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SUPPORT TO THE GOVERNMENT OF UKRAINE ON UPDATING ITS NATIONALLY DETERMINED CONTRIBUTION (NDC)

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REPORT 3/ MODELING REPORT

OECONOMIA FUNDATIO IMPERIUM

Project implemented by the Institute for Economics and Forecasting, NASU

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Key Messages

Issue

- The Paris Agreement, to which Ukraine is a signatory, implies at some point around mid-century or thereafter, the world needs to have "net zero" GHG emissions.
- As part of its Nationally Determined Contribution, we suggest that Ukraine sets a long-term target consistent with its contribution to tackling global climate change, as well as a series of near term targets.
- The analysis in this report has assessed different trajectories for the Ukrainian economy and its implications in terms of economic growth, cost and overall level of GHGs emissions.

What we are recommending and why

- A BAU path (Scenario 1), the path Ukraine is currently following, would not result in the decoupling of economic growth and GHG emissions, needed to transition into a low-carbon economy.
- The modelling results show that it is possible for Ukraine to move towards a path in the long-term, that deliver a sustainable low-carbon and climate resilient Ukrainian economy with deep emissions cuts consistent with the goals of the Paris Agreement.
- Focusing in the near-term on full implementation of existing and planned short-term policies and measures is critical. Our analysis has shown that this does not significantly alter the current economic composition, allows the possibility for Ukraine to enhance ambition and achieve net-zero emissions by 2070 (Scenario 2 and 3).
- Such enhanced ambition for the long-term (Scenario 3) will open up the potential for the country not only to transform economy into a carbon neutral economy, but also to foster innovation and competitiveness and provide a clean, service and technology-driven economy, avoiding capital lock-in into inefficient and stranded assets.
- The incremental economic cost difference between short-term low carbon pathway and long-term net-zero emissions pathway is estimated to be €562 billion, 49% incremental increase.

What must happen

- The country already has the foundation to deliver between now and 2030.
- However, the policies and measures to allow the economy to shift into this pathway need to be implemented. Targets and policies need to be set at respective targets. The difference between Scenario 1 and 2 illustrates this clearly.

- The changes required translate in to the following areas:
  - Further increase in renewable energy installed capacity
  - Early adoption of the new technologies e.g. hydrogen, CCS
  - Significantly more energy efficient buildings
  - Increased electrification of transports
  - Better waste management and water use
  - Increased organic crop production and reduction in methane in agriculture
  - Increased carbon sink through afforestation
- This means current climate-related legislations must become the top priorities of the new Government of Ukraine and start to be implemented in its entirety without further delay. That will set Ukraine on the path of economic transformation and innovation, underpinned by its Low Emission Development Strategy.
- The next deliverables of the project (including REPORT 4) will finalize modelling and scenario analysis with exploration of sensitivity options and carbon budget allocation, will provide an overview of sector-specific policies and measures that should be implemented, their implementation gap analysis and give recommendations on climate finance.

Executive Summary

1. Objective of the Report

This report is prepared under the EBRD project support to the Government of Ukraine (GoU) on developing the second NDC under Paris Agreement.

This report describes the process and the results of Ukraine's GHG emissions pathways modelling up to 2050 based on projections and forecasting made applying available in Ukraine models tools, including TIMES-Ukraine that was applied for Energy and Industrial Processes Sectors (IPCC), Ukraine General Equilibrium model and combined modelling approach to Waste Sector, Agriculture and LULUCF Sectors.

2. Structure of the Report

Section 1 of the report is providing brief overview of second Ukrainian NDC methodological approach that describes in details in the previous *Background Report*.

Section 2 of the report provides an overview of macroeconomic scenarios projections developed specially for the purpose of second Ukraine's NDC. Baseline Macroeconomic Scenario, applied for all three GHG emissions pathways Scenarios, assumes average GDP growth rate of 3,5–4,5% for 2018-2050 period of (see Fig. 2.2) as a result of macro structural reforms in Ukraine, the population forecasts the continued decline reaching 37.7 mln people in 2030 and 35.6 mln people in 2050 (see Fig. 2.3). The Baseline Macroeconomic Scenario uses the IEA World Energy Outlook 2018 energy prices forecasts (see Table 2.4) and estimates renewable energy sources potentials until 2050, using national experts' judgments approach and report developed under Heinrich Boell Foundation initiative.

Section 3 of the report provides an overview of GHG emissions pathways modelling results for Ukraine until 2050 for all IPCC sectors (Energy, Industrial Processes, Agriculture, LULUCF and Waste Sectors) through the three Scenarios, developed for the second Ukrainian NDC. They are Scenario 1 - Business as Usual Scenario, Scenario 2 - Reference Scenario and Scenario 3 - Climate Neutral Economy.

Section 4 of the report provides general economy wide modelling results for all three Scenarios, including IEA Sustainable Development Scenario and IPCC 1.5C Special Report Scenarios information while assuming that Ukraine's GHG emissions per capita target of 1.7 CO_2e by 2050 under Scenario 3 is within the range of IPCC Special Report Scenarios.

Section 5 provides short descriptions of the objectives and assumptions of sensitivity options that are proposed to be further explored and analyzed in Report 4.

3. Three GHG Emissions Pathways Scenarios of Ukraine's Second NDC

- ***Scenario 1/BAU Scenario:*** This scenario is based on current (limited) level of implementation of existing legislations, which involves significant delay between policy formulation, adoption and implementation. For example, although there has been progress in implementation of the energy efficiency and renewable measures, the corresponding targets declared in sectoral programs are not met in the mid-term.

- ***Scenario 2/Reference Scenario:*** This scenario is built to assess the integral impact of timely implementation of all existing legislations adopted as of September 1st, 2019, as well as draft climate-related legislation that are not yet adopted, but expected to be adopted.

- ***Scenario 3/Climate Neutral Economy Scenario:*** This scenario foresees timely implementation of existing and drafted legislation of Scenario 2 until 2030, as well as additional climate policies, measures and innovative industrially-proven technologies (e.g. carbon capture storage, hydrogen, fuel cells, power to gas/fuel/heat). This scenario is in line with the global efforts of holding the increase of the global average temperature to well below 1.5°C of pre-industrial levels.

The following key input assumptions were used for all three scenarios of GHG emissions pathways modelled under Ukraine's Second NDC development process:

<table>
<tr><th colspan="2">Key Input Assumptions</th><th>2015</th><th colspan="3">2030</th><th colspan="3">2050</th></tr>
<tr><th colspan="2"></th><th></th><th>S1</th><th>S2</th><th>S3</th><th>S1</th><th>S2</th><th>S3</th></tr>
<tr><td colspan="9">Economic parameters</td></tr>
<tr><td colspan="2">GDP, growth rate, %</td><td>-9.8</td><td colspan="3">4.2</td><td colspan="3">3.2</td></tr>
<tr><td colspan="2">Mining and quarrying, growth rate, %</td><td>-13.8</td><td colspan="3">1.7</td><td colspan="3">0.6</td></tr>
<tr><td colspan="2">Manufacturing, growth rate, %</td><td>-15.2</td><td colspan="3">5.1</td><td colspan="3">3.8</td></tr>
<tr><td colspan="2">Construction, growth rate, %</td><td>-18.4</td><td colspan="3">5.3</td><td colspan="3">3.9</td></tr>
<tr><td colspan="2">Services and Transport, share in GDP, %</td><td></td><td colspan="3">55.7</td><td colspan="3">58.4</td></tr>
<tr><td colspan="9">Demographic parameters</td></tr>
<tr><td colspan="2">Population, mln</td><td>42.9</td><td colspan="3">39.7</td><td colspan="3">35.6</td></tr>
<tr><td colspan="2">Average life expectancy, years</td><td></td><td colspan="3">73.9</td><td colspan="3">76.7</td></tr>
<tr><td colspan="2">Average population age, years</td><td></td><td colspan="3">42.7</td><td colspan="3">45.4</td></tr>
<tr><td colspan="2">Share of working-age population, %</td><td></td><td colspan="3">48.4</td><td colspan="3">43.0</td></tr>
<tr><td colspan="2">Number of retired per working persons, persons</td><td></td><td colspan="3">1.14</td><td colspan="3">1.49</td></tr>
<tr><td colspan="2">Share of rural population, %</td><td>32.8</td><td colspan="3">32.3</td><td colspan="3">31.8</td></tr>
<tr><td colspan="9">Energy prices</td></tr>
<tr><td rowspan="3">Energy Sources</td><td>Brent Oil, USD 2017/barrel</td><td>85</td><td colspan="3">83</td><td colspan="3">89</td></tr>
<tr><td>Energy Coal, EU, USD 2017/t</td><td>52</td><td colspan="3">96</td><td colspan="3">132</td></tr>
<tr><td>Natural Gas, EU, USD 2017/ mln BTU</td><td>5.8</td><td colspan="3">8.2</td><td colspan="3">9.9</td></tr>
<tr><td colspan="9">Renewable Energy (RE)</td></tr>
<tr><td rowspan="7">Potential of Renewable Energy (RE), GW</td><td>Wind, GW</td><td>0.428</td><td colspan="2">8</td><td>16</td><td colspan="2">24</td><td>60</td></tr>
<tr><td>Solar (ground), GW</td><td>0.359</td><td colspan="2">9</td><td>16</td><td colspan="2">36</td><td>90</td></tr>
<tr><td>Solar (roof-top), GW</td><td>0.022</td><td colspan="2">3</td><td>6</td><td colspan="2">12</td><td>36</td></tr>
<tr><td>Bioenergy, mtoe</td><td>2.1</td><td colspan="3">30</td><td colspan="3">42.1</td></tr>
<tr><td>Hydro (large), GW</td><td>5.9</td><td colspan="3">6.3</td><td colspan="3">6.3</td></tr>
<tr><td>Hydro (small), GW</td><td>0.09</td><td colspan="3">0.250</td><td colspan="3">0.375</td></tr>
<tr><td>Geothermal, GW</td><td>~0.0</td><td colspan="2">0.4</td><td>0.8</td><td colspan="2">0.6</td><td>1.4</td></tr>
</table>

