third of the needs of the domestic nuclear power industry, are shown. This was done in order to show Ukraine's dependence on imported uranium ore. In the way it is shown in EB, it looks like we extract all the necessary resources for domestic NPPs in Ukraine.

Table A.6.1.3 Import of energy resources, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	9,926	9,940	11,116	10,424	11,349	13,407	15,288	16,560	20,123
Gas	26,590	13,288	17,697	19,777	21,327	22,484	24,464	23,923	22,135
Crude oil and oil products	9,995	8,125	10,297	10,145	11,072	11,663	12,466	13,850	16,462
Uranium ore**	15,769	15,323	6,021	0	0	0	0	0	0
Electricity	8	193	19	19	19	19	20	20	20
Biofuel and waste	1	30	0	0	0	0	0	0	0
Total	62,289	46,899	45,150	40,365	43,767	47,573	52,237	54,353	58,739
Share in the structure of TPES	50.9%	52.0%	38.8%	31.2%	31.4%	31.7%	33.2%	33.2%	34.9%

* Statistical data. The sum of shares of energy resources extraction and import in the structure of TPES is more than 100%, since the export of energy resources in TPES is calculated with the minus sign.
** See the explanation below the table A.6.1.2.

Table A.6.1.4 Final Energy Consumption, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	9,212	5,952	6,336	7,658	8,567	9,674	10,603	11,391	12,033
Gas	21,698	13,741	15,998	16,922	17,512	18,518	19,485	20,286	20,578
Crude oil and oil products	11,347	8,776	11,075	12,162	13,234	14,242	14,912	15,433	15,891
Heat energy	11,865	7,526	10,263	10,723	11,285	11,876	12,307	12,792	13,283
Electricity	11,840	10,233	12,698	14,790	16,373	17,990	19,170	19,862	20,282
Biofuel and waste	1,029	1,282	1,427	1,607	1,498	1,736	2,032	2,524	3,039
Solar energy	0	0	0	0	0	0	0	0	0
Total	66,991	47,510	57,797	63,862	68,469	74,036	78,511	82,288	85,107
Share of direct RES consumption**	1.5%	2.7%	2.5%	2.5%	2.2%	2.3%	2.6%	3.1%	3.6%
Conditional share of RES that is considered***	2.6%	4.0%	4.3%	4.5%	4.2%	4.2%	4.4%	5.0%	5.5%

* Statistical data.
** This share shows only the direct consumption of RES by ultimate consumers. For example, the direct use of biomass for heating (combustion in household solid fuel boilers) by households, the use of solar energy to heat water (solar collector), the use of biofuel by vehicles, the use of biomass in the cement industry, etc.
*** This share shows the amount of directly consumed RES and electrical and thermal energy conditionally produced from RES which, in its turn, are calculated as an energy individually consumed by ultimate consumers multiplied by the respective shares of RES in the production of electric and thermal energy. For example, in 2050, final consumers consumed 20,283 thousand toe of electricity (Table A.6.1.4), and share of RES in the structure of electricity production in 2050 is 7.4% (Table A.6.1.11). Then, the amount of electricity conditionally produced from RES and consumed by ultimate consumers is 20,283*6.5%= 1,318 thousand toe, and this, in its turn, represents 1.6% of total final consumption. Similar calculations are made with thermal energy (Table A.6.1.4 and A.6.1.14): 13,382*1.7%= 227 thousand toe or 0.3% of total final consumption. Therefore, conditional share of RES that is considered is 3.6%+1.6%+0.3%=5.5%.

Table A.6.1.5 Final Energy Consumption by sectors, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Industry	24,844	16,408	18,212	21,797	24,539	27,684	29,883	31,532	32,756
Households	23,467	16,555	20,390	21,069	21,482	22,130	22,817	23,570	24,067
Transport	11,448	8,749	10,964	11,976	12,839	13,893	14,991	15,946	16,709
Service sector	5,037	3,838	5,986	6,541	6,916	7,429	7,762	8,054	8,283
Agriculture	2,195	1,960	2,245	2,480	2,694	2,899	3,058	3,186	3,292
Total	66,991	47,510	57,797	63,862	68,469	74,036	78,511	82,288	85,107

* Statistical data

Table A.6.1.6 Final Energy Consumption by industry, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	46	86	90	110	130	159	181	201	219
Heat from RES	5	10	38	42	48	57	60	68	76
Electricity from RES	325	232	433	585	680	727	732	737	748
Coal	8,310	5,569	5,515	6,915	7,893	9,107	10,149	11,032	11,761
Electricity	5,102	4,065	5,484	7,026	8,171	9,392	10,242	10,642	10,739
Gas	5,272	2,762	2,188	2,539	2,809	3,137	3,356	3,559	3,743
Heat	4,538	2,870	3,408	3,464	3,651	3,906	3,966	4,091	4,254
Crude oil and oil products	12,46	814	1,055	1,115	1,156	1,200	1,197	1,203	1,216
Total	24,844	16,408	18,212	21,797	24,539	27,684	29,883	31,532	32,756
Share of direct RES consumption**	0.2%	0.5%	0.5%	0.5%	0.5%	0.6%	0.6%	0.6%	0.7%
Conditional share of RES that is considered***	1.5%	2.0%	3.1%	3.4%	3.5%	3.4%	3.3%	3.2%	3.2%

* Statistical data
** See the explanation below the table. A.6.1.4
*** See the explanation below the table. A.6.1.4

Table A.6.1.7 Final Energy Consumption by households, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	936	1,097	413	332	234	137	39	0	0
Heat from RES	5	10	46	51	57	65	71	81	90
Electricity from RES	198	172	258	280	288	277	265	265	276
Coal	715	303	631	566	510	418	324	234	144
Electricity	3,105	3,012	3,271	3,360	3,464	3,577	3,702	3,828	3,959
Gas	13,760	9,083	11,658	12,289	12,627	13,172	13,736	14,281	14,357
Heat	4,677	2,864	4,044	4,191	4,301	4,485	4,680	4,880	5,091
Crude oil and oil products	71	14	69	0	0	0	0	0	148
Total	23,467	16,555	20,390	21,069	21,482	22,130	22,817	23,570	24,067
Share of direct RES consumption**	4.0%	6.6%	2.0%	1.6%	1.1%	0.6%	0.2%	0.0%	0.0%
Conditional share of RES that is considered***	4.9%	7.7%	3.5%	3.1%	2.7%	2.2%	1.6%	1.5%	1.5%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.1.8 Final Energy Consumption by transport, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	0	34	358	511	513	642	949	1,416	1,888
Electricity from RES	48	32	55	63	66	66	66	66	71
Coal	12	4	11	11	12	12	12	12	12
Electricity	750	553	695	753	790	854	922	960	1,020
Gas	2,050	1,572	1,364	1,223	1,137	1,210	1,345	1,356	1,361
Crude oil and oil products	8,588	6,554	8,481	9,414	10,321	11,109	11,697	12,136	12,357
Total	11,448	8,749	10,964	11,976	12,839	13,893	14,991	15,946	16,709
Share of direct RES consumption**	0.0%	0.4%	3.3%	4.3%	4.0%	4.6%	6.3%	8.9%	11.3%
Conditional share of RES that is considered***	0.4%	0.7%	3.8%	4.8%	4.5%	5.1%	6.8%	9.3%	11.7%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A 6.1.4

Table A.6.1.9 Final Energy Consumption by service sector, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	27	46	543	627	592	769	833	877	901
Heat from RES	2	5	27	32	37	42	46	53	58
Electricity from RES	118	101	158	180	193	192	186	188	195
Coal	161	67	164	150	136	119	99	94	96
Gas	463	195	663	733	791	841	883	918	941
Crude oil and oil products	78	92	62	72	57	89	63	48	49
Heat	2,326	1,555	2,370	2,580	2,798	2,903	3,045	3,163	3,242
Electricity	1,862	1,777	2,000	2,166	2,313	2,475	2,607	2,714	2,801
Total	5,037	3,838	5,986	6,541	6,916	7,429	7,762	8,054	8,283
Share of direct RES consumption**	0.5%	1.2%	9.1%	9.6%	8.6%	10.3%	10.7%	10.9%	10.9%
Conditional share of RES that is considered***	2.9%	4.0%	12.2%	12.8%	11.9%	13.5%	13.7%	13.9%	13.9%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.1.10 Final Energy Consumption by agriculture, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	20	19	24	26	28	29	30	31	31
Heat from RES	0	1	4	4	5	6	7	7	8
Electricity from RES	20	16	25	29	31	31	30	30	31
Coal	14	9	14	16	17	18	19	20	20
Electricity	312	289	343	377	406	430	448	461	472
Gas	153	129	125	138	149	158	166	171	176
Heat	312	211	327	358	388	413	433	449	463

Continuation of the table A.6.1.10

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Crude oil and oil products	1,364	1,302	1,408	1,562	1,700	1,844	1,956	2,046	2,121
Total	2,195	1,960	2,245	2,480	2,694	2,899	3,058	3,186	3,292
Share of direct RES consumption**	0.9%	1.0%	1.1%	1.1%	1.0%	1.0%	1.0%	1.0%	0.9%
Conditional share of RES that is considered***	1.8%	1.8%	2.3%	2.4%	2.4%	2.3%	2.2%	2.1%	2.1%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.1.11 Production of electricity, billion kWh

