Transition of Ukrainian Energy sector towards RES development till 2050

August 2017

Developed by the experts of:

Non-governmental organization "Renewable Energy Agency" in frames of the project "Advocate for Sustainable Energy Transition Armenia-Belarus-Macedonia-Serbia-Ukraine".
Coordinator: INFORSE-EUROPE, Gunnar Boye Olsen, ove@inforse.org

03067, Kyiv-67, P.O. box 66, Ukraine
Tel./fax: +30 (044) 456 94 62
www.rea.org.ua

Content

Disclaimer

Current report contains expert estimations and opinions of NGO "REA", which does not reflect the official opinion of INFORSE EUROPE and CISU. The authors' point of view may not correspond to the official position of INFORSE EUROPE and CISU and its affiliates; all information contained in the report is exclusively personal view and interpretation of authors.

Introduction

Energy sector of Ukraine starting is on the way of transformation from fossil fuel-based energy generation to sustainable energy generation from renewable energy sources. It is supported by serious changes in internal legislative and technical frameworks as well as integration in global renewable energy and climate change mitigation processes such as Association with EU, joining Energy Community, becoming Party of Paris Agreement, implementation of EU Third Energy package and others. Ukraine has approved National Plans on development of renewables and energy efficiency till 2020 – National Renewable Energy Action Plan (2014) and National Energy Efficiency Action Plan (2015) with concrete targets established. The supporting mechanisms for renewables includes, "green" tariff in power sector, incentives for equipment purchase, co-financing mechanisms, liberalization and first steps on introduction of competitiveness on energy markets, equalization of fossil energy prices and renewable energy prices and many others. Despite positive tendency of energy sector transition to renewables the comprehensive Energy Strategy serving as a document with long-term development targets of energy sector (till 2050) is still absent. The data from different available and approved strategic documents related to energy sector is somehow outdated, fragmentary and in most cases not consistent for different documents. The planning horizon is also not enough for new realities in energy sector (maximum 2035) as for example Paris Agreement considers 2050 and even 2100 horizon.

The current document is aimed at elaboration and presenting the consistent scenarios of energy sector transition till 2050 to follow best world tendencies. First time the demonstration of 100% RES scenario in 2050 is elaborated. It could serve as an orientation for Ukrainian policy-making in renewable energy sector for long term perspective depending on scenario chosen and demonstrate that 100% RES scenario in 2050 is principally possible.

Executive summary

Three scenarios were elaborated for demonstration of different ways of energy sector transition till 2050: Baseline scenario, Climate Action Scenario, 100% RES scenario. Baseline scenario represents "continuation of current trends" case without additional efforts and targets introduced in energy sector. Climate action scenario represents full implementation of climate obligations of Ukraine and even stricter potential obligation of Paris Agreement: -70% of emission reduction in 2050 from 2015 level, which shall corresponds to 2^0C temperature increase trajectory. 100% RES scenario is representing "highest possible efforts" towards energy transition to RES with the indicative target of 100% RES in power, heating/cooling, and transport sector and zero fossil component in 2050.

Results for Baseline Scenario show that it is possible to achieve 24% RES in TPES in 2050 with annual average pace of development 6%/year, mostly by increasing in biomass and heat pumps in heating and wind and solar in power energy supply. TPES for the scenario is 80.32 Mtoe (70% from the average 2010-2015 level), TFC is 61.56 Mtoe (91% from 2010-2015 level).

Results for Climate Action Scenario show that it is possible to achieve 42% RES in TPES in 2050 with average annual temp of development 8.5%/year, by balanced implementation of all kind of RES, mostly biomass, heat pumps and solar heat for heating and solar PV, wind installations and some additional share of biogas and geothermal energy supply in power sector. Also, calculation shows additional necessity for energy capacitors installation in power sector in total for 0.857 Mtoe (TPES) in 2050. TPES for the scenario is 71.62 Mtoe (62% from 2010-2015 level), TFC is 58.9 Mtoe (87% from 2010-2015 level).

Results for 100% RES (also called as High Commitment Scenario) show that 100% RES in TPES and GFEC is principally possible. Such level of RES utilization requires extraordinary temps of RES sector development (average annual increase +14%/year, increasing of RES absolute TPES from 3.2 to 62.75 Mtoe or in 20 times for 33 years). The potential of some of RES is fully utilized (solar PV and solar heat), for other – it is utilized on the level 40-70%. All RES are engaged in achieving 100% target, mostly biomass (41.6% from TPES, including 5% from liquid biofuels), solar PV (8% from TPES), solar heat (8% from TPES), wind power (20% from TPES), heat pumps (10% from TPES), geothermal generation (4% from TPES). Hydro generation is growing 1.5 times in period 2015-2050, but is not considered to be the major RES in 2050 (2.5% from TPES). TPES for the scenario is 62.75 Mtoe (54% from 2010-2015 level), TFC is 55.36 Mtoe (82% from 2010-2015 level).

1. Analysis of existing state-level strategic documents related to energy sector development in Ukraine

Currently, strategic documents in Ukraine are represented by international-level strategies and action plans (according to international obligations), national-level strategies, regional-level strategies, sectoral programmes, and enterprise-level development programmes. For the purpose of development of transition of Ukrainian energy sector for the period 2015-2050, it is necessary to use as intermediary points according to the available data on energy sector, for instance gross final energy consumption (GFEC), total primary energy supply (TPES), RES share, biomass share and others. Here we briefly analyse only those strategic documents, which contain available figures on energy sector developments. The main documents to be analysed are presented in Table 1.1.

Table 1.1 Main strategic documents of Ukraine, analyzed in this paper

#	Name	Status	Developer	Date of approval /publication
1.	Energy Strategy of Ukraine till 2035 (2016)	Draft	Razumkov Centre	December 2016
2.	Energy Strategy of Ukraine till 2035 (2014)	Draft	by National Institute for Strategic Studies, under edition of Sukhodolya O.M.	June 2014
3.	Energy Strategy of Ukraine till 2030	In effect	McKinsey & Company (Moscow office)	July 2013
4.	Strategy on Agriculture and Rural Development 2015-2020	In effect	Ministry of Agrarian Policy and Food of Ukraine	September 2015
5.	National Strategy of Regional Development for the period till 2020	In effect	Ministry of Economic Development and Trade of Ukraine	August 2014
6.	Ukrainian INDC 2015 edition	In effect	Ministry of Ecology and Natural Resources of Ukraine	September 2015
7.	National Concept of Climate Policy Realization in Ukraine	In effect	Ministry of Ecology and Natural	December 2016

	till 2030		Resources of Ukraine	
8.	National Energy Efficiency Action Plan till 2020	In effect	State Agency on Energy Efficiency and Energy Saving of Ukraine	November 2015
9.	National Renewable Energy Action Plan till 2020	In effect	State Agency on Energy Efficiency and Energy Saving of Ukraine	October 2014
10.	Concept of Sustainable Development "Ukraine 2020"	In effect	Administration of the President of Ukraine	січень 2015
11.	Ukrainian Low Emission Development Strategy and Low Carbon Development Strategy	Under development	International project USAID MERP	

Each of the documents makes a unique input to the data of energy sector development after 2015, which could be used as one of the thresholds for the RES transition forecast till 2050.

1.1. Current state and targets of effective and draft Energy strategies available in Ukraine

1) **Energy Strategy of Ukraine till 2035 (Draft) prepared by Razumkov Centre (ESU-2035, Razumkov Centre), date of publication: December 2016**[1]

The document is the latest available one on energy sector developments and thus using the latest input data for the prognosis. The key indicators of energy sector transition till 2035 are:

- 23% RES in TPES in 2035;
- 11 Mtoe primary energy supply from biomass;
- Overall TPES in 2035: 96 Mtoe;
- Energy consumption reduction (2015=100%)=107% in 2035;
- CO_2 emission reductions: 20% in 2035 from the level of 2010.

Such strategy could be considered as the most RES-oriented strategy from all available documents, because it stipulates the highest RES share in TPES in 2035. However, still the

[1] ESU-2035 (Draft, 2016), Razumkov Centre:
http://mpe.kmu.gov.ua/minugol/control/uk/publish/article?art_id=245165746&cat_id=245165726

share of RES is quite low, growing from 4.8% current with average annual increment of 0.9%/year. Forecasted data on reduction of energy consumption and GHG emissions is also not enough ambitious for present state of Ukrainian energy sector.

2) **Energy Strategy of Ukraine till 2035 (Draft) prepared by National Institute for Strategic Studies, under edition of Sukhodolya O.M. (ESU-2035 Sukhodolya), date of publication: June 2014**[2]

The document became available in 2014 and was the first strategy of Ukraine stipulating priority of RES development and energy efficiency in more ambitious way than any other previous strategies. The document provides energy data for each of 5 years for the prognosis period based on economic models TIMES-Ukraine. The key indicators of energy sector transition till 2035 are:

- 21% RES in TPES in 2035;
- 13 Mtoe primary energy supply from biomass;
- Overall TPES in 2035: 133 Mtoe;
- Energy consumption reduction (2015=100%)=147% in 2035;
- CO_2 emission reductions: 20% in 2035 from the level of 2010.

Such strategy was considered by the expert field as the most balanced as for the date of publishing and was announced on Parliament Committee of Fuel and Energy and other high-level discussions with parliament members and energy executives. However, the processes in Ukrainian energy sector after 2013 made dramatic correction of initial historical data. For example, the latest historical period used as input data for the model was 2010-2013 with 116-132 Mtoe in TPES, however right in the next 2014 year TPES dropped to 105.6 Mtoe due to different reasons (including, among others implementation of energy efficiency). Thus, the data of this document could be used as a threshold fragmentary, for example figure 20.4% RES is used in one of the scenarios "Climate Action" as point to be achieved in 2035.

3) **Energy Strategy of Ukraine till 2030 (in effect) prepared by international consultants of McKinsey & Company (Moscow office), date of adoption: July 2013**[3]

The document was developed and published in 2011 before its adoption in 2013 and was met with a lot of criticism of Ukrainian energy expert field. Despite it was developed by highly qualified experts, the key tendencies realized in the document were recognized as principally

[2] ESU-2035 (Draft, 2014), National Institute for Strategic Studies, under edition of Sukhodolya O.M.
http://www.niss.gov.ua/public/File/2014_nauk_an_rozrobku/Energy%20strategy%202035%20eng.pdf

[3] ESU till 2030 (in effect)
http://zakon3.rada.gov.ua/laws/show/n0002120-13

wrong. It consists of three different scenarios – baseline, pessimistic and optimistic, which differ basically on macroeconomic indicators – the level of population, GDP growth, GDP energy intensity, salaries of population, business indicators, etc. For one of the scenarios, for example, document foresaw implementation of additional 32 GW_{el} of installed capacity in power sector based on coal generation, as well as enhancement of nuclear power production through construction of new NPP. In fact, the main attention was paid to the electricity generation with detailed calculations of peak loads, network regulation issues, power network interconnection with IPS/EPS and others. Heating sector was also considered as important part of energy balance with "continuation of current practice" in all scenarios: natural gas-based heating, minimum energy efficiency efforts, and minimum natural gas substitution. RES and bioenergy were considered as perspective however without reflection in concrete ambitious targets in 2020 and 2030. During the modeling, internal Ukrainian demand-supply models were used, but not publicly shown. The key indicators of energy sector transition till 2030 are:

- 4-6% RES in power generation in 2030, no concrete figure in TPES and heating;
- 10-15 GW_{th} installed capacity in 2030 (approx. 5 Mtoe)+1.9 Mtoe motor biofuels;
- Overall TPES in 2030: 167-202 Mtoe;
- Energy consumption reduction (2015=100%)=187%-224% in 2030;
- CO_2 emission: no concrete figure available[4].

The data in the document is considered as outdated and does not correspond to current reality in energy sector of Ukraine. However, it contains useful figures on macroeconomic indicators, GDP decoupling, power system regulation (data on storages and regulation capacities needed for each RES type) and other issues. In addition, it shall be considered in further elaborations of the energy sector transition, as it is by far the only officially adopted Energy Strategy among other documents of the same level.

4) National Energy Efficiency Action Plan till 2020 (in effect), date of adoption: November 2015[5]

The document was developed according to the international obligations of Ukraine under Energy Community in 2013. It foresees reduction of energy consumption (GFEC) on 9% in 2020 in comparison with average base level 2005-2009 with total expected savings of 6.2 Mtoe in 2020 (mostly in residential sector – 2.3 Mtoe reduction and industry – 2.8 Mtoe reduction). It is developed according to the unified international methodologies with detailed sectoral division of targets (population, public buildings, industry, transport) and finance needed. In 2011-2012 Ukrainian indicators of GFEC achieved the level of reduction foreseen in the document, so

[4] according to fuel balance and TPES growth available, emissions in 2030 is achieving 1990 level for the optimistic scenario: 880 $MtCO_2$/year (estimation of authors)

[5] National Energy Efficiency Action Plan till 2020 (in effect) : http://saee.gov.ua/documents/NpdEE_eng.pdf

formally it is already fulfilled. Nevertheless, the tendency of GFEC reduction foreseen could be used for post-2015 prognosis as one of the thresholds.

5) **National Renewable Energy Action Plan of Ukraine till 2020 (in effect), date of adoption: October 2014**[6]

The document was developed according to the international obligations of Ukraine under Energy Community in 2013 and reviewed many times internally by the expert groups (including participation of NGO "REA" as consultants on biomass part). The key indicators are:

- 11% RES share in 2020 (with large hydropower), including
- 12.4% in heating and cooling;
- 11 % in power generation;
- 10% in transport.

Total GFEC in 2020: 77.5 - 86.4 Mtoe depending on the scenario (with 9% reduction or without respectively).

The progress of fulfilment of the document is monitored each year by the EC secretariat according to established reporting form. The targets on RES share in 2020 according to the document are not yet achieved and likely not will be achieved. The figure for 2020 is used for development of all three scenarios in the modelling as follows:

1) For "Baseline scenario" all NREAP-2020 targets on RES shares except of biomass are achieved on 50% level
2) For "Climate action" scenario all NREAP-2020 targets on RES shares including biomass are achieved on 50% level
3) For "High commitment" scenario all NREAP-2020 targets on RES shares are achieved on 100% level

1.2. Current state and targets of climate strategic documents

1) **Ukrainian INDC 2015 edition (in effect) date of adoption September 2015** [7]

Intended Nationally Determined Contribution was submitted by Ukraine according to the requirements, rules, and procedures for the Parties of Paris Agreement ratified in September 2015 by Ukrainian Parliament. Current INDC establishes the target of 40% emission reduction in 2030 in comparison with 1990 level, which corresponds to 3.5 ^{0}C temperature increasing

[6] National Renewable Energy Action Plan of Ukraine till 2020 (in effect)
http://saee.gov.ua/documents/NpdVE_eng.pdf
[7] Ukrainian INDC 2015 edition (in effect)
http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Ukraine/1/150930_Ukraine_INDC.pdf

trajectory (see Fig. 1.1). The INDC itself contains commitment of Ukraine to establish more ambitious obligations on GHG emission reduction in the next submissions.

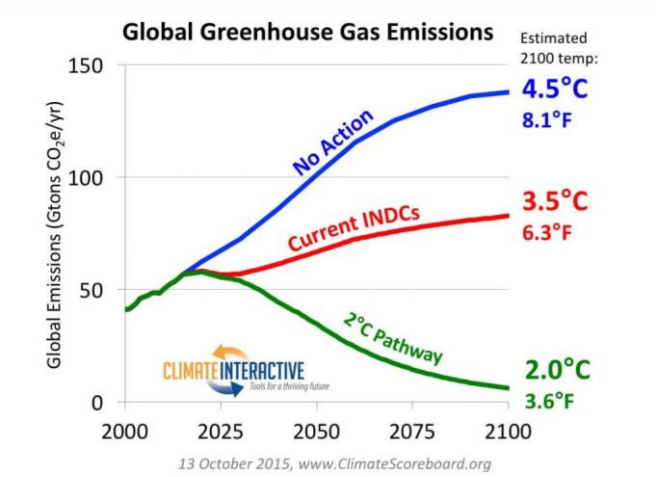


Fig. 1.1. Scenarios of global temperature increase depending on the level of GHG emissions

2) Ukrainian Low Emission Development Strategy and Low Carbon Development Strategy (in progress of implementation)[8]

One of the international obligations of the Parties under Paris Agreement is development of low-emission development strategies (LEDS) for each country. Such strategies were already submitted by some countries and are available at UNFCCC web site (USA, Mexico, Benin, France, Germany, Canada[9]). The international project USAID MERP is providing consultancy support for the development of such a strategy and linking it to the latest Ukrainian obligations in energy and other sectors. The first draft was publicly presented in November 2016 and is now under development. It consists of different climate technologies and their groups as well as scenarios with different intensiveness of their development till 2050 with final GHG emission reduction 40-70% in 2050 depending on the scenario. Additionally, under the LCDS and LEDS development, the group of consultants under USAID project is supporting capacity building and drafting of a necessary legislative basis for the provision of UA ETS as one of the instruments of

[8] Implementation progress on LEDS Ukraine
1) http://www.merp.org.ua/index.php?option=com_content&view=article&id=388:low-emission-development-strategy-of-ukraine&catid=32&Itemid=914&lang=us
2) http://www.lowemission.org.ua/
3) http://www.merp.org.ua/index.php?lang=us&Itemid=1052

[9] http://unfccc.int/focus/long-term_strategies/items/9971.php

achieving necessary emission reductions and making dissemination activities in this field (LEDS web-platform created).

3) **National Concept of Climate Policy Realization in Ukraine till 2030 (in effect), date of adoption: December 2016**[10]

The document was adopted according to the climate obligations of Ukraine as a Party of Paris Agreement. The key indicators are:

- 11% of RES in GFEC in 2020;
- 20% emission reductions in 2030 compared with 2015 level;
- GFEC reduction in 2020 to the level of 91% compared with 2005-2009 average level;
- 40% emission reductions in 2030 from 1990 level; "…taking more ambitious targets for 2^0C trajectory in next INDC submissions before 2020".

The last statement is additionally confirming the perspective of more ambitious climate targets till 2030 and 2050.

1.3. Other documents related to energy sector development

1) **Strategy on Agriculture and Rural Development 2015-2020 (in effect), date of adoption: September 2015**[11]

This comprehensive sectoral document is aiming mainly on the plans of agro sector reconstruction, however, touches also the energy efficiency, bioenergy, and renewable energy. The key indicators are:

- Enhancing of RES share to 10% in 2020 in agriculture;
- Increased area of energy crops to 300,000 ha;
- Increased volume of biomass consumption as a biofuel for transport by 10%;
- Production of pellets and briquettes from forestry and agricultural waste brought to 1.2 mln tonnes per annum;
- Increased number of production facilities for biogas and other types of biofuel at enterprises of the agri-industrial complex by 20%;
- Increased share of bioenergy in the total energy balance of Ukraine to 10%.

[10] National Concept of Climate Policy Realization in Ukraine till 2030 (in effect)
http://zakon2.rada.gov.ua/laws/show/932-2016-%D1%80
[11] Strategy on Agriculture and Rural Development 2015-2020 (in effect)
http://minagro.gov.ua/en/node/15990

The thresholds provided by the document could be used for the more accurate definition of biomass share in 2020 and serves as additional limitation factor in liquid biofuel production (10% share).

2) **National Strategy of Regional Development for the period till 2020 (in effect), date of adoption: August 2014**[12]

This regional-level document contains mainly the data on current and 2020 socio-economic indicators of regions development. It contains among others two key indicators of energy sector development: 11% RES in GFEC in 2020 and changing of GDP energy intensity of 0.075-0.3 toe/1000 USD depending on the region considered (the less industrialized region, the less is the figure). Additionally, the document covers data related to detailed population spread, residential areas, average salaries, access to water supply, workplaces, education and other social impact indicators per each region.

3) **Concept of Sustainable Development "Ukraine 2020" (in effect), date of adoption: January 2015**[13]

The document has state-level and stipulates mainly the general strategic targets for all main sectors – energy, finance, services, industry, army, sport, education, market deregulation, health care, others. The main indicator related to energy sector is fulfillment of NREAP and NEEAP till 2020 and achieving of 0.2 toe/1000 USD GDP energy intensity in 2020. Other priorities in the energy sector are reduction of GDP energy intensity on 20% from 2015 base through obligatory 100% implementation of fuel and energy monitoring systems, liberalization of electricity, heat and natural gas markets, implementation of competitiveness and unbundling, privatization of energy generation companies under the Third Energy Package requirements, modernization of energy generation, transmission and supply, diversifying of energy sources for energy production, consolidation of UPS with EPS.

[12] National Strategy of Regional Development for the period till 2020 (in effect)
http://zakon0.rada.gov.ua/laws/show/385-2014-%D0%BF

[13] Concept of Sustainable Development "Ukraine 2020" (in effect):
http://zakon2.rada.gov.ua/laws/show/5/2015/paran10#n10

1.4. Comparison of targets: conformities and contradictions

Table 1.2. Comparison of the goals of various strategic documents of Ukraine

Strategic document name	RES share in TPES			Energy from biomass	GDP intensity, toe/1000 USD			TPES overall	GFEC overall	Energy consumption (2015==100%)	Reduction of CO2
	2020	2030	2035		2020	2030	2035				
ESU till 2035 (Draft, 2016), Razumkov Centre	7.3%	14.6%	22.9%	11 Mtoe in 2035 in TPES	0.19	0.14	0.12	96 Mtoe in 2035		107% in 2035 to 2015	20% in 2035 from 2010 level
ESU till 2035 (Draft, 2014), National Institute for Strategic Studies, under edition of Sukhodolya O.M.	11.0%	18.9%	20.4%	13 Mtoe in 2035 in TPES	0.27	0.2	0.17	132.6 Mtoe in 2035	88.9 Mtoe in 2035	147% in 2035 to 2015 in TPES 175% in 2035 to 2015 in GFEC	20% in 2035 from 2010 level

ESU till 2030 (in effect)	1.4-6.5% in power sector depending on scenario	4%-6% in power sector depending on scenario	-	10-15 GWth installed capacity in 2030 (approx. 5 Mtoe)+1.9 Mtoe motor biofuels	0.13	0.1	-	167-202 Mtoe in 2030	-	185-224% in 2030 to 2015 in TPES	-
Strategy on Agriculture and Rural Development 2015-2020 (in effect)				10% in GFEC in 2020, +300 000 ha used for energy crops							
National Strategy of Regional Development for the period till	11% (GFEC)	-	-		0.075...0.3						

2020 (in effect)											
Ukrainian INDC 2015 edition (in effect)											40% in 2030 from 1990 level
Implementation process on LEDS and LCDS											40-70% in 2050 from 2015 level
National Concept of Climate Policy Realization in Ukraine till 2030 (in effect)	11% (GFEC)					20% reduction in 2030 to 2015				91% in 2020 to average 2005-2009 level	40% in 2030 from 1990 level with taking more ambitious targets for 2^0C trajectory in next INDC submissions (before 2020)

National Energy Efficiency Action Plan till 2020 (in effect)										91% in 2020 to average 2005-2009 level	
National Renewable Energy Action Plan of Ukraine till 2020 (in effect)	11% (GFEC)								78.1-86.4 Mtoe in 2020		
Concept of Sustainable Development "Ukraine 2020" (in effect)					0.2 (20% reduction from 2015)						

2. Review of existing energy statistics and energy balance of Ukraine, energy data needed for modeling performance

The State Statistics Service of Ukraine (SSSU) is the central statistical institution in Ukraine and is responsible for compilation of energy statistics, along with other statistical data. Since 1997, SSSU implemented a series of changes that included improvement of statistical forms, switch towards classification of economic activity types (CEAT), filling of five IEA questionnaires, preparation of the annual energy balance etc. Main improvements in methodological and organization basis of statistical observations on energy statistics appeared under the Strategy of State Statistics Development for the period till 2012 and further by Strategy of State Statistics Development for the period till 2017. These Strategies were intended to fulfil the Statistics obligations of Ukraine as a Contracting Party of the Energy Community Treaty.

As member of Energy Community Ukraine has to comply its energy statistics with core EU legislation namely Regulation (EU) 431/2014, Regulation (EC) 147/2013, Regulation (EC) No 1099/2008 and Directive 2008/92/EC of 22 October 2008. Compliance should cover the following fields:

- Annual Energy Statistics;
- Monthly Energy Statistics;
- Price Statistics.

Annual Energy Statistics of Ukraine already follows the Regulation (EC) 1099/2008 and 147/2013. Since 2011, SSSU compiles energy balance, using data from statistical surveys collected from producers, traders and distributors of primary and transformed energy, importers and exporters, household surveys, administrative information, evidence-based data and expert evaluation. Annually, consolidated statistical data are published in the "Statistical Yearbook of Ukraine". In December at the latest, SSSU publishes balances per product for the previous year and submits joint questionnaires to IEA. In 2016, Ukraine started transmitting its annual questionnaires to EUROSTAT and the Ukrainian annual energy statistics are now available in the EUROSTAT database.

Monthly Energy Statistics is available for electricity and the following fuels: coal, crude oil including NGL, natural gas, motor gasoline, gas/diesel oil, Residual Fuel Oil, LPG. Statistics is collected from surveys, as well as from state institutions namely the State Customs, NJSC "Naftogas of Ukraine", Ministry of Energy and Coal Industry of Ukraine and the National Electricity Regulatory Commission of Ukraine (NEURC). Today, SSSU compiles monthly Joint Organisations Data Initiative (JODI) questionnaires on oil and gas and submits them to the United Nations Statistics Division (UNSD).