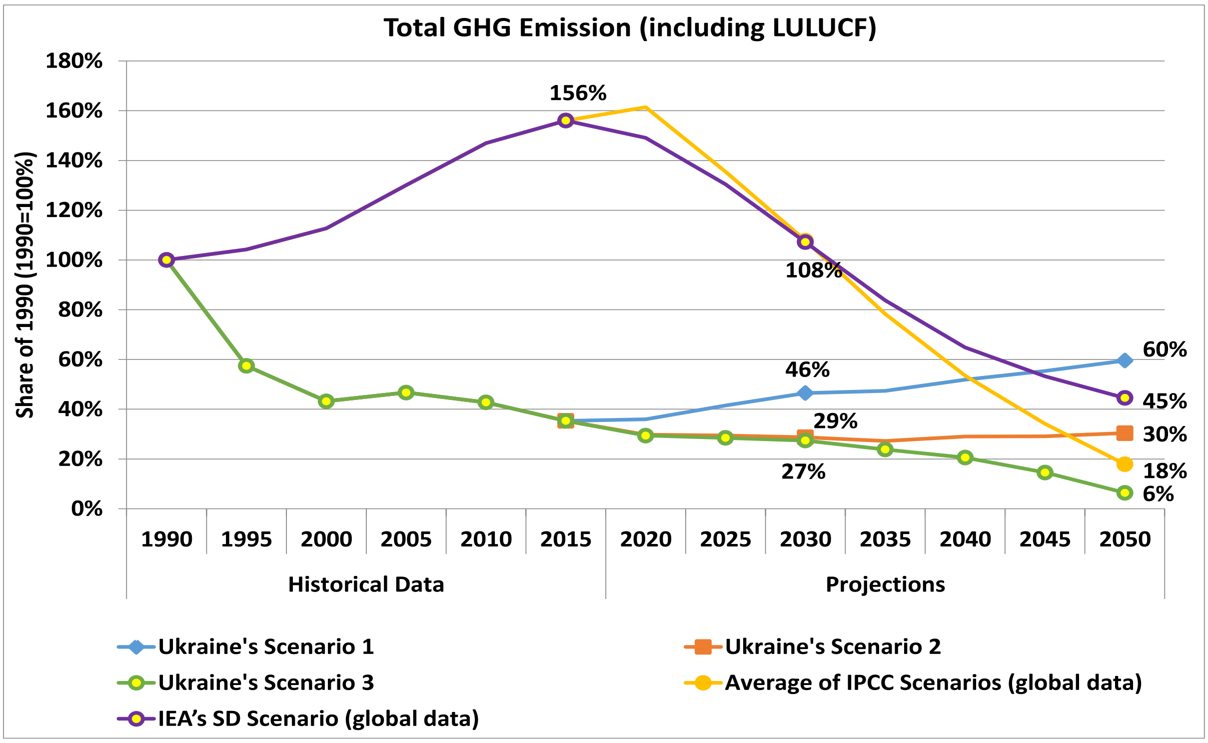
Key Input Assumptions	2015	2030			2050		
Share of renewables (incl. hydro power plants) in TPES, %	3	>4	>17	>17	>4	>25	>25
Share of renewables (incl. hydro power plants) in power, %	6	>9	>13	>13	>9	>25	>25
Share of renewables in GFEC, %	5	>9	>17	>17	>9	>25	>25
Share of renewables in district heating, %	1	>10	>35	>35	>10	>40	>40
Energy Efficiency (EE) Targets							
Primary Energy Intensity, toe/$1000 GDP (PPP)	0.29	0.23	0.18	0.18	0.18	N/T	N/T
Primary Energy (carbon-intensive resources) Intensity, toe/$1000 GDP (PPP)	0.23	0.19	0.11	0.11	0.13	N/T	N/T
Energy Losses							
Heat production losses, %	>20	N/T	11	<11	N/T	10	<10
Transportation electricity losses, %	12.1	N/T	8	<8	N/T	7	<7
Transportation gas losses, % of 2015	–	N/T	20	20	N/T	50	50
Power Sector							
Directive 2010/75/EU implementation (integrated pollution prevention and control), %	NO	NO	85	100	NO	100	100
Share of balancing techs comparing to wind/solar, %	NO	30/40			30/40		15/20
Accessibility of Carbon Capture and Storage Techs	N/A	N/A	N/A	AV	N/A	N/A	AV
Accessibility of Fuel Cells (FC) Techs	N/A	N/A	N/A	AV	N/A	N/A	AV
Accessibility of New Nuclear Techs (Small Reactors)	N/A	N/A	N/A	AV	N/A	N/A	AV
Building Sector							
Share of energy savings with retrofit measures in residential buildings, max %		15	50	50	20	75	75
Share of retrofit with retrofit measures in public buildings, max %		15	50	50	20	75	75
Share of solar techs for heating in residential buildings, max %	0	0.5	10	15	1.5	20	40
Share of solar techs for heating in public buildings, max %	0	1.5	10	25	5	25	50
Share of solar techs for water heating in residential buildings, max %	0	1.5	10	15	5	25	50
Share of solar techs for water heating in public buildings, max %	0	1.5	15	35	5	25	60
Industry							
Iron and Steel, % of energy saving comparing to S1		N/T	>10	M/R	N/T	>15	M/R
Ammonia, % of energy saving comparing to S1		N/T	>10	M/R	N/T	>15	M/R
Pulp and paper, % of energy saving comparing to S1		N/T	>10	M/R	N/T	>15	M/R
Cement, % of energy saving comparing to S1		N/T	>15	M/R	N/T	>40	M/R
Glass, % of energy saving comparing to S1		N/T	>15	M/R	N/T	>30	M/R
Lime, % of energy saving comparing to S1		N/T	>25	M/R	N/T	>50	M/R
Other Industries, % of energy saving comparing to S1		N/T	>25	M/R	N/T	>50	M/R
TOTAL Industry, % of energy saving comparing to S1		N/T	>15	M/R	N/T	>30	M/R
Transport							
Electric vehicles, % of new vehicles purchased	0	2	10	>20	5	>20	>50
Hydrogen vehicles, % of new vehicles purchased	0	N/A	N/A	>0	N/A	N/A	>0
Share of alternatives fuels (including LPG, biofuels, electricity, hydrogen), %	9	15	>20	>50	>20	>25	>50
Share of alternatives fuels (including LPG, biofuels, electricity, hydrogen) in urban public transport, %	9	15	>20	>50	>20	>25	>50
Share of hydrogen transport in urban public transport, %	0	N/A	N/A	>0	N/A	N/A	>0
GHG Emissions Targets							
Total CO_2 equivalent emissions including LULUCF, Mt CO_2e	310.2	N/T	N/T	<S2	N/T	N/T	<60
Carbon Intensity – t CO_2e per capita	7.2	M/R	M/R	<S2	M/R	M/R	<1.7
Carbon Intensity – t CO_2e /$1000 GDP (PPP)	1.0	M/R	M/R	<S2	M/R	M/R	<0.1

Key Input Assumptions	2015	2030			2050		
Waste Sector							
MSW generation per capita, tons/capita/year	0.33	0.39	0.39	0.39	0.48	0.48	0.48
Share of MSW landfilling, % of generation	94.4	93.4	30	20	93.4	20	5
Landfill methane utilization, % of landfill methane generation	3.5	4.5	23	30	4.5	36	63
Water supply intensity, compared to 2015 in %	100	100	70	60	100	50	35
Agriculture Sector							
Cattle population, thousand heads	2667	3697			4047		
Poultry population, mln heads	217.4	257.3			282.5		
Methane removal by biogas production facilities from total methane produced from manure, %	0	0	16	31	0	25	50
Area of organic crop production, thousand ha	270	270	963	1751	270	2000	4000
Land use, land-use change and forestry (LULUCF)							
Forest Cover, % of total area of Ukraine	16,1	16.2	17.0	17.0	16.5	20.0	20
Yearly afforestation, thousand ha	5.23	7.81	60.36	60.36	7.81	90.5	90.5
Share of final clear, % of 2015	100	100	83	83	100	50	50
Area of cropland and grassland, thousand ha	28786	30147			31347		
Efficiency of synthetic N fertilizers application, % of 2015	100	100	110	113	100	130	140

Acronyms: ***S1*** *– Scenario 1;* ***S2*** *– Scenario 2;* ***S3*** *– Scenario 3;* ***TPES*** *– Total Primary Energy Supply;* ***GFEC*** *– Gross Final Energy Consumption;* ***GDP*** *– Gross Domestic Product;* ***PPP*** *– Purchasing Power Parity;* ***NO*** *– not implemented or no constraints;* ***N/T*** *– No targets in a scenario;* ***N/A*** *– Not available in a scenario;* ***AV*** *– available in a scenario;* ***M/R*** *– Modelling Results.*

4. Overall Modelling Results – Economy-Wide Results

The report summarizes overall modelling results for all IPCC sectors, including GHG emissions trajectories and pathways and one can observe that implementation of both Scenario 2 and 3 keeps Ukraine GHG emissions on track with IEA Sustainable Development Scenario, and Scenario 3 implementation will bring Ukraine's GHG emissions within and below the IPCC Special Report 1.5C scenario pathways.



Key Output Assumptions	2015	2030			2050		
		S1	S2	S3	S1	S2	S3
Total Greenhouse Gas Emission							
GHG Emissions, *Mt CO_2e*	**310.5**	**408.5**	**252.7**	**241.1**	**523.7**	**267.3**	**56.5**
Energy and IPPU sectors	*267.3*	*359*	*217*	*215*	*466*	*249*	*57.2*
Agriculture sector	*37.3*	*40.0*	*38.1*	*36.6*	*40.1*	*36.4*	*33.1*
LULUCF sector	*-6.3*	*-3.2*	*-12.2*	*-18.3*	*3.0*	*-24.2*	*-36.1*
Waste	*12.2*	*12.7*	*9.8*	*7.8*	*14.6*	*6.1*	*2.3*
Shares of 1990 level of Total GHG Emission, *%*	**35**	**46**	**29**	**27**	**60**	**30**	**6**
Energy and IPPU sectors	*32*	*43*	*26*	*25*	*55*	*30*	*7*
Agriculture sector	*45*	*48*	*46*	*44*	*48*	*44*	*40*
LULUCF sector	*11*	*5*	*21*	*31*	*-5*	*41*	*61*
Waste	*103*	*107*	*82*	*65*	*123*	*51*	*19*
GHG emissions by population, *t CO2e per capita*	**7.2**	**10.1**	**6.2**	**6.0**	**14.2**	**7.3**	**1.5**
Carbon Intensity, *t CO2e / $1000 GDP PPP*	**0.99**	**0.77**	**0.48**	**0.46**	**0.58**	**0.29**	**0.06**
Total Primary Energy Supply							
Total primary energy supply (TPES), *mtoe*	**89.5**	**124.7**	**98.6**	**99.8**	**162.3**	**117.3**	**106.7**
Coal, %	*30.2*	*38.5*	*23.5*	*23.1*	*36.2*	*24.7*	*2.0*
Gas, %	*29.0*	*28.5*	*27.8*	*27.3*	*25.7*	*18.6*	*13.8*
Oil, %	*11.8*	*11.3*	*7.9*	*7.8*	*12.1*	*5.9*	*3.4*
Nuclear, %	*25.5*	*16.8*	*24.7*	*25.4*	*19.4*	*26.9*	*39.5*
Electricity, %	*-0.1*	*-0.1*	*0.1*	*-0.1*	*0.0*	*0.0*	*0.0*
Hydro, %	*0.6*	*0.8*	*1.1*	*1.1*	*0.7*	*0.9*	*1.1*
Wind, %	*0.1*	*0.3*	*1.9*	*2.0*	*0.7*	*4.3*	*8.5*
Solar, %	*0.0*	*0.9*	*1.4*	*2.3*	*1.0*	*4.6*	*7.8*
Biofuels & Waste, %	*2.3*	*2.5*	*11.0*	*11.0*	*4.2*	*14.1*	*23.4*
Geothermal, %	*0.6*	*0.5*	*0.6*	*0.1*	*0.0*	*0.0*	*0.5*
Share of renewables in TPES, *%*	**3.6**	**5.0**	**16.1**	**16.5**	**6.5**	**24.0**	**41.1**
Share of non-carbon energy (incl. nuclear) in TPES, *%*	**29.3**	**21.8**	**40.9**	**41.9**	**25.9**	**50.9**	**80.6**
Primary Energy Intensity, *toe / $1000 GDP PPP*	**0.29**	**0.24**	**0.19**	**0.19**	**0.18**	**0.13**	**0.12**
Primary Carbon-Intensive Energy Intensity, *toe / $1000 GDP PPP*	**0.21**	**0.19**	**0.11**	**0.11**	**0.13**	**0.06**	**0.02**
Final Energy Consumption by Fuels							
Total Final energy consumption (FEC), *mtoe*	**47.5**	**60.9**	**50.5**	**50.7**	**80.0**	**55.9**	**50.4**
Coal, %	*12.5*	*11.7*	*11.9*	*12.3*	*14.9*	*19.5*	*0.6*
Gas, %	*29.0*	*25.0*	*21.0*	*21.0*	*19.5*	*12.3*	*4.4*
Oil, %	*18.5*	*21.2*	*13.9*	*13.2*	*21.9*	*9.9*	*6.1*
Electricity, %	*21.5*	*21.9*	*27.6*	*29.1*	*23.8*	*38.6*	*60.6*
Heat, %	*15.8*	*18.7*	*18.1*	*17.8*	*17.9*	*14.8*	*18.3*
Solar, %	*0.0*	*0.1*	*0.5*	*0.5*	*0.2*	*3.1*	*3.4*
Biofuels & Waste, %	*2.7*	*1.4*	*7.0*	*6.1*	*1.8*	*1.8*	*6.6*
Share of renewables in Gross Final Energy Consump., *%*	**4.1**	**6.3**	**20.7**	**21.5**	**8.7**	**32.3**	**58.4**
Final Energy Consumption by Sectors							
Total Final energy consumption (FEC), *mtoe*	**47.5**	**60.9**	**50.4**	**50.7**	**80.0**	**55.9**	**50.4**
Industry, %	*34.5*	*36.6*	*39.2*	*39.6*	*46.7*	*50.6*	*42.4*
Residential, %	*34.9*	*28.9*	*26.6*	*25.9*	*19.7*	*17.7*	*21.2*
Transport, %	*18.4*	*21.4*	*20.4*	*20.1*	*21.3*	*18.3*	*21.0*
Commercial, %	*8.1*	*9.4*	*9.5*	*9.7*	*9.2*	*8.9*	*9.7*
Agriculture, %	*4.1*	*3.7*	*4.3*	*4.7*	*3.1*	*4.5*	*5.7*
Electricity production							
Electricity production, *TWh*	**157**	**210**	**198**	**207**	**280**	**299**	**385**
Coal, %	*33*	*43*	*18*	*16*	*40*	*14*	*0.0*
Gas, %	*5*	*4*	*7*	*5*	*2*	*0*	*1.3*
Nuclear, %	*56*	*38*	*46*	*46*	*42*	*40*	*41*
Biofuels & Waste, %	*0*	*1*	*5*	*5*	*2*	*8*	*9*
Wind, %	*1*	*2*	*11*	*11*	*5*	*20*	*26*