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)	90	88	65	52	32	20	13	13	13
NPP (new)	0	0	0	7	20	34	34	34	34
TPP (existing ones)	79	58	89	96	100	98	97	97	97
TPP (new, coal)	0	0	11	28	45	67	87	105	121
TPP (new, gas)	0	0	0	7	11	14	18	13	1
CHPP and isolated generating plants	18	8	22	27	32	32	35	34	35
HPP and PSPP (large ones)	11	7	10	11	12	12	12	12	12
HPP (new small ones)	0,3	0,2	0,5	0,6	0,6	0,7	0,8	0,8	0,9
WPP	0,3	1,1	3,0	4,3	4,4	4,5	4,6	4,6	5,0
SPP (ground mounted)	0,3	0,5	0,2	0,2	0,5	0,6	0,5	0,5	0,5
SPP (roof mounted)	0	0	0,1	0,4	0,4	0,4	0	0	0
Geothermal Power Plant	0	0	0	0,3	0,7	0,9	0,9	0,9	0,9
Bio CHP/TPP	0	0,1	0,9	1,0	1,0	1,1	1,2	1,3	1,4
Total	199	162	202	235	260	285	304	315	322
Share of RES	6.0%	5.4%	7.3%	7.7%	7.7%	7.2%	6.7%	6.5%	6.5%

* Statistical data

Table A.6.1.12 Installed capacity of thermal power plants, GW

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)	13.8	13.8	9.8	7.8	4.8	3.0	2.0	2.0	2.0
NPP (new)	0	0	0	1.0	3.0	5.0	5.0	5.0	5.0
TPP (existing ones)	25.4	25.5	25.5	27.0	26.0	24.4	24.2	24.0	24.1
TPP (new, coal)	0	0	2.5	6.4	10.6	15.4	19.9	24.0	27.6
TPP (new, gas)	0	0	1.6	3.2	5.6	8.0	9.6	9.6	8.8
CHPP and isolated generating plants	8.0	7.7	11.4	12.8	13.8	13.9	13.8	13.4	12.8
HPP and PSPP (large ones)	5.5	6.1	6.1	6.3	6.3	6.3	6.3	6.3	6.3
HPP (new small ones)	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.4
WPP	0.2	0.5	1.4	2.0	2.0	2.1	2.1	2.1	2.3
SPP (ground mounted)	0.3	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.8
SPP (roof mounted)	0	0	0.1	0.3	0.3	0.3	0.3	0.3	0.2
Geothermal Power Plant	0	0	0	0.1	0.2	0.2	0.2	0.2	0.2
Bio CHP/TPP	0.0	0.1	0.3	0.3	0.3	0.3	0.4	0.4	0.4
Total	53.3	54.6	59.7	68.2	74.1	80.0	84.9	88.6	90.8
Share of RES	11.5%	13.9%	15.0%	14.8%	13.9%	13.0%	12.4%	11.9%	11.7%

* Statistical data

Table A.6.1.13 Capital investments in electric power industry facilities, million EUR

	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)*	0	234	234	0	934	0	0
NPP (new)	0	1,625	11,180	13,000	0	0	0
TPP (existing ones)	144	802	593	3,584	4,416	7,127	9,555
TPP (new, coal)	3,735	6,150	6,660	7,680	7,170	6,405	5,580
TPP (new, gas)	1,280	1,280	2,016	2,016	1,280	0	0
CHPP and isolated generating plants	3,932	1,477	1,473	1,514	1,482	852	931

Continuation of the table A.6.1.13

	2020	2025	2030	2035	2040	2045	2050
HPP and PSPP (large ones)	95	280	0	0	0	0	0
HPP (new small ones)	622	88	93	82	81	36	87
WPP (ground mounted)	1,361	944	69	66	62	0	237
SPP (ground mounted)	57	0	0	0	0	0	0
SPP (roof mounted)	90	180	0	0	0	0	0
Geothermal Power Plant	0	193	465	127	0	0	149
Bio CHP/TPP	536	56	59	56	54	52	255
Total	11,851	13,309	22,841	28,125	15,480	14,473	16,794
Share of RES	23.3%	13.1%	3.0%	1.2%	1.3%	0.6%	4.3%

* Investments to extend the life time of the operating units of NPPs

Table A.6.1.14 Total thermal energy production by type of fuel, thousand toe

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Biomass and waste	14	37	135	152	176	202	228	258	291
Coal	620	705	3,552	4,463	5,721	6,366	7,420	7,919	8,709
Electricity	19	75	0	0	0	0	0	0	0
Gas	12,830	9,870	8,252	7,839	7,527	7,471	7,495	7,445	7,573
Oil products	6	6	6	4	3	2	1	0	0
Nuclear energy	163	160	119	114	120	135	127	127	127
Total	13,652	10,853	12,064	12,573	13,546	14,176	15,270	15,749	16,701
Share of RES	0.1%	0.3%	1.1%	1.2%	1.3%	1.4%	1.5%	1.6%	1.7%

Table A.6.1.15 Energy consumption by boiler houses of Central Heating Units (CHU) and autoproducers of thermal energy (boiler houses and cogeneration plants), thousand toe

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	536	594	352	288	294	286	258	292	333
Coal	1,402	1,278	3,809	4,568	5,391	5,859	6,352	6,614	7,013
Electricity	63	147	14	7	6	3	0	0	0
Gas	10,458	8,206	5,526	5,332	5,383	5,284	5,254	5,154	5,257
Oil products	128	174	72	55	51	52	45	38	38
Total	12,587	10,398	9,773	10,250	11,125	11,483	11,909	12,097	12,641
Share of RES	4.3%	5.7%	3.6%	2.8%	2.6%	2.5%	2.2%	2.4%	2.6%

Table A.6.1.16 Capital investments in thermal energy production, million EUR

	2020	2025	2030	2035	2040	2045	2050
Boiler houses of CHUs	239	749	427	736	623	608	321
Boiler plants	26	3	2	7	1	5	2
Heat recovery units	0	237	236	316	262	180	142
Total	264	989	664	1,058	886	794	465

Table A.6.1.17 Greenhouse gas emissions*, million tons CO_2-equivalent

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	6	6	8	8	9	10	10	11	11
Service sector	8	8	10	12	14	14	15	16	16
Electricity and heat production sector	105	74	117	143	162	178	194	204	213
Industry	101	73	89	107	119	136	148	160	169
Households	37	36	37	38	39	40	41	42	44
Supply sector	73	40	66	78	87	95	103	108	110
Transport	21	19	20	22	25	27	28	29	30
Total	353	255	347	408	455	500	540	570	592
% of 1990	43.2%	31.3%	42.6%	49.9%	55.7%	61.3%	66.1%	69.9%	72.5%

* GHG emissions include emissions from “Energy sector” and “Industrial Processes Sector” as they are understood by the Intergovernmental Panel on Climate Change

Table A.6.1.18 Energy intensity and carbon intensity

Indicators	2012	2015	2020	2025	2030	2035	2040	2045	2050
Primary energy intensity, toe/$1,000 2010 GDP (PPP)	0.33	0.29	0.32	0.28	0.24	0.22	0.20	0.18	0.17
Final energy intensity, toe/$1,000 2010 GDP (PPP)	0.18	0.15	0.16	0.14	0.12	0.11	0.10	0.09	0.09
Carbon intensity, t CO_2-equivalent /$1,000 2010 GDP (PPP)	0.95	0.82	0.96	0.88	0.80	0.72	0.67	0.63	0.60
Primary energy intensity, toe/person	2.69	2.09	2.62	2.97	3.25	3.59	3.85	4.11	4.32
Final energy intensity, toe/person	1.47	1.11	1.30	1.46	1.60	1.77	1.92	2.06	2.19
Carbon intensity, t CO_2-equivalent/person	7.76	5.97	7.82	9.34	10.63	11.97	13.23	14.30	15.21

Table A.6.1.19 Costs and investments, million EUR*

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Cost of fuel	20,408	13,507	12,331	13,485	15,069	16,750	18,532	19,776	20,803
New capital investments in electricity and heat production technologies	-	8	643	1,509	2,861	4,598	5,799	6,752	7,756
New capital investments in final energy consumption technologies	-	3,326	11,513	20,841	26,543	30,292	32,835	34,874	36,630
New capital investments in intermediate technologies	-	21	367	974	1,619	2,401	3,089	3,522	3,751
Costs of transportation, supply and intermediate technologies	1,614	1,328	2,227	3,665	5,247	7,148	8,711	9,639	10,085
Maintenance expenses (electric energy and heat production)	1,515	1,592	2,039	2,765	3,744	4,931	6,167	7,188	8,039
Maintenance expenses (final energy consumption technologies)	2,880	3,067	5,582	9,657	14,196	19,035	23,294	26,302	28,458
Subsidies (feed-in-tariff)	157	286	322	384	335	0	0	0	0
Total	26,418	22,859	34,882	53,146	69,454	85,191	98,426	108,053	115,521

* For most energy technologies (thermal power plants, final consumption appliances, etc.), capital expenditures accrue over the entire period of their operation, and annual cash flow is calculated taking into account the period of use of a technology and the cost of capital. These annual payments, together with relevant maintenance expenses, constitute the total costs of the energy system. The annual investment costs of technologies introduced in previous periods are not calculated and, accordingly, are not included in the target function.