Until 2016, the only data on electricity and gas prices were available only for households. The National Electricity Regulation Commission of Ukraine reported these data on its website. In 2016, the SSSU has started to establish a reporting system for electricity and gas prices as required by Directive 2008/92/EC. In July 2016, SSSU compiled the first sets of average gas and electricity prices charged to industrial customers and to households, disaggregated per taxation level from 2013 onward, and submitted them to EUROSTAT and the Secretariat for review. Following the adoption of the Gas Market Law in 2016, SSSU in cooperation with NEURC started preparing questionnaires to collect half-yearly gas prices charged to industrial end-users and households. The same process is expected for electricity prices, after the adoption of the new Electricity Market Law, which passed the first reading on September 22, 2016. Current information on electricity prices refers only to supplies at regulated tariffs.

2.1. Analysis of energy statistics available, report form of energy balance of Ukraine and IEA reporting data

Energy statistics for Ukraine is available on the website of SSSU, as well as on the EUROSTAT and IEA websites, as Ukraine completes questionnaires of these institutions.

Since 2011, SSSU provides energy balance in IEA format on its website http://ukrstat.gov.ua/ with additional data per industry and transport sub-sectors. Since 2014, Energy Balance of Ukraine excludes temporarily occupied territories of Autonomous Republic of Crimea, Sebastopol and part of the anti-terrorist operation zone (Table 2.1).

Along with energy balance, Ukraine country profile on the IEA website contains additional information, provided by SSSU, such as Key indicators, Statistics on coal by type, Statistics on oil by type, Natural gas statistics, as well as Electricity and heat statistics and separate statistics for Renewables and Waste. Although, this information and energy balance it-self appear on the IEA website later, than it is published on the website of SSSU. Energy balance in IEA format is presented on Figure 2.1.

The EUROSTAT website provides statistics for Ukraine, to find which one should use a search tool of the website. EUROSTAT format for energy balance differs from format of IEA and SSSU (uses IEA format). Energy balance in EUROSTAT format is presented on Figure 2.2.

Table 2.1. Energy balance of Ukraine 2015[14], ktoe

SUPPLY AND CONSUMPTION	Coal & peat	Crude oil	Oil products	Natural Gas	Nuclear	Hydro	Geotherm. solar etc.	Biofuels & waste	Electricity	Heat	Total
Production	17423	2618	-	14814	22985	464	134	2606	-	571	61614
Imports	9940	238	7887	13288	-	-	-	30	193	-	31575
Exports	-487	-22	-90	-	-	-	-	-539	-309	-	-1447
Intl. Bunkers	-	-	-124	-	-	-	-	-	-	-	-124
Stock changes	469	17	27	-2047	-	-	-	5	-	-	-1529
TPES	**27344**	**2851**	**7700**	**26055**	**22985**	**464**	**134**	**2102**	**-116**	**571**	**90090**
Transfers	-	230	-200	-	-	-	-	-	-	-	30
Statistical differences	127	-	-228	-42	-	-	-	-	-502[15]	-	-644
Electricity Plants	-14566	-	-127	-104	-22836	-464	-134	-15	12920	-	-25327
CHP Plants	-1686	-	-158	-3532	-149	-	-	-523	1021	3251	-1776
Heat Plants	-658	-	-141	-4933	-	-	-	-37	-	5210	-558
Blast furnaces	-3480	-	-	-	-	-	-	-	-	-	-3480
Gas works	-31	-3	-	-	-	-	-	-	-	-	-34
Coke/pat.fuel/BKB plants	758	-	-	-	-	-	-	-	-	-	758
Oil Refineries	-	-3057	2726	-	-	-	-	-	-	-	-331
Petrochemical plants	-	-	-	-	-	-	-	-	-	-	-
Other Transformation	-182	-	-	-	-	-	-	-243	-	-	-426
Energy industry own use	-908	-5	-116	-957	-	-	-	-1	-1590	-599	-4176
Losses	-416	-7	-1	-466	-	-	-	-	-1500	-905	-3295
TFC	**6302**	**8**	**9455**	**16022**	**-**	**-**	**-**	**1283**	**10233**	**7527**	**50831**
INDUSTRY	**5569**	**-**	**814**	**2762**	**-**	**-**	**-**	**86**	**4297**	**2880**	**16409**
Iron and steel	4930	-	101	1463	-	-	-	9	1503	827	8832
Chemical and petrochemical	2	-	22	151	-	-	-	1	265	560	1001

[14] Excluding temporarily occupied territories of Autonomous Republic of Crimea, Sebastopol and part of the anti-terrorist operation zone

[15] Data include values distributed to temporarily occupied territories of Autonomous Republic of Crimea, Sebastopol and part of the anti-terrorist operation zone

Non-ferrous metals	105	-	5	137	-	-	-	-	143	245	635
Non-metallic minerals	505	-	51	355	-	-	-	18	203	49	1180
Transport equipment	-	-	13	15	-	-	-	-	86	41	156
Machinery	2	-	36	119	-	-	-	1	229	80	466
Mining and quarrying	1	-	276	293	-	-	-	1	844	75	1490
Food and tobacco	21	-	114	165	-	-	-	7	350	740	1397
Paper Pulp and Printing	-	-	8	18	-	-	-	2	76	117	221
Wood and wood products	1	-	16	12	-	-	-	47	52	80	209
Construction	2	-	155	25	-	-	-	1	64	16	263
Textile and leather	-	-	3	3	-	-	-	-	26	18	50
Non-specified	1	-	14	5	-	-	-	1	457	32	509
TRANSPORT	**4**	**-**	**6554**	**1572**	**-**	**-**	**-**	**34**	**585**	**-**	**8750**
Domestic aviation	-	-	-	-	-	-	-	-	-	-	-
Road	-	-	6364	25	-	-	-	34	-	-	6423
Rail	4	-	138	-	-	-	-	-	516	-	658
Pipeline transport	-	-	3	1546	-	-	-	-	33	-	1582
Domestic Navigation	-	-	48	-	-	-	-	-	-	-	48
Non-specified	1	-	-	1	-	-	-	-	37	-	38
OTHER	**379**	**-**	**1408**	**9406**	**-**	**-**	**-**	**1163**	**5351**	**4647**	**22353**
Residential	303	-	14	9083	-	-	-	1097	3184	2874	16554
Comm. and Publ. Services	67	-	92	195	-	-	-	46	1878	1560	3838
Agriculture/forestry	9	-	1300	129	-	-	-	19	287	212	1957
Fishing	-	-	2	-	-	-	-	-	2	-	4
Non-specified	-	-	-	-	-	-	-	-	-	-	-
NON-ENERGY USE	**349**	**8**	**679**	**2281**	**-**	**-**	**-**	**-**	**-**	**-**	**3318**
in Industry/Transf./Energy	349	8	607	2281	-	-	-	-	-	-	3245
of which: Feedstocks	-	1	105	2193	-	-	-	-	-	-	2298
in Transport	-	-	8	-	-	-	-	-	-	-	8
in other	-	-	65	-	-	-	-	-	-	-	65

Source: State Statistics Service of Ukraine[16]

[16] http://ukrstat.gov.ua/operativ/operativ2016/energ/en_bal/Bal_2015_e.zip

	Coal*	Crude oil*	Oil products	Natural gas	Nuclear	Hydro	Geothermal, solar, etc.	Biofuels and waste	Electricity	Heat	Total**
Production	31891	2817	0	15022	23191	729	134	2399	0	745	76928
Imports	10374	193	8117	15720	0	0	0	25	8	0	34437
Exports	-4915	-70	-747	0	0	0	0	-502	-733	0	-6967
International marine bunkers***	0	0	0	0	0	0	0	0	0	0	0
International aviation bunkers***	0	0	-131	0	0	0	0	0	0	0	-131
Stock changes	-1774	102	407	2671	0	0	0	11	0	0	1417
TPES	**35576**	**3043**	**7645**	**33412**	**23191**	**729**	**134**	**1934**	**-725**	**745**	**105683**
Transfers	0	222	-195	0	0	0	0	0	0	0	27
Statistical differences	185	0	44	-848	0	0	0	0	-464	0	-1082
Electricity plants	-17632	0	-44	-314	-23035	-729	-134	-25	14485	0	-27428
CHP plants	-2311	0	-59	-4086	-157	0	0	-457	1164	3780	-2125
Heat plants	-845	0	-85	-5794	0	0	0	-34	0	6074	-684
Gas works	-9	0	0	0	0	0	0	0	0	0	-9
Oil refineries	0	-3308	3394	0	0	0	0	0	0	0	86
Coal transformation	-4382	0	0	0	0	0	0	0	0	0	-4382
Liquefication plants	0	0	0	0	0	0	0	0	0	0	0
Other transformation	-230	70	0	0	0	0	0	-215	0	0	-375
Energy industry own use	-1019	-5	-555	-961	0	0	0	-1	-1732	-634	-4906
Losses	-153	-14	-3	-455	0	0	0	0	-1687	-1032	-3345
Total final consumption	**9180**	**8**	**10141**	**20955**	**0**	**0**	**0**	**1201**	**11041**	**8933**	**61460**
Industry	**8408**	**0**	**921**	**3324**	**0**	**0**	**0**	**48**	**4678**	**3192**	**20570**
Transport	**7**	**0**	**7312**	**2273**	**0**	**0**	**0**	**41**	**694**	**0**	**10327**
Other	**371**	**0**	**1461**	**12708**	**0**	**0**	**0**	**1113**	**5669**	**5741**	**27062**
Residential	290	0	32	11743	0	0	0	1070	3352	3897	20384
Commercial and public services	73	0	107	836	0	0	0	28	2016	1604	4663
Agriculture / forestry	9	0	1320	129	0	0	0	15	300	239	2012
Fishing	0	0	2	0	0	0	0	0	2	0	4
Non-specified	0	0	0	0	0	0	0	0	0	0	0
Non-energy use	**395**	**8**	**447**	**2650**	**0**	**0**	**0**	**0**	**0**	**0**	**3500**
-of which chemical/petrochemical	*0*	*0*	*108*	*2571*	*0*	*0*	*0*	*0*	*0*	*0*	*2679*

Figure 2.1. Energy balance of Ukraine, 2014, in thousands of tons of oil equivalent, IEA format.

Ukraine, 2014 (ktoe)	Total (all products)	Solid fossil fuels	Crude oil & petroleum products	Gas	Nuclear heat	Renewable energies	Non-renewable wastes	Electricity	Derived heat
+ Primary production	70 568	26 483	2 839	15 026	22 957	3 263			
+ Primary production receipt	67		67						
+ Other sources (recovered products)	5 475	5 408	67						
+ Recycled products									
+ Imports	34 529	10 506	8 265	15 724		26		8	
+ Stock changes	1 415	- 1 776	508	2 671		11			
- Exports	7 072	5 021	817			502		733	
- Bunkers									
- Direct use	67		67						
Gross inland consumption	104 914	35 600	10 862	33 422	22 957	2 798		- 725	
Transformation input	73 599	34 647	3 519	11 638	22 957	837			
+ Conventional thermal power stations	24 765	18 551	102	5 629		482			
+ Nuclear power stations	22 957				22 957				
+ District heating plants	6 768	640	85	6 008		34			
+ Coke ovens	12 108	12 108							
+ Blast furnaces	2 966	2 966							
+ Gas works	31	31							
+ Refineries	3 332		3 332						
+ Patent fuel plants	33	33							
+ BKB/PB plants	91	91							
+ Charcoal production plants	321					321			
+ Coal liquefaction plants									
+ For blended natural gas									
+ Gas-To-Liquids (GTL) plants									
+ Non-specified Transformation Input	228	228							
Transformation output	44 191	10 305	3 331	5 064		105		14 784	10 601
+ Conventional thermal power stations	11 375							7 184	4 191
+ Nuclear power stations	7 757							7 600	157
+ District heating plants	6 253								6 253
+ Coke ovens	12 222	10 141		2 080					
+ Blast furnaces	2 966			2 966					
+ Gas works	18			18					
+ Refineries	3 331		3 331						
+ Patent fuel plants	50	50							
+ BKB/PB plants	113	113							
+ Charcoal production plants	106					106			
Exchanges, transfers and returns	30		30			- 863		863	
Consumption of the energy branch	4 601	188	506	1 541		1		1 731	634
Distribution losses	3 345	14	17	595				1 687	1 032
Available for final consumption	67 591	11 056	10 181	24 713		1 203		11 504	8 935
Statistical difference	*1 246*	*2*	*- 47*	*828*				464	
Final non-energy consumption	3 538	428	455	2 655					
Final energy consumption	62 806	10 626	9 773	21 230		1 203		11 039	8 935
+ Industry	25 295	10 220	913	6 244		48		4 678	3 193
+ Iron and Steel	17 033	9 568	106	4 782		3		1 749	824
+ Chemical and Petrochemical	1 159	3	19	176		0		329	632
+ Non-ferrous metals	637	112	5	139				143	237
+ Non-metallic minerals	1 249	504	71	404		16		200	53
+ Transport eEquipment	191		18	27				86	60
+ Machinery	508	3	22	141		1		243	99
+ Mining and Quarrying	1 559	2	309	307				859	82
+ Food, Beverages and Tabacco	1 679	27	147	206		6		386	906
+ Paper, Pulp and Printing	240		8	22		0		79	131
+ Wood and Wood products	185		14	14		19		54	85
+ Construction	272	1	166	11		0		73	20
+ Textile and Leather	54		3	5		0		27	19
+ Not elsewhere specified (Industry)	530	1	23	10		1		450	45
+ Transport	10 430	7	7 412	2 274		42		694	
+ Rail	674	7	133					534	
+ Road	7 166		7 100	23		42			
+ International aviation	130		130						
+ Domestic aviation	1		1						
+ Domestic navigation	43		43						
+ Pipeline transport	2 316		5	2 248				63	
+ Not elsewhere specified (Transport)	100	1		2				97	
+ Other sectors	27 081	399	1 448	12 711		1 113		5 668	5 742
+ Commercial and public services	4 665	75	107	836		28		2 015	1 604
+ Residential	20 413	315	32	11 747		1 070		3 351	3 898
+ Agriculture / Forestry	2 000	9	1 308	129		15		299	239
+ Fishing	4		2					2	0
+ Not elsewhere specified (Other)									

Figure 2.2. Energy balance of Ukraine, 2014, in EUROSTAT format

2.2. Energy data needed for modeling performance

Modelling of energy mix till 2050 will be based on starting data from energy statistics, data on potential of each renewable energy source and current Ukrainian and EU energy trends. Energy statistics indicators used in modelling will be Total Primary Energy Supply (TPES) and Total Final Consumption (TFC). Data on potential of RES is available from the website of the State Agency of Energy Efficiency and Energy Saving of Ukraine (SAEE). Current Ukrainian RES targets are fixed in the National Renewable Energy Action Plan till 2020 and current trends are available from the Progress Reports on Promotion of the Use of Energy from Renewable Sources and Consumption in Ukraine, prepared by SAEE. Furthermore, modelling of RES scenarios for Ukraine used EU energy targets and trends as a reference.

Analysis of such energy statistics indicators as TPES and TFC shows a decrease of share of main fossil fuels, such as coal and natural gas in recent years in Ukraine. In 2015, TPES decreased by 26.5% (Table 2.2.) and TFC decreased by 30% compared to 2013 (Table 2.3). This trend has political and economic reasons. The political one is linked to the inaccessibility of the statistical data from the Autonomous Republic of Crimea and part of the Donetsk and Lugansk regions, which are now a zone of the anti-terroristic operation, due to their isolation. Besides, there is a political will for energy independence of Ukraine, which should therefore decrease import of energy resources.

Donetsk and Lugansk regions supplied Ukrainian thermal power plants with coal, as well as annually increased exported volumes from **1842** thousand toe in 2000 to **6200** thousand toe in 2013. After events of 2014 and the following unsolved situation with the eastern territories, the production of coal dropped dramatically from **40801** thousand toe in 2013 to **31891** thousand toe in 2014. The main consumers of coal in 2013 and before were electricity plants (20137 thousand toe), coal transformation sector (7234 thousand toe), CHP plants (2320 thousand toe) and heat plants (1294 thousand toe). Consumption of these main consumers in 2014 decreased mainly for electricity plants (17632 thousand toe) and coke plants (4382 thousand toe) due to problems of coal supply from the zone of the anti-terroristic operation and switch to use of imported coal from South Africa, that was not suitable for Ukrainian TPPs.

Table 2.2. Total Primary Energy Supply (TPES) in Ukraine for 2012-2015 (ktoe)[17].

	2012		2013		2014		2015	
	TPES	%	TPES	%	TPES	%	TPES	%
Coal & peat	42545	**34.7**	41427	**35.7**	35576	**33.7**	27344	**30**
Crude oil & oil products	11632	**9.5**	9906	**8.5**	10688	**10**	10551	**12**

[17] Source: IEA, http://www.iea.org/statistics/statisticssearch/report/?country=UKRAINE&product=balances&year=2014

Natural gas	43019	**35**	39444	**34**	33412	**31.6**	26055	**29**
Nuclear	23653	**19.3**	21848	**19**	23191	**22**	22985	**26**
Hydro	901	**0.7**	1187	**1**	729	**0.7**	464	**0.5**
Geothermal, solar etc.	53	**0.04**	104	**0.1**	134	**0.2**	134	**0.2**
Biofuels and waste	1695	**1.4**	1875	**1.6**	1934	**1.8**	2102	**2.3**
Total	**122512**	**100**	**115940**	**100**	**105683**	**100**	**90090**	**100**

Table 2.3. Total Final Consumption (TFC) of energy in Ukraine for 2012-2015 (ktoe).

	2012		2013		2014		2015	
	TFC	**%**	**TFC**	**%**	**TFC**	**%**	**TFC**	**%**
Coal & peat	8717	12	8698	12.5	9180	14.9	6302	12.4
Crude oil & Oil products	12490	17.2	11284	16.2	10149	16.5	9463	18.6
Natural gas	26605	36.7	24926	35.8	20955	34	16022	31.5
Electricity	11839	16.3	11828	17	11041	18	10233	20.1
Heat	11865	16.4	11702	16.8	8933	14.5	7527	14.8
Biofuels and waste	1030	1.4	1118	1.6	1201	2	1283	2.5
Total	**72 548**	**100**	**69 557**	**100**	**61 460**	**100**	**50 831**	**100**

The reason for natural gas consumption decrease is mostly the introduction of new substituting heat capacities. According to State Energy Efficiency and Energy Saving Agency, natural gas consumption decreased in 2014/2015 heating season by 19% compared to 2013/2014 heating season and by 14% in 2015/2016 compared to 2014/2015 heating season. Totally, by 30% in 2015/2016 compared to 2013/2014. These amounts were substituted with 452 MW of heating capacities in 2014, which were increased to 752 MW of heating capacities in 2015, mainly on biomass. This trend should be even increased, as, according to the National Renewable Energy Action Plan until 2020 Ukraine has to substitute 7.2 billion of cubic meters of natural gas in 2020 (**Fig. 2.3.**).

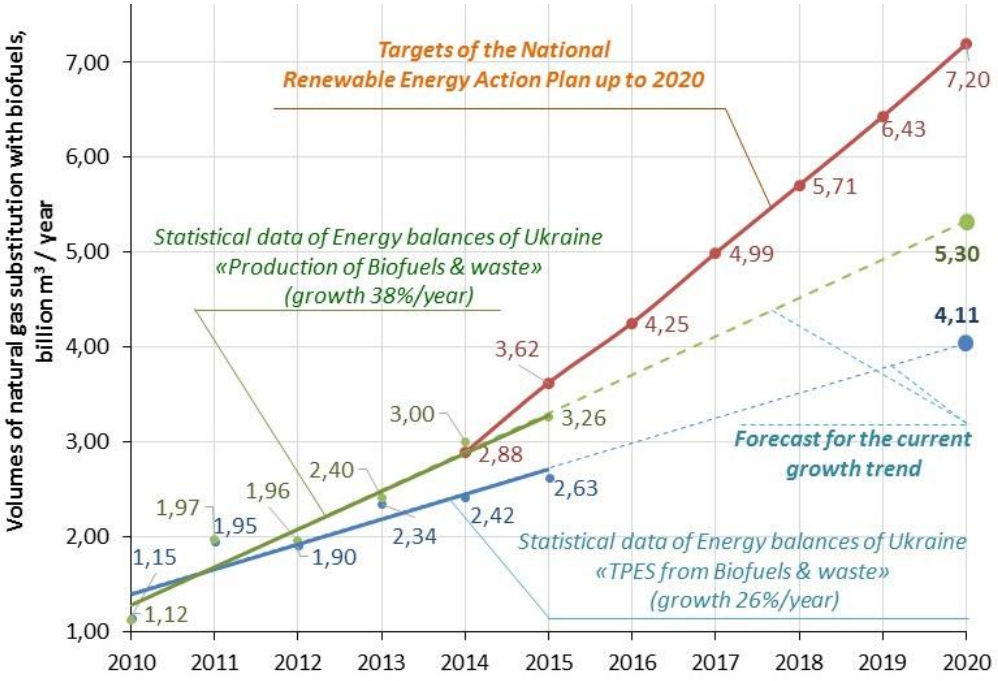


Figure 2.3. Dynamics of bioenergy growth in Ukraine[18]

With adoption of the National Renewable Energy Action Plan (NREAP) till 2020, Ukraine set targets to RES share in electricity (11%), heating and cooling (12.4%), and transport (10%) sectors, as well as an overall RES share in gross final energy consumption (11%) in 2020 (Table 2.4). The NREAP was approved by the Cabinet of Ministers of Ukraine on the 1 October 2014.

Table 2.4. National targets and estimated trajectory of RES share growth in heating and cooling, electricity and transport and in gross final consumption of energy up to 2020.

Indicators	2009	2014	2015	2016	2017	2018	2019	2020
RES – heating, %	**3.4**	**5.7**	**6.7**	**7.7**	**8.9**	**10.0**	**11.2**	**12.4**
GFC of RES – heating, ktoe	**1473**	**2580**	**3083**	**3576**	**4139**	**4692**	**5261**	**5850**
Geothermal (without heat pumps)		30	33	36	39	42	46	50
Solar		140	150	160	170	180	190	200
Biomass	1433	2280	2700	3100	3580	4050	4525	5000

[18] Bioenergy Association of Ukraine assessment, based on data of energy balances of Ukraine.

Heat pumps	40	130	200	280	350	420	500	600
RES – electricity, %	**7.1**	**7.6**	**8.3**	**8.8**	**9.7**	**10.4**	**10.9**	**11**
GFC of RES – electricity, ktoe	**980**	**1275**	**1427**	**1540**	**1720**	**1890**	**2060**	**2235**
Gross production from RES – electricity, GWh	11471	14805	16809	18726	20678	22464	24225	26000
Installed capacity of RES – electricity, MW	4625	6394	7156	7977	8709	9431	10155	10900
Hydro, MW / GWh	4549	4788	4898	4987	5077	5167	5258	5350
	11430	12045	12215	12440	12660	12885	13110	13340
Geothermal, MW / GWh		6	8	10	12	14	17	20
		30	44	56	73	84	105	120
Solar, MW / GWh		860	1000	1250	1450	1700	2000	2300
		900	1050	1310	1520	1780	2100	2420
Wind onshore, MW / GWh	76	700	1000	1350	1650	1900	2100	2280
	41	1680	2400	3240	4125	4845	5460	5900
Biomass (CHP), MW / GWh		40	250	380	520	650	780	950
		150	1100	1680	2300	2870	3450	4220
RES – transport, %	**1.5**	**4.1**	**5**	**6.5**	**7.5**	**8.2**	**9**	**10**
GFC of RES – transport (sustainable), ktoe	**52**	**174**	**221**	**298**	**351**	**395**	**445**	**505**
RES-electricity for transport, ktoe	52	64	71	78	86	95	105	115
Biofuels, ktoe		110	150	220	265	300	340	390
RES contribution to transport for RES-T target	130	380	477	635	745	837	942	1068
GFC from RES	**2505**	**4404**	**4925**	**5528**	**6166**	**6860**	**7645**	**8590**

Since approval of the NREAP, the responsible governmental body – State Agency of Energy Efficiency and Energy Saving – based on the data, provided by SSSU, calculates the shares of energy from renewable sources in Ukraine, using the program SHARES. The calculation results are available from two Progress Reports on Promotion of the Use of Energy from Renewable Sources and Consumption in Ukraine for 2014-2015[19] and 2012-2013[20] respectively, prepared in frames of Energy Community cooperation (Table 2.5, Table 2.6, Table 2.7, Table 2.8, Table 2.9). In addition, these reports contain data on supply of biomass, available for use for energy purposes (Table 2.10) and current domestic agricultural land use for production of crops dedicated to energy production (Table 2.11). These data represents the current state-of-the-art of RES development in Ukraine. The main renewable source in the structure of RES production is biofuel, which accounts for 81.3%.

Table 2.5. The overall and sectoral (electricity, heating and cooling, and transport) shares of energy from renewable sources in 2012-2015.

Share of RES, %	2012	2013	2014	2015	2020 (target)
Overall	**3.41**	**4.56**	**3.9**	**4.87**	**11**
Heating and cooling	2.99	3.96	3.37	4.57	12.4
Electricity	6.42	8.71	7.40	7.92	11
Transport	0.55	1.21	1.80	1.85	10

Table 2.6. Estimated share of renewable energy sources in gross final consumption of energy by sectors (ktoe) in 2012-2015

Gross final consumption of RES, thousand toe	2012	2013	2014	2015
Heating and cooling	1370	1747	1409.0	1534.5
Electricity	980	1312	1057.7	1054.0
Transport	51	107	143.2	130.8
Total	**2401**	**3101**	**2609.9**	**2719.3**

Table 2.7. Total actual share (installed capacity, gross production of electricity) of each RES technology, 2012-2015.