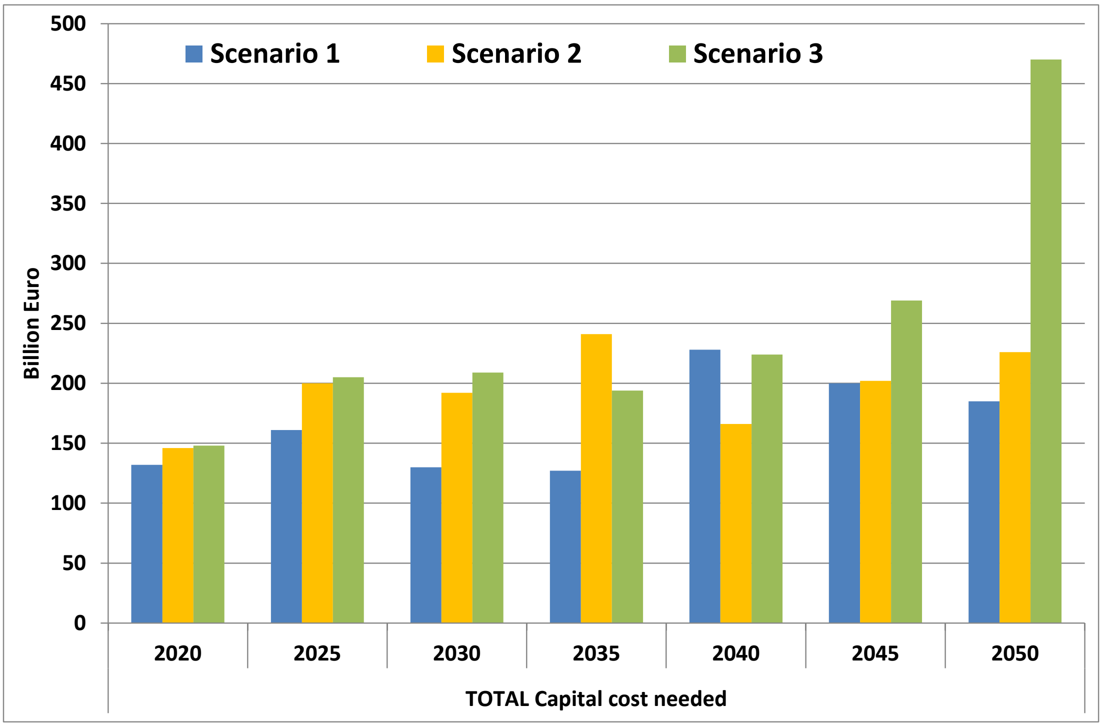
Key Output Assumptions	2015	2030			2050		
Solar, %	*0*	*6*	*7*	*11*	*5*	*14*	*18*
Hydro, %	*5*	*6*	*6*	*6*	*4*	*4*	*3.4*
Geothermal, %	*0*	*0*		*0.3*	*0*	*0*	*1.1*
Share of renewables, *%*	**5.9**	**14.1**	**29.7**	**34.1**	**16.5**	**46.3**	**57.7**
Share of nuclear, *%*	**56**	**38**	**46**	**46**	**42**	**41**	**40**
Share of non-carbon electricity, *%*	**62**	**52**	**76**	**80**	**59**	**86**	**99**

Total investments (cumulatively for 5 years) based on modeling results, bln Euro

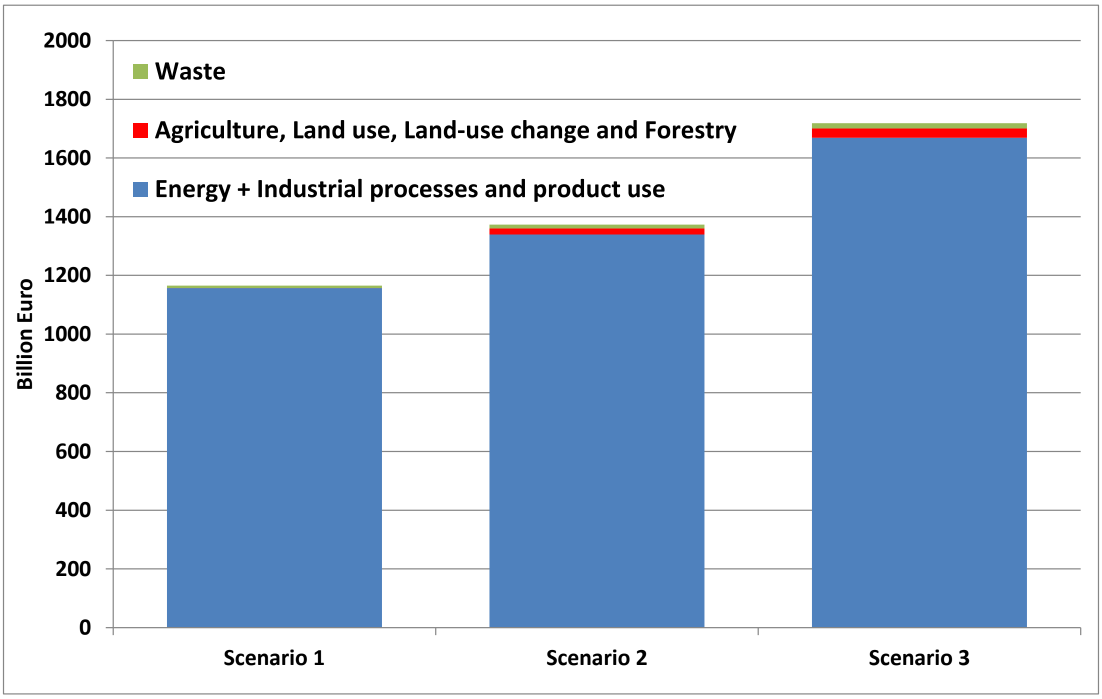
Scenarios	2020	2025	2030	2035	2040	2045	2050
Energy and IPPU sectors							
Scenario 1	132	160	129	126	227	199	184
Scenario 2	144	196	187	236	160	196	220
Scenario 3	145	199	202	187	216	260	460
Agriculture and LULUCF sectors							
Scenario 1	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Scenario 2	1.7	2.1	2.6	3.0	3.5	3.9	4.3
Scenario 3	1.9	2.8	3.7	4.5	5.4	6.3	7.1
Waste sector							
Scenario 1	0.04	0.21	0.23	0.25	0.27	0.30	0.32
Scenario 2	0.4	2.1	2.1	2.1	2.1	2.1	2.1
Scenario 3	0.6	2.8	2.9	2.9	2.9	2.9	2.9
Total investments needs in all sectors							
Scenario 1	132	160	129	126	227	199	184
Scenario 2	146	200	192	241	166	202	226
Scenario 3	148	205	209	194	224	269	470

Acronyms: ***Scenario 1*** *– Business As Usual or Barriers Scenario;* ***Scenario 2*** *– Reference Scenario or Current Policy Scenario;* ***Scenario 3*** *– Alternative Scenario or Climate Neutral Economy Scenario;* ***IPPU*** *– Industrial processes and product use;* ***LULUCF*** *– Land use, land-use change and forestry.*

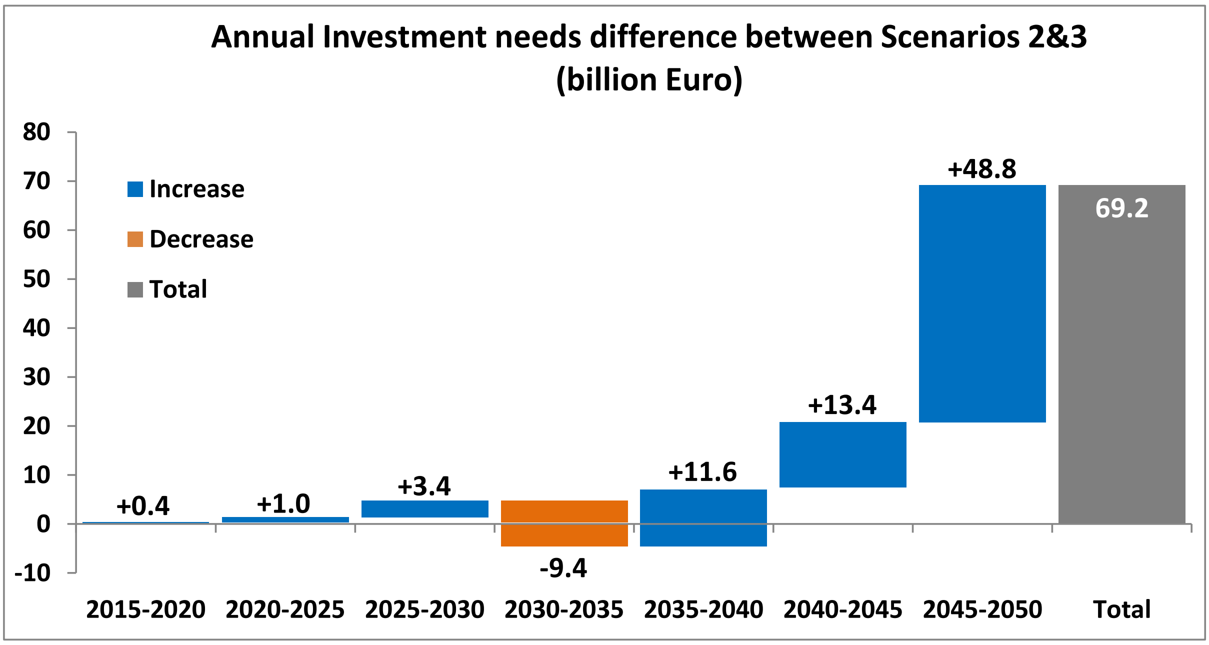
Total investment needs for implementation of GHG emissions pathways scenarios are estimated in 5-years' time period cycles.