A.6.2 Liberal Scenario

Table A.6.2.1 Total primary energy supply, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	42,718	27,344	37,141	38,627	37,604	42,564	43,572	43,993	43,365
Gas	43,018	26,055	31,671	29,646	27,147	25,847	24,008	21,971	20,626
Crude oil and oil products	11,609	10,551	11,581	11,826	12,473	12,720	11,797	10,738	8,912
Nuclear energy	23,653	22,985	16,951	15,544	12,183	8,991	8,865	8,902	8,902
Electricity	-987	-116	-190	-143	-84	-57	-36	-24	2
Hydroelectric power	901	464	906	991	1,111	1,113	1,115	1,117	1,118
Wind energy	25	94	772	1,324	1,876	2,342	2,777	3,209	3,641
Solar energy	28	40	252	642	1,033	1,861	2,747	3,641	4,377
Biofuel and waste	1,522	1,465	4,026	4,296	4,419	5,744	7,864	10,448	14,496
Total	122,487	89,519**	103,110	102,753	97,761	101,126	102,708	103,995	105,438
Share of RES	2.0%	2.3%	5.8%	7.1%	8.6%	10.9%	14.1%	17.7%	22.4%

* Statistical data
** Thermal energy was not taken into account as primary energy

Table A.6.2.2 Domestic extraction (production) of energy resources, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	40,256	17,423	29,698	31,005	28,891	33,727	33,096	33,090	32,508
Gas	15,403	14,814	16,247	16,736	17,219	18,552	19,196	19,887	20,626
Crude oil	3,414	2,618	3,232	3,879	3,007	2,315	1,566	1,014	1,239
Uranium ore**	7,884	7,662	10,931	15,544	12,183	8,991	8,865	8,902	8,902
Hydroelectric power	901	464	906	991	1,111	1,113	1,115	1,117	1,118
Wind energy	25	94	772	1,324	1,876	2,342	2,777	3,209	3,641
Solar energy	28	40	252	642	1,033	1,861	2,747	3,641	4,377
Biofuel and waste	1,565	2,606	4,394	4,290	4,388	5,429	6,331	7,001	9,062
Total	69,477	45,721	66,432	74,411	69,707	74,329	75,693	77,860	81,472
Share in the structure of TPES	56.7%	51.1%	64.4%	72.4%	71.3%	73.5%	73.7%	74.9%	77.3%

* Statistical data
** See the explanation below the table A.6.1.2

Table A.6.2.3 Import of energy resources, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	9,926	9,940	9,020	8,146	9,049	9,073	10,629	10,995	10,856
Gas	26,590	13,288	15,423	12,911	9,928	7,296	4,812	2,084	0
Crude oil and oil products	9,995	8,125	9,263	8,835	9,975	10,655	10,384	9,808	7,757
Uranium ore**	15,769	15,323	6,021	0	0	0	0	0	0
Electricity	8	193	63	57	44	33	23	11	2
Biofuel and waste	1	30	0,3	0,4	0,2	0,2	0,1	0,0	0
Total	62,289	46,899	39,790	29,948	28,997	27,057	25,848	22,898	18,616
Share in the structure of TPES*	50.9%	52.0%	38.6%	29.1%	29.7%	26.8%	25.2%	22.0%	17.7%

* The sum of shares of energy resources extraction and import in the structure of TPES is more than 100%, since the export of energy resources in TPES is calculated with the minus sign.
** See the explanation below the table A.6.1.2

Table A.6.2.4 Final Energy Consumption, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	9,212	5,952	6,278	7,371	7,973	8,850	9,588	10,223	10,662
Gas	21,698	13,741	14,804	14,224	12,586	12,679	11,887	10,061	9,566
Crude oil and oil products	11,347	8,776	10,619	10,921	11,591	11,688	10,749	9,599	7,749
Heat	11,865	7,526	9,984	9,669	9,335	8,737	7,764	6,980	6,173
Electricity	11,840	10,233	11,813	12,284	12,459	13,795	15,235	16,607	17,482
Biofuel and waste	1,029	1,282	1,051	1,057	855	1,011	1,411	1,879	3,630
Solar energy	0	0	0	0	0	279	1,492	3,414	5,396
Total	66,991	47,510	54,548	55,525	54,800	57,039	58,125	58,763	60,658
Share of direct RES consumption**	1.5%	2.7%	1.9%	1.9%	1.6%	2.3%	5.0%	9.0%	14.9%
Conditional share of RES that is considered***	2.6%	4.0%	6.6%	8.2%	9.9%	12.9%	17.7%	23.5%	30.8%

* Statistical data
** See the explanation below the table A.6.1.4.
*** See the explanation below the table A.6.1.4.

Table A.6.2.5 Final Energy Consumption by sectors, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Industry	24,844	16,408	17,992	20,172	20,794	22,578	23,941	25,100	25,766
Households	23,467	16,555	18,563	16,790	14,542	14,091	13,513	13,523	13,842
Transport	11,448	8,749	10,856	11,481	12,117	12,661	12,660	11,608	11,831
Service sector	5,037	3,838	5,248	4,964	5,020	5,181	5,347	5,741	6,093
Agriculture	2,195	1,960	1,889	2,117	2,326	2,528	2,664	2,791	3,125
Total	66,991	47,510	54,548	55,525	54,800	57,039	58,125	58,763	60,658

* Statistical data

Table A.6.2.6 Final Energy Consumption by industry, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	46	86	52	73	94	123	153	184	211
Heat from RES	5	10	280	348	407	600	736	771	905
Electricity from RES	325	232	856	1,335	1,766	2,325	2,848	3,246	3,651
Coal	8,310	5,569	5,445	6,670	7,371	8,307	9,170	9,934	10,558
Electricity	5,102	4,065	4,982	5,065	4,618	4,786	4,849	4,696	4,514
Gas	5,272	2,762	2,151	2,381	2,371	2,417	2,432	2,474	2,467
Heat	4,538	2,870	3,168	3,168	3,027	2,845	2,571	2,441	2,139
Crude oil and oil products	12,46	814	1,058	1,132	1,142	1,176	1,182	1,352	1,322
Total	24,844	16,408	17,992	20,172	20,794	22,578	23,941	25,100	25,766
Share of direct RES consumption**	0.2%	0.5%	0.3%	0.4%	0.5%	0.5%	0.6%	0.7%	0.8%
Conditional share of RES that is considered***	1.5%	2.0%	6.6%	8.7%	10.9%	13.5%	15.6%	16.7%	18.5%

* Statistical data
** See the explanation below the table A.6.1.4.
*** See the explanation below the table A.6.1.4.

Table A.6.2.7 Final Energy Consumption by households, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	936	1,097	430	319	225	137	39	0	0
Solar energy	0	0	0	0	0	170	1,091	2,426	3,713
Heat from RES	5	10	317	346	361	433	423	387	406
Electricity from RES	198	172	462	619	812	1,032	1,244	1,465	1,705
Coal	715	303	646	566	510	418	324	195	16
Electricity	3,105	3,012	2,690	2,349	2,124	2,124	2,117	2,119	2,108
Gas	13,760	9,083	10,419	9,446	7,823	7,722	6,794	5,707	4,934
Heat	4,677	2,864	3,588	3,146	2,687	2,056	1,480	1,224	960
Crude oil and oil products	71	14	10	0	0	0	0	0	0
Total	23,467	16,555	18,563	16,790	14,542	14,091	13,513	13,523	13,842
Share of direct RES consumption**	4.0%	6.6%	2.3%	1.9%	1.5%	2.2%	8.4%	17.9%	26.8%
Conditional share of RES that is considered***	4.9%	7.7%	6.5%	7.6%	9.6%	12.6%	20.7%	31.6%	42.1%

* Statistical data
** See the explanation below the table A.6.1.4.
*** See the explanation below the table A.6.1.4.

Table A.6.2.8 Final Energy Consumption by transport, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	0	34	239	491	447	422	612	756	1,213
Electricity from RES	48	32	108	168	247	380	637	1,031	1,274
Coal	12	4	11	11	12	12	12	12	12
Electricity	750	553	630	636	645	783	1,084	1,492	1,575
Gas	2,050	1,572	1,574	1,778	1,820	1,984	2,015	1,119	1,414
Crude oil and oil products	8,588	65,54	8,295	8,397	8,947	9,080	8,301	7,198	6,343
Total	11,448	8,749	10,856	11,481	12,117	12,661	12,660	11,608	11,831
Share of direct RES consumption**	0.0%	0.4%	2.2%	4.3%	3.7%	3.3%	4.8%	6.5%	10.3%
Conditional share of RES that is considered***	0.4%	0.7%	3.2%	5.7%	5.7%	6.3%	9.9%	15.4%	21.0%

* Statistical data
** See the explanation below the table A.6.1.4.
*** See the explanation below the table A.6.1.4.