[19] Report on Promotion of the Use of Energy from Renewable Sources and Consumption in Ukraine in 2014-2015

[20] Report on Promotion of the Use of Energy from Renewable Sources and Consumption in Ukraine in 2012-2013

	2012		2013		2014		2015	
	MW	**GW*h**	**MW**	**GW*h**	**MW**	**GW*h**	**MW**	**GW*h**
Hydro power stations:	4 656.5	10 634.9	4 669.31	13 993.19	5 851	9 321.4	5 883	6 970.5
Less than 1 MW	26.6	171.9	21.97	285.986	30	110.2	32	82.8
1-10 MW	46.9		53.34		54	173.8	58	104.0
More than 10 MW	4 583	10 463	4 594	13 707.2	4 581	8 194.1	4 607	5 210.1
Pumped-storage					1 186	843.3	1 186	1 573.6
Solar (photovoltaic)	371.6	333.6	748.4	562.9	411	429	432	476.5
Wind (onshore, normalised)	193.8	257.5	334	636.5	411	1 130 (776.6)	426	1 084 (951.5)
Biomass:	10.2	21.2	28.7	43.4	66	130	69	145
solid	6.2	17.7	17.2	32.4	52	90.7	52	80.6
biogas	4	3.5	11.5	11	14	39.3	17	64.4
Total **(normalised)**	**5 232.1**	**11 247.2**	**5 780.41**	**15 235.99**	**6 739**	**11 010.4** (13 688.5)	**6 810**	**8 676.0** (14 310.4)
of which in CHP					20	48.0	41	98.0

Table 2.8. Gross final energy consumption of each RES technology in heating and cooling systems (ktoe).

	2014	2015
Solar	0.1	0.1
Biomass:	1408.3	1533.8
solid	1408.1	1425.2
biogas	0.2	8.6
Renewable energy from heat pumps	0.6	0.6
Total	**1409.0**	**1534.5**
In households	1069.2	1096.1

Table 2.9. Gross final energy consumption of each RES technology in transport sector (ktoe).

	2014	2015

Bioethanol / bio-ETBE	42.4	35.1
Electricity from renewable sources (with coefficient 2.5 for electricity RE in rail transport)	46.8 (100.8)	41.2 (95.7)
RE in rail transport (with coefficient 2.5)	36 (90)	36.31 (90.8)
RE in all other transport modes	10.8	4.9
Total (with coefficient 2.5 for electricity RE in rail transport)	**89.2 (143.2)**	**76.3 (130.8)**

Table 2.10. Supply of biomass available for use for energy purposes in 2012-2015.

	Amount of domestic raw material				Primary energy in domestic raw material (ktoe)			
	2012	**2013**	**2014**	**2015**	**2012**	**2013**	**2014**	**2015**
Biomass supply for heating and electricity								
Biomass supply for heating and electricity: Direct supply of wood biomass from forests and other wooded land energy generation (from fellings etc), thousand m^3	4086	4211.9	5317.5	5991.7	836.3	910	1099.6	1274.3
a) timber harvesting – fire wood, thousand m^3	2926	3238	3860	4512.4	778.3	861.3	1026.8	1200.3
b) wood waste, thousand m^3	1160	973.9	1457.5	1479.3	58	48.7	72.9	74
Indirect supply of wood biomass (residues and co-products from wood industry etc.), thousand m^3	518	524.6	529.4	635.5	47.2	46.6	47.6	57.2
Sunflower husk, thousand t (for heat energy	900	1054	1190	800	238.5	289.3	320	215
Wheat straw, thousand t (for production of solid	21	50	50	14	5.5	13.25	13.25	3.71

biofuel)								
Biomass from household waste, thousand t	149.9	147.6			45	44.3		
Animal and plant waste, thousand t	526.9	412.4			157.8	123.72		
Biomass supply for transport								
Sugar beets during production of sugar and bioethanol from molasses, thousand tons	2257	5783	4407	3068	80	204		

Table 2.11. Current domestic agricultural land use for production of crops dedicated to energy production

Land use	**Area*, ha**			
	2012	**2013**	**2014**	**2015**
Common arable crops (wheat, sugar beets etc.) and oil crops (rapeseed, sunflower etc.)	2 467 110 (total growing area)	2 976 330	984 167 (for production of energy)	-
Sugar beets for production of biofuel (Molasses is a sugar beet process' by-product used for production of bioethanol)	58 020	148 660	**330 200** (total area of sugar beets production) / **111 667** (for production of bioethanol	77 672 (for production of bioethanol)
Sunflower seeds for production of energy (husks are used to generate heat energy for the needs of oil-crushing plants in agribusiness sector)	2 403 840 (total)	2 815 170 (total)	5 212 200 (total area) / 860 000 (for production of energy	865 000 (estimated)
Wheat for production of energy (straw is used for production of solid biofuel to generate heat energy)	5 250	12 500	125 000	41 500

Short rotation willow	400	3200	3600	3610
Energy grass Miscanthus	60	500	500	500
Energy grass Sorghum		84	80	80

* - Total arable area of Ukraine for 2016: 25 million ha without Temporary Occupied Territories (TOT) and Crimea[21]

Renewables' annual technically achievable energy potential according to SAEE data of February 2015 was 68.9 Mtoe (Table 2.12) per year.

Table 2.12. Renewable energy sources potential in Ukraine, 2015[22][23]

RES type	TWh/yr	Mtoe/yr
Wind	**60**	**15**
Solar*	**38.2**	**4.2**
Electricity	5.7	1.4
Thermal	32.5	2.8
Hydro	**28.7**	**7**
Small	8.6	2.1
Large	20.1	4.9
Bioenergy	**178**	**21.7**
Electricity	27	7.2
Thermal	151	14.5
Geothermal	**97.6**	**8.4**
Energy of environment (Heat Pumps)	**146.3**	**12.6**
Total	**548.8**	**68.9**

* - according to renewed estimations of technical potential made by LUT[24], Ukrainian expert opinion of solar sector, other sources (see section 9), this potential is too low. Also it is not enough according to first run of the model for 100% RES and climate action scenarios, so that RES sector is not balanced (share of solar energy is too low (<2%) from total RES). So this potential is used for Baseline scenario only. For other scenarios enhanced potential is used (see Section 9 for clarifications)

[21] http://www.ukrstat.gov.ua/operativ/operativ2016/sg/ksgp/XLS/ksgp_11_u.zip

[22] http://saee.gov.ua/uk/activity/vidnovlyuvana-enerhetyka/potentsial;

[23] https://www.irena.org/remap/IRENA_REmap_Ukraine_paper_2015.pdf

[24] https://www.researchgate.net/publication/308986145_Transition_towards_a_100_Renewable_Energy_System_by_2050_for_Ukraine

Potential of biomass resources economically feasible for energy accounts for the biggest share of RES potential in Ukraine. According to adjustments of the Bioenergy Association of Ukraine, based on SSSU 2015 data, bioenergy potential amounts 25-35 Mtoe depending on the year of estimation (Table 2.13).

Table 2.13. Potential of biomass available for energy in Ukraine (2015, 2050).

Type of biomass	Theoretical potential, Mt	Share, available for energy, %	Economic potential, 2015 Mtce	Economic potential, 2050, Mtce
Straw of grain crops	35.14	30	5,22	7,83
Straw of rape	3.1	40	0,62	0,93
By-products of grain corn production (stalks, cobs)	30.3	40	3,31	4,97
By-products of sunflower production (stalks, heads)	21.2	40	1,74	1,74
Secondary agricultural residues (husk, bagasse)	6.6	47	0,53	0,58
Wood biomass (firewood, felling residues, wood processing waste)	6.0	94	1,98	2,97
Wood biomass (dead wood, wood from shelterbelt forests)	11.0	58	1,47	1,47
Biodiesel (rapeseed)	-	-	0,27	0,27
Bioethanol (corn and sugar beet)	-	-	0,77	0,77
Biogas from waste and by-products of agriculture	1.6 billion m^3 CH_4	50	0,97	3,40
Landfill gas	0.6 billon m^3 CH_4	34	0,26	0,85
Sewage gas (industrial and municipal wastewater)	1.0 billion m^3 CH_4	23	0,27	0,56
Energy crops:				
- willow, poplar, miscanthus (from 1 mill ha)	11,5	90	6,28	18,84
- corn for biogas (from 1 mill ha)	3,3 billion m^3 CH_4	90	3,68	14,72

Peat	-	-	0,40	0,40
TOTAL	-	-	**27,77**	**60,29**

Modelling of RES development in Ukraine till 2050 follows the general EU trajectory (Fig.2.4.) with annual growth of average 0.7-1.3%, as well as takes into account the EU rate of development of each renewable energy source (Fig. 2.4).

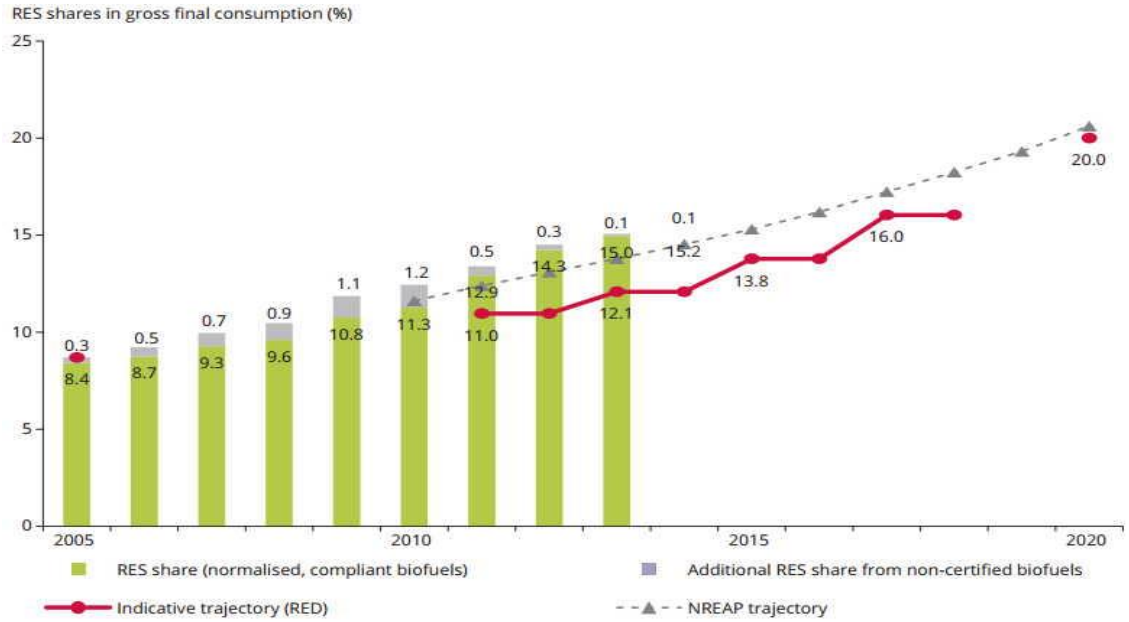


Figure 2.4. EU-28 RES shares in gross final consumption and approximated progress to interim and 2020 targets (%)[25]

[25] Renewable energy in Europe 2016. Recent growth and knock-on effects, European Environment Agency, Report No 4/2016. http://www.eea.europa.eu/publications/renewable-energy-in-europe-2016/download

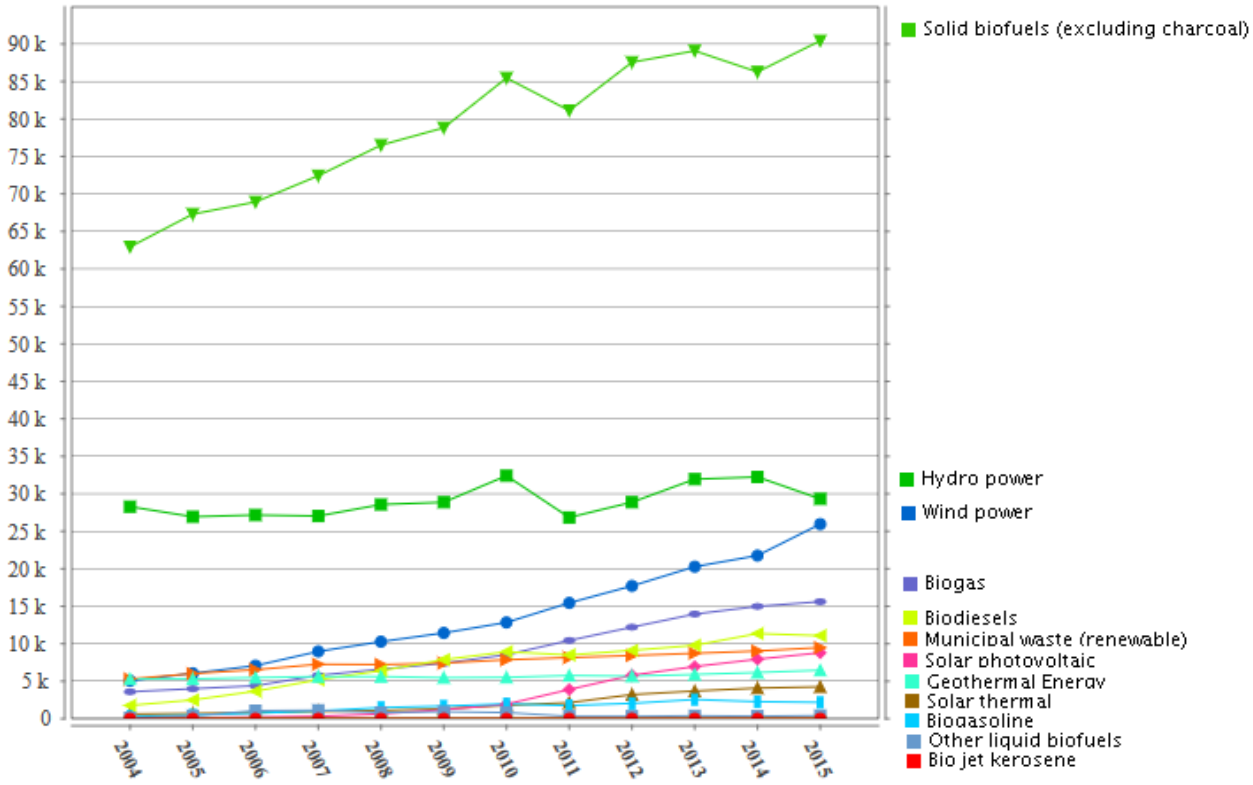


Figure 2.5. Primary production of RES by type in EU-28, 2004-2015.

3. Obligations of Ukraine under EU Association, European Community and Paris Agreement

Ukraine is now in the process of fulfilment of its obligations under Energy Community Treaty and EU Association Agreement. These documents are called to bring Ukrainian legislation in energy and related areas in line with legislation of the EU through adopting the core EU energy legislation, the so-called "acquis communautaire". Energy policy areas covered by Energy Community Treaty of 2005 include the following: Electricity, Gas, Infrastructure, Oil, Competition, Renewable Energy, Energy Efficiency, Environment and Statistics that are also called "acquis".

3.1. Key obligations under EU Association related to energy sector

EU Association Agreement in 2014 between Ukraine and European Union confirmed cooperation in the framework of the Energy Community Treaty, enhancing energy cooperation and promoting energy efficiency and the use of renewable energy sources as well as achieving a high level of nuclear safety and security.

According to EU Association Agreement Ukraine is prohibited to implement dual pricing, resulting in higher price for exports of energy goods, than price at the local market, unless this difference is justified. Besides, there is also prohibition on custom duties and quantitative restrictions on the import and export of energy goods between Ukraine and the EU.

The EU Association Agreement confirmed energy cooperation between Ukraine and the European Union for the enhancement of energy security, competitiveness and sustainability including through gradual approximation in the energy sector and through participation in regional energy cooperation. Access to affordable energy for consumers and protection from unfair selling prices should be ensured.

According to the EU Association agreement Agreement mutual energy cooperation covers, among others, the following areas:

- implementation of energy strategies and policies and development of forecasts and scenarios along with improvement of the statistical recording system;
- establishing effective mechanisms to address potential energy crisis situations;
- modernization and enhancement of existing energy infrastructure, including energy generating capacities, along with full rehabilitation of the energy transit infrastructure and the installation of cross-border metering systems on Ukraine's external borders;
- development of competitive, transparent and non-discriminatory energy markets in convergence with EU rules and standards through regulatory reforms;
- promotion of energy efficiency and energy savings;
- development of and support for renewable energies;
- scientific and technical cooperation and exchange of information for the development and improvement of technologies in energy production, transportation, supply and end-use;
- cooperation in the framework of European and international standardisation bodies in the field of energy;
- cooperation within the framework of the European Statistical System on energy issues, including balances.

3.2. Key obligations under European Community related to energy sector

Obligations of Ukraine under Energy Community Treaty in each of ten energy policy areas[26], as well as current state of their implementation are presented on the website of Energy Community.

Electricity

[26] Ukraine Country Report 2016 to Energy Community

- Commission Regulation 543/2013on submission and publication of data in electricity markets
- Regulation (EU) No 838/2010 on laying down guidelines relating to the inter-transmission system operator compensation mechanism and a common regulatory approach to transmission charging;
- Directive 2009/72/EC 13 July 2009 concerning common rules for the internal market in electricity;
- Regulation (EC) No 714/2009 of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity

The existing legal framework on electricity is not in line with the Third Energy Package. The Electricity Market Law, which will transpose Directive 2009/72/EC and Regulation (EC) 714/2009, was approved on November 26, 2016. This Law will bridge the outstanding compliance gaps, in particular with respect to:

- Ownership unbundling model and certification of Ukrenergo;
- Access to transmission and allocation of cross-border capacities - coordinated auctions on all borders where applicable;
- Eligibility and switching requirements;
- Diverse market platforms for organized trading; market-based provision of balancing and network services; universal service/supply of last resort established through public service obligation; effective mechanisms for balance responsibility and imbalance settlement; and
- Protection of vulnerable customers as a responsibility for the Government of Ukraine.

Natural Gas

- Directive 2009/73/EC of 13 July 2009 concerning common rules for the internal market in natural gas;
- Regulation (EC) 715/2009 of 13 July 2009 on conditions for access to the natural gas transmission networks.

The Law "On the Natural Gas Market" of 8 May 2015 was developed jointly with the Secretariat of the Energy Community in accordance with Directive 2009/73/EC on common rules for the internal market of natural gas and Regulation (EC) 715/2009 on conditions for access to the network of natural gas transportation.

The main purpose of this Law is the creation of a competitive environment in the natural gas market based on Ukraine's commitments regarding implementation of the requirements of the EU Third Energy Package. The Law is the legislative arrangement for the reform of the gas sector and its implementation plan; it also contains the concept of reforming the NJSC "Naftogaz of Ukraine", including the plan of restructuring the company. Still, Ukraine has to improve secondary legislation, amend the relevant outdated laws and implement the reforms in practice, including the correct unbundling of Naftogaz.

Oil

- Council Directive 2009/119/EC on imposing an obligation on Member States to maintain minimum stocks of crude oil and/or petroleum products. Deadline: 1 January 2023.

Environment

- Directive 2010/75/EU of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Deadline for Ukraine: 1 January 2018;
- Directive 2004/35/CE on environmental liability with regard to the prevention and remedying of environmental damage. Deadline for Ukraine: 1 January 2021;
- Directive 2001/80/EC of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants. Deadline for Ukraine: 1 January 2018;
- Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment. Deadline for Ukraine: 31 March 2018;
- Directive 1999/32/EC of 26 April 1999 relating to a reduction in the sulphur content of certain liquid fuels; Deadline for Ukraine: 1 January 2012;
- Directive 2011/92/EU of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment.

To comply with the Directive 2011/92/EU a Draft Law on Environmental Impact Assessment was developed in 2014. After its approval by Parliament on 4 October 2016, it received comments from the President and now waits for final voting.

Concerning Ukraine's obligation to comply with Sulphur in Fuels Directive the Decree on the Requirements for Car Petrol, Diesel, Marine and Boiler Fuel was prepared in 2013. However, the thresholds stipulated by the resolution on the sulphur content of heavy fuel oil and gas oil did not comply with those of the directive and the Ministry of Energy and Coal Industry drafted amendments to the decree and submitted those to the Government of Ukraine for approval. However, the draft decree was sent back due to change of government and today the situation with this resolution is unclear.

Until the end of 2017, Ukraine has to comply with Large Combustion Plants Directive as well as with Industrial Emissions Directive. Ukraine has 147 plants falling under the scope of the Large Combustion Plants Directive with a total rated thermal input of 107.778 MW. Most plants are coal-fired while a number of them are run on natural gas.

In 2015, the Ministerial Council adopted a decision allowing certain existing plants in Ukraine to use the opt-out mechanism for not more than 40.000 operational hours starting from 1 January 2018 and ending no later than 31 December 2033.

According to the same decision, a National Emission Reduction Plan in Ukraine may be applied up to 31 December 2028 for SO_2 and dust and up to 31 December 2033 for NOx. At the same time, the ceilings for the year 2028 for SO_2 and dust and the ceiling for the year 2033 for NOx

shall be calculated on the basis of the relevant emission limit values set out in Part 1 of Annex V of the Industrial Emissions Directive.

Until then, the ceilings have to provide a linear decrease between 2018 - 2028 for SO_2 and dust and 2018 - 2033 for NOx. Ukraine submitted its draft National Emission Reduction Plan in November 2015 to the Secretariat. Its assessment is currently underway.

Renewables

- Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources.

With the adoption of Directive 2009/28/EC, Ukraine committed to a binding 11% target of energy from renewable sources in gross final energy consumption in 2020 compared with a share of 5.5% in 2009. In 2014, according to energy balance published by EUROSTAT, the country has achieved a 3.8% share of energy from renewable sources, well below the second indicative trajectory of 7.2%. This dramatic drop in the share of renewable sources in power sector is a result of the loss of RES capacities in energy balance of Ukraine due to occupation of the Autonomous Republic of Crimea and escalation of the conflict in the country's east. Other factors that influenced the RES trajectory were introduction of an emergency in the electricity market during 2014-2015, cancellation of tax benefits for producers of power from renewable energy sources, as well as economic downturn during 2014 – 2015. Therefore, investment climate deterioration in Ukraine led to:

- a rise in credit interest rates that discourages investment;
- a rise in interest on the insurance risks;
- necessity for bailment against the loan guarantee that may exceed the principal amount of the loan;
- drastic devaluation of local currency.

The main institutions responsible for the implementation of renewable energy policy are the State Agency on Energy Efficiency and Energy Savings (SAEE) under the auspices of the Ministry of Regional Development, Building and Housing and Communal Services of Ukraine and the National Energy and Utilities Regulatory Commission (NEURC).

Ukraine Country Report, prepared by Energy Community, analysed Ukraine's renewable energy state of compliance to eight key provisions of the Directive 2009/28/EC, such as National Renewable Energy Action Plan, Cooperation Mechanisms, Support Schemes, Administrative Procedures, Access to and Operation of the Grids, Guarantees of Origin, Renewable Energy in Heating and Cooling, Renewable Energy in Transport. According to the results of the analysis, the NREAP is incomplete, as its binding targets are not transposed in the legal framework.

Energy Efficiency

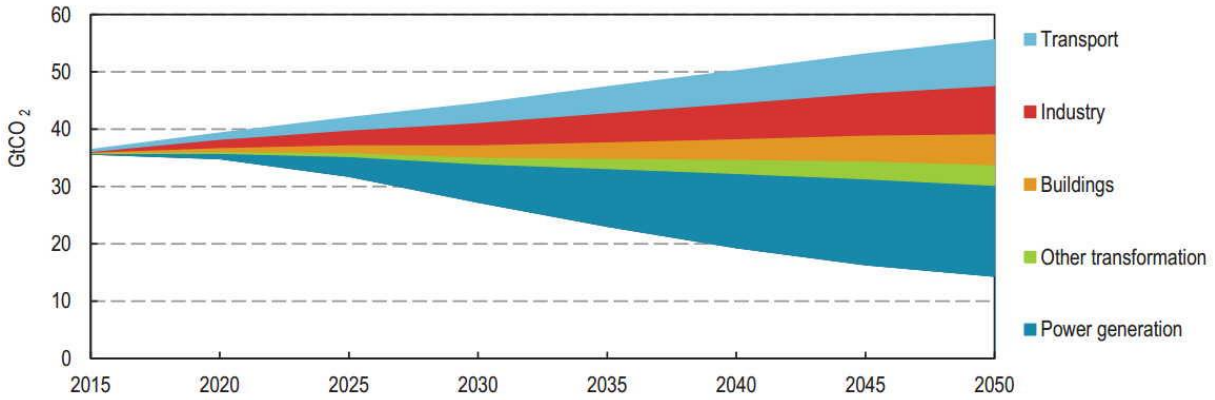
- Directive 2012/27/EU on energy efficiency;
- Directive 2010/30/EU on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products;
- Directive 2010/31/EU on the energy performance of buildings;

Directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services.

3.3. Influence of Paris agreement on the energy sector development till 2050

Key and long-term global goal of the Paris Agreement is to limit warming to "well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C". All countries that ratified the Agreement will need to implement what they have pledged under it – their Nationally Determined Contributions (NDCs). A common framework will be developed to track progress towards, and achievement of, countries' NDCs, with built-in flexibility for Parties' different capacities. NDCs are to be communicated every five years and are to reflect each Party's "highest possible ambition". These periodic global stocktakes of countries' NDCs will start after 2018 facilitative dialogue, supporting COP21 decision, and the first such stocktake is scheduled for 2023.

The goal of keeping average global temperature rise below 2 °C will require a rapid reduction in carbon dioxide (CO_2) emissions from the power generation sector, which today generates about 40% of energy sector emissions. At present, coal and gas power plants account for about two-thirds of global power generation with 90% of all CO_2 emissions. According to IEA Energy Technology Perspectives (ETP) 2°C Scenario (2DS), 39% of energy emissions reductions needed to limit global temperature increase to 2 °C come from the power sector (**Fig. 3.1.**).