Most investments will be required in the Energy and Industrial Processes sector for all three Scenarios with relatively insignificant increase in investment needs in Agriculture, LULUCF and Waste sectors.



By averaging the investment needs annually and taking the differences between Scenario 3 and 2, it shows that investment needs do not significantly more between them till 2035, when Scenario 3 will require less investments than Scenario 2. Only from 2035 onwards, the investment needs will be greater for Scenario 3, mainly because the cost assumptions for the new technologies, such as CCSs, are estimated high by current market conditions.



5. Modelling Results of the Three Scenarios by Sector

Sector	Number	Scenario Name	Modelling results (GHG emissions reduction compared to 1990 level)	
			2030	2050
Energy, transport and industrial sector	1	BAU Scenario	-57% (43% level)	-45% (55% level)
	2	Reference Scenario	-74% (26% level)	-70% (30% level)
	3	Climate Neutral Economy Scenario	-75% (25% level)	-93% (7% level)
Agriculture	1	BAU Scenario	-52% (48% level)	-52% (48% level)
	2	Reference Scenario	-54% (46% level)	-56% (44% level)
	3	Climate Neutral Economy Scenario	-56% (44% level)	-60% (40% level)
LULUCF*	1	BAU Scenario	-95% (5% level)	-105% (-5% level)
	2	Reference Scenario	-79% (21% level)	-59% (41% level)
	3	Climate Neutral Economy Scenario	-69% (31% level)	-39% (61% level)
Waste	1	BAU Scenario	+7% (107% level)	+23% (123% level)
	2	Reference Scenario	-18% (82% level)	-49% (51% level)
	3	Climate Neutral Economy Scenario	-35% (65% level)	-81% (19% level)
Economy-wide	1	BAU Scenario	-54% (46% level)	-40 (60% level)
	2	Reference Scenario	-71% (29% level)	-70% (30% level)
	3	Climate Neutral Economy Scenario	-73% (27% level)	-94% (6% level)

*LULUCF – in this sector, it is reported that there will be a decrease in carbon sequestration.

Energy and Industrial Processes sectors modelling results presented in the report show that under current trends of existing legislation implementation level, the dynamic of GHG emissions will simply follow the economy growth without decoupling.

- Scenario 1 implementation assumes that GHG emissions will be at the level of 43% in 2030 and 55% and 2050 respectively compared to 1990 (will reach the pre-war level of 2012 in 2030).
- Scenarios 2 and Scenario 3, assuming the full implementation of existing legislation, including existing ambitious targets on energy efficiency and renewable energy, forecast that GHG emissions pathways will reach the level of 26% under Scenario 2 in 2030 and 25% under Scenario 3 comparing to 1990.
- The GHG emissions pathways under Scenario 2 and 3 are identical until 2030 due to similar input assumptions. However, after 2030, the level of GHG emissions under Scenario 3 will gradually decline as proposed innovative technologies are adopted in due course; whereas the GHG emissions under Scenario 2 will grow as only existing legislation on climate policies and targets were modelled under this Scenario without any new ones coming into force.

- Renewable energy targets achievement will provide substantive contribution to electricity and heat generation, while energy efficiency measures will become more economically attractive, especially in building sector. TPES will be higher than the level of 2015 within the whole modelling period with about 98-100 mtoe in 2030 and 106-117 mtoe in 2050 for scenarios 2 and 3, and the share of renewables in TPES is projected to increase from 3-4% in 2012-2015 to 16% in 2030 and 24-41% in 2050.

Agriculture is an important sector in Ukraine, it is crucial to consider food security issues, when devising climate policies for the sector.

- Under Scenario 1, the GHG emissions will be 52% lower than in 1990 in 2030.
- Under Scenario 2, the Agriculture sector GHG emissions will on the level of 46% in 2030 and 44% in 2050 correspondingly compared to 1990.
- Under Scenario 3, GHG emissions will be on the level of 44 % of 1990 in 2030 and 40 % in 2050. GHG emissions reduction potential in Ukraine in agriculture mostly depends on the number of livestock.
- While new technologies and practices implementation in Agriculture will unlock the potential for low carbon development pathways, due to the complexity and high uncertainty of possible environment impacts on biodiversity and human habitats, these innovations implementation should have strong scientific background to prevent adverse effects.

LULUCF sector is projected to keep the status of net sink under the condition that implementation of GHG emissions reduction measures or removals will increase. Otherwise, there is a serious risk that this sector will become a net source of emissions in 2050.

- LULUCF sector under Scenario 1 will become net source of emissions in 2050, still being net sink in 2030.
- Under Scenario 2, in 2030 removals are estimated to be on the level of 21 % of 1990, and in 2050 – around 41 %.
- Under Scenario 3 it is expected, that in 2030 GHG removals will be lower by 69 % than in 1990, and in 2050 by 39 % lower than in 1990.

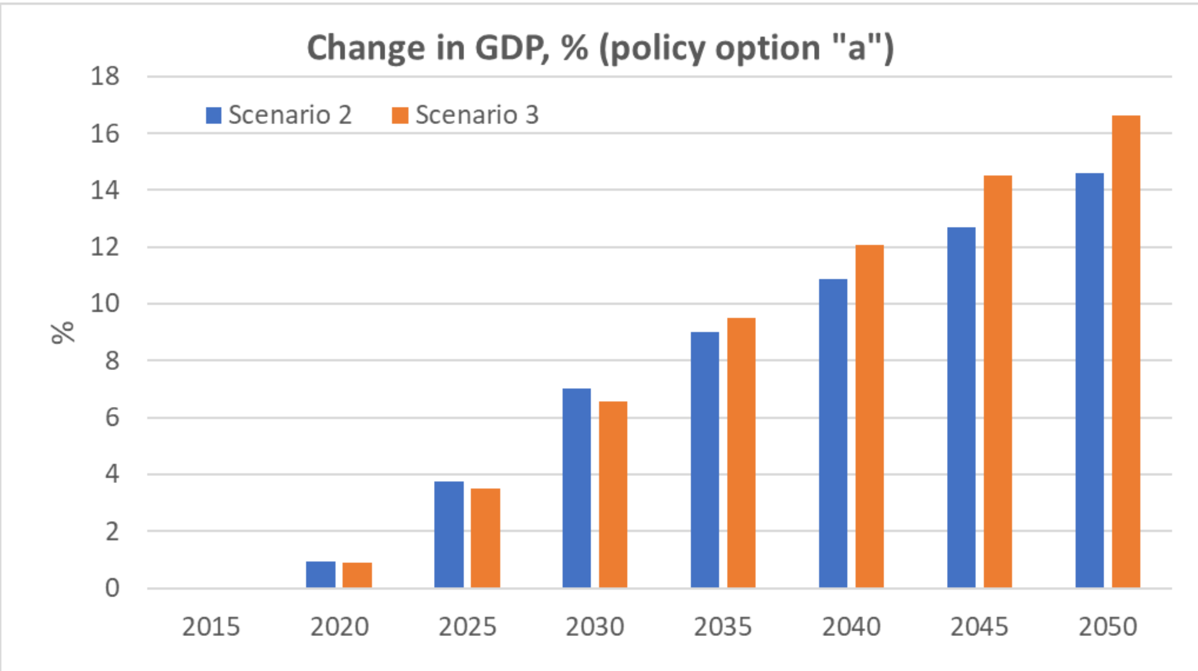
Waste sector is expected to follow best EU practices in waster hierarchy management system, reaching municipal solid waste per capita rate of 1% by 2030 with 100% coverage of the population by centralized municipal solid waste collection system and share of municipal solid waste disposed at anaerobic managed covered landfills[1] reaching 100% under Scenario 3.

[1] 2006 Guidelines for National Greenhouse Gas Inventory, Volume 5, Chapter 3: Anaerobic managed landfills have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: cover material; mechanical compacting; or levelling of the waste.

- Under Scenario 1, GHG emissions from waste sector will increase by 7% in 2030 and 23% in 2050 compared to 1990 due to the increase of municipal solid waste (MSW) and wastewater generation per capita caused by the overall economy growth.
- Under Scenario 2, the GHG emissions will decline by 18% in 2030 and 49% in 2050 compared to 1990, due to wide deployment of composting and incineration technologies and reuse and recycle practices, leading to corresponding rapid reduction of MSW landfilling share, as well as methane utilization/recovery technologies in waste sector both for solid and liquid waste.
- Under scenario 3, in 2030 GHG emissions will decline by 35% in 2030 and 81% in 2050, compared to 1990. Such a trend will be maintained due to minimization of municipal solid waste disposal (through dissemination of modern incineration, composting, reuse and recycling practices), modernization of wastewater facilities and ubiquitous technically available dissemination of methane recovery and flaring technologies both for solid and liquid waste.