Table A.6.2.9 Final Energy Consumption by service sector, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	27	46	311	152	66	82	78	78	79
Solar energy	0	0	0	0	0	109	400	988	1,683
Heat from RES	2	5	191	233	298	425	483	422	387
Electricity from RES	119	101	264	375	527	654	769	885	991
Coal	161	67	164	110	67	100	70	72	74
Gas	463	195	556	503	445	432	527	656	716
Crude oil and oil products	78	92	63	48	21	20	21	22	23
Heat	2,326	1,555	2,163	2,120	2,217	2,014	1,689	1,337	915
Electricity	1,861	1,777	1,536	1,423	1,379	1,346	1,310	1,281	1,226
Total	5,037	3,838	5,248	4,964	5,020	5,181	5,347	5,741	6,093
Share of direct RES consumption**	0.5%	1.2%	5.9%	3.1%	1.3%	3.7%	8.9%	18.6%	28.9%
Conditional share of RES that is considered***	2.9%	4.0%	14.6%	15.3%	17.7%	24.5%	32.4%	41.3%	51.5%

* Statistical data
** See the explanation below the table A.6.1.4.
*** See the explanation below the table A.6.1.4.

Table A.6.2.10 Final Energy Consumption by agriculture, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	20	19	19	21	23	248	529	861	2,127
Heat from RES	0	1	23	31	40	63	85	95	137
Electricity from RES	20	16	42	66	95	119	140	160	196
Coal	14	9	12	13	15	13	11	9	1
Electricity	312	273	242	249	248	246	239	231	243

Continuation of the table A.6.2.10

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Gas	153	129	104	115	126	126	119	105	36
Heat	312	211	255	278	299	301	296	302	324
Crude oil and oil products	1,364	1,302	1,194	1,345	1,481	1,412	1,245	1,027	62
Total	2,195	1,960	1,889	2,117	2,326	2,528	2,664	2,791	3,125
Share of direct RES consumption**	0.9%	1.0%	1.0%	1.0%	1.0%	9.8%	19.9%	30.9%	68.0%
Conditional share of RES that is considered***	1.8%	1.8%	4.4%	5.5%	6.8%	17.0%	28.3%	40.0%	78.7%

* Statistical data
** See the explanation below the table A.6.1.4.
*** See the explanation below the table A.6.1.4.

Table A.6.2.11 Production of electricity, billion kWh

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)	90	88	65	52	32	20	13	13	13
NPP (new)	0	0	0	7	14	14	20	20	20
TPP (existing ones)	79	58	42	19	2	0	0	0	0
TPP (existing modernised)	0	0	0.9	5	9	26	27	27	27
TPP (new, coal)	0	0	18	29	39	39	39	39	39
TPP (new, gas)	0	0	5	7	9	7	7	7	7
CHPP and isolated generating plants	18	8	26	28	31	32	34	36	33
HPP and PSPP (large ones)	11	7	10	11	12	12	12	12	12
HPP (small ones)	0.3	0.2	0.5	0.5	0.6	0.6	0.6	0.6	0.6
WPP (ground mounted)	0.3	1.1	9	15	22	27	32	37	42
SPP (ground mounted)	0.3	0.5	3	5	7	9	12	14	16
SPP (roof mounted)	0	0	0.3	3	5	12	20	28	35
Geothermal Power Plant	0	0	0.3	0.3	0.4	0.4	0.4	0.3	0.3
Bio CHP/TPP	0	0.1	4	4	5	5	5	6	6
Total	199	162	182	186	187	205	224	242	253
Share of RES	6.0%	5.4%	14.7%	20.9%	27.7%	32.7%	37.0%	40.9%	44.7%

* Statistical data

Table A.6.2.12 Rated capacity of thermal power plants, GW

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)	13.8	13.8	10	8	5	3	2	2	2
NPP (new)	0	0	0	1	2	2	3	3	3
TPP (existing ones)	25.4	25.5	25	24	22	18	12	7	1
TPP (existing modernised)	0	0	0.2	1	2	6	7	7	6
TPP (new, coal)	0	0	4	7	9	9	9	9	9
TPP (new, gas)	0	0	1	2	2	2	2	2	2
CHPP and isolated generating plants	8.0	7.7	11	12	12	12	12	11	11
HPP and PSPP (large ones)	5.5	6.1	6	6	6	6	6	6	6
HPP (small ones)	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
WPP (ground mounted)	0.2	0.5	3	5	7	8	10	11	13
SPP (ground mounted)	0.3	0.8	3	5	7	9	11	13	15
SPP (roof mounted)	0	0	0.3	3	5	12	19	27	33
Geothermal Power Plant	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Bio CHP/TPP	0.0	0.1	1.0	1.0	1.1	1.2	1.3	1.4	1.6
Storage capacities	0	0	3	7	11	18	26	34	40
Total	53.3	54.6	67	80	92	107	120	134	143
Share of RES	11.5%	13.9%	23.9%	32.7%	40.3%	51.5%	61.9%	69.8%	76.3%

* Statistical data

Table A.6.2.13 Capital investments in electric power industry facilities, million EUR

	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)*	0	234	234	0	934	0	0
NPP (new)	0	1,625	4,680	0	6500	0	0
TPP (existing ones)	0	0	0	0	0	0	0
TPP (existing modernised)	184	964	1,125	4,325	388	0	214
TPP (new, coal)	6,405	3,735	3,480	0	0	0	0
TPP (new, gas)	980	800	50	0	0	0	0
CHPP and isolated generating plants	3,502	1,317	1,140	1,096	1,345	807	598
HPP and PSPP (large ones)	95	0	280	0	0	0	0
HPP (small ones)	601	53	57	17	17	17	0
WPP (ground mounted)	3,012	2,165	2,100	1,885	3,776	3,254	3,105
SPP (ground mounted)	2,257	1,661	1,587	1,563	1,394	1,262	1,933
SPP (roof mounted)	334	1,894	1,814	4,816	4,832	4,440	3,338
Geothermal Power Plant	249	14	101	0	0	108	11
Bio CHP/TPP	2,913	151	234	224	216	311	731
Storage capacities	1,126	1,030	724	971	1,133	1,085	814
Total	21,657	15,642	17,606	14,897	20,535	11,283	10,743
Share of RES	48.9%	44.5%	39.2%	63.6%	55.4%	92.8%	92.4%

* Investments to extend the life time of the operating units of NPPs

Table A.6.2.14 Total thermal energy production by type of fuel, thousand toe

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Biomass and waste	14	37	986	1,169	1,387	1,963	2,294	2,387	2,644
"Clean" utilized heat (CUH)*	0	1	2	4	7	15	142	196	208
Coal	620	705	3,676	4,511	4,915	5,250	5,606	5,740	5,187
Electricity	19	75	0	0	0	0	0	0	0
Gas	12,830	9,869	7,388	6,045	5,351	4,059	2,817	2,343	1,460
Oil products	6	6	6	4	3	1	0	0	0
Nuclear energy	163	160	119	114	105	78	90	91	91
Total	13,652	10,853	12,176	11,848	11,768	11,366	10,949	10,756	9,589
Share of RES (including, CUH)	0.1%	0.4%	8.1%	9.9%	11.8%	17.4%	22.2%	24.0%	29.7%

* "Clean" recovered heat is thermal energy obtained from recovery boilers, cooling installations, water heaters, etc. which operate on the basis of the following energy resources: a) heat departed from the cooling systems of the production units (blast furnaces and open-hearth furnaces, pyrite furnaces, gas generators, heating furnaces, etc.); b) sensible heat of production products including rejected heat at the intermediate stages of the technological process (heat of hot coke, heated metal, refined products, chemical products); c) waste-gas heat from industrial furnaces and boiler units, waste slag heat, etc.; d) heat of steam exhausted from the heat installations: presses, steam drives of pumps and compensators, etc.