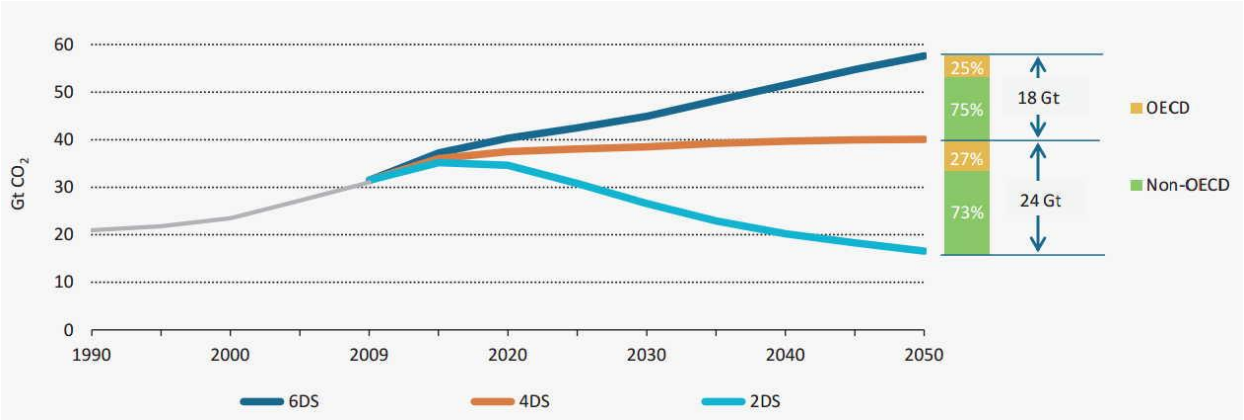
Source: IEA (2016a), Energy Technology Perspectives 2016.

Fig. 3.1. Reduced power generation emissions lead reductions to the 2°C pathway

4. Brief consideration of worldwide tendencies of energy sector transition to RES: best practices and related incentive mechanisms

4.1. State and tendencies of worldwide energy shift to RES

Energy sectors of world countries started their transition to RES after the reveal of the global climate change problem with increase of greenhouse gas emissions in the atmosphere because of the growth of industrial production. To prevent global warming, in 1997 countries responsible for 64% of greenhouse gas emissions in the world joined the adopted Kyoto Protocol. Despite the efforts of the 192 countries to implement the Kyoto Protocol, they could not stop the global warming. On 12 December 2015 at the meeting of the Conference of the UN Framework Convention on Climate Change, a new climate Paris Agreement was signed and entered into force on 4 November 2016. As energy sector accounts for 68% of global GHG emission, the International Energy Agency in 2012 presented 3 scenarios based on different pathways of future energy systems **(Fig.4.1)**. A low carbon energy system is linked to a 2DS scenario, which stipulates to reduce by half global energy-related CO_2 emissions in 2050 compared to 2009 levels to limit the global temperature increase to 2°C. To perform the 2DS scenario the energy intensity of the global economy should significantly decline in a result of decoupling of energy use from economic activity **(Fig.4.2.)**. Without this decoupling, achieving the 2DS



becomes very costly, if not impossible.

6DS, 4DS, 2DS – scenarios of increasing of the average temperature by 6 ºC, 4 ºC, 2 ºC, respectively

Fig. 4.1. Growth of GHG emissions in the world and climate change scenarios[27]

[27] Energy Technology perspectives 2012. Pathway to a Clean Energy System, IEA, 2012 https://www.iea.org/publications/freepublications/publication/ETP2012_free.pdf

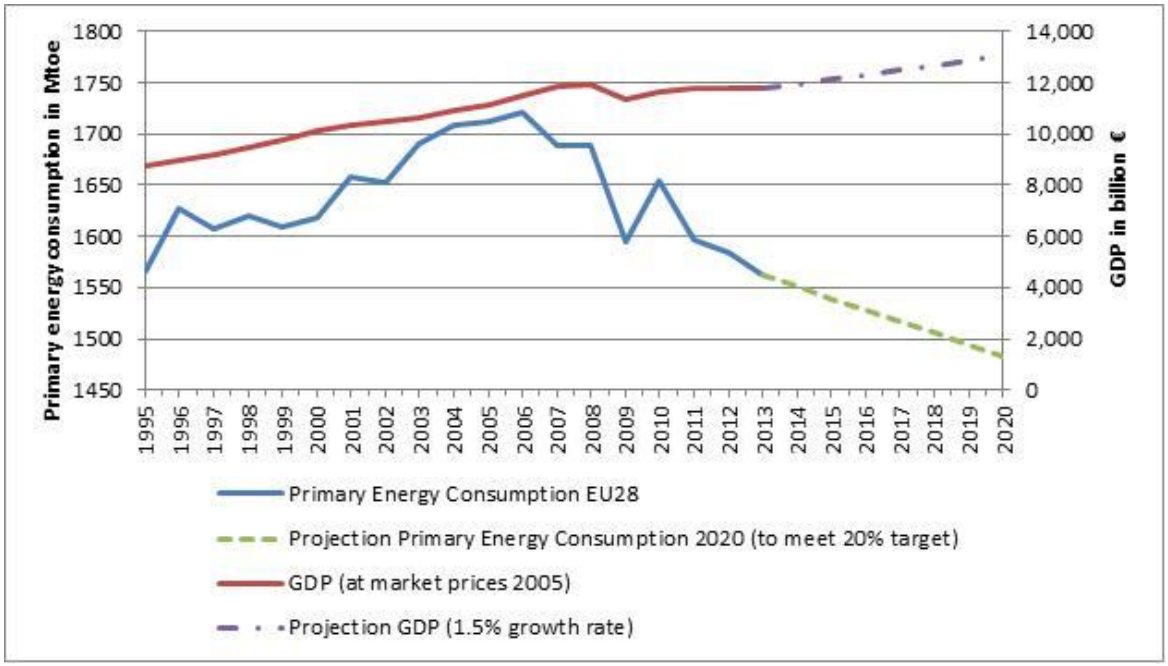


Fig. 4.2. Trends of the primary energy consumption and GDP in the EU-28[28]

To address the 'energy trilemma' of achieving environmental sustainability, energy security, and energy equity, the World Energy Council (WEC) has elaborated two scenarios for development of global energy until 2050 – Jazz and Symphony[29]. A consumer-driven Jazz focuses on achieving individual access and affordability of energy through economic growth, while a voter-driven Symphony scenario envisages achieving of environmental sustainability through internationally coordinated policies and practices. Development of renewable energy in Jazz scenario is slow with achieving a target of 20% in TPES in 2050 **(Fig. 4.3.)**. The TPES itself increases by 38% compared to 2010 (from 546 EJ/yr in 2010 to 879 EJ/yr in 2050). The voter-driven Symphony scenario takes place in case of priority development of RES and energy efficiency technologies. This results in 30% share of RES in TPES in 2050 and 50% in power production and the total energy supply during 2010 -2050 will increase only by 22%.

[28] COM(2014) 520 Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:52014DC0520

[29] World Energy Scenarios. Composing energy futures to 2050. Prepared by World Energy Council, 2013. https://www.worldenergy.org/wp-content/uploads/2013/09/World-Energy-Scenarios_Composing-energy-futures-to-2050_Full-report.pdf

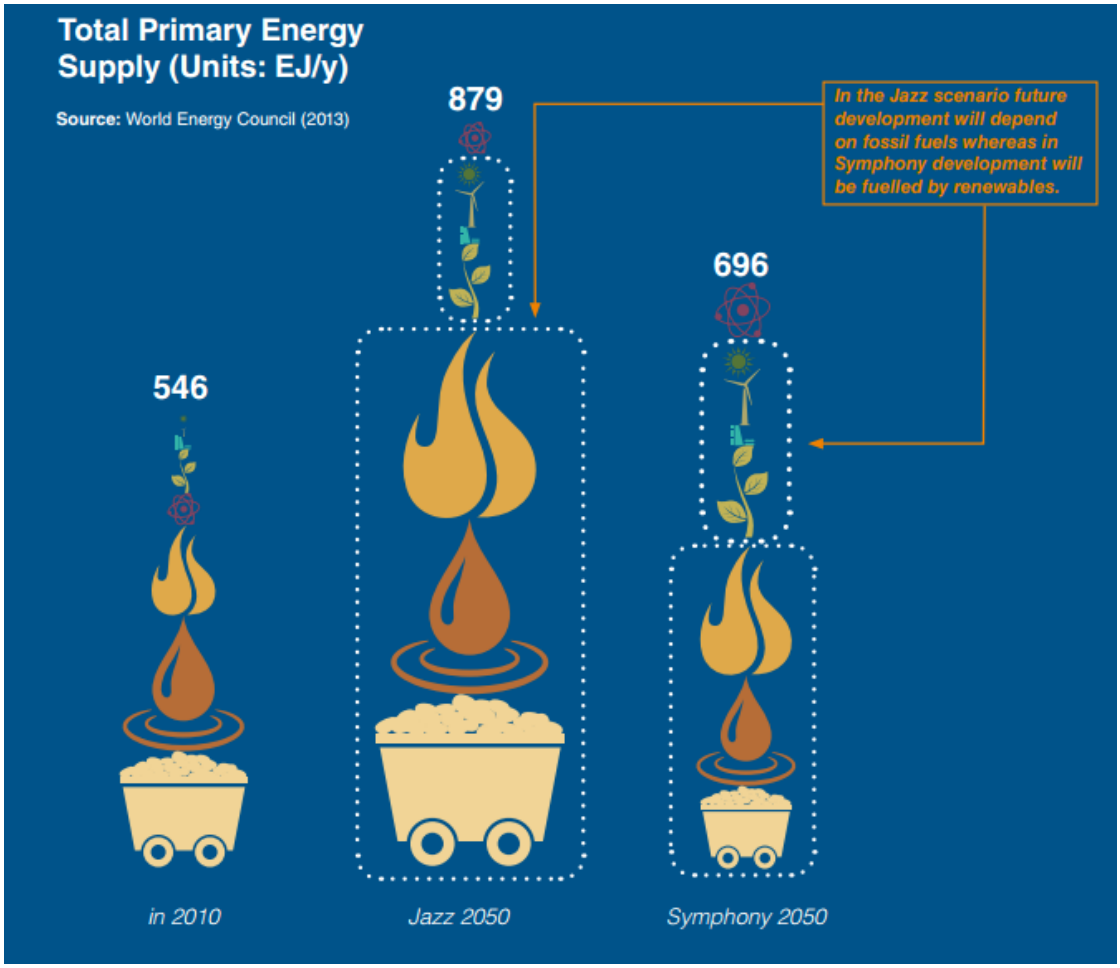


Fig. 4.3. Structure of energy resources in 2050 according to Jazz and Symphony scenarios developed by WEC[29]

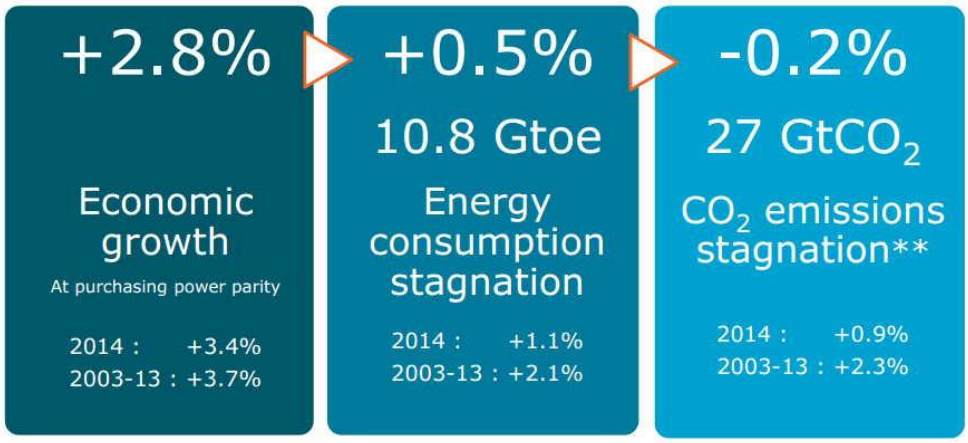
4.2. Strategies and targets of countries to RES transition

Since Kyoto Protocol adoption, nearly all industrialized countries worldwide have renewable energy targets and support policies in place. As of year-end 2015, 173 countries have established renewable energy targets at state/provincial level. Targets for RES share in GFEC for EU-28 are 20% in 2020 and 27% in 2030 with 80% reduction of GHG emissions in 2050[30]. Some other countries of G20 have even more ambitious targets: Brazil – 45% in 2020, France – 23% in 2020 and 32% in 2030, Germany – 30% in 2030 and 60% in 2050. In 2015, at the G20 Energy Ministers Meeting in Istanbul, energy ministers of G20 countries and heads of international organizations endorsed an 11-point Communiqué, including the adoption of a renewable energy toolkit, which provides options for G20 countries to take a long-term,

[30] A Roadmap for moving to a competitive low carbon economy in 2050. COM(2011) 112 final, 8.3.2011 http://eur-lex.europa.eu/resource.html?uri=cellar:5db26ecc-ba4e-4de2-ae08-dba649109d18.0002.03/DOC_1&format=PDF

integrated and sustainable approach towards enhanced deployment of renewable energy. The toolkit adopted by the G20 has five focus areas: driving down technology costs; exchanging good practices on enabling policy frameworks and power system integration; mobilizing finance through risk mitigation; technology potentials and roadmaps, and accelerating the deployment of modern bioenergy[31].

In 2015, G20 countries that account for 80% of global energy consumption and for more than 80% of CO_2 emissions slowly decreased economic growth, energy consumption and GHG emissions **(Fig. 4.4.)**.



*** CO_2-energy emissions from energy combustion (>80% of CO_2 emissions)*

Fig. 4.4. G20 Key energy figures in 2015

About 38 countries around the world have the same ambitious targets as EU for 2020 and even set targets for longer periods: until 2030, 2040 and 2050 (**Table 5.1**).

Table 4.1. Shares of RES in the final energy consumption of countries with targets 20% and more till 2020 and beyond[32].

Country	2013/ 2014	2020	2030	Country	2013/ 2014	2020	2030
EU-28	16%	20%	27%	Guinea			30%
Albania		38%		Iceland	77.1%	64%	
Algeria		40%		Kosovo		25%	

[31] IRENA, "G20 embraces renewables at energy ministers meeting," press release (Istanbul: 2 October 2015), http://www.irena.org/news/Description.aspx?NType=A&News_ID=424&PriMenuID=16&Mnu=Pri

[32] Renewables 2016. Global Status Report

Austria	33.1%	45%		Lao PDR		30% by 2025	
Belarus	5.7%	32%		Latvia	38.7%	40%	
Belgium	8%	20%		Lithuania	23.9%	23%	
Bosnia and Herzegovina		40%		Macedonia		28%	
Brazil	39.4%	45%		Madagascar		54%	
China	11.1%		20%	Montenegro	31.1%	33%	
Croatia	27.9%	20%		Norway	69.2%	67.5%	
Denmark	29.2%	35%	100% by 2050	Palestine		25%	
Estonia	26.5%	25%		Portugal	27%	31%	40%
Fiji			23%	Romania	24.9%	24%	
Finland	38.7%	38%	40% by 2025	Serbia		27%	
France	14.3%	23%	32%	Slovenia	21.9%	25%	
Germany	13.8	18%	30%, 45% by 2040, 60% by 2050	Spain	16.2%	20.8%	
Greece	15.3%	20%		Sweden	52.6%	50%	
Gabon		80%		Thailand		25% by 2021	30% by 2036
Guatemala		80% by 2026		United Arab Emirates	<1%	24% by 2021	

Far more challenging targets to achieve 100% of energy from renewable sources are set by a number of countries and cities:

Countries:

- Denmark: 50% of total economy by 2030 and **100%** in 2050.

- Iceland has reached **99%** of electricity and **70%** of the final consumption of all energy from RES
- Scotland: **100%** of electricity from RES by 2020 and **30%** of the total energy needs.
- Maldives: **100%** of energy from RES by 2020.

Cities:

Today in the USA, three cities have completely switched to renewable energy (Aspen, Burlington, Vermont). Other cities may be noted:

- Vancouver (Canada): in 2015, obligations were assumed to transfer the city for **100%** energy from RES.
- Frankfurt (Germany): decarbonization of the city due to renewables and alternative automotive fuel by 2050.
- Copenhagen (Denmark): **100%** of electricity and heat from RES by 2025/2030 and **100%** in all sectors by 2050.
- Munich (Germany): **100%** of electricity from RES for homeowners by 2015 and for all consumers by 2025.
- Malmö (Sweden): **100%** of renewable electricity by 2020.
- Sydney (Australia): **100%** of electricity, heat and cold from RES by 2030.

American cities such as San Francisco, Palo Alto, San Diego, Ithaca, Greensburg, Georgetown, and San Jose took a goal to switch to renewable energy and already have adopted programs. Every year the number of cities increases.

It should be also noted that Asian and African countries follow the global trend and implement their projects, especially in the regions where it is difficult or impossible to provide a centralized power supply. As for Australia, it also started a program to promote renewable energy among the population, the aim of which is the country's switch to 100% renewable energy in the future.

According to the Paris Agreement, all Parties should develop and present their long-term low greenhouse gas emission development strategies, taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances. In 2016, France, Benin, United States, Mexico, Germany and Canada have already provided their long-term low carbon strategies to the UNFCCC[33].

At present renewable energy sources cover about **19%** of the world final energy consumption including traditional biomass **9%**, modern renewables over **10%** (production of heat and

[33] http://unfccc.int/focus/long-term_strategies/items/9971.php

power, motor fuels) (**Fig. 4.5**). About **14%** of the final energy consumption is covered by biomass (traditional and modern).

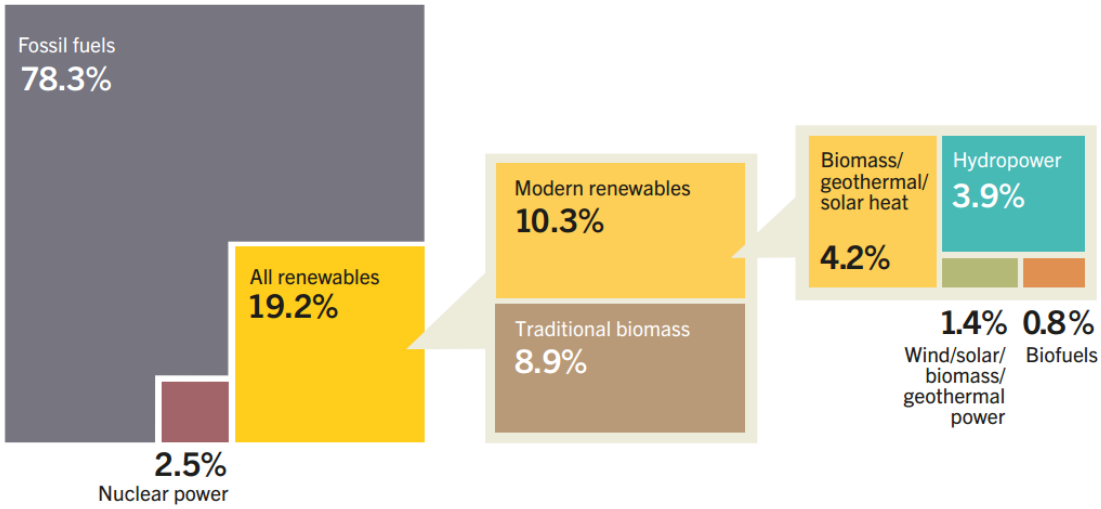


Fig. 4.5. Structure of the world final energy consumption, 2014[32].

4.3. Best cases and key policies for RES

Transition towards renewables needs efficient policies, which allow moving towards the set RES targets quicker. At the beginning of 2016, Renewable Energy Policies, such as targets, incentives and enabling mechanisms were implemented in 145 countries all over the world. Support to power, heating and cooling, and transport sectors was not equal. Power generation from RES received the widest support, mostly through feed-in-tariff scheme. In 2015, more than 80 countries around the world used them at national and local level to support the electricity generation from RES that cover over 87% of the world population[32]. Transport sector policies adopted in 66 countries support mainly production and use of biodiesel and ethanol mostly through biofuel blend mandates, which specify a minimum share or volume of renewable fuel to be blended with traditional transport fuel. The lowest expansion of policy regulations is in heating and cooling sector, as only 21 country have adopted them. The main policy measures are heat obligations of two types: solar obligations and technology-neutral heat obligations, introduced primarily in residential and commercial buildings. Heating in utilities and industry are supported in Austria, Denmark, Germany, India, Mexico and Tunisia.

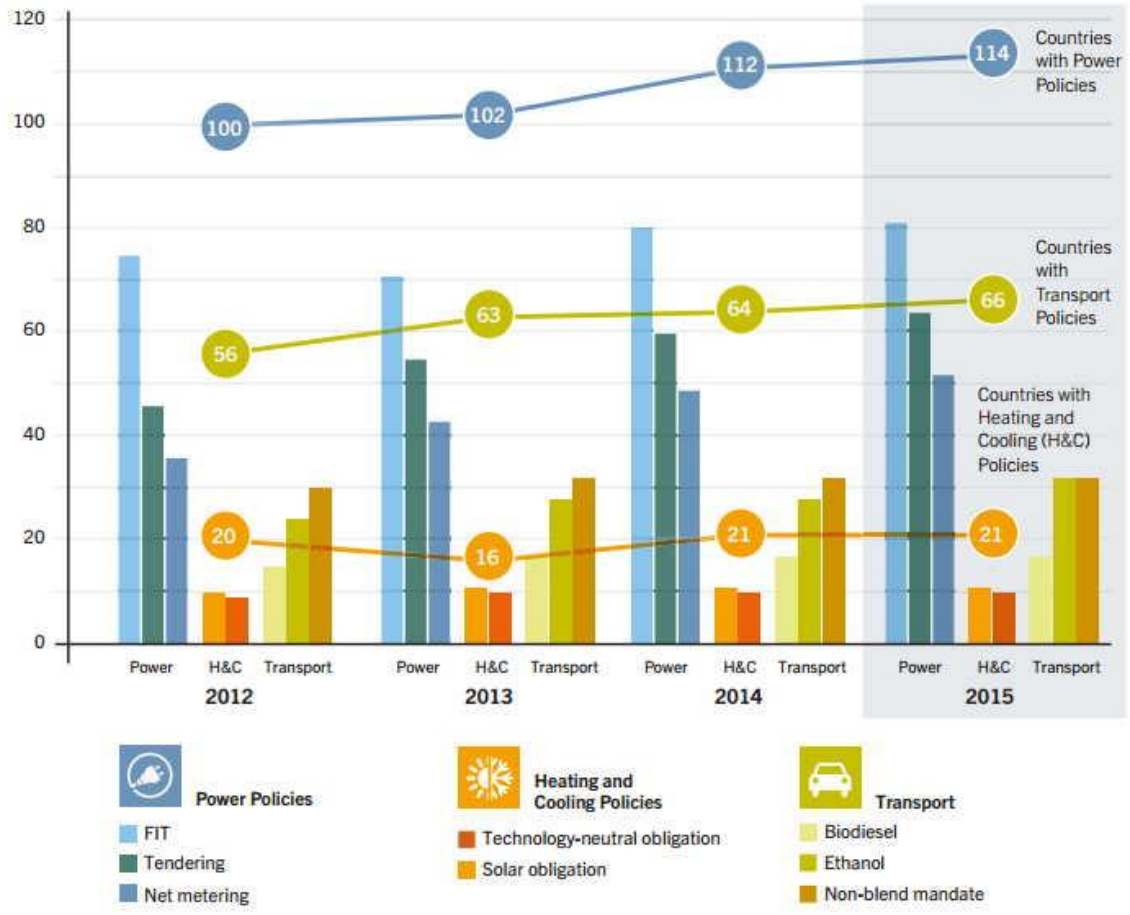


Fig. 4.6. Number of Renewable Energy Policies and Number of Countries with Policies, by Type 2012-2015

All the policies, implemented in countries worldwide, can be divided into two groups:

- Regulatory policies;
- Fiscal incentives and public financing.

Among regulatory policies, the following are usually implemented:

- Feed-in tariff/ premium payment;
- Electric utility quota obligation/ renewable portfolio standards;
- Net metering/ net billing;
- Transport obligation/ mandate;
- Heat obligation/ mandate;
- Tradable Renewable energy Certificate;
- Tendering.

The Fiscal incentives and public financing usually include the following measures:

- Capital subsidy/ grant, or rebate;
- Investment or production tax credits;

- Reductions in sales, energy, VAT and other taxes;
- Energy production payment;
- Public investment, loans, or grants.

According to Eurostat statistics of 2015, eleven countries have already reached the level required to meet their national RES targets: Bulgaria (18.2% vs 13%, the Czech Republic (15.1% vs 13%), Denmark (30.8% vs 30%), Estonia (28.6% vs 25%), Croatia (29% vs 20%), Italy (17.5% vs 17%), Lithuania (25.8% vs 23%), Hungary (14.5% vs 13%), Romania (24.8% vs 24%), Finland (39.3% vs 38%) and Sweden (53.9% vs 49%). Two countries Austria and Slovakia are about 1% from their 2020 targets, at respectively 33% and 12.9% of RES in gross final energy consumption in 2015. Key supporting RES policies of these countries include premium and feed-in tariffs for electricity production, biofuel quotas, as well as tax exemptions and various state subsidies.

Table 4.2. Support policies for RES in EU countries that reached National RES targets for 2020.