6. Economic Impact Assessment Results

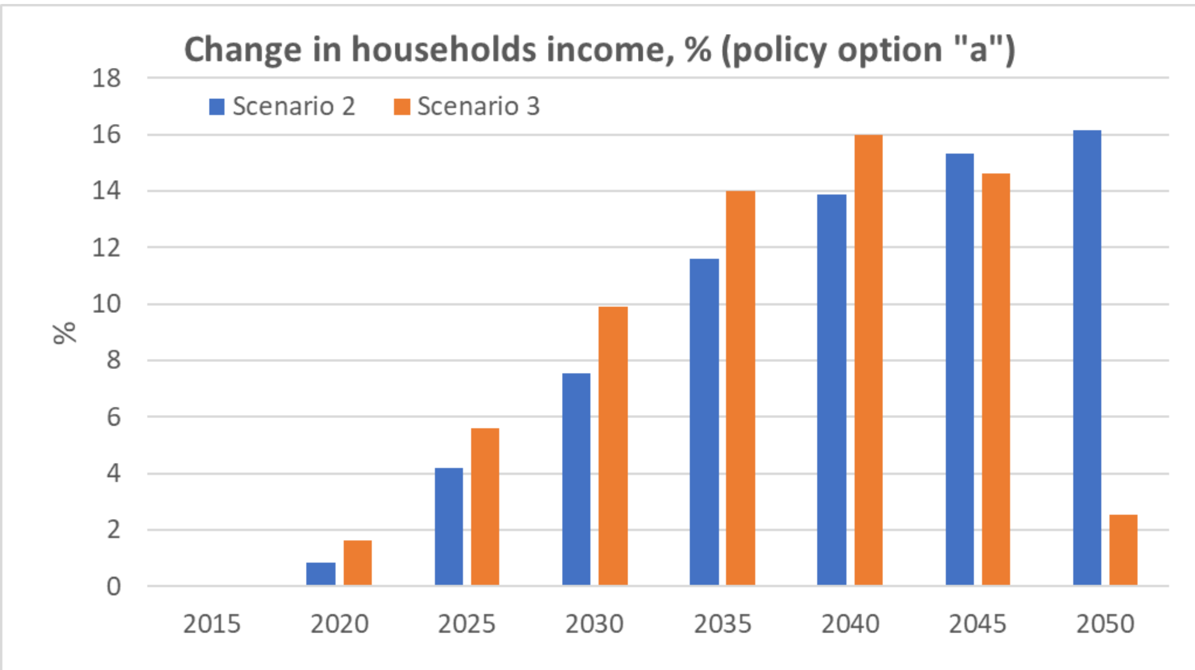
This Section outlines methodological approach and provides assessment of the economic impacts of climate policy scenarios (Scenarios 2 and 3) under different policy options. All impacts reported in this subsection are measured relative to the baseline case (Scenario 1). Therefore, negative numbers for changes in macroeconomic or sectoral indicators in most cases correspond to the slowdown in the growth **rates, rather than reductions in value relative to the beginning of the period** (2015 reference year).



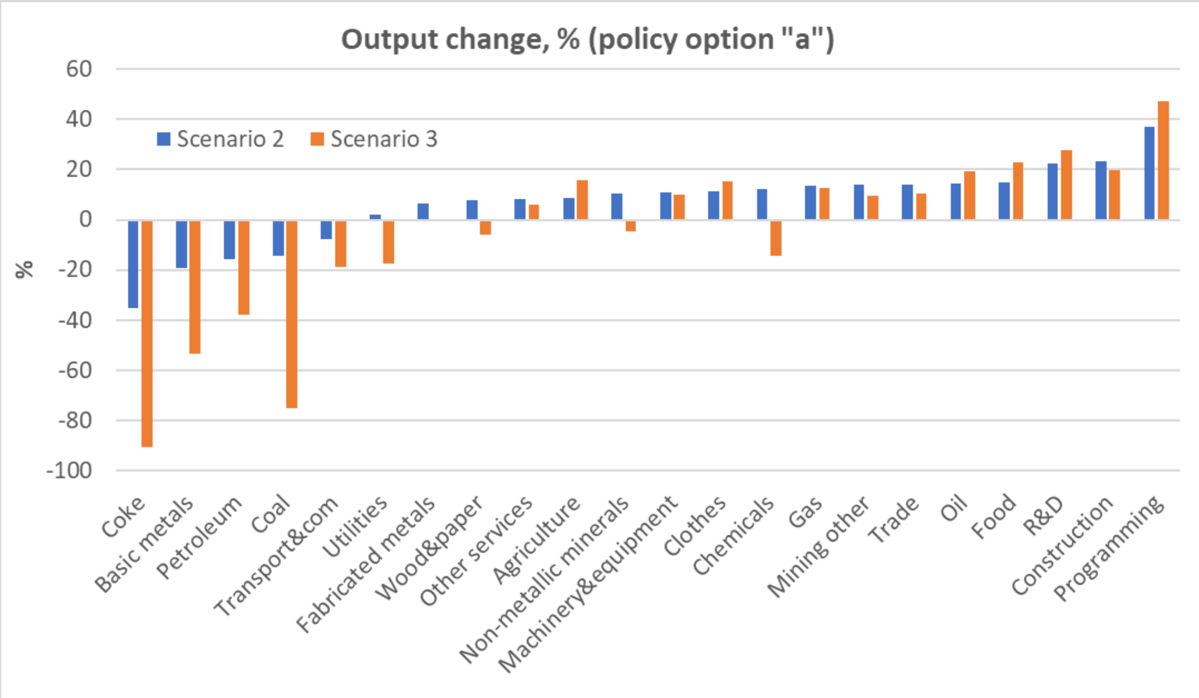
Analysis focuses on macroeconomic and sectoral impacts, as well as provide a discussion of the potential co-benefits that would be associated with the low carbon emission development pathways and that are not directly captured in our economic assessment approach.

Among analysed policy options (see Section 4 for additional details), investment-intensive pathway with investments allocated to the energy efficient technologies is as the most attractive option from both macroeconomic and sectoral perspectives. **Both the economy and environment significantly benefit in this case, which according to our estimates, GDP would grow by around 14%-16% in 2050, relative to baseline under both climate scenarios**. **Due to the higher level of investments and energy efficiency improvements, as well as relatively low cost of carbon reductions before 2035-2040, GDP is growing at a higher pace in the Scenario 3, compared to the Scenario 2.** At the same time, after around 2035, following higher level of carbon reduction ambitions and corresponding increase in the price of carbon (Annex 4), additional GDP growth rates in Scenario 3 are slowing down.

Qualitatively, the household incomes result a similar trend, although in this case Scenario 2 results in a higher growth rate. Residential consumers are facing much higher carbon prices in Scenario 3 (Annex 4), which affects their cost of consumption. At the same time, even in the 2040-2050 timeframe, when carbon prices under Scenario 3 exceed \$100/ton CO_2-eq. and reach \$1300/ton CO_2-eq. in 2050, residential users still experience increase in real income relative to Scenario 1. **Energy efficiency improvements play a key role in making this possible, as they significantly bring down production costs and lower prices for households.**



At the sectoral level, there are significant transformations in the output structure, which results in the significant reduction of carbon and energy intensities per GDP. This is especially the case for Scenario 3, where production of coke and coal fall by over 75% in 2050, relative to baseline. Other energy intensive sectors, such as basic metals production, petroleum production, utilities and fabricated metal production also significantly reduce their output under Scenario 3. At the same time, there is a shift towards sectors that generate investments and related services. The latter case includes increase in output of the programming sector and research and development activities. Construction sector increases its output as a key supplier of the investment goods. Increasing output of food and agricultural sectors is driven mainly by increasing exports of these commodities.



While investment-intensive pathway with investments allocated to the energy efficient technologies could be considered the most attractive from both macroeconomic and sectoral perspectives, our analysis does not capture some of the possible risks and uncertainties associated with this scenario.

In particular, it is assumed that all investments within this pathway are allocated to the domestic economy, which is one of the key sources of the observed economic growth. Impacts might not be so positive if a large share of capital goods would be purchased from abroad.

Another critical assumption is that facing increasing carbon taxes, producers and consumers not only shift their production and consumption patterns facing higher costs, but also invest into more energy efficient equipment. For instance, households not only travel less due to the higher cost of petroleum products, but they also buy a more efficient cars, than in the baseline scenario. In Section 4 we show that if this assumption does not hold, observed macroeconomic and sectoral impacts are much less positive.

Finally, we assume that required levels of investments are reached within both policy scenarios and carbon taxes serve as a source for these investments, significantly increasing the saving rate within the economy. In reality, it might not necessarily be the case and money collected from the carbon taxes might be transferred to government budget (to increase expenditures) or transferred to households. In Section 4 we explore these cases and show that there are significant risks for the long-term macroeconomic growth under these possible options.

Numerous studies have estimated that stringent climate mitigation policies are associated with **significant co-benefits**, including reductions in local air pollution, energy security improvement and avoidance of the climate change impacts. Our results suggest that in **the case of Scenario 2 in 2050 monetized benefits from carbon emissions reduction, following application of the social cost of carbon approach, would be between $9.2 billion and $33.6 billion, with a central value of $21.4 billion. In the case of Scenario 3, larger emission reductions would result in a much higher gain – between $17.1 billion and $62.9 billion in 2050.**

In terms of air quality improvement our estimates suggest that even assuming that cost of outdoor air pollution in Ukraine does not change over time (relative to the 2014 levels), **Scenario 3 would bring additional benefits of around $68 billion in 2050 relative to the reference case and over half of this number (around $34 billion) relative to the Scenario 2.**

7. Next Steps

Next reports will incorporate 1) results of the sensitivity analysis as described in Section 5 to inform specific policy and measures; 2) analysis of the carbon budget allocation by sector; and 3) the corresponding key policies and measures for GHG emissions reduction by sectors and sub-sectors, including building sector, industry, transport, agriculture, waste, power and heat supply sector and forestry. It will also analyse the climate finance needs through both domestic and international mechanisms to implement those policies and measures.

The harmonization of national legislation on domestic Ukrainian ETS legislation with EU Directive 2003/87/EC is one of the provisions of EU-Ukraine Association Agreement. However, Ukraine's second NDC carbon pricing mechanisms modelling, including domestic cap-and-trade emission trading scheme and/or carbon tax will come up as a next step under Sensitivity Analysis process due to challenging timeframe and political/administrative constraints, such as delays in adoption of MRV law and sub-legislation developed under World Bank PMR Initiative, but not adopted as of December 2019.

Modelling Report (Tasks E, F, G)

Supporting the development of Ukraine's second NDC

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LIST OF ABBREVIATION

BAU	Business as usual
BTU	British Thermal Unit
CCS	Carbon Capture and Storage
CGE	Computable General Equilibrium model
CHP	Cogeneration Plant
EBRD	European Bank for Reconstruction and Development
EE	Energy Efficiency
ETS	Emission Trading Scheme
EU	European Union
FC	Fuel Cells
FEC	Final Energy Consumption
GDP	Gross Domestic Product
GFEC	Gross Final Energy Consumption
GHG	Greenhouse Gas
GoU	Government of Ukraine
HPP	Hydro Power Plant
ICE	internal combustion engine
IEA	International Energy Agency
IEF	Institute for Economics and Forecasting
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
LEDS	Low Emission Development Strategy
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Monitoring, Reporting and Verification
MSW	Municipal Solid Waste
NASU	National Academy of Sciences of Ukraine
NDC	Nationally Determined Contributions
NDC2	2^{nd} Nationally Determined Contributions
NEEAP	National Energy Efficiency Action Plan
NPP	Nuclear Power Plant
NREAP	National Renewable Energy Action Plan
OECD	Organisation for Economic Co-operation and Development

PMR	Partnership for Market Readiness, the World Bank project
PPP	Purchasing Power Parity
RE	Renewable Energy
S1	Scenario 1 / Business As Usual (BAU) Scenario
S2	Scenario 2 / Reference Scenario
S3	Scenario 3 / Climate Neutral Economy Scenario
SAEE	State Agency on Energy Efficiency and Energy Saving of Ukraine
SCC	Social Cost of Carbon approach
TIMES	The Integrated MARKAL-EFOM System / family of energy system models
TPES	Total Primary Energy Supply
TPP	Thermal Power Plant
UES	United Energy System of Ukraine
UGEM	dynamic Ukrainian General Equilibrium Model
UWEA	Ukrainian Wind Energy Association
WEO	World Energy Outlook by IEA
WPP	Wind Power Plant

SECTION 1. SCENARIO ANALYSIS APPROACH FOR THE SECOND NDC OF UKRAINE

1.1 Methodological Approach for the 2nd NDC of Ukraine

Methodological approach proposed for assessment of the Ukraine's Second NDC (NDC2) targets is broadly described in the Background Report (Section 2.3) and provides for and extensive scenario analysis to be conducted using a set of modelling tools established by the Project Team (Figure 1.1), including:

- The energy system TIMES-Ukraine model, which covers Energy and Industrial processes Sectors (IPCC);
- A waste sector model, modelling tool for Agriculture and LULUCF sectors, that together with TIMES-Ukraine model will be used for the estimation of the GHG emission pathways corresponding to various policy and technological assumptions;
- A dynamic Ukrainian General Equilibrium (UGEM) model used to estimate the social and economic impacts of the resulting energy decarbonisation policies and measures;
- Visualisation and Analysis tool (V&A tool) to be used to ensure comprehensive visualisation of the current national GHG inventory data of Ukraine, existing data at sectoral and sub-sectoral levels with trend analysis and comparison to other Parties.