Table A.6.2.15 Energy consumption by boiler houses of Central Heating Units (CHU) and autoproducers of thermal energy (boiler houses and cogeneration plants), thousand toe

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	536	594	1,120	1,265	1,398	1,745	1,907	1,696	1,671
Coal	1,402	1,278	4,229	4,930	5,585	6,475	7,079	7,576	7,110
Electricity	63	147	7	1	0,2	0,04	0	0	0
Gas	10,458	8,206	4,816	3,481	2,600	1,285	538	305	133
Oil products	128	174	149	115	75	40	0	0	0
Total	12,587	10,398	10,320	9,791	9,658	9,545	9,524	9,577	8,914
Share of RES	4.3%	5.7%	10.9%	12.9%	14.5%	18.3%	20.0%	17.7%	18.7%

Table A.6.2.16 Capital investments in thermal energy production, million EUR

	2020	2025	2030	2035	2040	2045	2050
Boiler houses of CHUs	459	163	100	229	4	62	0
Boiler plants	200	72	12	76	89	3	2
Heat recovery units	0.004	190	209	168	176	155	157
Total	659	425	321	473	269	220	159

Table A.6.2.17 Greenhouse gas emissions*, million tons CO_2-equivalent

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	6	6	6	9	13	16	18	19	16
Service sector	8	8	11	10	10	10	10	11	11
Electricity and heat production sector	105	74	79	73	68	77	76	75	72
Industry	101	73	86	98	99	103	108	113	116
Households	37	36	33	30	25	24	21	17	14
Supply sector	73	40	54	56	52	59	60	60	61
Transport	21	19	20	22	24	24	22	18	17
Total	353	255	289	297	290	313	315	313	307
% of 1990	43.2%	31.2%	35.4%	36.4%	35.6%	38.4%	38.6%	38.4%	37.6%

* GHG emissions include emissions from "Energy sector" and "Industrial Processes Sector" as they are understood by the Intergovernmental Panel on Climate Change

Table A.6.2.18 Energy intensity and carbon intensity

Indicators	2012	2015	2020	2025	2030	2035	2040	2045	2050
Primary energy intensity, toe/$1,000 2010 GDP (PPP)	0.33	0.29	0.28	0.22	0.17	0.15	0.13	0.12	0.11
Final energy intensity, toe/$1,000 2010 GDP (PPP)	0.18	0.15	0.15	0.12	0.10	0.08	0.07	0.07	0.06
Carbon intensity, t CO_2-equivalent/$1,000 2010 GDP (PPP)	0.95	0.82	0.80	0.64	0.51	0.45	0.39	0.35	0.31
Primary energy intensity, toe/person	2.69	2.09	2.32	2.35	2.29	2.42	2.52	2.61	2.71
Final energy intensity, toe/person	1.47	1.11	1.23	1.27	1.28	1.37	1.42	1.47	1.56
Carbon intensity, t CO_2-equivalent/person	7.76	5.97	6.51	6.80	6.79	7.50	7.72	7.85	7.89

Table A.6.2.19 Costs and investments, million EUR*

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Cost of fuel	20,405	13,500	10,334	9,763	9,569	9,647	9,180	8,380	7,296
New capital investments in electricity and heat production technologies	-	7	1,856	3,063	4,317	5,410	6,300	6,835	7,087
New capital investments in final energy consumption technologies	-	3,750	12,411	22,049	28,282	31,697	33,290	34,217	35,318
New capital investments in intermediate technologies	-	21	445	982	1,420	2,004	2,629	2,966	3,083
Costs of transportation, supply and intermediate technologies	1,614	1,307	1,714	2,336	2,710	3,436	4,217	4,639	4,735
Maintenance expenses (electric energy and heat production)	1,515	1,592	2,336	2,996	3,665	4,071	4,768	5,371	5,718
Maintenance expenses (final energy consumption technologies)	2,880	3,067	5,429	9,657	13,803	17,516	20,304	22,165	23,633
Subsidies (feed-in-tariff)	157	286	2,113	3,619	3,673	0	0	0	0
Total	26,414	23,254	36,372	54,219	67,257	74,882	80,688	84,573	86,870

* See the explanation below the Table A.6.1.19

A.6.3 Revolutionary Scenario

Table A.6.3.1 Total primary energy supply, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	42,718	27,344	35,081	31,508	27,427	28,773	26,905	24,156	3,706
Gas	43,018	26,055	33,355	28,954	24,394	21,453	19,196	15,564	12,261
Crude oil and oil products	11,609	10,551	11,293	9,959	8,440	6,986	5,222	2,849	1,224
Nuclear energy	23,653	22,985	16,951	13,738	8,551	5,339	21	0	0
Electricity	-987	-116	-47	-144	-97	-80	-57	-33	2
Hydroelectric power	901	464	905	989	1,071	1,071	1,110	1,111	1,114
Wind energy	25	94	772	3,877	6,836	8,124	10,058	11,282	13,996
Solar energy	28	40	252	1,099	1,946	3,268	4,881	7,332	11,342
Biofuel and waste	1,522	1,465	5,857	8,226	10,808	13,863	17,818	20,832	29,136
Total	122,487	89,519**	10,4419	98,203	89,376	88,801	85,154	83,093	72,782
Share of RES (including, large HPP and PSPP)	2.0%	2.3%	7.5%	14.4%	23.1%	29.6%	39.8%	48.8%	76.4%

* Statistical data
** Thermal energy was not taken into account as primary energy

Table A.6.3.2 Domestic extraction (production) of energy resources, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	40,256	17,423	27,755	25,543	24,549	23,629	18,313	15,514	2,951
Gas	15,403	14,814	16,247	16,736	17,219	18,552	19,196	15,564	12,261
Crude oil	3,414	2,618	3,232	3,442	963	1,087	890	615	375
Uranium ore**	7,884	7,662	10,931	13,738	8,551	5,339	21	0	0
Hydroelectric power	901	464	905	989	1,071	1,071	1,110	1,111	1,114
Wind energy	25	94	772	3,877	6,836	8,124	10,058	11,282	13,996
Solar energy	28	40	252	1,099	1,946	3,268	4,881	7,332	11,342
Biofuel and waste	1,565	2,606	6,247	8,241	10,650	13,206	16,321	18,032	24,734
Total	69,477	45,721	66,341	73,664	71,784	74,274	70,790	69,450	66,774
Share in the structure of TPES	56.7%	51.1%	63.5%	75.0%	80.3%	83.6%	83.1%	83.6%	91.7%

* Statistical data
** See the explanation below the table A.6.1.2

Table A.6.3.3 Import of energy resources, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal	9,926	9,940	8,017	6,488	3,214	5,380	8,745	8,734	754
Gas	26,590	13,288	17,108	12,218	7,175	2,902	0	0	0
Crude oil and oil products	9,995	8,125	9,250	7,123	7,640	6,046	4,433	2,294	893
Uranium ore**	15,769	15,323	6,021	0	0	0	0	0	0
Electricity	8	193	206	54	32	14	2	2	2
Biofuel and waste	1	30	0,3	0,4	0,2	0,2	0,1	0,03	0
Total	62,289	46,899	40,603	25,883	18,061	14,342	13,181	11,030	1,650
Share in the structure of TPES	50.9%	52.0%	38.9%	26.4%	20.2%	16.2%	15.5%	13.3%	2.3%

* Statistical data. The sum of shares of energy resources extraction and import in the structure of TPES is more than 100%, since the export of energy resources in TPES is calculated with the minus sign.
** See the explanation below the table A.6.1.2

Table A.6.3.4 Final Energy Consumption (FEC), thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Coal**	9,212	5,952	6,270	6,301	6,032	5,419	4,006	2,790	621
Gas	21,698	13,741	14,417	12,353	9,167	7,615	6,748	4,562	460
Crude oil and oil products	11,347	8,776	10,240	8,988	7,361	5,874	4,132	1,706	3
Heat	11,865	7,526	10,054	10,173	10,543	10,340	9,851	9,583	9,050
Electricity	11,840	10,233	11,874	13,631	14,966	17,420	20,369	23,832	27,212
Biofuel and waste	1,029	1,282	1,891	3,318	4,724	5,696	6,264	6,220	7,335
Solar energy	0	0	0	0	163	657	1,490	2,790	4,316
Total	66,991	47,510	54,746	54,765	52,957	53,020	52,860	51,483	48,998
Share of direct RES consumption***	1.5%	2.7%	3.5%	6.1%	9.2%	12.0%	14.7%	17.5%	23.8%
Conditional share of RES that is considered****	2.5%	4.0%	8.8%	19.0%	30.3%	40.1%	51.6%	64.1%	90.6%

* Statistical data
** In this scenario, coal remains at the level of 1%; it is used in "conditional" industrial processes (and a little in the service sector) which by their specialization do not belong to industrial types of activities or service sector. In this case, it is difficult to identify where exactly coal is consumed. The same applies to gas. Theoretically, they may be disregarded, but in practice it is necessary to conduct more detailed studies on the replacement of fossil fuels with renewable energy sources, first of all, in industry.
*** See the explanation below the table A.6.1.4
**** See the explanation below the table A.6.1.4

Table A.6.3.5 Final Energy Consumption by sectors, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Industry	24,844	16,408	18,034	19,415	19,544	20,077	20,206	19,720	18,825
Households	23,467	16,555	18,568	16,991	15,170	14,807	14,403	14,039	13,723
Transport	11,448	8,749	10,768	10,756	10,266	9,918	9,868	9,032	7,390
Service sector	5,037	3,838	5,236	5,258	5,415	5,436	5,433	5,625	5,883
Agriculture	2,195	1,960	2,140	2,346	2,562	2,782	2,950	3,068	3,176
Total	66,991	47,510	54,746	54,765	52,957	53,020	52,860	51,483	48,998