Country	Policy	Related sector	RES+GHG cut[34]+EE (target and achieved)
Austria	**Feed-in tariff** (differentiated depending on the technology used and redefined annually through a decreasing promotional volume of the overall support.). **State subsidy** (investment grants for the construction of small and medium-sized hydro-electric power stations; for PV installations on rooftops and building-integrated installations with a capacity 5-200 kW additionally to feed-in tariff; for off-grid installations that generate electricity from RES in form of an investment subsidy in addition to feed-in tariff).	RES-E	**2020 (target):** RES 34% RES-T 10% **2015 (achieved):** RES 33% RES-E 70.3% RES-H&C 32% RES-T 11.4% **2014 (achieved):** **GHG** -3.2%
	State subsidies (for small-scale RES-H&C by the Environmental Assistance in Austria programme; special investment incentives for solar thermal installations, heat pumps, geothermal and biomass heating plants).	RES-H&C	
	Biofuel quota (the substitution target	RES-T	

[34] without LULUCF, with indirect CO2. Source: European Environment Agency (EEA) (2015), Greenhouse gas emissions by countries: http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

	amounts to 5.75 %, measured by the total fossil petrol or diesel introduced or used in the federal territory). **Tax regulation mechanism** (petrol and diesel from a minimum content of 4.6 % and respectively 6.6 % of biogenic material are subject to a lower mineral oil tax. Mineral oil solely from biogenic material and E85 are exempt from this tax).		
Bulgaria	**Feed-in tariff** (the amount of tariff is determined annually by the Energy and Water Regulatory Commission. The feed-in tariff and the purchase obligation apply to power purchase agreements (PPAs) signed for projects implemented before the achievement by the Republic of Bulgaria of the RES end consumption mandatory targets under the National Renewable Energy Action Plan.).	RES-E	**2020 (target):** RES 16% RES-T 10% **2015 (achieved):** RES 18.2% RES-E 19.1% RES-H&C 28.6% RES-T 6.5% **2014 (achieved):** **GHG** -45%
	Loan (from the Bulgarian Energy Efficiency Fund in form of financing grants for projects aiming at improving the energy efficiency of public, industrial and residential buildings). **Tax regulation mechanism** (tax incentives for building owners).	RES-H&C	
	Biofuel quota (Persons introducing liquid fuels of crude oil origin for transportation shall be obliged to offer market fuels for diesel and petrol engines blended with biofuels). **Tax regulation** (A reduced rate of excise duty to unleaded petrol or gas oil if a share of more than 4 % of bioethanol or biodiesel has been added).	RES-T	
Croatia	**Premium tariff** (addition to the selling price obtained on the electricity market). **Guaranteed feed-in tariff** (for installations of less than 30 kW) allocated through tenders. Loans (of the Environmental Protection and Energy Efficiency Fund; of the Environmental Protection Programme of the HBOR).	RES-E	**2020 (target):** RES 20% RES-T 10% **2015 (achieved):** RES 29% RES-E 45.4% RES-H&C 38.6%
	Biofuel quota obligation (set the %-share	RES-T	

	of biofuels on the fuel market annually up to 2020). **Tax regulation mechanism** (sets excise duty for biofuels to 0)		RES-T 3.5% **2014 (achieved):** GHG -26.6%
Czech Republic	**Feed-in tariff** (only to operators of RES plants with an installed capacity up to 100 kW (30 kW in case of rooftop or facade PV installations or 10 MW in case of hydro power). PV and biogas plants, put into operation before 31.12.2013, are eligible. Wind, hydro, geothermal or biomass plants up to 100 kW put into operation before 31.12.2015 with building permit issued before 2.10.2013 are eligible. Feed-in tariffs are paid by the "mandatory purchasers" selected by the Ministry of Industry and Trade.). **Green bonus** (received in an annual or hourly mode on top of the regular market price of electricity. PV and biogas plants put into operation before 31.12.2013 are eligible. Wind, hydro, geothermal or biomass plants with the building permit issued before 2.10.2013 are eligible.). **State subsidies** (for small hydropower plants up to 10 MW under the Operational Programme "Entrepreneurship and Innovation for Competitiveness" 2014-2020 (OP PIK) funded by the ERDF.).	RES-E	**2020 (target):** RES 13% RES-T 10% **2015 (achieved):** RES 15.1% RES-E 14.1% RES-H&C 19.8% RES-T 6.5% **2014 (achieved):** **GHG** -36.8%
	Tax regulation mechanism (operators of renewable heating plants are exempt from real estate tax). **State subsidies** (for the support of renewable heat from the Operational Programmes (OP) funded by the ERDF.)	RES-H&C	
	Biofuel quota (obligatory biofuel share for petrol (4.1% by volume) and diesel (6% by volume) fuel introduced on the Czech market). **Tax regulation mechanism** (pure biofuels as well as the biofuel content of mixed fuels are exempt from consumption tax. Eligible are hydrogenated vegetable oils, liquefied biogas,	RES-T	

	mineral oil produced from non-food biomass or organic waste).		
Denmark	**Premium tariff** (based on bonus payments, paid on top of the market price. The sum of the market price and the bonus shall not exceed a statutory maximum per kWh, which depends on the source of energy used and the date of connection of a given plant.). **Tenders** (Premium tariff for offshore wind parks is awarded through tenders). **Loan guarantees** (Associations of wind energy plant owners and other local initiatives may apply for guarantees for loans for feasibility studies that are conducted in the run-up to the construction of a wind-energy plant. District heating companies, including biomass and solar receive loan guarantees.)	RES-E	**2020 (target):** RES 30% RES-T 10% **2015 (achieved):** RES 30.8% RES-E 51.3% RES-H&C 39.6% RES-T 6.7% **2014 (achieved):** **GHG** -27.6%
	Tax regulation mechanism (RES are exempt from taxes on the production, processing, possession, receipt and dispatch of fossil fuels for heating). **Price-based mechanisms** (use of biogas for heating purposes receives direct premium tariff for gigajoule of used biogas).	RES-H&C	
	Biofuels quota (providers of petrol or diesel fuels have to ensure that biofuels make up at least 5.75% and advanced biofuels at least 0.9% measured by energy content of the company's total annual fuel sales. The obligation must be fulfilled by the end of each calendar year). **Tax regulation mechanism** (companies producing, processing, possessing, receiving or dispatching energy products are obliged to pay a defined amount of tax. This amount is reduced for fuels blended with biofuels).	RES-T	

	Price-based mechanism (Selling of biogas for transport purposes is supported through a direct premium tariff).		
Estonia	**Premium tariff** (sale at free market with receiving a bonus on the top of the market price; maximum 12 years)	RES-E	**2020 (target):** RES 25% RES-T 10% **2015 (achieved):** RES 28.6% RES-E 15.1% RES-H&C 49.6% RES-T 0.4% **2014 (achieved):** GHG -47.3%
	Investment subsidies (for the reconstruction of RES CHP plants; for the reconstruction of private houses and apartment buildings)	RES-H&C	
	Blending mandate (at least 3.3% share of biocomponents in petrol and diesel my May 2017 with gradual rise to 10% by 2020); **Support schemes** (for purchase of electric cars that use power from RES; for biomethane use in transport).	RES-T	
Finland	**Premium tariff** (for wind, biomass and biogas); **State subsidies** (for investments and research projects)	RES-E	**2020 (target):** RES 38% RES-T 10% **2015 (achieved)** RES 39.3% RES-E 32.5% RES-H&C 52.8% RES-T 22% **2014 (achieved):** GHG -17.1%
	"Heat bonus" (to CHP plants on biogas and wood fuel). **State subsidies** (for investment in RES; for investment support for farmers).	RES-H&C	
	Quota system (companies selling petrol or diesel fuels should ensure that biofuels compose a defined percentage of the company's total annual sale of fuel). **Tax regulation** (excise duty on liquid fuels based on energy content and carbon dioxide emission of separate fuel components, thus reduced taxation for biofuels).	RES-T	
Iceland	**State Subsidies** (from National Energy Fund for the exploitation of RES and for special projects in the field of economical energy use.	RES-E	**2020 (target):** RES 64% RES-T 10%

			2015 (achieved) RES 70.2% RES-E 93.1% RES-H&C 63.4% RES-T 5.7% **2014 (achieved):** GHG +26.5%
Lithuania	**Sliding feed-in premium** (RES plants with installed capacities above 10kW acquire the guaranteed tariff rate by participating in tenders; tariff rates for RES plants of up to 10 kW are set by the National Commission for Energy Control and Prices on a quarterly basis). **Tenders** (operators of RES plants of above 10kW acquire guaranteed tariffs (sliding feed-in premium) by taking part in tenders. Maximum tariff levels for these RES plants for the subsequent tenders are set every quarter). **State subsidies** (from the Lithuanian Environmental Investment Fund (LEIF) for RES-E projects except geothermal energy; from the Climate Change Special Programme for all RES-E technologies in the form of loans or subsidies). **Net-Metering** (exemption from payment of Public Service Obligation for solar power producers on the electricity produced for their own needs). **Relief from Excise Duty.**	RES-E	**2020 (target):** RES 23% RES-T 10% **2015 (achieved)** RES 25.8% RES-E 15.5% RES-H&C 46.1% RES-T 4.6% **2014 (achieved):** GHG -59.5%
	Guaranteed purchase of heat from RES. **Biogas purchase obligation** (for gas system operators to purchase biogas and inject it into natural gas transmission and/or distribution system at a tariff set by the National Commission for Energy Control and Prices (NCC)**.** **State subsidies** (from LEIF to cover also the conversion of heating plants to switch from	RES-H&C	

	solid fuels to biofuels and geothermal resources). **Environmental Pollution Tax exemption** (for use of biogas, solid and liquid biofuels for heating purposes).		
	State Subsidy (reimbursement for the part of the price of rapeseed oil used for the production of rapeseed methyl (ethyl) ester (RME) and part of the price of rapeseed and cereal grain purchased for the production of dehydrated ethanol). **Fuel blending obligation** (for fuel traders to sell petrol containing 5-10% biofuels and diesel containing at least 7% biofuels). **Excise Tax Relief** (to biofuels for transport (bioethanol, biodiesel, bio-ETBE, vegetable oil) in proportion to the percentage of biomass per tonne of biofuel). **Environmental Pollution Tax Exemption** (for using biofuels in vehicles).	RES-T	
Norway	**Quota system** (in terms of quota obligations and a certificate trading system. Electricity suppliers and certain electricity consumers are obliged to prove that a certain quota of the electricity supplied by them was generated from RES. They can prove it through tradable certificates allocated to renewable energy producers. Sweden and Norway introduced a common electricity certificate market on 1 January 2012).	RES-E	**2020 (target):** RES 67.5% RES-T 10% **2015 (achieved)** RES 69.4% RES-E 106.4% RES-H&C 33.8% RES-T 8.9%
Romania	**Quota system** (based on quota obligations, tradable certificates, and minimum and maximum prices. Electricity suppliers and producers are obliged to present a certain number (or quota) of green certificates. These tradable certificates are allocated to the producers of electricity from RES. The quota system cannot be accessed by new installations since 1 January 2017 any longer). **State subsidies** (from the National Rural Development Programme for the agricultural	RES-E	**2020 (target):** RES 24% RES-T 10% **2015 (achieved)** RES 24.8% RES-E 43.2% RES-H&C 25.9% RES-T 5.5% **2014 (achieved):**

	sector, promoting amongst others the use of RES for the applicants own consumption).		GHG -56.2%
	State subsidies (from the National Rural Development Programme for all RES-H technologies for own consumption; from the Romanian Environmental Fund both for natural persons and administrative-territorial units, religious institutions and public institutions for the installation of heating systems using RES).	RES-H&C	
	Quota system (fuel retailers are obliged to ensure that biofuels make up a prescribed percentage of their annual sales).	RES-T	
Sweden	**Quota system** (in terms of quota obligations and a certificate trading system. Energy suppliers are obliged to prove that a certain quota of the electricity supplied by them was generated from RES. Energy suppliers shall provide this evidence by presenting tradable certificates allocated to the producers of electricity from RES.). **State subsidy** (for photovoltaic installations). **Tax regulation mechanisms** (electricity from wind is eligible for a real estate tax reduction. Electricity produced in electricity generators with a capacity lower than 50 kW is not taxable. For electricity from wind, wave and solar this capacity margin is higher as authorised by the Energy Tax Act. Since 2015, a tax reduction for the micro production of RES-E is in place.).	RES-E	**2020 (target):** RES 49% RES-T 10% **2015 (achieved)** RES 53.9% RES-E 65.8% RES-H&C 68.6% RES-T 24%
	Tax reduction for households (RES-related installation works in households and the replacement of the conventional heating sources with renewable ones may be deducted from tax). **Energy and carbon dioxide taxes** (for supply, import and production of fossil fuels for heating purposes. RES are exempt from these taxes). **Nitrous oxide tax** (the producers of heat are	RES-H&C RES-T	**2014 (achieved):** GHG -24.4%

	obliged to pay a tax according to their nitrous oxide emissions. Heat producers using RES are exempt from this obligation).		
Ukraine	**Feed-in tariff** (the so-called "green tariff". The wholesale electricity market of Ukraine is obliged to buy the electricity generated by renewable energy plants at "green tariff" rates. The "green tariff" is granted to all RES technologies (up to a capacity of 10 MW in the case of hydropower). There is also an additional premium for producers using at least 30% of equipment of Ukrainian origin).	RES-E	**2020 (target):** RES 11% RES-T 10% EE 9% GHG 14% below 1990 **2015 (achieved)** RES 4.87% RES-E 7.92% RES-H&C 4.57% RES-T 1.85% **2014 (factual):** GHG -60% to 1990 level
	Stimulating heat tariff (for RES-heat, except CHPs. Tariff is established by local self-government authorities (municipalities), financed from the state or local budgets and for district heating is at the level of 90% of tariff, established for the supplier of heat produced from natural gas for the respective category of consumers or of the average tariff for heat produced from natural gas, established by State Agency on Energy Efficiency and Energy Saving of Ukraine, according to the procedure established by the Ukrainian government. The average tariff for heat should be calculated for each region (oblast).	RES-H	

5. Brief overview of current state of renewable energy sector in Ukraine: legislative, technical and financial framework, opportunities and barriers

5.1. Legislative framework

To better assess the perspective of the sectors' development it is necessary to identify starting and planned legislation framework. Below the brief explanations of legislation framework is presented.

Table 5.1.

Mechanism	Short description	Related sector	Link	Date of approval
In effect				
"Green" tariff	Multiplication factor for enhanced power generation tariff Biomass: 2.3 Wind: 1.08…1.89 Solar: 2.79…3.72 Hydro: 1.94…3.24 Geothermal: 2.79 -10% 2020-2025 -10% 2025-2030	Power generation	Law of Ukraine "About electricity" with amendments 2010-d [35]	2009
Stimulating tariff in heating sector	Changing of tariff formation method: heat tariff from alternative energy	Heat generation	Law of Ukraine 1959-VIII[36] (approved 21 March 2017)	2017

[35] http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=55219

[36] http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=58568

	sources = 0.9*gas tariff established			
State co-financing programme "Warm" Credits	Co-financing scheme: 20%-70% of loan body compensation by state for new non-gas heating installations and thermo-modernization measures in residential sector	Heating of households and public buildings	CMU Decree #1056 with amendments #63[37]	2014
VAT redemption	Redemption of 20% VAT for renewable energy equipment	Renewable energy generation	CMU Decree #902[38]	2006
Carbon tax	1.3 Eurocents/t CO_2 emissions	All sectors	Tax Code of Ukraine	2011
Planned				
Competitive heat market	Introduction of mechanism of independent heat producers entrance to heat market to broke the monopoly of existing local heat supply companies	Heat generation		2018-2019
Establishment of internal competitive biofuel market	Simplification of access of business to the existing forest and agro	Fuel markets	Concept paper developed	2018

[37] http://www.oschadbank.ua/ua/private/loans/oschad_home/post_kmu.pdf

[38] http://zakon2.rada.gov.ua/laws/show/902-2014-%D1%80

including stock market of biofuels	residues, creating a platform for biomass auctions			
Low-carbon energy premium	Low carbon projects cycle and related activities (supply chain, production of equipment, etc.)	Energy generation, distribution and consumption	Concept paper developed	Post-2020
Establishment of an effective mechanism of energy cooperatives	Framework conditions for energy cooperatives are to be created	Energy generation and consumption	Dissemination activities performed (2015-2016) with help of FNR Germany	Post-2020
Introduction of energy tax and/or carbon tax	Reforming existing carbon tax mechanism, establishment of carbon tax on the level of 2 EUR/tCO_2, creation of supporting activities framework (monitoring and verification system, carbon tax fund for tax distribution, capacity building of regulator)	Energy generation, distribution and consumption	Concept paper developed	Post-2020
Establishment of basis for biomethane production	Introduction of primary and secondary legislation, national biomethane registry, added green tariff for	Energy generation, distribution and consumption	Concept paper developed	Post-2020

	biomethane-to-power			
Establishment of incentive mechanism for use of biomass capacities for balancing of energy system (peak load coverage)	Premium for peak electricity supply to grid for biogas and solid biomass-to-power generation objects	Energy generation, distribution and consumption	-	Post-2020
Establishment of waste-to-energy incentive tariff	Premium for MSW incineration, bio-mechanical treatment and sorting	Energy generation, distribution and consumption, waste management, water supply and sanitation.	-	Post-2020

5.2. Technical framework

The technical framework of technological development and commercialization/market penetration rates of different RES-to-energy technologies is to be analyzed with purpose to identify order of development of each technological group. Below the estimation of the market condition with technical point of view is presented.

Colors meaning are the following:

Not developed subsector, R&D level of technology, few demonstration projects available
Underdeveloped technology, commercial level of implementation possible
Developed sector, moderate variety, market penetration and commercial implementation
Highly developed sector, high variety, market commercialization, no technical problems

BIOMASS-TO-HEAT

Producers of main equipment	**Small boilers and stoves** (individual heating, 10 kW-50 kW): >50 local producers >50 international dealers, some with capacities in Ukraine **Medium size boilers** (for public heating, 50 kW-1.5 MW): >20 local producers >30 international dealers >10 international companies with capacities in Ukraine **Large boilers** (industrial and district heating, 1.5 MW-15 MW) <5 local producers >10 international dealers **Auxiliary equipment suppliers** Pumps: >50 local and international companies Control systems: >50 local and international companies Power systems and automation: >50 local and international companies Heat exchangers: >20 local and international companies Waste heat utilization equipment: 5-10 local and international companies Biomass feeding systems: only international dealers (up to 20) Flue gas cleaning: only international dealers (up to 10) Fittings, valves, ladders, estacades, tubing: >50 local and international companies **Special equipment suppliers** (SCADA, EMS, precise laboratory meters) Up to 10 local suppliers >20 international suppliers **Pre-insulated heat networks producers (district heating)** >30 local companies >30 international dealers and companies **Individual heating substations** Up to 10 local suppliers >20 international suppliers
EPC and service contractors, design and O&M	Local: up to 10 companies International: up to 50 companies
Vertically integrated	Up to 10 Ukrainian companies (independent heat producers) mainly, in public heating, household heating, and local district heating in frames of existing

companies (biomass-to-heat providers)	communal companies. Total capacity of boilers of biomass-to-heat providers: up to 1 GW_{th}.
Logistics and supply chain organization	**Producers of storages, terminals, special vehicles**: Up to 5 local companies Up to 10 international dealers without own capacities in Ukraine **Biomass logistics providers:** Up to 10 local companies Up to 5 international companies with biomass logistics departments (biomass logistics is not the core activity)
Pellets and briquettes	**Producers:** Wood pellets: >200 producers, total annual production up to 400 000 t/year (2016), supply on internal market and export Wood briquettes: >100 producers, total annual production up to 100 000 t/year (2016), main supply on internal market Straw pellets: >40 producers, total annual production up to 150 000 t/year (2016), supply on internal market and limited export Straw briquettes: >20 producers, total annual production unknown, supply on internal market Husk pellets: >100 producers, total annual production >1 000 000 t/year, main supply on export Other pellets: >50 producers, total annual production >50 000 t/year, supply on export and internal market. **Pelletizing equipment suppliers:** Up to 5 local producers >10 international dealers **Traders:** >30 local companies
I-st and II-nd generation biofuels	Existing local capacities of bioethanol from rapeseed and agrobiomass waste up to 500 000 t/year, currently not working due to critical legislative and financial barriers.
Gasification	Up to 100 MW_{th} capacity of wood chips and peat gasification installations in industry. Most of them currently not working due to economic reasons.
Pyrolysis	No serial industrial installations of local production. Number of local laboratory prototypes available. Different pyrolysis concepts (fast pyrolysis, ablative, screw reactor), bio oil productivity 1-200 kg/hour. Technology is on R&D level in Ukraine, international projects are not developed.

Torrefaction	No industrial installations. Number of local prototypes available. International projects are not developed
Bio-refining	No industrial installations. Number of local prototypes available. International projects are not developed
BIOMASS-TO-POWER	
Steam boilers	Local producers: 2 companies Capacities: 10 MW_{th}-30 MW_{th}; Fuel: wood chips, husk waste; Steam parameters: up to 100 bar, 465 ^0C, International dealers: >10 Capacities: 5 MW_{th}-200 MW_{th} Fuel: all types of solid biomass, combined combustion decisions (coal+biomass, agro+wood, peat+biomass), synthesis gas. Steam parameters: up to 150 bar, 535 ^0C
Steam turbogenerators	Local producers: 4 (1)[39] Capacity: 1 MW_{el}-20 MW_{el} Efficiency: 15-25% International: >10 Capacity: 0.25 MW_{el}-50 MW_{el} Efficiency: 12%-33% (in IGCC cycle up to 45%)
ORC	Local producers: 1[40] Capacity: 4 MW_{th}, 8 MW_{th}, 16 MW_{th} Fuel: wood waste, straw waste International dealers: >10 Capacities: 0,5 MW_{th}-20 MW_{th} Fuel: all types of solid biomass, biogas, combined combustion decisions, synthesis gas.
Mini CHP Stirling	Local producers: 0

[39] Only 1 local producer currently makes turbines suitable for biomass-to-power steam parameters provided by biomass low parameter steam boilers available on the market. Other producers make large energy turbines with high steam parameters, however, considering possibilities to change production practice to produce smaller turbines suitable for biomass steam boilers (starting from 2018-2019).

[40] Produce only boiler for ORC. Other spare parts are supplied internationally.

	International dealers: 2
Thermo-electric	Local producers: 0 International dealers: 1
EPC and service contractors, design and O&M	Local: up to 3 International: > 10
BIOGAS-TO-ENERGY TECHNOLOGIES	
Biogas reactors and auxiliary equipment	**Reactors and spare parts (mixers, loaders, heating units)** Local producers: up to 5 International dealers: up to 10 **Automation** Local producers: up to 5 International dealers: up to 40 **Silage and manure storage units** Local producers: up to 5 International dealers: up to 20 **Gasholders** Local producers: up to 5 International dealers: up to 30 **Other auxiliary** Tubing system, collection points, covering materials (for landfill re-cultivation), drainage, separators, dryers, flares Local producers: >20 International dealers: >30
Biogas-to-power engines	**Biogas turbines** Local producers: 1 International dealers: up to 10 **Biogas-piston engines** Local producers: 2 International dealers: >20 **Ranking cycle (biogas steam boiler+steam turbine):** Local producers: 0 International dealers: up to 5

Biogas-to-biomethane purification systems	Local suppliers: 0 International suppliers (dealers not available in Ukraine): >20
EPC and service contractors, design and O&M	Local: up to 5 International: > 20
SOLAR PV AND WIND POWER STATIONS	
Solar PV elements	Local producers: up to 5 International suppliers: >20, including capacities in Ukraine
Wind turbines	Local producers: 0 International suppliers: >10, including capacities in Ukraine
Auxiliary equipment	Controllers, connectors, inverters, converters, current frequency regulators, charging systems, capacitors, monitoring systems, EMS: >10 local companies >40 international suppliers and dealers
EPC and service contractors, design and O&M	Local: up to 5 International: > 10
GEOTHERMAL HEAT AND POWER STATIONS	
Drilling technologies, exploration, geodesy service	Local producers: 0 International suppliers and dealers: 0
Auxiliary equipment	Special construction materials, high temperature heat exchangers, condensers, high pressure tubing Local producers: 0 International suppliers: 0
EPC and service contractors, design and O&M	Local: 0 International: 0
HEAT PUMPS	
Heat pumps (all kinds)	Local producers: up to 5 International suppliers: >10, including capacities in Ukraine
EPC and service contractors, design and O&M	Local: up to 5 International: >10
HYDRO POWER	

Hydro turbines	Local producers: up to 5 (capacity range 100 kW_{el}-25 MW_{el}) International dealers: >20 (capacity range 30 kW_{el}-100 MW_{el})
Hydro accumulation stations	Local producers: up to 5 (capacity range up to 25 MW_{el}) International dealers: >20 (capacity range 30 kW_{el}-100 MW_{el})
Dam construction	n/d
Auxiliary equipment	Local producers: >10 International dealers: >10
EPC and service contractors, design and O&M	Local: up to 5 International: >20

5.3. Financial and investment framework

The financial framework is crucial to assess the market volumes of RES technologies in Ukraine (current and potential). Below the estimation of the market volumes for each technology group is presented.

RES category		Specific investments, EUR/kWth, EUR/kWel	Current market volume, million EUR	Potential market volume, million EUR	Share in total market volume (current)	Share in total market volume (potential)
Biomass heating	min	75	275,7	3 244,1	17,82%	1,78%
	max	450	1 654,5	19 464,5	33,83%	3,99%
Biomass CHP	min	1800	33,6	6 488,2	2,17%	3,57%
	max	6500	121,3	23 429,5	2,48%	4,80%
Biogas CHP (agro+landfill)	min	2300	85,9	8 290,4	5,55%	4,56%
	max	7750	289,3	27 935,1	5,91%	5,72%
Biogas to biomethane	min	2500	0,0	9 011,3	0,00%	4,95%
	max	8500	0,0	30 638,5	0,00%	6,27%
Solar PV	min	1500	599,3	22 707,4	38,73%	12,48%
	max	3500	1 398,4	52 983,9	28,59%	10,85%
Solar heating	min	300	0,0	2 486,0	0,00%	1,37%
	max	800	0,0	6 629,5	0,00%	1,36%
Wind power	min	1000	426,2	86 585,5	27,54%	47,59%
	max	2500	1 065,4	216 463,7	21,79%	44,33%
Geothermal heat	min	550	0,0	5 768,4	0,00%	3,17%
	max	1300	0,0	13 634,4	0,00%	2,79%

Geothermal power	min	3500	0,0	12 236,0	0,00%	6,73%
	max	10000	0,0	34 960,0	0,00%	7,16%
Heat pumps	min	350	0,0	16 780,8	0,00%	9,22%
	max	800	0,0	38 356,2	0,00%	7,85%
Hydro power	min	700	126,6	8 343,8	8,18%	4,59%
	max	2000	361,8	23 839,4	7,40%	4,88%
Total	min		1 547,3	181 942,0	0,85%	100,00%
	max		4 890,7	488 334,7	1,00%	100,00%

Currently the largest market share with respect to investments is occupied by biomass heating, wind power and solar PV with approximately even proportion. The largest potential market volume has wind power generation and biomass (46% and 25% respectively) due to high resource potential and relatively low constantly falling cost of implementation. This data is used as additional threshold for determination of order of technological implementation.