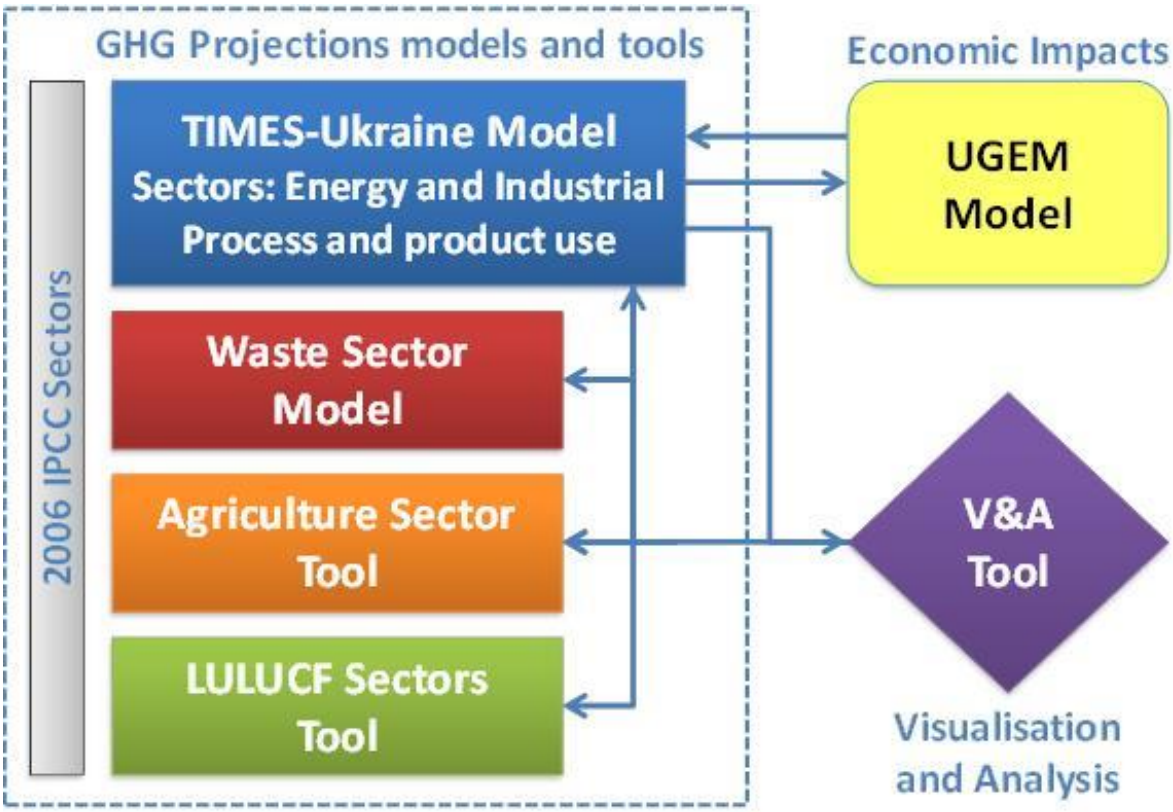

Figure 1.1. NDC2 modelling framework

Combination of the optimization least cost energy system model, macroeconomic (CGE) and sectoral models is the most common approach to determine long term, cost-optimal energy/emissions pathways, based on a range of different assumptions – for example, GDP growth rates, cost-effective energy saving and renewable energy potential, foreign trade flows, development of various generation types, energy production, transformation and consumption technologies, including carbon capture and storage, etc.

TIMES-Ukraine as a core of this modelling framework is a *technology-rich model* and provides information *across sectors* on the *types of energy used by year, technology uptake, GHG emissions and the costs across energy system*. For more details see https://iea-etsap.org/.

Waste sector modelling is based on national tools applied mass balance approach that was used for National Waste Management Strategy till 2030. Forestry and agriculture sectors emissions modelling applied combined IPCC and national bottom-up approach. All fuel combustion of waste and forestry sectors were modelled under TIMES-Ukraine forecasting process.

To provide economic assessment of the NDC policies in Ukraine we use a soft-linkage of TIMES-Ukraine and UGEM models, **described in Annex 4**.

After this modelling framework was considered and accepted by the Ministry of Energy and Environment Protection of Ukraine (at that time – Ministry of Ecology and Natural Resources of Ukraine), and endorsed during Inter-Ministerial Working Group on NDC2 Development in June 2019, the Project Team proceeded to apply the framework for the modelling exercises.

1.2 Key assumptions of the modelling

Prior to the assessment of different GHG emissions policies and targets, the set of assumptions has to be prepared, which determines the dynamics of the main drivers of energy consumption/GHG emissions.

There are several types of assumptions normally made for such kind of modelling, including:

- **Exogenous assumptions** (also called as **uncontrolled variables**): Not directly related to the subject of research, and set the common framework of modelling – such as economic and demographic assumptions, international energy prices, fossil fuel reserves or renewable energy potential, technical parameters of energy technologies;
- **Endogenous assumptions** (or **controlled variables**): Used to compose the scenario to study latter on via modelling calculations, in our case – technological and policy options in energy and environment.

The estimation of exogenous parameters is an important analytical preparatory task within scenario analysis algorithm, as these assumptions can significantly affect obtained solution, e.g. the range of involved emission processes (technologies) and the intensity of their use.

This study follows **the principle of "perfect foreseen modelling,"** meaning demands (energy demands, transportation demands, feeding demands) are explicitly defined by exogenous assumptions and could be met by processes (technologies) with a different level of emissions.

The set of such processes is estimated via modelling, considering endogenous assumptions by scenario. For example, space heating demand is assessed as floor area (but not in energy units) using the number and category of residential dwellings in urban and rural areas, taking into account the dynamics of population at the place of residence and composition of households, growth rate of the specific dwelling area per resident, as well as construction of new buildings with centralized and autonomous heating systems.

The economically optimal solution on fuel and technology mix is then made by the model, based on analysis of alternative technological options of heat production, supply and consumption, or energy saving measures, with respect to imposed energy/environmental policy constraints. Non-technological measures that can affect predefined demands, such as triggered changes of social attitude, shift in transport mode, diet or workstyle were not considered in this report.

Assumptions on exogenous parameters are described in the following Section 2. GDP development by sector and other economic assumptions **are based on the integrated economic projection i.e. short-term projection until 2022, prepared by the Ukrainian Government on May, 2019, was then extended by the IEF experts till 2050**. Macroeconomic projection is **supplemented by:**

- **The demographic forecast** prepared by the Institute of Demography and Social Studies, NASU
- **The global energy price projection** from the IEA World Energy Outlook 2018
- Energy sector specific assumptions such as EE&RE potential by sector, as these parameters are also exogenous for this report.

While exogenous assumptions are common for all scenarios, endogenous assumptions are scenario-specific, as they are imposed to reflect specific policy option to be modelled and assessed, such as energy or GHG targets, market penetration of new technologies or introduction of carbon tax. Such sequence of assumptions and scenarios is important to guarantee the adequate comparability of modelling calculations by the Scenario. For example, if achieving the target (endogenous assumption) is assessed, both calculations (with and without target constrain) needs to be based on the same economic and technological assumptions (exogenous assumptions).

For this reason, three GHG Emissions Pathways Scenarios (NDC2 Scenarios) presented in this report, **differ from each other with energy/environmental policy assumptions**, such as perspective EE or GHG targets, and further described in Section 3. Meanwhile, to make modelling calculations of the Scenarios mutually comparable, **other Scenarios' assumptions that predetermine the development of the energy system,** such as macroeconomic (GDP, value added and production by sector, energy prices), demographic (quantity and income of the population, housing stock) and technological (costs of technologies, available RE&EE potential) assumptions, **were kept uniform for all three Scenarios.**

1.3 The modelling process

1.3.1 Developing a baseline projection

The development of a baseline projection is a crucial step for understanding GHG emission reduction potential in the current year and up to 2050. For example, it is not possible to identify mitigation measures in the energy sector without knowledge of the "normal" prospective energy demand trajectory across different sectors. Energy supply/demand baseline calculations provide information on existing fuel use, types of technologies used and policies and measures in place.

- Scenario 1 or the **"Business as usual (BAU) Scenario"** is set as an "exploratory scenario," assuming that no fundamental changes take place, and particularly no additional emission reduction measures are implemented during the projected period.
- Energy consumption, agrarian production or processing of waste, together with corresponding GHG emissions under BAU Scenario just follow the development drivers, without additional constraints or exogenous elements affecting these drivers.

The main purpose of the BAU scenario is to create a basis for comparison with other Scenarios.

1.3.2 Formulating the policy scenarios

The next step is to formulate and run policy scenarios to assess contribution from various mitigation measures towards GHG emissions reduction:

- The Scenario 2 or the **"Reference Scenario"** contains numerous targets and indicators to be achieved according to existing and drafted legislation modelled as policy constrains with policy-specific timeline (e.g. Energy Strategy indicators and targets ought to be achieved by 2035, NEEAP, NREAP, LEDS indicators).
- The Scenario 3 or the **"Climate Neutral Economy Scenario"** contains the same set of policy targets were applied as for the Reference Scenario with an additional target constrain imposed on the level of GHG emissions per capita by 2070 (GHG emissions per capita).

1.3.3 Checking that the scenarios are fit-to-purpose

The BAU and Reference scenarios by design have the models estimate the GHG emissions until 2050. In the case of **BAU,** it would be a result of a limited implementation of existing and drafted legislations and policies. Whereas in the case of the **Reference Scenario,** it would be the outcome of the full implementation of the relevant existing and drafted legislation and policy implementation, carried out at most economically viable way that results the GHG emissions estimation, but not as an in-built cap.