* Statistical data

Table A.6.3.6 Final Energy Consumption by industry, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	46	86	88	170	278	478	680	889	1,235
Heat from RES	5	10	344	611	812	1,268	1,693	1,953	2,335
Electricity from RES	325	232	952	2,811	4,554	5,728	7,401	9,132	12,946
Coal**	8,310	5,569	5,444	5,575	5,439	4,910	3,739	2,603	547
Electricity	5,102	4,065	4,921	4,484	3,320	3,374	3,116	3,038	983
Gas	5,272	2,762	2,146	2,059	1,830	1,552	1,152	776	276
Heat	4,538	2,870	3,084	2,815	2,538	2,090	1,516	1,106	503
Crude oil and oil products	12,46	814	1,055	891	774	676	909	223	0
Total	24,844	16,408	18,034	19,415	19,544	20,077	20,206	19,720	18,825
Share of direct RES consumption***	0.2%	0.5%	0.5%	0.9%	1.4%	2.4%	3.4%	4.5%	6.6%
Conditional share of RES that is considered****	1.5%	2.0%	7.7%	18.5%	28.9%	37.2%	48.4%	60.7%	87.7%

* Statistical data
** See the explanation below the table A.6.3.4
*** See the explanation below the table A.6.1.4
**** See the explanation below the table A.6.1.4

Table A.6.3.7 Final Energy Consumption by households, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	936	1097	430	319	225	137	39	0	0
Solar energy	0	0	0	0	163	642	1,372	2,265	3,304
Heat from RES	5	10	399	734	1,110	1,739	2,377	2,980	3,873
Electricity from RES	198	172	512	1,145	1,782	2,251	2,990	3,763	5,309
Coal	715	303	638	578	510	395	176	109	0
Electricity	3,105	3,012	2,645	1,827	1,299	1,325	1,259	1,252	403
Gas	13,760	9,083	10,351	9,012	6,609	5,450	4,061	1,981	0
Heat	4,677	2,864	3,572	3,378	3,471	2,867	2,129	1,689	834
Crude oil and oil products	71	14	22	0	0	0	0	0	0
Total	23,467	16,555	18,568	16,991	15,170	14,807	14,403	14,039	13,723
Share of direct RES consumption**	4.0%	6.6%	2.3%	1.9%	2.6%	5.3%	9.8%	16.1%	24.1%
Conditional share of RES that is considered***	4.9%	7.7%	7.2%	12.9%	21.6%	32.2%	47.1%	64.2%	91.0%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.3.8 Final Energy Consumption by transport, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	0	34	950	2,207	3,169	3,521	3,663	3,306	3,787
Electricity from RES	48	32	120	363	724	1,098	1,632	2,251	3,346
Coal	12	4	11	11	12	12	10	5	0
Electricity	750	553	620	580	528	647	687	749	254
Gas	2,050	1,572	1,250	670	220	214	1,191	1,522	0,1
Crude oil and oil products	8,588	6,554	7,818	6,924	5,613	4,426	2,684	1,199	3
Total	11,448	8,749	10,768	10,756	10,266	9,918	9,868	9,032	7,390
Share of direct RES consumption**	0.0%	0.4%	8.8%	20.5%	30.9%	35.5%	37.1%	36.6%	51.2%
Conditional share of RES that is considered***	0.4%	0.7%	9.9%	23.9%	37.9%	46.6%	53.7%	61.5%	96.5%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.3.9 Final Energy Consumption by service sector, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	27	46	311	218	313	440	391	180	80
Solar energy	0	0	0	0	0	14	118	525	1012
Heat from RES	2	5	236	411	545	747	901	897	850
Electricity from RES	119	101	293	806	1,387	1,642	2,018	2,410	3,252
Coal	161	67	164	130	67	100	79	72	74

Continuation of the table A.6.3.9

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Gas	463	195	542	488	388	295	267	233	184
Crude oil and oil products	78	92	60	28	0	0	2	0	0
Heat	2,326	1,555	2,117	1,892	1,704	1,231	807	508	183
Electricity	1,861	1,777	1,513	1,286	1,011	967	849	802	247
Total	5,037	3,838	5,236	5,258	5,415	5,436	5,433	5,625	5,883
Share of direct RES consumption**	0.5%	1.2%	5.9%	4.1%	5.8%	8.4%	9.4%	12.5%	18.6%
Conditional share of RES that is considered***	2.9%	4.0%	16.0%	27.3%	41.5%	52.3%	63.1%	71.3%	88.3%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.3.10 Final Energy Consumption by agriculture, thousand toe

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
Biofuel and waste	20	19	112	404	739	1,119	1,491	1,845	2,232
Solar energy	0	0	0	0	0	0	0	0	0
Heat from RES	0.3	1	30	59	88	150	226	288	388
Electricity from RES	20	16	49	127	208	245	293	327	439
Coal	14	9	13	7	4	2	1	1	0
Electricity	312	273	251	203	152	144	123	109	33
Gas	153	129	128	125	120	104	77	51	0
Heat	312	211	272	274	275	247	202	163	84
Crude oil and oil products	1,364	1,302	1,286	1,146	974	771	536	285	0
Total	2,195	1,960	2,140	2,346	2,562	2,782	2,950	3,068	3,176
Share of direct RES consumption**	0.9%	1.0%	5.2%	17.2%	28.8%	40.2%	50.5%	60.1%	70.3%
Conditional share of RES that is considered***	1.8%	1.8%	8.9%	25.2%	40.4%	54.4%	68.1%	80.2%	96.3%

* Statistical data
** See the explanation below the table A.6.1.4
*** See the explanation below the table A.6.1.4

Table A.6.3.11 Production of electricity, billion kWh

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)	90	88	65	52	32	20	0.1	0	0
NPP (new)	0	0	0	0	0	0	0	0	0
TPP (existing ones)	79	58	42	20	2	1	1	1	0
TPP (existing modernised)	0	0	1	5	9	24	31	32	0
TPP (new, coal)	0	0	19	25	26	26	26	26	0
TPP (new, gas)	0	0	7	4	1	0	4	0	7
CHPP and isolated generating plants	18	8	18	18	20	21	23	25	19
HPP and PSPP (large ones)	11	7	10	11	12	12	12	12	12
HPP (small ones)	0.3	0.2	0.5	0.5	0.5	0.5	0.6	0.6	0.6
WPP (ground mounted)	0.3	1.1	9	45	80	94	117	131	163
SPP (ground mounted)	0.3	0.5	3	10	17	27	40	63	96
SPP (roof mounted)	0	0	0.3	3	5	11	17	23	36
Geothermal Power Plant	0	0	0.1	0.1	0.1	0.1	0.1	0.126	1
Bio CHP/TPP	0	0.1	7	8	9	10	14	18	31
Total	199	162	180	200	214	247	285	330	366
Share of RES	6.0%	5.4%	16.2%	38.5%	57.8%	62.9%	70.4%	75.0%	92.9%

* Statistical data

Table A.6.3.12 Installed capacity of thermal power plants, GW

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)	13.8	14	10	8	5	3	0.01	0	0
NPP (new)	0	0	0	0	0	0	0	0	0
TPP (existing ones)	25	25	25	24	22	18	12	7	1
TPP (existing modernised)	0	0	0	1	2	6	7	7	7

Continuation of the table A.6.3.12

	2012*	2015*	2020	2025	2030	2035	2040	2045	2050
TPP (new, coal)	0	0	4	6	6	6	6	6	6
TPP (new, gas)	0	0	2	2	2	2	2	2	2
CHPP and isolated generating plants	8	8	9	9	9	9	8	8	8
HPP and PSPP (large ones)	5	6	6	6	6	6	6	6	6
HPP (small ones)	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
WPP (ground mounted)	0.2	1	3	14	24	28	35	39	52
SPP (ground mounted)	0.3	1	3	10	17	25	35	56	91
SPP (roof mounted)	0	0	0.3	3	5	10	16	21	34
Geothermal Power Plant	0	0	0.02	0.02	0.02	0.02	0.02	0.02	0.2
Bio CHP/TPP	0.01	0.1	1.6	1.8	2.2	2.4	3.2	4.1	7.3
Storage capacities	0	0	2.7	14	25	37	52	73	114
Total	53	55	66	98	125	151	183	229	327
Share of RES	11.5%	13.9%	25.0%	49.5%	63.2%	72.1%	81.1%	87.2%	93.0%

* Statistical data

Table A.6.3.13 Capital investments in electric power industry facilities, million EUR

	2020	2025	2030	2035	2040	2045	2050
NPP (existing ones)*	0	234	234	0	0	0	0
NPP (new)	0	0	0	0	0	0	0
TPP (existing ones)	0	0	0	0	0	0	0
TPP (existing modernised)	184	964	1,125	3,678	1,964	0	0
TPP (new, coal)	7,070	1,765	308	0	0	0	0
TPP (new, gas)	1,280	0	0	0	0	0	800
CHPP and isolated generating plants	840	665	488	524	1,254	720	962
HPP and PSPP (large ones)	95	0	0	0	280	0	0
HPP (small ones)	587	42	18	0	35	0	34
WPP (ground mounted)	3,012	12,339	10,715	4,776	10,010	14,065	20,504
SPP (ground mounted)	2,257	5,859	5,554	5,852	7,246	12,132	19,921
SPP (roof mounted)	334	1,894	1,814	3,749	3,334	3,023	7,416
Geothermal Power Plant	62	14	0	0	12	48	443
Bio CHP/TPP	5,015	686	999	734	2,229	2,319	8,632
Storage capacities	1,126	2,952	2,001	1,542	1,900	2,963	4,120
Total	21,862	27,413	23,254	20,854	28,265	35,269	62,832
Share of RES	57.1%	86.8%	90.7%	79.9%	88.6%	98.0%	97.2%