5.4. Barriers and opportunities for investments

Barriers	Opportunities
Biomass-to-heat	
Underdeveloped framework conditions to enter district heating market in municipal and residential sectors	Large and concentrated heat demand in cities with developed district heating systems
Wrong non-market tariff formation method: expenditures + 3-5% interest rate for any fuel (the lower expenditures the lower tariff, no incentive to decrease expenditures)	Biomass heat is competitive fuel and in most cases cheaper than heat from other fuels (natural gas, coal, electricity)
Lack of EPC contracting	Relatively developed technical background
Absence of internal biomass market, lack of companies which provide reliable biomass supply services, no interest of forestries and agro companies in biomass supply business	Availability of large unused local biomass potential
Absence of CO_2 monetization mechanism, biomass certification system, sustainability criteria, land registry, monitoring and	Additional benefits from CO_2 emission reductions

verification	
Biomass-to-power	
Relatively large initial capital investments for large projects (the larger project, the better payback)	Strategic projects: electricity sector not sensitive to crisis, power from biomass becomes cheaper each year
Non-predictable operational expenses due to dramatic fuel price fluctuations in emerging market	"Pioneering": full-cycle of biomass-to-power supply chain creation on emerging market
• Feed-in tariff for biogas-to-power is enough only for large projects (>5 MWel), • No incentives for biomethane-to-power, • Risk of feed-in tariff review due to "special conditions in power sector" (March-April 2014, February 2017), • Tariff is not provided for biomass co-firing and MSW incineration	Feed-in tariff in place guaranteed till 2030
Problems with connection, extremely high (6 times) increasing of grid connection payment (January 2017[41]).	Purchase of produced electricity is guaranteed by law, no need to compete with other power sources
Strong business and political lobby of coal-to-power generation, monopoly of coal-to-power generation	Possibility of peak load coverage due to lack of maneuver capacities in the grid after coal supply blockade from the temporary occupied territories
Absence of CO_2 monetization mechanisms	Additional benefits from CO_2 emission reductions
Biogas-to-energy technologies	
"Green" tariff is enough only for large projects	"Green" tariff for electricity guaranteed till 2030

[41] http://www.nerc.gov.ua/data/filearch/Materialy_zasidan/2017/31.01.2017/p14_31-01-2017.pdf

Large initial capital investment due to additional stage of waste-to-biogas transformation	Large share of large scale farms which have large amount of all necessary input resources for biogas (animal manure, agrosilage, other waste)
MSW treatment projects are risky due to weak predictability of biogas yield (uncontrolled landfills with fluctuations of waste morphology)	Additional ecological effects due to waste treatment and hygienization
No stimulating heat tariff in place	Possibility of additional heat supply (including peak load coverage) by instantly rising heat tariffs
Absence of legislative basis of biomethane production and utilization	Wide possibility of further biogas usage (for biomethane, transport, fuel for direct combustion, etc.)
Lack of own local producers of equipment and EPC contracting companies	Competitive with natural gas price, perspective of trading of biobased products with EU-27 ("green" certificates trading).
Solar PV and wind power stations	
Relatively large initial capital investments, problems with local land allocation and connection	Capital investments are rapidly decreasing from year to year
Periodic nature of generation, necessity of capacitors and reserve loads, comparably low efficiency	• Absence of fuel component in operational expenditures; • Possibility of establishment of smart grids self-distributed generation.
Infrastructure problems: distributed generation, far connection points to the grid network	Improving of existing infrastructure, implementation of innovative technology in energy sector
Low local content in total equipment and works	Perspective of creation by solar PV project owners of full cycle of production, supply and EPC

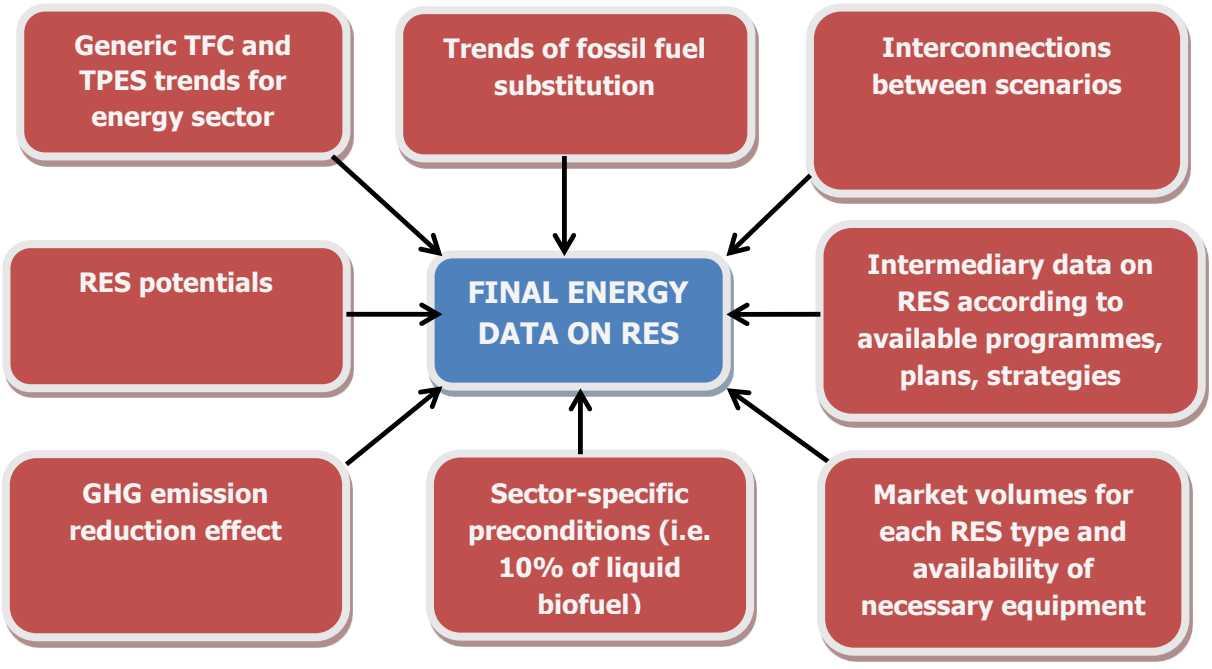
Geothermal heat and power stations, heat pumps	
Relatively low potential in comparison with other renewables	Relatively new sector with underdeveloped market
Lack of feasible drilling technology, absolute absence of local producers and EPC contractors, design organizations and necessary infrastructure	Absence of fuel component in operational expenses
No real example of working geothermal plant in Ukraine due to large paybacks without real working incentive mechanism in place (# 4334 partly close this issue)	Multiplication effects for macroeconomy (local geological surveys, additional sector of producing and service)
Negative effect on GHG emission reduction due to high grid emission factor (coal based power generation)	Possibility of multi-generation (co-generation and tri-generation) and distributed generation
Hydro power	
Almost all potential of rivers is already used	Possibility of electricity supply for higher "zone" tariff
Ecological problems due to flooding of large land territories	New market of tide and wave hydro power

6. Description of the modeling approach and methodology

The modeling approach is based on solving of inverse problem. From one side the indicative targets are established for 2050 prior to any calculations to define final points for respective scenarios of energy sector development. From the other side the initial conditions are established based on the generalization of statistical data from energy balances of Ukraine defining the approximate tendency of energy sector including RES utilization development for latest 6 years (2010-2015). Additionally the tendency of RES development in the EU-27 for different periods is defined on the basis of available energy statistics of Eurostat. For example., it is known, that till 2030 the EU-27 approved target of 27% RES share in GFEC, having base point of 20% in 2020, which means 0,7%/year average increment. It is foreseen that indicators of RES developments for Ukraine in the period 2015-2050 are to be in line (but not always and not for all RES types) with European tendencies in period 1980-2015.

The indicative energy consumption decreasing target is 30% in 2030, having base point of 20% in 2020, which means 1%/year average decrement. The indicative targets on RES developments are also part of the Ukrainian obligations under NREAP till 2020. The known trajectory of renewables and energy consumption development between 2015 and 2020 according to NREAP is used as the figure of average annual increment of RES (from 4,8% to 11% for 6 years or 1%/year). The increments of RES generation is used as a thresholds for narrowing the trajectories of energy sector development till 2050.

Additionally to statistical extrapolation, definition of the final data on energy from RES for all scenarios is based on the specific constraints and limitations applied:



- Generic TFC and TPES trends: the projected values on RES growth shall be in line with latest EU-27 tendencies and statistical Ukrainian tendencies;
- Trend of fossil fuel substitution: the average increment is defined for the period 2010-2015 (statistical data for Ukraine according to energy balances) and is used to define the trend for future developments. The normalization of temps of RES development is performed by comparison between current Ukrainian trends and EU-27 trends.
- Interconnections between scenarios: realization of principle "less efforts for the worst scenario" – the continuous and increasing gap baseline vs climate action vs 100% RES scenarios on TFC/TPES from RES and energy consumption reduction is controlled for each 5-year period to avoid sudden increases and decreases and used as additional limitation.
- Intermediary data on RES: currently available programmes with thresholds on RES and EE in future is used to set check-points for respective years (for example, for 2020 – NREAP, for 2035 – INDC, Draft Energy Strategy of Ukraine, for 2050 – Paris Agreement) to adjust calculation data to this targets for respective scenarios according to the assumptions for each scenario.
- Market volumes and availability of equipment is used to assess the priority of RES technologies implementation – the larger market volume, the larger is implementation of respective technology;
- Sector specific preconditions is used for determination and additional specification of technologies prioritization: additional targets set for liquid biofuels, separately defined biomass-to-energy production, additional solar potential;
- GHG emission reduction effects is used for each scenario as key threshold for 2050 (40% for baseline, 70% for climate, 100% for high commitment).
- RES potentials is used as general constraint – it shall not be exceeded in any year by any scenario.

The mentioned thresholds and key check-points are incorporated in model in such a way, that each of them for each point of calculation shall be satisfied thus decreasing the variety of trajectories 2015 to 2050.

7. Elaboration and description of Excel-based methodological tool for modeling performance

The modeling tool is represented by the Excel spreadsheet as shown at the figure below. Here for demonstration purposes the example of one of the possible "test" scenarios calculated for heating sector of category "population" is presented.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1						Additional equipment					Fossil fuel replacement			%	%				TOTAL investments	
2			Individual average installed capacity					Investments			toe	toe	NG	NG	biomass potential	CO2 reduction	Heat production	calculated		
3	Equipment/consumer categories/biomass types	units	MWth	Mwel	MWth	Mwel	units	€/kW 23.10.16	UAH/kW	hr/year	Mtoe/year	Mtoe/year	billion m3/ year	%	%	Mt CO2/year	TWh/year	ths.Gcal	Million UAH	Million EUR
4	Population / stoves / wood logs	50000							300	4000	0,00	0,00	0,00	0,0%		0,00	0,00	0	0	0
5	2015	80 000	0,01		800		30000	50	1250	4000	0,79	0,55	0,32	2,0%	18%	0,53	3,20	2749	1008	39
6	2020	180 000	0,01		1800		100000	50	1250	4000	1,77	1,24	0,73	4,6%	wood logs	1,43	7,20	6186	1260	49
7	2025	200 000	0,01		2000		20000	50	1250	4000	1,97	1,38	0,81	5,1%		1,59	8,00	6874	252	10
8	2030	250 000	0,01		2500		50000	50	1250	4000	2,46	1,72	1,01	6,3%		1,98	10,00	8592	630	25
9	2035	280 000	0,01		2800		30000	50	1250	4000	2,75	1,93	1,13	7,1%		2,22	11,20	9623	378	15
10	2040	300 000	0,01		3000		20000	50	1250	4000	2,95	2,06	1,21	7,6%		2,38	12,00	10310	252,0	9,8
11	2045	320 000	0,01		3200		20000	50	1250	4000	3,15	2,20	1,29	8,1%		2,54	12,80	10998	252,0	9,8
12	2050	350 000	0,01		3500		30000	50	1250	4000	3,44	2,41	1,42	8,9%	64%	2,78	14,00	12029	378,0	14,7
13	Population / Individual heating boilers / wood logs (25%) + wood pellets (25%) + agro pellets (25%) +wood chips (25%) 10-40 kWth	50000	0,03		1500				800	4000	0,69	0,49	0,61							
14	2015	100 000	0,015		1500		50000	60	1512	4000	0,69	0,49	0,61	3,8%	8%	1,19	6,00	5155	1134	45
15	2020	230 000	0,015		3450		130000	60	1512	4000	1,60	1,12	1,40	8,7%	wood logs	2,74	13,80	11857	2948	117
16	2025	250 000	0,015		3750		20000	60	1512	4000	1,73	1,21	1,52	9,5%	9%	2,97	15,00	12888	454	18
17	2030	300 000	0,015		4500		50000	58	1462	4000	2,08	1,46	1,82	11,4%	agro pellet	3,57	18,00	15465	1096	44
18	2035	350 000	0,015		5250		50000	56	1411	4000	2,43	1,70	2,12	13,3%		4,16	21,00	18043	1058	42
19	2040	400 000	0,015		6000		50000	54	1361	4000	2,78	1,94	2,43	15,2%	12%	4,76	24,00	20621	1021	41
20	2045	420 000	0,015		6300		20000	52	1310	4000	2,91	2,04	2,55	15,9%	agro res	5,00	25,20	21652	393	16
21	2050	450 000	0,015		6750		30000	50	1260	4000	3,12	2,19	2,73	17,1%	10%	5,35	27,00	23198	567	23
22	Population/ Reversed connection to DH systems/ agro residues (straw bales+maize stalks)	10										0,00								
23	2015	50	2,00		100		40	400	10080	4000	0,046	0,03	0,040	0,3%	0%	0,08	0,40	344	806	32
24	2020	250	5,00		1250		200	350	8820	4000	0,58	0,40	0,51	3,2%	agro res	0,99	5,00	4296	8820	350
25	2025	500	5,00		2500		250	320	8064	4000	1,156	0,81	1,011	6,3%		1,98	10,00	8592	10080	400
26	2030	1 000	5,00		5000		500	300	7560	4000	2,313	1,62	2,023	12,6%		3,96	20,00	17184	18900	750
27	2035	1 200	5,00		6000		200	280	7056	4000	2,775	1,94	2,427	15,2%		4,76	24,00	20621	7056	280
28	2040	1 300	5,00		6500		100	270	6804	4000	3,007	2,10	2,630	16,4%		5,15	26,00	22339	3402	135
29	2045	1 400	5,00		7000		100	260	6552	4000	3,238	2,27	2,832	17,7%		5,55	28,00	24057	3276	130
30	2050	1 500	5,00		7500		100	250	6300	4000	3,469	2,43	3,034	19,0%	17%	5,95	30,00	25776	3150	125
31	TOTAL POPULATION	100010				0						0,00								
32	2015	180050			2400	0					1,53	1,07	0,97	6,1%		1,27	0,40	5400	1940	77
33	2020	410250			8500	0					3,04	2,76	2,63	16,4%		4,36	22,00	18902	12770	506
34	2025	450500			8250	0					4,80	3,40	3,34	20,9%		0,38	32,20	27000	11704	467
35	2030	551000			12000	0					0,85	4,80	4,85	30,3%		0,12	40,00	36523	20248	803
36	2035	631200			14050	0					7,90	5,57	5,88	36,8%		10,90	55,00	47255	8744	347
37	2040	701300			15500	0					8,73	6,11	6,27	39,2%		12,13	61,20	52582	4801	190
38	2045	741400			16500	0					9,30	6,51	6,68	41,7%		12,93	65,20	56010	3021	155
39	2050	801500			17750	0					10,03	7,02	7,18	44,9%		13,84	69,80	59971	3000	157

According to the modeling approach the step of modeling is 5 years from 2015 to 2050. The figures in columns A,B,C,H are the main input data for the model and represents the category, equipment quantity, equipment capacity and investments needed respectively. The first figure in column B (cell #B4) represents the current (2014) level of equipment installed (type "stoves") in the respective category "population" (50000 units). The fuel type used is the biomass residues "wood logs". The figure for 2020 (cell # B6) reflects the quantity of equipment defined after inversing of data from known energy production from RES needed to fulfill the NREAP 2020 targets. Figure in 2035 (cell# B9) is based on the indicative target of RES share according to Draft NES 2035 and again is defined by inverse calculation. Other figures in column "B" are also defined according to specific limitations and constrains of the respective

category/equipment/biomass type. For example, it could be seen that energy potential of wood logs in 2015 was used on the level of 18% (cell #O4) and in 2050 on the level of 64% (cell #O12) which is quite high indicator because the prerequisites of exactly this scenario foresees population with stoves as the main consumer of biomass type "wood logs". Remained 46% of wood logs is divided between the next category "wood boilers for individual heating of population", "pellets and briquettes production", "local district heating with capacity below 1,5 MWth", "reverse connection to local district heating systems", "small scale budget and public heating". Column "N" represents the respective natural gas substitution in millions m3 calculated on the basis of energy values from data on installed equipment. It could be seen that for category "population individual heating" by biomass type "wood logs" in the equipment "stoves" it is not relevant till 2050 (half of the wood logs potential utilization provides up to 9% natural gas substitution). However, for example in total for category "population" (cell # N39) natural gas substitution is 45% in 2050 (compared to NG consumption level in 2015) which is relevant. On default, if the NG replacement exceeds 100% of current the figures are adjusted accordingly and recalculation cycle started. The NG substitution figures can be entered manually as the initial prerequisite of the scenario and then will serve as the threshold indicator for calculation.

The columns "S" and "T" represent the needed investments for the implementation of estimated equipment. These figures are used as the upper thresholds to monitor the amount and trend of the investment for modeling period to avoid rapid increasing or drops. In the presented example the investments does not influence on final results because of the implementation of relatively cheap and tested technologies so that total investments are below the determined upper limit of the model which is calculated on the basis of benchmark indicators of investment trends in the respective sector/category for previous years (2012-2015) in Ukraine and taking into account the best practices in the EU-27 in respective sector/category. However, if for example in category "population" we will assume implementation of some expensive technologies (for instance, "Stirling engines for individual heating and power production" "Solar PV+heat pumps nearly zero building", "bio-oil for heating", etc.) or if conventional technologies will be overestimated, then the investments will grow rapidly and will mark such scenario as not economically feasible, starting recalculation cycle of model until the investment benchmarks will come back to defined limits.

Another part of the fixed points for modeling results adjustments is total biomass potential utilized by all categories (see Table 2.13). One of the possible examples of final consolidated data for heating sector with respect to biomass potential utilization is presented above. It could be seen, that "wood waste biomass" and "sunflower husk primary waste" potentials are exceeded which means that the consumption of equipment estimated in the scenario is overestimated. At the same time utilization of "secondary waste of agrosector" is on the much lower level of 61%, which signalize about possible underestimation of this biomass type. Biogas utilization is on the level of 29% however this can be considered as normal result because according to the modeling assumptions for this scenario biogas is not used much in heating, but in power generation and biomethane production. In this case the calculation needs to be

adjusted respectively for balancing of biomass utilization for each type and possible decreasing of estimated equipment quantities.

The model also is adjusted by the ratio of heat energy produced by biomass boilers and CHPs. For example, below the ratio for each step of modeling is presented for the same calculated scenario. The range of this ratio in normal trend of energy sector development is between 15% and 30%. In 2015 and in 2050 this ratio is exceeding the normal range. For 2015 it is caused by statistical data and this figure shall not be adjusted. Figure for 2050 is result of the calculation so it shall be adjusted with proportional decreasing of CHP input (including biogas) and increasing of boilers input.

billion m3

	Natural gas substitution from boiler houses only	Natural gas substitution from CHP only	Ratio CHP/boilers
2015	3,05	0,10	**3,1%**
2020	6,12	1,10	18,0%
2025	7,32	1,34	18,3%
2030	9,53	1,58	16,6%
2035	11,15	1,86	16,7%
2040	12,19	2,40	19,7%
2045	12,90	3,22	24,9%
2050	13,72	4,35	**31,7%**

Additionally the model includes the block of final result adjustments for whole sector "heating" with respect to natural gas substitution in GFEC for all categories. For each step of the modeling the natural gas substitution levels are determined. For the example below it could be seen that in 2020 natural gas substitution in sector "heating" is 7.2 billion m3, which fully corresponds with the NREAP 2020 target for heating (so the calculation is right because this was initial scenario prerequisite). For 2050 the calculated figure is 18 billion m^3, which comprise 50% substitution.

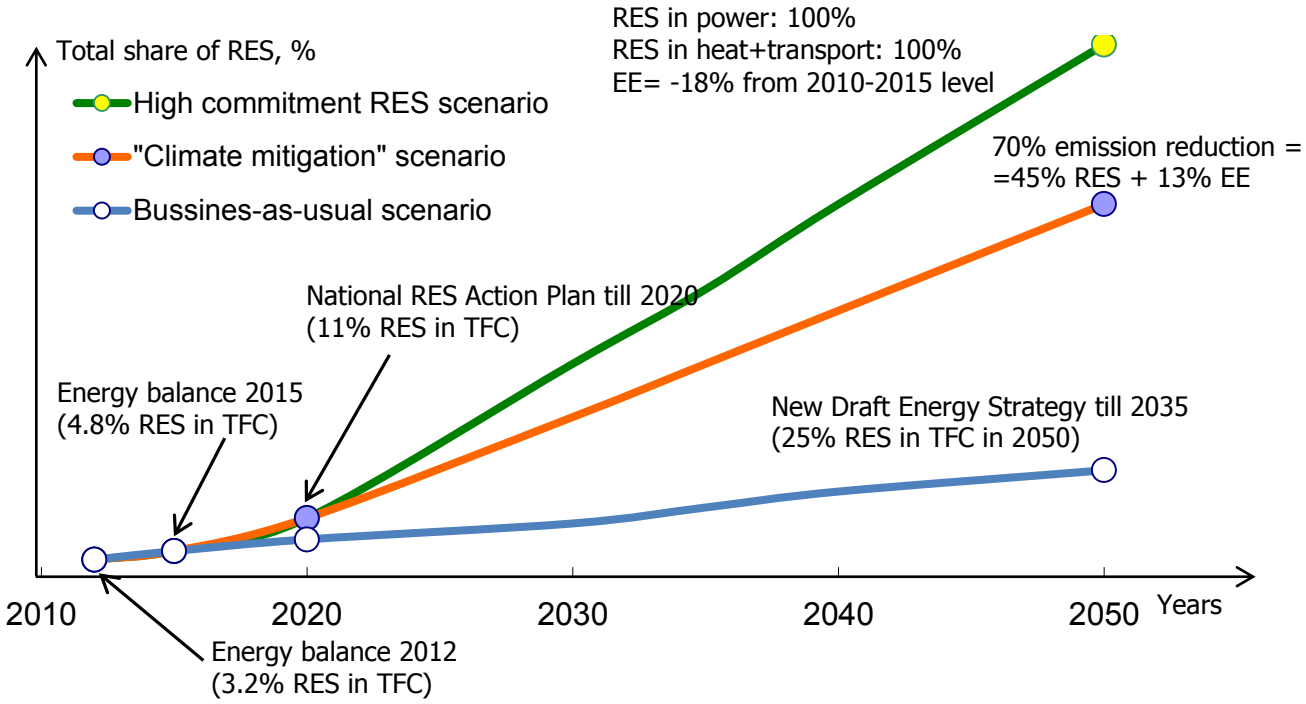
	Natural gas substitution, billion m3/year				
	Population	District heating ar	Industry	TOTAL	
2015	0,97	0,09	2,09	3,15	**8,75%**
2020	2,63	1,66	2,93	7,22	**20,05%**
2025	3,34	1,91	3,42	8,66	**24,06%**
2030	4,85	2,28	3,98	11,11	**30,87%**
2035	5,68	2,70	4,63	13,01	**36,15%**
2040	6,27	3,06	5,25	14,58	**40,50%**
2045	6,68	3,63	5,82	16,12	**44,78%**
2050	7,18	4,35	6,53	18,07	**50,18%**
Total substitution in 2050 out of NG consumption in 2015				**50,18%**	

Depending on the scenario, some limits or indicative targets of the NG substitution in heating sector could be incorporated here. For example, if we incorporate target according to Climate action scenario "70% GHG emission reductions in 2050" the respective natural gas substitution in heating could be incorporated proportionally as "-70% natural gas utilization in 2050". This will adjust the data on equipment used (proportionally: +20% increase of natural gas substitution and as consequence biomass energy production). However, if at the same time biomass potential will be not enough to achieve such target or investment volumes will rise extremely rapidly in comparison with previous periods, then model recalculates data in the way when all conditions are met. This may, in its turn, change proportional distribution of target -70% and adjust it according to the new calculation data. This is the key idea of the modeling approach: to reduce the uncertainty of modeling result making recalculations according to strictly defined thresholds from different points of view.

While all the limitations and constraints for chosen initial conditions are settled down by model the calculation is deemed final and the data on energy values (toe) of RES utilization till 2050 is presented as separate trajectory for scenario which corresponds to set up initial conditions at the scenario identification stage.