On the other hand, the **Climate Neutral Economy Scenario** sets a clear cap on GHG emissions per capita level on maximum of 1.7 t CO2e / year in 2050 (in line with the IPCC Special Report of Global Warming of 1.5 ºC) and the modelling is made based on this default value. Based on the Article 4 of Paris Agreement,[2] Scenario 3 assumes that net-zero carbon neutral economy of Ukraine can be achieved by 2070.

Scenario assumptions by sector are elaborated in Section 3. For each scenario (BAU, Reference and Climate Neutral Economy), the models calculate the development trajectories of the system – under simulation approach for the Waste and LULUCF sectors and the least cost (or maximum surplus) optimization approach for the energy and industrial processes i.e. energy supply and demand by sector and fuel type, dual or shadow energy prices, the optimal technology mix, GHG emissions, investments etc.

Scenario analysis of this report is finalized with an economic assessment to understand the economic impact of the Scenarios' assumptions. Economic impact assessment for Scenario 2 and 3 is summarized in Section 4.

1.3.4 Consideration of costs and investments

Calculation of the trajectory of the energy system development and the corresponding GHG emissions under certain scenario conditions is normally made upon criteria of minimization of **total energy system costs**[3], which includes:

- capital investments (costs) both for the construction of new energy assets (that should be considered exactly as an investment in accordance with accepted macroeconomic statistics terminology), and for the purchase of final energy consumption appliances, some of which could be considered as not investment, but intermediate production or final consumer costs (for energy

[2] According to the Article 4 of Paris Agreement, "…Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty."

[3] This methodological approach is generally accepted, for example, see Impact Assessment. Energy Roadmap 2050 https://ec.europa.eu/energy/sites/ener/files/documents/sec_2011_1565_part1.pdf or Impact Assessment of the Energy Efficiency Directive (2012/27/EU) for the Energy Community https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/3304025/Report_for_web.pdf

management, installation of modern control systems, thermal modernization of buildings, purchase of household appliances or vehicles, etc.);

- fixed and variable operating and maintenance costs for energy production, transportation and consumption technologies;
- energy and fuel costs (expenditures) assessed on the basis of the marginal cost of each type of fuel, taking into account the cost of imported resources;
- concessions, rental or other payments (target allowances, emission tax, etc.).

This methodological approach allows developing energy/environmental projections from the standpoint of *minimization of social costs, and at the same time maximization of utility of energy producers and consumers*. Thus capital investments, considered in TIMES model, are not just investments in the energy sector, but more precisely are *«energy related investments», accounting for about 60-70% of total investments in the economy*.

Depending on the way the scenario is formulated, the total energy system costs provide some metrics when comparing different scenarios. For example, implementing cost-effective energy efficiency measures will reduce overall costs if fuel savings offset additional investment for the purchase of new equipment (as in Scenario 1). At the same time, if rigorous energy efficiency targets are set, investment in the necessary equipment may be unjustified in terms of potential energy-saving effects over modeling horizon leading to an increase in total system costs (as in Scenario 2 and 3).

The additional economic effects and benefits resulting from implementation of energy or environmental policies (such as those improving foreign trade balance or generating demand for manufacturing, effecting economic performance or employment in industry, services, construction etc.) **are not considered in the TIMES-Ukraine model.** However, experience shows that the true impact of such policies should be sought across the whole economy. Therefore, the **assessment of the cross-sectoral effects of the implementation of policy scenarios was carried out in this study using the UGEM model (Section4)**, **and disaggregated energy system costs by sector are used as an input data for such analysis.** The approach of mapping TIMES-Ukraine-based costs and investments with UGEM classification is broadly described in Annex 4.

1.3.5 Planning for sensitivity analysis on key assumptions

Scenario analysis of this report will be further elaborated with a sensitivity analysis, where additional assumptions (economic, technological or policy) will be applied to check the variability of calculations, and then finalized with an economic assessment to understand the economic impact of the Scenarios' assumptions.

SECTION 2. CONDITIONS AND ASSUMPTIONS OF THE NDC2 SCENARIOS

2.1 Macroeconomic projections

2.1.1 Short-term macroeconomic projections

The Project team has updated macroeconomic scenarios previously developed and presented in the Background Report, in order to get them fully consistent with the official short-term governmental macroeconomic projection until 2022[4].

Two scenarios have been developed for the macroeconomic projection of this report:

1. **Short-Term Macroeconomic Scenario 1 (Projection 1):** Assumes a continuation of the current trends towards increase of investment and exports of higher value-added goods.
2. **Short-Term Macroeconomic Scenario 2 (Projection 2):** Assumes that the Ukraine's economy will develop according to a consumer model. The consumer model assumes a more significant increase in household consumption, stimulated by higher increases in state social standards, which will give more impetus to the economic development during the initial phase. This translates as to higher demand at the initial phase, but with some decline by the end of the projection period.

In this short-term governmental projection, the difference of the aggregated GDP per scenario is not highly evident – 3.7% average growth rate in Projection 1 and 3.5% in Projection 2 (Fig. 2.1).

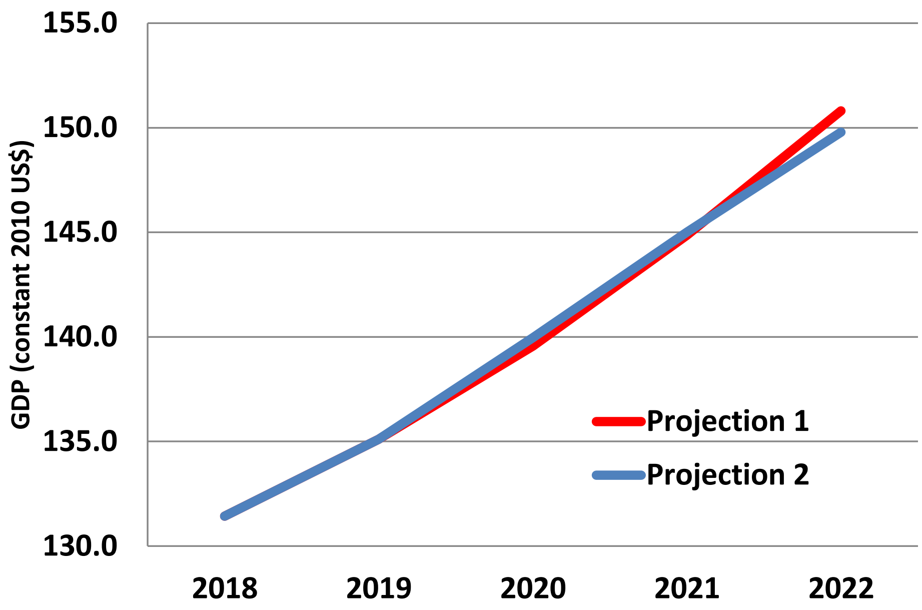

Figure 2.1. Short-term GDP Projection

[4] Projection of the economic and social development of Ukraine for 2020-2022, adopted by the Cabinet of Ministers of Ukraine on May 15, 2019 (No. 555) https://zakon.rada.gov.ua/laws/show/555-2019-%D0%BF

However, more significant differences are observed in the minimum and average wages, consumer demand, foreign trade, growth rates of consumer-oriented and investment-oriented industries, inflation rate, migration flows and overall population, and various macroeconomic balances (see Table 2.1).

More details on the governmental projection are available on the Ministry of economy's website[5].

Table 2.1. Parameters of the short-term projections

Indicators	Projection 1	Projection 2
GDP, %, average annual	3,7	3,5
Industry production index, %, average for period	4,1	3,8
Food production, %, average for period	3,8	4,2
Heavy machinery production, %, average for period	7,5	6,1
Consumer price index, %, average annual, average for period	6,3	7,2
Wages/Salary, average monthly in 2022, UAH.	15 224	16 682
Goods and services balance, in 2022, USD mln	-16 113	-17 250
Current expenses account, in 2022, USD mln	-6 829	- 7 685
Industry share in GDP, in 2022, %	21,3	21,5

2.1.2 Long-term Macroeconomic Projections

In order to develop a long-term projection, IEF experts extrapolated the assumptions from the governmental projections until 2050[6], while keeping the primary concept of economic development per each scenario. This means assuming inertial vastly socially-orientated development with a focus on recovery of existing production facilities (hereafter referred to as the **"Baseline Macroeconomic Scenario**", aligned with Projection 2 of the short-term macroeconomic scenario) and innovative development supported by the accelerated investment activities (**"Optimistic Macroeconomic Scenario,"** consistent with Projection 1 of the short-term macroeconomic scenario).

The Baseline Macroeconomic Scenario is used for all NDC scenarios described below, while the Optimistic Macroeconomic NDC Scenario will be used for the **sensitivity analysis later.**

Despite various economic reforms and market transformations of the last decades, the economy of Ukraine remains resource-intensive, low competitive and technologically backward, comparing to other European countries. Slight structural

[5] Projection of the economic and social development of Ukraine for 2020-2022. Supplementary report. http://www.me.gov.ua/Files/GetFile?lang=uk-UA&fileId=ac8b12ca-b073-4fae-8d02-a334a37a3060
[6] Macroeconomic projections for 2022-2050 were carried out with a use of modified Input-output balance model developed in the Institute of Economics and Forecasting, National Academy of Sciences of Ukraine and led by prof. Mariya Skrypnychenko.

transformations still could be observed, enhancing diversification and resistance of the national economy and supporting some (slow) economic growth. However, in this study we assume that, as a result of successful implementation of much ambitious macroeconomic structural reforms in Ukraine, it would be possible to achieve the sustainable growth of GDP with **at least 3,5 – 4,5% on average for the period 2018-2050 (Figure 2.2).**

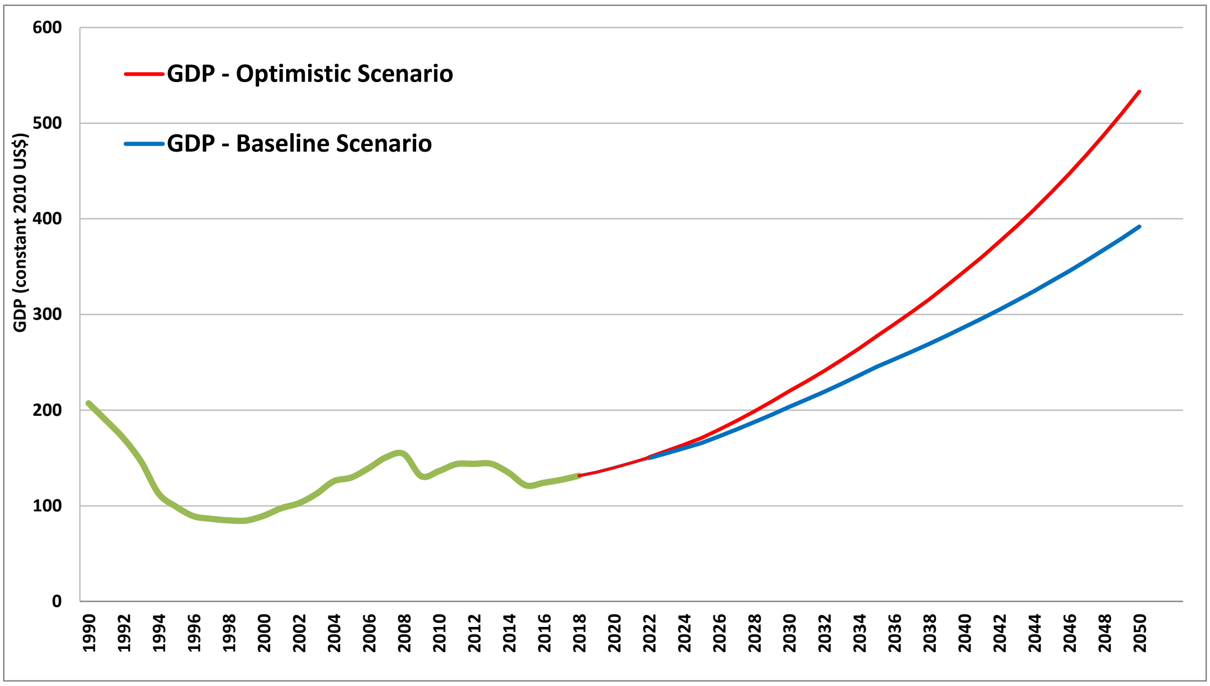

Figure 2.2. Long-term GDP Projection

The most important assumptions/conditions that determines global economic projections for the next 30 years are the following:

- **Significant acceleration of technological progress, shifting the world economy into the new technological mode:** We assume that the next technological shift is more like to be provided by nano- and cellular technologies that reduce energy and material intensity of production and open up new possibilities for managing the properties of materials and organisms;

- **The Services sector will become a driving force of economic development:** Important feature of the post-industrial economic model is the fundamental redistribution of resources between the primary (Agriculture and Mining), secondary (Manufacturing) and tertiary (Services) sectors. As the global economy goes through the "tertiary revolution," the service sector is expected strengthen.