* Investments to extend the life time of the operating units of NPPs

Table A.6.3.14 Total thermal energy production by type of fuel, thousand toe

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Biomass and waste	14	37	1,165	1,696	2,285	3,335	4,933	6,835	10,192
"Clean" utilized heat (CUH)*	0	1	2	285	470	898	1,045	1,210	1,213
Coal	620	705	1,722	1,670	1,613	1,694	1,742	1,708	0
Electricity	19	75	23	37	52	111	183	235	234
Gas	12,830	9,869	8,593	7,314	6,876	5,130	3,428	2,615	2,223
Oil products	6	6	6	4	2	2	1	0	0
Nuclear energy	163	160	119	97	71	44	0,2	0	0
Total	13,652	10,853	11,630	11,103	11,368	11,214	11,331	12,604	13,862
Share of RES (including, CUH)	0.1%	0.4%	10.0%	17.8%	24.2%	37.8%	52.8%	63.8%	82.3%

* See the explanation below the table A.6.2.14

Table A.6.3.15 Energy consumption by boiler houses of Central Heating Units (CHU) and autoproducers of thermal energy (boiler houses and cogeneration plants), thousand toe

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	536	594	775	1,242	1,520	2,345	3,046	3,183	3,296
Coal	1,402	1,278	2,284	1,927	1,881	2,890	2,939	2,632	0
Electricity	63	147	35	56	79	155	250	312	311
Gas	10,458	8,206	6,215	5,107	4,619	3,071	1,603	1,120	1,372
Oil products	128	174	142	105	98	59	34	13	0
Total	12,587	10,398	9,450	8,436	8,197	8,520	7,871	7,260	4,979
Share of RES	4.3%	5.7%	8.2%	14.7%	18.5%	27.5%	38.7%	43.8%	66.2%

Table A.6.3.16 Capital investments in thermal energy production, million EUR

	2020	2025	2030	2035	2040	2045	2050
Boiler houses of CHUs	215	81	594	300	149	43	4
Boiler plants	257	230	53	200	108	44	217
Heat recovery units	0	180	172	162	150	108	89
Total	471	491	819	661	407	196	310

Table A.6.3.17 Greenhouse gas emissions*, million tons CO_2-equivalent

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	6	6	6	6	6	5	4	3	0,4
Service sector	8	8	9	7	5	3	3	2	1
Electricity and heat production sector	105	74	81	70	58	68	74	71	14
Industry	101	73	86	82	79	76	66	56	45
Households	37	36	33	28	21	17	12	6	0
Supply sector	73	40	51	46	43	44	40	37	23
Transport	21	19	18	17	15	12	9	5	1
Total	353	255	284	257	227	225	207	181	85
% of 1990	43.2%	31.2%	34.8%	31.4%	27.8%	27.5%	25.4%	22.1%	10.4%

* GHG emissions include emissions from "Energy sector" and "Industrial Processes Sector" as they are understood by the Intergovernmental Panel on Climate Change

Table A.6.3.18 Energy intensity and carbon intensity

Indicators	2012	2015	2020	2025	2030	2035	2040	2045	2050
Primary energy intensity, toe/$1,000 2010 GDP (PPP)	0.33	0.29	0.29	0.21	0.16	0.13	0.11	0.09	0.07
Final energy intensity, toe/$1,000 2010 GDP (PPP)	0.18	0.15	0.15	0.12	0.09	0.08	0.07	0.06	0.05
Carbon intensity, t CO_2-equivalent /$1,000 2010 GDP (PPP)	0.95	0.82	0.78	0.55	0.40	0.33	0.26	0.20	0.09
Primary energy intensity, toe/person	2.69	2.09	2.35	2.25	2.09	2.13	2.09	2.08	1.87
Final energy intensity, toe/person	1.47	1.11	1.23	1.25	1.24	1.27	1.30	1.29	1.26
Carbon intensity, t CO_2-equivalent/person	7.76	5.97	6.39	5.88	5.31	5.38	5.08	4.53	2.19

Table A.6.3.19 Costs and investments, million EUR*

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Cost of fuel	20,405	13,500	10,866	9,246	8,322	7,204	6,150	4,934	4,123
New capital investments in electricity and heat production technologies	-	7	1,957	4,735	6,990	8,639	10,395	11,563	14,801
New capital investments in final energy consumption technologies	-	3,750	12,408	23,085	30,593	35,162	36,707	37,827	41,277
New capital investments in intermediate technologies	-	21	460	1,285	1,729	2,308	2,807	3,083	3,345
Costs of transportation, supply and intermediate technologies	1,614	1,307	1,743	2,346	2,758	3,472	4,184	4,628	4,798
Maintenance expenses (electric energy and heat production)	1,515	1,592	2,260	3,053	3,698	4,216	5,049	5,878	7,081
Maintenance expenses (final energy consumption technologies)	2,880	3,067	5,392	9,686	14,430	18,559	21,565	23,892	26,155
Subsidies (feed-in-tariff)	157	286	2,445	7,621	8,827	0	0	0	0
Total	26,414	23,254	37,265	60,814	77,164	81,958	86,856	91,805	101,579

* See the explanation below the table A.6.1.19

Annex A.7 Sectoral effects of implementing energy policy measures

Table A.7.1 Sectoral effects of implementing energy policy measures within the Liberal Scenario (deviation of output volumes from the Reference (Conservative) Scenario, %)

Sector/Period	2018	2020	2025	2030	2040	2050
Agriculture, forestry and fishing	0.1	0.6	1.7	2.6	3.8	4.8
Mining of coal, lignite, and extraction of peat; mining of uranium and thorium ores	-1.7	-3.5	-7.9	-12.1	-19.9	-26.6
Extraction of hydrocarbons and related services	-0.8	-1.2	-2.3	-3.6	-6.7	-9.8
Extraction of mineral resources, other than fossil fuels	0.6	1.5	3.3	4.7	6.7	8.1
Manufacture of food products, beverages and tobacco products	0.2	1.1	3.1	4.7	7.2	9.0
Manufacture of textiles, wearing apparel, leather, leather goods and other materials	-0.1	0.2	0.8	1.2	1.8	2.1
Manufacture of products of wood, paper products, and printing	0.0	0.5	1.6	2.4	3.9	6.4
Manufacture of coke and coke products	0.5	0.3	-0.1	-0.8	-2.2	-3.6
Manufacture of refined petroleum products	-0.9	-1.6	-3.4	-5.2	-8.8	-12.1
Manufacture of chemicals and chemical products	-0.3	0.8	3.0	4.8	7.8	10.3
Production of essential medicines and pharmaceuticals	0.0	0.6	1.9	3.0	4.4	5.4
Manufacture of rubber and plastics products and other non-metallic mineral products	0.7	1.4	2.9	4.0	5.4	5.9
Manufacture of metals and fabricated metal products, except machinery and equipment	1.4	2.1	3.6	4.9	7.0	8.7
Manufacture of computers, electronic and optical products	0.5	0.1	-0.8	-1.7	-3.4	-4.8
Manufacture of electrical equipment	1.0	1.2	1.8	2.2	2.8	3.1
Manufacture of machinery and equipment not elsewhere classified	1.9	1.7	1.4	1.0	0.2	-0.4
Manufacture of motor vehicles, trailers and semi-trailers, and other vehicles	0.7	0.4	-0.3	-1.0	-2.2	-3.2
Manufacture of furniture, other products, repair and installation of machinery and equipment	0.3	0.6	1.2	1.7	2.3	2.8
Generation and distribution of electricity	0.3	0.7	1.7	2.5	3.6	4.2
Manufacture and distribution of gas	-2.4	-4.3	-9.2	-13.8	-22.4	-30.0
Steam and hot water supply	1.3	3.4	8.3	12.8	20.4	23.9
Water supply; sewage, waste management	0.9	2.4	5.7	8.5	13.0	16.3
Construction	3.1	3.3	3.6	3.9	4.2	4.4
Wholesale and retail trade, repair of motor vehicles and motorcycles	0.2	0.6	1.6	2.4	3.4	4.1
Transport, warehousing, postal and courier activities	0.2	0.4	0.7	1.0	1.2	1.1
Temporary accommodation and food service activities	0.0	0.4	1.1	1.6	2.0	2.2
Publishing activities, motion picture, video and television programme production, music publishing, television programming and broadcasting activities	-0.1	0.1	0.5	0.7	1.0	1.2
Telecommunications (electrical communication)	0.0	0.5	1.4	2.1	3.1	3.6
Computer programming and provision of other information services	-0.1	-0.1	-0.3	-0.7	-1.5	-2.3
Financial and insurance activities	0.0	0.2	0.5	0.7	0.8	0.7
Real estate activities	0.2	1.0	2.7	3.9	5.7	6.8
Legal and accounting activities; activities of head offices; management consultancy activities; architectural and engineering activities; technical testing and analysis	0.0	0.1	0.1	0.1	-0.1	-0.4
Scientific research and development	0.8	1.0	1.5	1.8	2.4	2.9
Advertising and market research, other professional, scientific and technical activities; veterinary activities	-0.1	0.3	1.0	1.4	2.0	2.3
Administrative and support service activities	0.2	0.6	1.5	2.1	3.1	3.7
Public administration and defense; compulsory social security	0.2	1.3	3.8	5.8	9.1	11.5
Education	0.5	1.8	4.7	7.2	11.2	14.1
Human health and social work activities	0.3	1.6	4.4	6.7	10.4	13.1
Arts, sports, entertainment and recreation	0.1	0.8	2.5	3.8	5.8	7.2
Other service activities	0.1	0.5	1.4	2.1	3.0	3.6