8. Description of the proposed scenarios for energy sector development till 2050 with enhancing targets of RES: prerequisites, assumptions and limitations.

It is foreseen to develop three different scenarios under described modeling approach. Each of the scenarios represents the separate way of energy sector transition till 2050 and is linked with three separately determined trends of energy sector development. These trends are set up by the individual initial conditions for the model. They are connected with obligations of Ukraine and determined ex ante on the basis of the known and estimated identified targets. The schematic diagram representing three trajectories for three scenarios is presented below.



8.1. Scenario 1: Baseline scenario.

The scenario represents continuation of current practice in energy sector development. Under this scenario the dominant role of fossil fuel energy generation is stipulated, however some progress is also foreseen in renewable energy and energy efficiency development according to current obligations and legislative framework of Ukraine. GHG emissions in 2050 shall not exceed 40% in comparison with current level (INDC level for 2035 submitted under Paris Agreement).

All regulatory framework existing at present time for support of renewables and bioenergy is fully working, including "green" tariff for electricity production, natural gas price equalization for population, district heating, industry and budget/public heating, state credit programmes, equalization of tariffs on heat from biomass and fossil fuels, preferential energy efficiency programmes.

The following assumptions are applied for the scenario:

- National Renewable Action Plan: fulfilled 100% in biomass part in 2050, 50% fulfillment for RES targets (without biomass) in TFC in 2020;
- Energy efficiency: 9% decreasing of TFC in 2050 in comparison with average 2010-2015 level.
- Suspended fulfillment of New Energy Strategy till 2035: 25% RES share in TFC in 2050 (in comparison with 2015 level);
- Current INDC target: 40% GHG emission reduction shall not be exceeded in 2050.
- Liquid biofuels share in transport: 5% in 2050 (bearing in mind transport energy consumption in 2015=2050).
- Solar energy potential utilization: 100% in 2050 according to IRENA REMAP 2030 data (4.2 Mtoe);
- Biomass as the leading source of renewable energy for all points 2015-2050.

8.2. Scenario 2: Climate Action scenario

The scenario is linked to the potential climate obligations of Ukraine under Paris Agreement and European Union in frames of Association with the EU Member states – 70% emission reductions in 2050 to 2015 level. It is stipulated that climate obligations may be fulfilled by the increasing of energy production from renewables from one side and reduction of energy consumption from the other side as well as the restructuring of energy supply from fossil fuels (+12% additional reductions).

The assumption is that 70% reduction shall be achieved in energy sector as combination of energy efficiency, renewables and fossil fuel generation restructuring in proportion: 13%/45%/12% respectively.

The following assumptions are applied for the scenario:

- National Renewable Energy Action Plan: 50% fulfillment of all targets in 2020;
- Energy efficiency: 13% decreasing of TFC in 2050 in comparison with average 2010-2015 level;
- 45% RES share in 2050 to average 2010-2015 TFC levels;
- New Energy Strategy till 2035: 25% RES share in TFC in 2035;

- Revised GHG emission reduction target: 70% GHG emission reduction in 2050 in comparison with 2015;
- Implementation and fulfillment of Directives #2009/75/EC (on particle matters, SOx, NOx emissions from LCP) and Directive # 2009/87/EC aimed on UA ETS implementation.
- Liquid biofuels share in transport: 10% in 2050 (bearing in mind transport energy consumption 2015=2050).

8.3. Scenario 3: High commitment 100% RES scenario

The scenario is linked to the "maximum possible efforts" case in developments of renewable energy and energy consumption decreasing. It is defined by the indicative targets of 100% RES share in power, heat and transport sectors. On such level of RES utilization there are some critical limitations with respect to energy system stability, investment volumes needed, total renewable energy potential available in Ukraine, general economic conditions during modeling period. It includes incorporation of all possible regulatory incentives for bioenergy, opening and supporting of large scale of direct financing programmes, realization of large scale power and heat generation projects as serial stable technologies. All stakeholders (including population) take active part in the process, starting from 2035 the obligatory targets for stakeholders on RES shares in energy consumption with penalties of non-fulfillment are incorporated. Fully competitive markets of heat and electricity create more possibilities to attract financial sources. High productive agrosector and growth of wood processing and wood management industries provides as far as twice biomass potential in 2050 in comparison with 2015.

Decreasing of total TFC is performed due to the obligations of implementation of energy efficiency measures for old and new constructions through regulative mechanisms, introduction of state standards on energy consumption for special building type, development of the nearly-zero energy buildings concept which is becoming standard practice for new construction after 2035.

Regulatory framework includes the following minimum efforts:

- State support in form of co-financing of such project with 20-40% state guaranteed payback of loan ("warm credit" lines);
- Improvement of mechanism of state co-financing of renewable energy projects (return of capital investments share and/or bank interest rate);
- Incentive mechanisms for renewable energy facilitation in heat generation and CHP generation: "feed-in" heat tariff, "green" energy premium;
- Establishment of the internal biofuel market and related issues (biofuel stock exchange, certification procedures, sustainability requirements implementation, etc.)
- Establishment of procedure for simplification of access of business to the existing forest and agro residues;
- Establishment of an effective mechanism of energy cooperatives launching;
- Introduction of Energy tax and/or carbon tax ;

- Launching of UA ETS from 2020, linking with EU ETS from 2025;
- Introduction of "low carbon energy premium" for low carbon projects technological chain cycles and related activities (supply chain, production of equipment, energy efficiency measures from supply side, etc.);
- Establishment of basis for biomethane production (introduction of primary and secondary legislation, certification system, national biomethane registry, added green tariff for biomethane-to-power);
- Establishment of incentive mechanism for use of biomass capacities for balancing of energy system (peak load coverage);
- Establishment of waste-to-energy incentive tariff.
- Application of obligatory dynamic share of biomass and renewable energy for new buildings.
- For supply side obligatory energy marking with energy efficient class with minimum requirements of efficiency of equipment (for example, restriction for new biomass boilers implementation with efficiency less than 90 % after 2035).

The following assumptions are applied for the scenario:

- National Renewable Energy Action Plan: 100% fulfillment of all targets in 2020;
- Energy efficiency: 18% decreasing of TFC in 2050 in comparison with average 2010-2015 level;
- Trend of TFC from RES growth (average) is up to 4%/year;
- For the period 2040-2050 TFC is starting decreasing to meet 100% RES in 2050;
- 100% emission reductions in 2050;
- Liquid biofuels share in transport: 15% in 2050 (bearing in mind transport energy consumption 2015=2050).
- Solar energy potential utilization: 100% in 2050 according to LUT transition model data (11.7 Mtoe).

9. Key figures of energy sector transition till 2050 as per identified scenarios.

9.1. Scenario 1: Baseline scenario

The scenario is representing less ambitious development of RES sector. It is normalized according to limitations and interim targets extrapolation of current trends of RES developments. The key thresholds are: achievement of 50% NREEAP-2020 targets for all RES in 2020 and for biomass – 100% target in 2050, and achievement of 23% RES in 2050 in TPES.

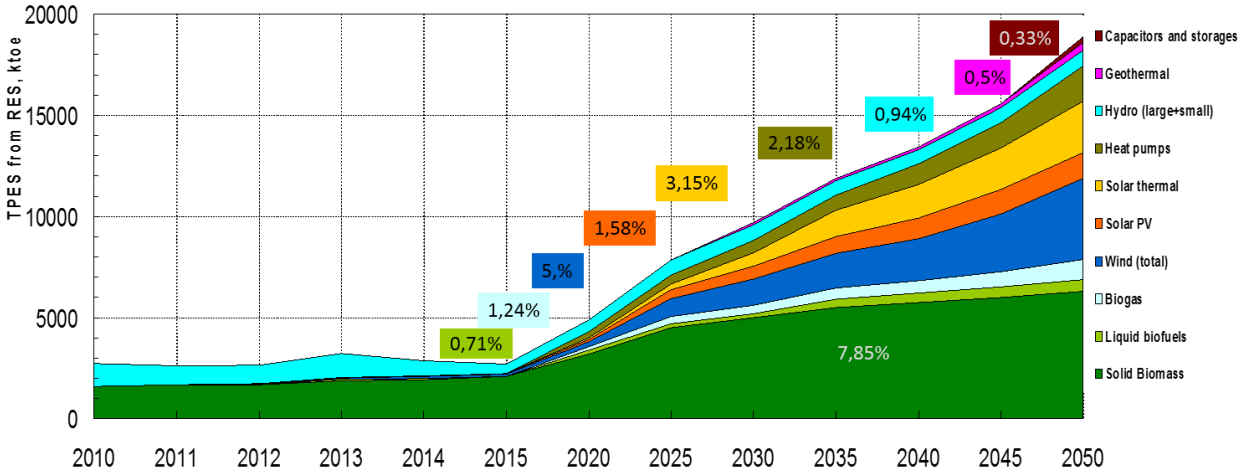


Figure 9.1. Development of TPES from RES 2010-2050, ktoe/year

Primary energy supply from RES in 2050 equals to 18.86 Mtoe or 24% from total primary energy supply (80.32 Mtoe in 2050). Biomass, wind, solar and heat pumps provide main input in renewable energy TPES, hydro generation is remaining stable without growth and decrements. Share of biomass in TPES in 2050 equals to 9.8%, used mainly in heat production sector. Biomass share from total primary energy supply of all RES equals to 41.7% in 2050.

Table 9.1. Share of biomass and other renewables in total RES (TPES) in Baseline Scenario, %

RES types	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Biomass + Biogas + Biofuels	58.4	63.9	64	59.9	69.7	78.3	72.8	64.2	57.7	54.5	50.7	46.7	41.7
Wind	0.2	0.3	0.9	1.7	3.4	3.5	5.2	11.3	13.5	14.3	15.4	18.3	21.3

Solar PV + thermal	-	0.1	1.1	1.5	1.3	1.3	4.2	9.1	13.5	17.9	20.1	21.0	20.1
Heat pumps	-	-	-	-	-	-	6.1	5.7	6.2	6.3	7.4	8.0	9.3
Hydro	41.4	35.7	34.0	36.9	25.6	16.9	11.7	9.7	8.1	6.1	5.2	4.7	4.0
Geothermal	-	-	-	-	-	-	-	-	1.0	0.8	1.1	1.3	2.1

Scenario includes some additional capacity of non-fossil energy capacitors (in power generation) equals to 0.263 Mtoe in 2050 (see the basic assumptions in next section for climate action scenario).

Solar PV and solar heat together achieve 4.2 Mtoe in 2050 or 100% from total solar potential provided in section 2.

Figure 9.2. RES and energy savings (TPES – upper graph and TFC – lower graph) against conventional fuels, ktoe/year

TPES in 2050 is 30% less in comparison with average 2010-2015 level (80.32 against 115.49 ktoe), TFC is 9% less. The average decrement of TFC is 0.25%/year.

Table 9.2. TPES and TFC of Baseline scenario, 2010-2050, ktoe

2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Total primary energy supply												
132308	126438	122488	115940	105683	90090	91000	89000	87000	85000	83000	81500	80328
Fossil fuels and nuclear energy												
129576	123805	119839	112697	102822	87390	86112	81142	77306	73130	69569	65941	61470
Energy efficiency												
-	-	-	-	-	-	24491	26491	28491	30491	32491	33991	35163
Solid biomass												
1597	1682	1695	1879	1934	2102	3200	4500	5000	5500	5750	6000	6302
Biogas												
-	-	-	-	-	14.3	162	350	400	550	600	750	1000
Wind												
4.29	7.63	24.69	54.77	96.86	93.2	253.5	890	1305	1700	2075	2853	4016
Solar PV												
0.09	2.57	28.54	48.86	36.77	40.97	104	445	653	850	1037.5	1222.5	1269.2
Solar thermal												
-	-	-	-	-	-	100	267	653	1275	1660	2038	2530
Heat pumps												
-	-	-	-	-	-	300	450	600	750	1000	1250	1750
Hydro (large + small)												
1131	941	901	1187	729	464	573.5	761	789	728	696	733	756
Geothermal												
-	-	-	-	-	-	-	-	100	100	150	200	400
Liquid biofuels												
-	-	-	48.4	42.4	35.1	195	195	195	416	463	514	571
Capacitors and storages												
-	-	-	-	-	-	-	-	-	-	-	-	263
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total final consumption												
74004	75852	73107	69557	61460	50831	52273	53155	54382	55964	57540	59423	61561
Industry												
25327	26253	24845	21864	20570	16409	17940	18242	18664	19206	19747	20393	21127
Transport												
12627	12611	11448	11280	10327	8750	8947	9098	9308	9579	9849	10171	10537

Residential												
23 813	23 604	23 466	23 495	20 384	16 554	16 366	16 643	17 027	17 522	18 016	18 605	19 274
Commercial												
4 643	4 802	5 037	5 745	4 663	3 838	3 530	3 590	3 673	3 780	3 886	4 013	4 158
Agriculture												
2 036	2 246	2 195	2 242	2 016	1 961	1 563	1 589	1 626	1 673	1 720	1 776	1 840
Other												
5 547	6 008	6 116	4 932	3 500	3 318	3 900	3 966	4 057	4 175	4 293	4 433	4 593

Table 9.3. Employment in RES sectors according to Baseline scenario

RES type	2015	2020	2025	2030	2035	2040	2045	2050
Solid Biomass	8408	12800	18000	20000	22000	23000	24000	25208
Biogas	100	1131	2450	2800	3850	4200	5250	7000
Wind	872	2282	8010	11745	15300	18675	25673	36148
Solar PV	404	1144	4895	7178	9350	11413	13448	13961
Solar thermal	0	400	1068	2610	5100	6640	8150	10121
Heat pumps	0	3000	4500	6000	7500	10000	12500	17500
Geothermal	0	0	0	600	600	900	1200	2400
Liquid Biofuels	263	1463	1463	1463	3123	3471	3856	4285
Total in RES	**10048**	**22219**	**40386**	**52395**	**66823**	**78298**	**94076**	**116623**

9.2. Scenario 2: Climate action scenario

The scenario is representing climate-oriented development of energy sector, out of which RES sector and energy efficiency provide main input, while restructuring of fossil fuel generation also provide additional input into emission reductions. It is linked to the potential climate action target of 70% emission reduction in 2050 in comparison with 2015. The key thresholds are: achievement of 50% NREEAP-2020 targets in 2020, achievement of 25% RES in 2035-2040 period in TPES.

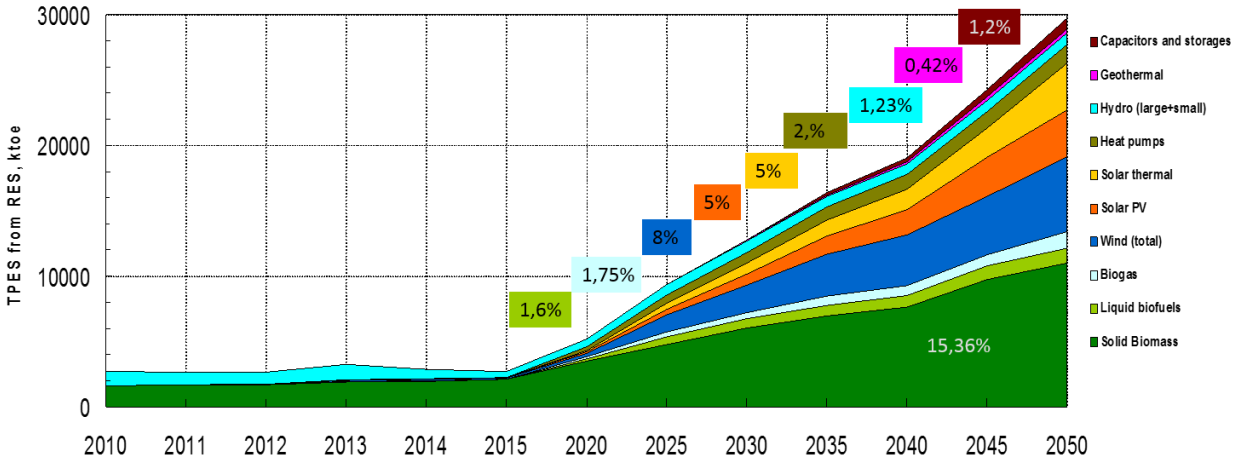


Figure 9.3. Development of all RES 2010-2050, ktoe/year

Primary energy supply from RES in 2050 equals to 29.7 Mtoe or 42% from total primary energy supply (71.62 Mtoe in 2050). Biomass, solar heat and heat pumps provide main input in heating, wind, solar PV, hydro and biogas provide main power RES input in TPES. Total share of biomass in TPES in 2050 equals to 18.7%, used in heat production sector and in power production mostly in CHP regime. Biomass share from total primary energy supply of all RES equals to 45% in 2050.

Table 9.4. Share of biomass and other renewables in total RES (TPES) in Climate Action Scenario, %

RES types	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Biomass + Biogas + Biofuels	58.4	63.9	64	59.9	69.7	78.3	74.3	61.3	56.6	51.6	48.7	47.9	45.0
Wind	0.2	0.3	0.9	1.7	3.4	3.5	4.9	13.9	16.3	19.6	20.3	18.4	19.3
Solar PV + thermal	-	0.1	1.1	1.5	1.3	1.3	3.9	9.3	13.1	15.9	18.3	21.5	24.1
Heat pumps	-	-	-	-	-	-	5.8	6.9	6.5	6.1	6.1	5.4	4.8

Hydro	41.4	35.7	34.0	36.9	25.6	16.9	11.1	8.5	6.6	4.9	4.1	3.4	3.0
Geothermal	-	-	-	-	-	-	-	-	0.8	0.6	1.0	1.2	1.0

Scenario includes additional capacity of non-fossil energy capacitors (in power generation) equals to 0.857 Mtoe in 2050. The basic assumption is that after total RES production exceeds 13 Mtoe (i.e. 50% from current energy supply in power sector for 2015) in TPES and/or RES share in TPES is more than 20%, whichever is true, fossil fuel grid balancing capacities are not enough to provide stable grid functioning. For each installed capacity of solar PV and wind in power generation additional installed capacity shall be reserved as capacitors conditionally equaling 20% additional energy supplied. Biomass and biogas are considered at the same time self-regulated capacities, which operate in stable base load and does not need additional compensation loads (also the forecasted share of biomass and biogas is quite low in power generation in comparison with other sources). Hydro generation needs only 75% as much capacitors as other sources because it already have accumulation capacities currently used for compensation of peak loads, so this type of generation can make self-regulation.

Another additional distinguishing feature of climate action scenario in comparison with baseline is much higher quantity of solar PV and solar heat installations. During the first run of the model the solar energy potential used (4.2 Mtoe) limited solar energy development too much, providing very low figure of its share from total RES (2% in 2050), which was considered as not consistent. If such a limit is strictly followed the scenarios are not well balanced, so that solar share in total RES (in TPES) does not change much from baseline to climate action and from climate action to high commitment So additional efforts has been done to find the background to enhance solar potential so it shall not limit this sector development. The following table provides comparison of solar energy potentials by different sources. Most of them provide the low potential 4.1-5.1 Mtoe (PV+heating). However the renewed data of LUT transition model[42] for Ukraine was found and is considered as more precise and consistent. After second run of the model with new data, the climate action and 100% RES scenario demonstrated more balanced share of solar PV and solar heat as two RES components. This data is used for limitation for climate action and 100% RES scenarios. The total energy from Solar PV and Solar heat in climate action equals to 7.1 Mtoe (3.5 Mtoe each) in 2050 (10% in TPES, 5% each).

Table 9.5. Solar energy utilization potential from different sources

[42] http://www.neocarbonenergy.fi/wp-content/uploads/2016/02/3_Child.pdf

Source	Type	Year	GW installed	TWh/ year	Energy, ktoe	Comment
USELF, Black & Veatch	Solar PV	2011	12.5		1 286	
Konechenkov expert data	Solar PV	2009		16	4 156	
	Solar heat	2009		75	6 429	
Ost-Ausschuss der Deutschen Wirtschaft	Solar total	2010		28.8	4 200	
IRENA REMAP 2030	Solar PV	2015			1 400	
	Solar heat	2015			2 800	
Atlas of RES of Ukraine, Kudrya	Solar PV			5.7	1 400	
	Solar heat	2009		32.5	2 800	
Polish Institute of International Affairs	Solar PV	2015		5,6	1 375	
	Solar heat	2015		32.5	2 786	
	Geothermal*	2015		97	8 314	
IEA Road Map 2050	Solar PV*	2014	229		23 554	for EU-28 overall in 2050[43]
	Solar heat	2014	28		12 480	
OECD Programme	Solar PV	2012		5	1 299	
BF Consulting estimation per regions	Solar total	2014			3 500	
	Biomass**	2014			15 050	
Michael Child LUT transition model	Solar theoretical total	2016		720	62 000	Over-estimated theoretical potential
	Solar technical	2016		34	2 920	

[43] Forecast for EU-28 till 2050. Making the assumptions, that the territory of EU-28=4.47 million km^2, the territory of Ukraine=0.603 million km^2, average solar radiation factor for EU-28 equals Ukrainian (1000 kWh/m^2), we can assume that in 2050 for Ukraine solar total potential may be defined as ratio between areas: 4.47/0.63=(23.55+12.48)/x, where x=5.1 Mtoe, which corresponds with most of other sources

Heinrich Boll 100% RES	Solar total calculated in model	2017		132*	11340***	

* - corresponds to IRENA REMAP 2030 and SAEE, so taking into consideration for the model
** - for information purposes
*** - figure used as enhanced solar potential for climate action and 100% RES scenarios

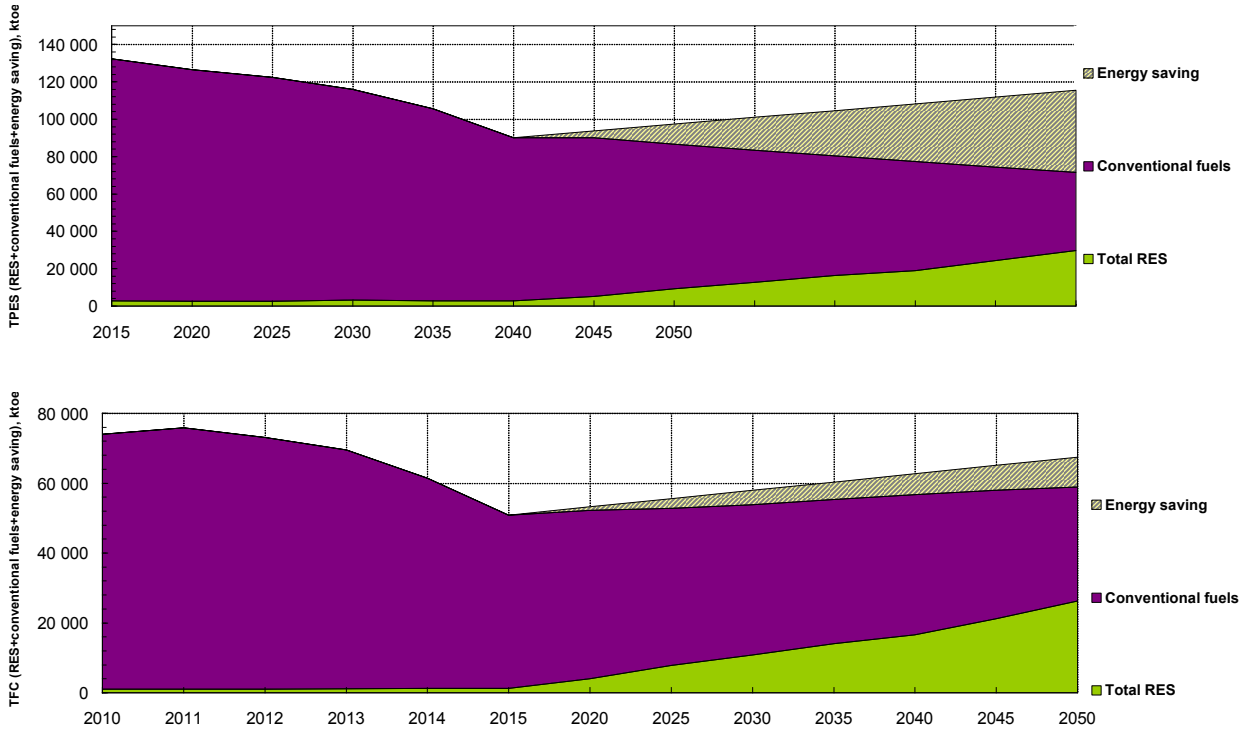


Figure 9.4. RES and energy savings (TPES – upper graph and TFC – lower graph) against conventional fuels, ktoe/year

TPES in 2050 is 38% less in comparison with average 2010-2015 level (71,620 ktoe against 115,491 ktoe), TFC is 13% less in comparison with 2010-2015 TFC average.