Table A.7.2 Sectoral effects of implementing energy policy measures within the Revolutionary Scenario (deviation of output volumes from the Reference (Conservative) Scenario, %)

Sector/Period	2018	2020	2025	2030	2040	2050
Agriculture, forestry and fishing	0.2	0.9	2.3	3.5	5.1	6.4
Mining of coal, lignite, and extraction of peat; mining of uranium and thorium ores	-6.4	-8.8	-15.6	-22.8	-36.3	-47.4
Extraction of hydrocarbons and related services	-1.1	-1.7	-3.7	-6.1	-11.3	-16.5
Extraction of mineral resources, other than fossil fuels	0.4	1.9	4.8	6.9	9.7	11.4
Manufacture of food products, beverages and tobacco products	-0.1	1.3	4.2	6.4	9.4	10.9
Manufacture of textiles, wearing apparel, leather, leather goods and other materials	0.1	0.4	0.9	1.2	1.7	2.1
Manufacture of products of wood, paper products, and printing	0.2	1.3	4.0	6.8	14.5	27.4
Manufacture of coke and coke products	-2.4	-4.1	-9.6	-16.0	-28.7	-40.0
Manufacture of refined petroleum products	-2.5	-5.4	-12.1	-18.0	-27.8	-35.1
Manufacture of chemicals and chemical products	-0.6	0.5	2.3	3.6	5.6	7.7
Production of essential medicines and pharmaceuticals	-0.1	0.7	2.3	3.5	4.9	5.5
Manufacture of rubber and plastics products and other non-metallic mineral products	0.2	2.6	6.3	7.9	6.7	-0.9
Manufacture of metals and fabricated metal products, except machinery and equipment	1.7	6.0	14.5	20.9	29.9	35.3
Manufacture of computers, electronic and optical products	3.1	1.9	-0.8	-3.0	-6.0	-7.2
Manufacture of electrical equipment	2.5	3.1	3.9	4.4	4.7	4.8
Manufacture of machinery and equipment not elsewhere classified	5.2	5.1	4.1	3.0	1.4	0.7
Manufacture of motor vehicles, trailers and semi-trailers, and other vehicles	2.9	2.4	0.9	-0.4	-2.4	-3.2
Manufacture of furniture, other products, repair and installation of machinery and equipment	0.3	0.8	1.7	2.1	2.4	2.2
Generation and distribution of electricity	-4.0	-0.1	7.8	13.3	20.7	25.5
Manufacture and distribution of gas	-4.6	-7.4	-14.7	-21.8	-34.8	-45.9
Steam and hot water supply	0.1	2.8	8.6	13.6	21.1	22.7
Water supply; sewage, waste management	-0.2	2.4	7.7	11.7	17.4	20.6
Construction	9.2	9.6	10.0	10.1	10.3	10.3
Wholesale and retail trade, repair of motor vehicles and motorcycles	0.2	1.0	2.5	3.5	4.7	5.3
Transport, warehousing, postal and courier activities	0.8	1.7	3.4	4.5	5.5	5.3
Temporary accommodation and food service activities	-0.2	0.0	0.1	0.1	-0.3	-0.6
Publishing activities, motion picture, video and television programme production, music publishing, television programming and broadcasting activities	-0.1	0.0	-0.1	-0.3	-0.7	-0.9
Telecommunications (electrical communication)	-0.3	0.3	1.5	2.3	3.3	3.8
Computer programming and provision of other information services	0.3	-0.1	-1.1	-2.1	-3.6	-4.5
Financial and insurance activities	0.1	0.3	0.7	0.8	0.8	0.8
Real estate activities	-0.2	1.1	3.5	5.2	7.3	8.3
Legal and accounting activities; activities of head offices; management consultancy activities; architectural and engineering activities; technical testing and analysis	0.3	0.4	0.2	0.0	-0.6	-1.1
Scientific research and development	2.4	2.6	2.8	3.1	3.7	4.2
Advertising and market research, other professional, scientific and technical activities; veterinary activities	-0.2	0.2	1.0	1.4	1.8	1.9
Administrative and support service activities	0.3	1.0	2.3	3.1	4.1	4.5
Public administration and defense; compulsory social security	-0.7	1.1	4.9	7.9	12.0	14.1
Education	-0.3	1.7	6.0	9.5	14.3	16.9
Human health and social work activities	-0.5	1.6	5.9	9.3	14.0	16.4
Arts, sports, entertainment and recreation	-0.5	0.6	2.9	4.6	6.9	8.1
Other service activities	0.0	0.6	1.8	2.6	3.6	4.2

Annex A.8 Impact of the implementation of energy policy measures on the sectoral labor force redistribution

Table A.8.1 Impact of the implementation of energy policy measures on the sectoral labor force redistribution (deviation of the value of employed population from the Reference (Conservative) Scenario, thousand people; in 2015, the actual number of employed people)

Sector/Period	2015	Liberal		Revolutionary	
		2030	2050	2030	2050
Agriculture, forestry and fishing	2871	-6	-7	-14	-13
Mining of coal, lignite, and extraction of peat; mining of uranium and thorium ores	124	-34	-55	-57	-89
Extraction of hydrocarbons and related services	59	-12	-20	-19	-31
Extraction of mineral resources, other than fossil fuels	69	2	2	4	6
Manufacture of food products, beverages and tobacco products	365	6	11	4	7
Manufacture of textiles, wearing apparel, leather, leather goods and other materials	95	-2	-3	-4	-5
Manufacture of products of wood, paper products, and printing	83	-2	-1	2	23
Manufacture of coke and coke products	25	-2	-3	-9	-15
Manufacture of refined petroleum products	23	-3	-5	-8	-12
Manufacture of chemicals and chemical products	84	0	1	-2	-2
Production of essential medicines and pharmaceuticals	17	0	0	-1	-1
Manufacture of rubber and plastics products and other non-metallic mineral products	158	0	-2	0	-11
Manufacture of metals and fabricated metal products, except machinery and equipment	346	1	1	36	48
Manufacture of computers, electronic and optical products	50	-1	-2	-2	-2
Manufacture of electrical equipment	61	-1	-3	-2	-4
Manufacture of machinery and equipment not elsewhere classified	182	-4	-8	-5	-10
Manufacture of motor vehicles, trailers and semi-trailers, and other vehicles	151	-7	-11	-10	-15
Manufacture of furniture, other products, repair and installation of machinery and equipment	147	-2	-3	-4	-6
Generation and distribution of electricity	319	-22	-35	-10	7
Manufacture and distribution of gas	44	-11	-18	-17	-26
Steam and hot water supply	26	-2	-4	-1	-2
Water supply; sewage, waste management	144	4	6	6	8
Construction	642	-1	-7	10	1
Wholesale and retail trade, repair of motor vehicles and motorcycles	3511	-21	-34	-47	-70
Transport, warehousing, postal and courier activities	998	-40	-66	-34	-65
Temporary accommodation and food service activities	277	-4	-7	-12	-16
Publishing activities, motion picture, video and television programme production, music publishing, television programming and broadcasting activities	53	-1	-2	-3	-4
Telecommunications (electrical communication)	111	0	1	-2	-1
Computer programming and provision of other information services	110	-7	-12	-14	-19
Financial and insurance activities	244	-8	-13	-13	-19
Real estate activities	268	5	9	6	9
Legal and accounting activities; activities of head offices; management consultancy activities; architectural and engineering activities; technical testing and analysis	218	-6	-10	-10	-15
Scientific research and development	146	0	0	1	0
Advertising and market research, other professional, scientific and technical activities; veterinary activities	59	-1	-1	-2	-3
Administrative and support service activities	299	-2	-3	-3	-5
Public administration and defense; compulsory social security	975	63	106	82	123
Education	1497	77	127	100	150
Human health and social work activities	1041	40	67	54	80
Arts, sports, entertainment and recreation	208	6	10	5	8
Other service activities	345	-2	-3	-5	-6

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Дослідження **«Перехід України на відновлювану енергетику до 2050 року»** виконано у 2016-2017 роках Державною установою «Інститут економіки та прогнозування Національної академії наук України» за підтримки Представництва Фонду ім. Гайнріха Бьолля в Україні у співпраці з організаціями громадянського суспільства, органами державної влади, профільними асоціаціями та незалежними експертами. В роботі представлено результати моделювання базового та альтернативних сценаріїв розвитку енергетичного сектору України до 2050 р., а також продемонстровано, яким чином може бути досягнутий перехід від викопних видів палива до відновлюваних джерел енергії, та які економічні наслідки це матиме.