Table 9.6. TPES and TFC of Climate action scenario, 2010-2050, ktoe

2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Total primary energy supply												
132308	126438	122488	115940	105683	90090	90090	86712	83460	80330	77318	74418	71629
Fossil fuels and nuclear energy												
129576	123805	119839	112697	102822	87390	84912	77354	70698	63957	58264	50163	41871
Energy efficiency												
-	-	-	-	-	-	25401	28780	32031	35161	38173	41073	43863
Solid Biomass												

1597	1682	1695	1879	1934	2102	3489	4769	6039	6952	7616	9750	11000
Biogas												
-	-	-	-	-	14.3	162	400	500	700	750	850	1250
Wind												
4.29	7.63	24.69	54.77	96.86	93.2	254	1301	2087	3213	3866	4465	5730
Solar PV												
0.09	2.57	28.54	48.86	36.77	40.97	104	434	835	1406	1933	2977	3581
Solar thermal												
-	-	-	-	-	-	100	434	835	1205	1546	2233	3581
Heat pumps												
-	-	-	-	-	-	300	650	835	1004	1160	1302	1433
Hydro (large + small)												
1131	941	901	1187	729	464	574	799	847	795	775	834	881
Geothermal												
-	-	-	-	-	-	-	-	100	100	200	300	300
Liquid Biofuels												
-	-	-	48.4	42.4	35.1	195	571	686	800	914	1028	1143
Capacitors and storages												
-	-	-	-	-	-	-	-	-	198	294	516	858
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total final consumption												
74004	75852	73107	69557	61460	50831	52273	52765	53874	55385	56718	57996	58927
Industry												
25327	26253	24845	21864	20570	16409	17 940	18 108	18 489	19 008	19 465	19 904	20 223
Transport												
12627	12611	11448	11280	10327	8750	8 947	9 031	9 221	9 480	9 708	9 927	10 086
Residential												
23 813	23 604	23 466	23 495	20 384	16 554	16 366	16 520	16 868	17 341	17 758	18 158	18 450
Commercial												
4 643	4 802	5 037	5 745	4 663	3 838	3 530	3 564	3 639	3 741	3 831	3 917	3 980
Agriculture												
2 036	2 246	2 195	2 242	2 016	1 961	1 563	1 577	1 611	1 656	1 696	1 734	1 762
Other												
5 547	6 008	6 116	4 932	3 500	3 318	3 900	3 937	4 019	4 132	4 231	4 327	4 396

Table 9.7. Employment in RES sectors according to Climate action scenario

RES type	2015	2020	2025	2030	2035	2040	2045	2050
Solid Biomass	8408	13957	19077	24156	27809	30465	39000	44000
Biogas	100	1135	2800	3500	4900	5250	5950	8750
Wind	872	2282	11706	18778	28919	34793	40186	51572
Solar PV	404	1144	4769	9181	15464	21262	32744	39395
Solar thermal	0	400	1734	3338	4820	6185	8930	14326
Heat pumps	0	3000	6503	8346	10041	11598	13023	14326
Geothermal	0	0	0	600	600	1200	1800	1800
Liquid Biofuels	263	1463	4285	5142	5998	6855	7712	8569
Total in RES	**10048**	**23381**	**50874**	**73042**	**98551**	**117609**	**149346**	**182738**

9.3. Scenario 3: 100% RES high commitment scenario

The scenario is representing highest efforts in RES developments. It is linked to the 100% RES share in TPES and TFEC in 2050 in all sectors (power+heating/cooling+transport). The key thresholds are: achievement of 100% NREEAP-2020 targets in 2020, achievement of 46% reduction of TPES in 2050 in comparison with 2010-2015 level, 18% reductions in GFEC, 15% share of biofuels in TFEC on transport.

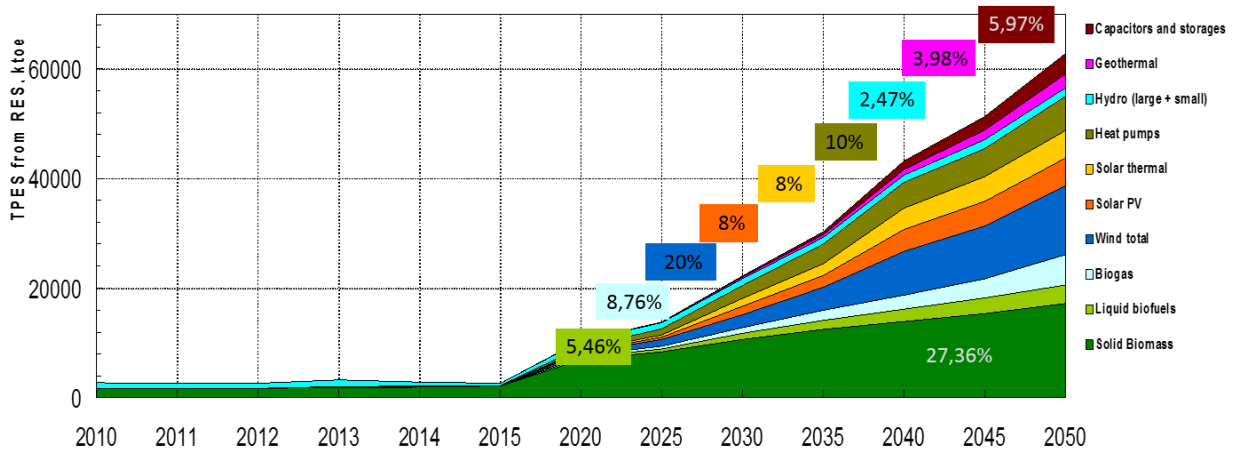


Figure 9.5. Development of all RES 2010-2050 according to 100% RES scenario, ktoe/year

Primary energy supply from RES in 2050 equals to 62.75 Mtoe (100% from total primary energy supply in 2050). All RES types are more or less proportionally engaged in achieving the target,

the priority is for biomass, solar and wind power production. Total share of biomass in TPES in 2050 equals to 41.6%, used in heat production sector, liquid biofuel production and power production.

Table 9.8. Share of biomass and other renewables in total RES (TPES) in High Commitment Scenario, %

RES types	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Biomass + Biogas + Biofuels	58.4	63.9	64.0	59.9	69.7	78.3	73.9	68.0	57.7	52.5	43.2	42.4	41.6
Wind	0.16	0.29	0.93	1.70	3.41	3.52	4.87	8.98	10.33	14.04	18.46	18.73	20.0
Solar PV + thermal	-	0.10	1.08	1.52	1.29	1.34	3.92	5.99	13.78	14.04	18.46	17.48	16.0
Heat pumps	-	-	-	-	-	-	5.76	7.49	10.33	11.70	10.77	9.99	10.0
Hydro	41.39	35.74	34.01	36.86	25.65	16.88	11.01	8.52	5.62	4.18	3.18	3.18	2.47
Geothermal	-	-	-	-	-	-	0.58	0.43	1.13	1.65	2.31	3.41	3.98

Scenario includes much higher share of energy capacitors and accumulators (in power generation), especially high growth of capacitors is for the period 2035-2050 and equals to 3,746 ktoe in 2050 (6% from TPES). No fossil fuels are foreseen to perform grid regulation issues, only biomass capacities, hydro accumulation and other types of capacities and storages are used for this purpose in power sector. In addition, scenario foresees the highest share of biofuels increased to 3.4 ktoe/year (15% share on transport, another 85% is provided by plug-in grid electricity from RES).

TPES in 2050 is 38% less in comparison with average level 2010-2015 (62,750 ktoe against 115,491 ktoe), TFC is 18% less.

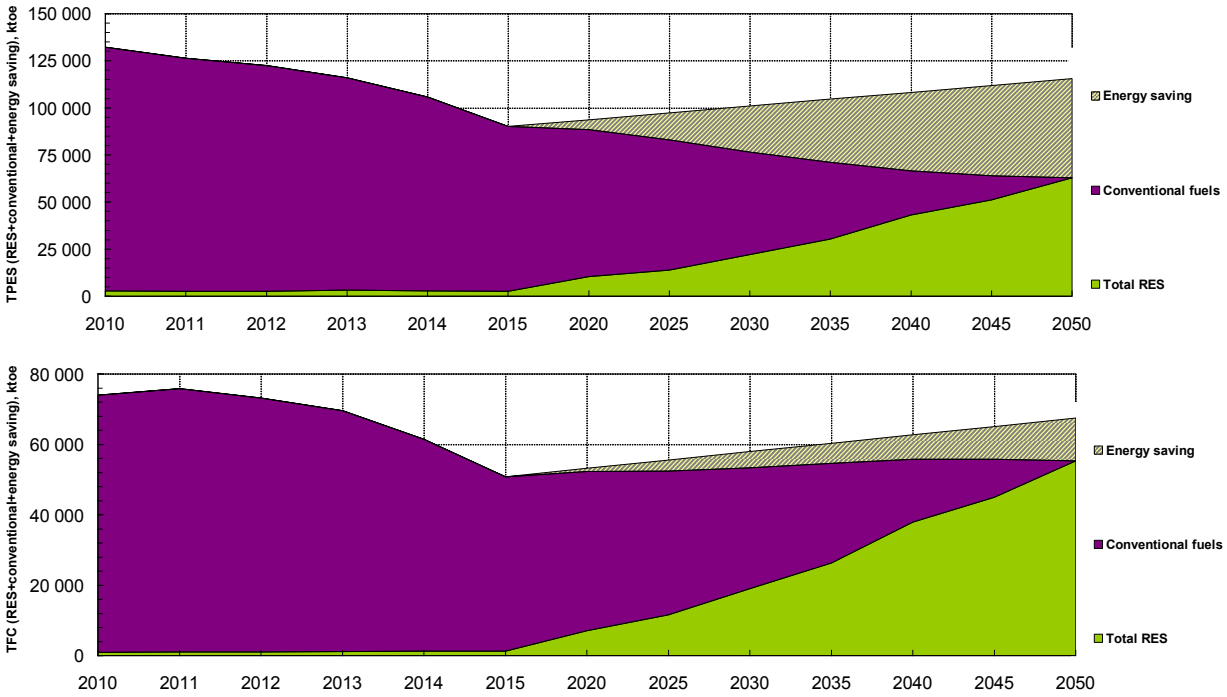


Figure 9.6. RES and energy savings (TPES – upper graph and TFC – lower graph) against conventional fuels, ktoe/year

Table 9.9. TPES and TFC of 100% RES scenario, 2010-2050, ktoe

2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Total primary energy supply												
132308	126438	122488	115940	105683	90090	88500	83000	76500	71000	66500	64000	62750
Fossil fuels and nuclear energy												
129576	123805	119839	112697	102822	87390	78084	69143	54287	40667	23268	12751	-
Energy efficiency												
-	-	-	-	-	-	26991	32491	38991	44491	48991	51491	52741
Solid Biomass												
1597	1682	1695	1879	1934	2102	6978.7	8356.4	10665	12458	13896	15383	17169
Biogas												
-	-	-	-	-	14.3	325	500	1000	1750	2500	3500	5500
Wind												
4.29	7.63	24.69	54.77	96.86	93.2	507	1245	2295	4260	7980	9600	12550
Solar PV												
0.09	2.57	28.54	48.86	36.77	40.97	208	415	1530	2130	3990	4480	5020

Solar thermal												
-	-	-	-	-	-	200	415	1530	2130	3990	4480	5020
Heat pumps												
-	-	-	-	-	-	600	1037.5	2295	3550	4655	5120	6275
Hydro (large + small)												
1131	941	901	1187	729	464	1147	1180	1248.2	1268.6	1375	1631.8	1547
Geothermal												
-	-	-	-	-	-	60	60	250	500	1000	1750	2500
Liquid Biofuels												
-	-	-	48.4	42.4	35.1	390	571.3	1142.6	1713.8	2285	2856.4	3427.7
Capacitors and storages												
-	-	-	-	-	-	-	76.4	257.1	572.6	1560.2	2448.6	3746
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total final consumption												
74004	75852	73107	69557	61460	50831	52273	52383	53290	54647	55771	55724	55 362
Industry												
25327	26253	24845	21864	20570	16409	17 940	17 977	18 289	18 754	19 140	19 124	19 000
Transport												
12627	12611	11448	11280	10327	8750	8 947	8 966	9 121	9 354	9 546	9 538	9 476
Residential												
23 813	23 604	23 466	23 495	20 384	16 554	16 366	16 401	16 685	17 110	17 462	17 447	17 333
Commercial												
4 643	4 802	5 037	5 745	4 663	3 838	3 530	3 538	3 599	3 691	3 767	3 764	3 739
Agriculture												
2 036	2 246	2 195	2 242	2 016	1 961	1 563	1 566	1 593	1 634	1 667	1 666	1 655
Other												
5 547	6 008	6 116	4 932	3 500	3 318	3 900	3 908	3 976	4 077	4 161	4 157	4 130

Table 9.10. Employment in RES sectors according to 100% RES scenario

RES type	2015	2020	2025	2030	2035	2040	2045	2050
Solid Biomass	8408	27915	33426	42661	49831	55585	61530	68676
Biogas	100	2275	3500	7000	12250	17500	24500	38500
Wind	872	4563	11205	20655	38340	71820	86400	112950
Solar PV	404	2288	4565	16830	23430	43890	49280	55220

Solar thermal	0	800	1660	6120	8520	15960	17920	20080
Heat pumps	0	6000	10375	22950	35500	46550	51200	62750
Geothermal	0	360	360	1500	3000	6000	10500	15000
Liquid Biofuels	263	2925	4285	8569	12854	17139	21423	25708
Total in RES	**10048**	**47126**	**69375**	**126285**	**183724**	**274444**	**322753**	**398884**

9.4. Scenario comparison

The main differences in scenarios are: TPES and TFC dynamics (energy efficiency), RES share in TPES, total energy produced and supplied by RES, annual average increment of TPES from renewables. Below on the diagrams the main differences of the scenarios are demonstrated.

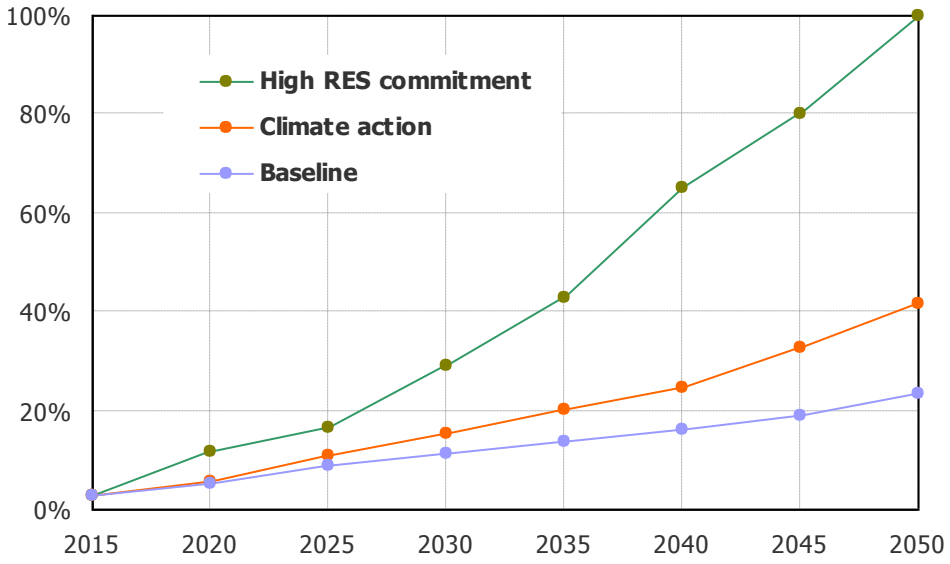


Figure 9.6. Share of RES in TPES for three scenarios, %

Total share of RES in 2050 are 24 %, 42% and 100% in TPES for baseline, climate action and high commitment scenarios respectively.

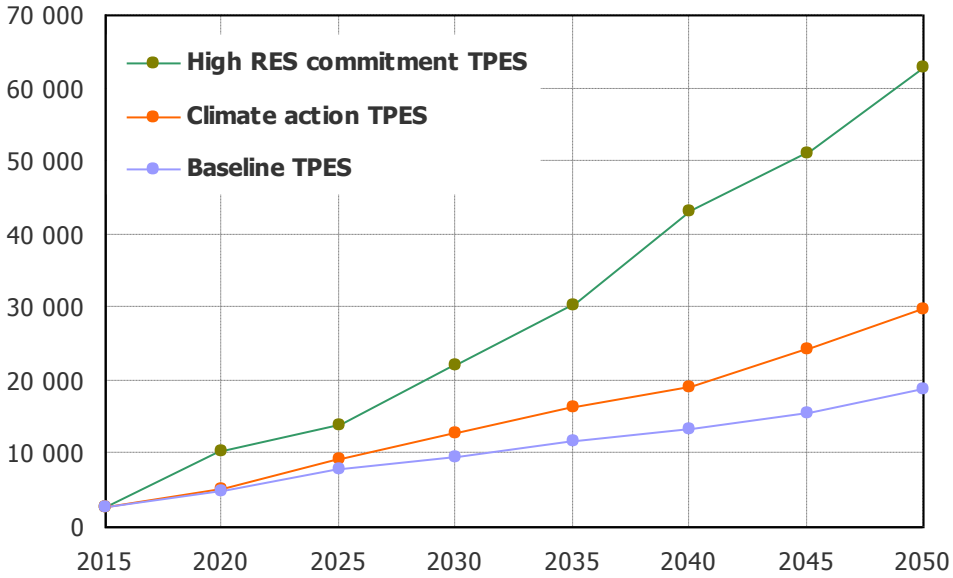


Figure 9.7. TPES from RES for three scenarios, ktoe/year

TPES from RES in 2050 is 18.86, 29.75 and 62.75 Mtoe for baseline, climate action and high commitment scenarios respectively and TFC is 16.74, 26.3 and 55.36 Mtoe respectively.

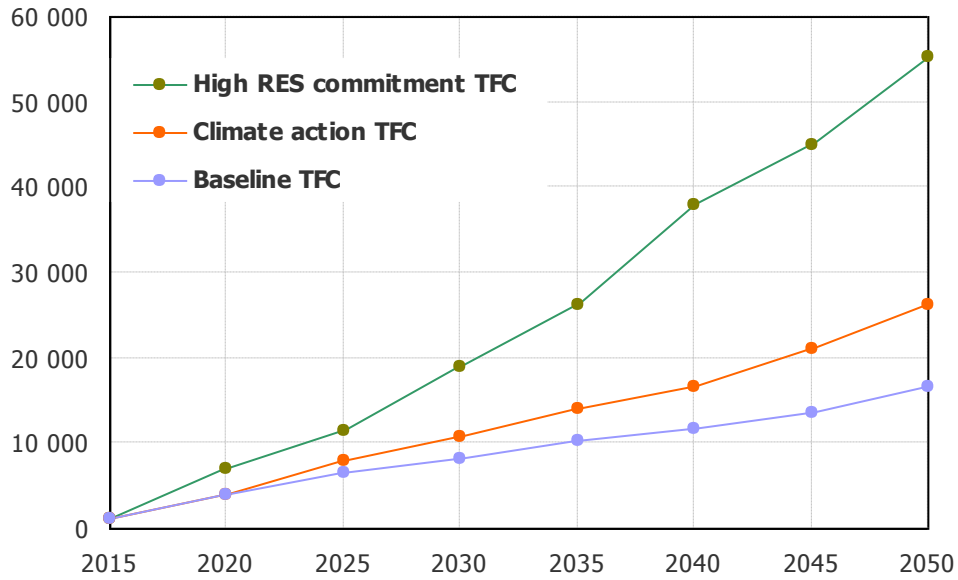


Figure 9.8. TFC from RES for three scenarios, ktoe/year

The RES potentials used for all scenarios are distributed and utilized differently, not according to direct proportion principle. For example, for baseline the potentials of biomass, solar PV + solar heat as well as hydropower are used more than others due to higher commercialization rate. Market volume and availability of these technologies. At the same time for high commitment scenario almost all RES potentials (partly exception is only geothermal energy, which is expected to be non-commercial till 2030-2035 in Ukraine) are used more balanced.

Potential of RES utilized, 2050

RES type	Total potential, 2050, ktoe	Potential used, 2050, ktoe			Potential used, %		
		Baseline	Climate action	100% RES	Baseline	Climate action	100% RES
Solid biomass+ biogas + liquid biofuels	**43 420**	**7 873**	**13 392**	**26 097**	**18.10%**	**30.80%**	**60.10%**
Wind (total)	**19 600**	4 016	5 730	12 550	20.50%	29.20%	64.00%
Solar PV	**5 850**	1 269	3 581	5 020	21.70%	61.20%	85.80%
Solar thermal	**5 850**	2 530	3 581	5 020	43.30%	61.20%	85.80%
Heat pumps	**12 600**	1 750	1 432	6 275	13.90%	11.40%	49.80%
Hydro (large+small)	**4 900**	756	881	1 547	15.40%	18.00%	31.60%
Geothermal	**8 400**	400	300	2 500	4.80%	3.60%	29.80%

Energy efficiency effect is reduction of TPES in 2050 normalized to average 2010-2015 level on 30%, 38% and 46% for baseline, climate action and high commitment scenarios respectively. TFC decreasing is 9%, 13% and 18% respectively.

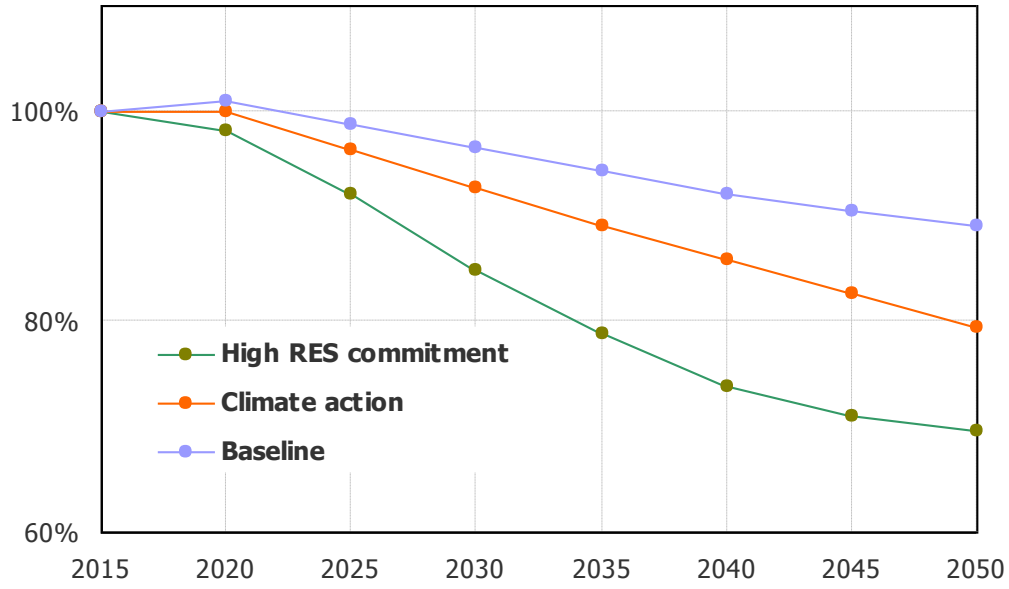


Figure 9.9. Dynamics of TPES changing for three scenarios, 100%= average for 2010-2015

The absolute figures of energy savings in TFC are represented in Table 9.12.

Table 9.12. Energy efficiency in TFC for Baseline, Climate Action and High Commitment Scenarios

Energy efficiency, ktoe, (current year)/2010-2015 average	2015	2020	2025	2030	2035	2040	2045	2050
Baseline	0	935	2 429	3 579	4 374	5 175	5 669	5 907
Climate action	0	935	2 820	4 087	4 953	5 997	7 096	8 542
100% RES	0	935	3 202	4 671	5 691	6 944	9 368	12 107

Energy efficiency effect in 2050 is 2 times higher for high commitment against baseline and 1.4 times higher for high commitment against climate action scenarios. Energy efficiency effect for climate action scenario is 1.44 times higher in comparison with baseline.

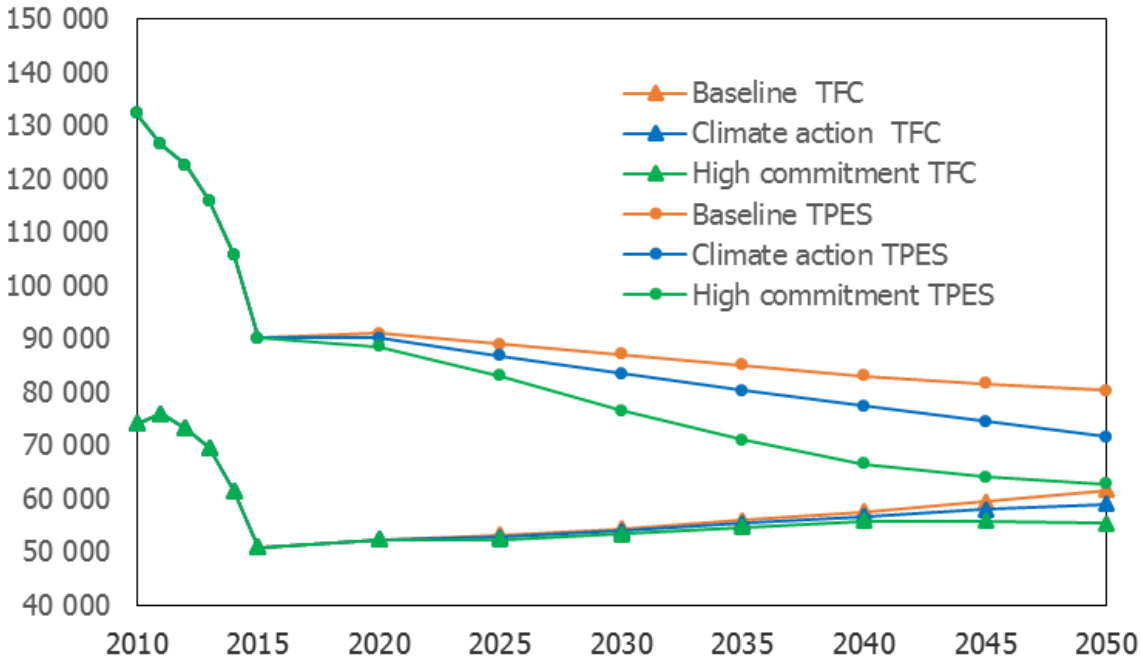


Figure 9.10. Dynamics of TFC and TPES changing for three scenarios, 100%=average 2010-2015

The total TPES and TFC changing in ktoe/year for 2010-2050 for three scenarios is presented below. All scenarios foresee decreasing of TPES and TFC in 2050 in comparison with average 2010-2015 and increase of TFC for all three scenarios compared to absolute 2015 values.

The highest fall is observed in High RES commitment scenario -46% in TPES in 2050 to 2010-2015 average level and -18% in TFC for the same years but is tend to stabilize after 2045-2050. The lowest fall is in Baseline Scenario -30% in TPES and -9% in TFC for 2050 against 2010-2015 average level with tendency of continuation of decreasing after 2050.