- **Global average annual growth will be between 2-3%, with emerging market average growth ranging between 3.5 and 5%:** Most of the latest studies provide for slowdown of the global economy in the long-term perspective. In line with this, the global economic growth over 2025-2050 is assumed to not exceed 2-3% annually. Specifically, in the EU area, the average GDP growth rate is assumed as 1.5-2%, while China, India and other economies in Asia and Africa are assumed to make 3.5-5% annual growth.

Table 2.2. Parameters of the long-term economic projection

Indicators	2021-2030		2031-2040		2041-2050	
	Base	Opt	Base	Opt	Base	Opt
GDP, %, average for period	3.8	4.6	3.5	4.6	3.2	4,4
Mining and quarrying, growth rate in %, average for period	2.0	2.2	1.2	1.2	0.6	0.4
Manufacturing, growth rate in%, average for period	4.5	5.6	4.2	5.6	3.8	5.3
Industry, growth rate in%, average for period	3.5	4.3	3.2	4.3	2.9	4.2
Construction, growth rate in %, average for period	5.0	6.7	4.3	6.1	3.9	5.6
Services, share in GDP, average for period, %	52.7	52.9	54.3	55.3	55.7	57.4
Agriculture, share in GDP, average for period, %	9.3	9.2	8.2	7.8	7.3	6.6

Although in the past economic development in Ukraine did not always follow the global trends (in particular in terms of favourable economic transformations), in this study **we assume gradual convergence of the Ukrainian economy with a common dynamic**:

- GDP growth rates in Ukraine in the projection period will somewhat exceed the world average growth rates, that should be considered as typical for small-scale economies started to implement effective structural reforms.

- Restructuring of economy will provide a gradual shift from the orientation on raw-commodities in foreign trade, which will cause a reduction in the share of Mining and Agriculture in GDP in favor of the Manufacturing industries.

- Gradual increase in household incomes will ensure the harmonization of household spending and lead to an increase in the share of the services sector.

- Modernization of the Ukrainian economy will be targeted on ensuring the energy/resource efficiency and environmental safety in all spheres of production and life.

Baseline and Optimistic Macroeconomic Scenarios differ in GDP growth rates, household incomes and investment potential, which leads to different rates and depth of structural transformation.

2.1.2.1 Baseline Macroeconomic Scenario

In the Baseline Scenario the annual growth of GDP during 2018-2050 will be 3.5% on average that will result in three time's increase of GDP until the end of the projection period. Household income will annually increase on average by 5-6%.

Mining, Power generation and Agriculture will slow down relative to other activities: Agriculture will grow with average annual growth rate of 2.3%, Mining – 1.3%, the share of Agriculture will decrease from 10% to 7%, Mining – from 6% to 3%. Agrarian sector products will be more heavily targeted for processing internally in Ukraine, resulted in 4 times increase of **Food production** till 2050 with an average annual growth up to 3.8%. The share of **Mechanical engineering** will increase significantly, with vehicle production increasing more than 8 times, computers, electronic and optical equipment more than 7 times, and electrical equipment more than 6 times. A slower increase in household incomes will limit the development of services and its share in GDP will increase up to 56%. Computer programming, consultancy and tourism related services will show the largest growth among **Services**.

Modelling results show minor changes in the structure of GVA until 2030 as this period is when industry will recover to the level of 2013. Thus, more evident structural changes in output of goods and services are observed in the long run (see Table 2.2).

Actual GDP growth in Ukraine will depend on the successful implementation of structural reforms, product and geographical diversification of exports and, in particular, the development of domestic market. This requires a large-scale investment campaign, the growth rate of gross fixed capital accumulation during 2020-2025 should reach at least 8-14%, and in 2021-2050 - 15-18% on average, while the rate of fixed capital accumulation to GDP should reach 20-24%, which is a prerequisite for accelerated economic growth.

Among other important factors that should ensure economic growth in Ukraine, there are **political consensus and termination of the violent conflict with Russian Federation**. In such case, Ukrainian economy will receive a strong impulse for development due to extension of domestic market and the need to restore the destroyed infrastructure.

Modelling estimation of growth rates by sector could be found in Annex 1.

2.1.2.2 Optimistic Macroeconomic Scenario

The Optimistic Macroeconomic Scenario was developed with the objective of being used for sensitivity analysis. According to the Optimistic Scenario, the average annual GDP growth rate will be 4.45%, making GDP in 2050 more than 4 times higher compared to 2017. Household income is expected to grow with higher rates of 7-9% per year.

Expected GDP and household growth rates will provide sufficient investment potential for the implementation of the energy efficiency programs and the corresponding structural reform of the Ukrainian economy, which will reduce the energy intensity of the products and services. Consequently, the growth rates of oil, gas, coal, and electricity production will slow down relative to the growth rates in other sectors.

The key projected trends are:

- In the **Manufacturing,** the share of mechanical engineering will increase significantly, first of all, in manufacture of computers, electronic and optical products (will triple), manufacture of building materials, pharmaceuticals, which will be facilitated by active import substitution policy. Instead, the shift towards new technologies and newly created materials will result in reduction of the shares of manufacture of wood, coke and metallurgical production in GDP.

- Although the share of Manufacturing and Construction will increase significantly, the slower growth rates in **Mining, Agriculture and Energy sector** will cause the decline of the share of real sector from 49% to 42%, and the share of Services will respectively increase from 51% to 58%.

- The need for modernization of industrial and social infrastructure supported by the increase of financial capacity of the Government and households will cause the high growth rates of **Construction** – production in this sector will increase more than 7 times, and its share in GDP will double by 2050.

- The largest growth among **Services** will be in computer programming, consultancy and related activities: production of services there will increase by almost 9 times, and it's share in GDP will grow from 2.3% to almost 4.8%. Tourism services such as Accommodation and food service activities and Arts, entertainment and recreation will grow with higher rates than GDP. Research activities will also have substantially higher growth rates than average, doubling its share in GDP by the end of the projection period.

- In the **Agriculture** the livestock production will show high growth rates, while it is less likely to expect significant increase in crop production in Ukraine as it is constrained by natural and climatic conditions. Overall production in Agriculture is expected to increase by 2.6-2.7 times by 2050. The products of this sector will be mainly processed internally, which will result in a significant increase in food production and an increase of the share of Food industry in GDP from 3.3% to 4.5%.

2.2 Demographic projections

Macroeconomic scenarios prepared for the Second Ukraine's NDC predefine perspective economic structure, corresponding energy use and GHG emissions, as well as set conditions of the perspective demographic development.

For the purpose of this project, experts from the Institute of Demography and Social Studies, NASU, have updated their demographic projections aligned with available official statistics and assumptions made for macroeconomic projections described above.

For the Medium and High demographic scenarios (consistent with Baseline and Optimistic Macroeconomic Scenarios respectively) different assumptions were made with regard to life expectancy, mortality rate, TFR (children per woman), number of survivors, probability of death, born alive, migration and other standard demographic parameters by age and gender. Resulted estimations of these projections are shown in Figure 2.3 and summarized in Table 2.3.

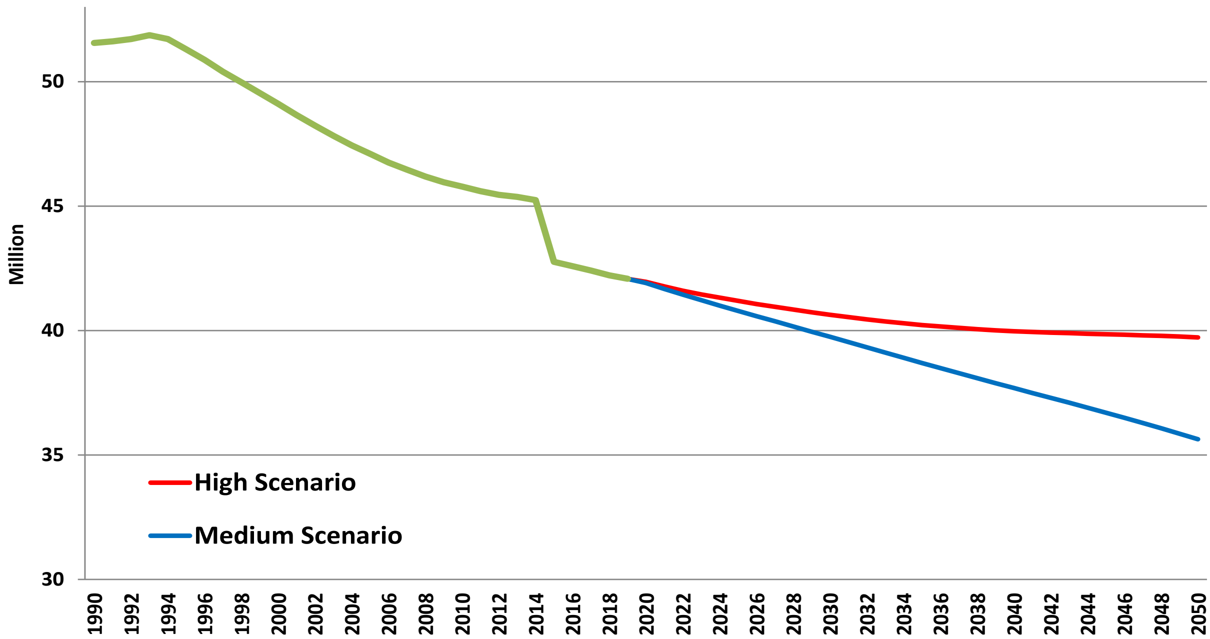

Figure 2.3. Long-term Demographic projection

Table 2.3. Parameters of the long-term demographic projection

Indicators	2018	2030		2040		2050	
		Med	High	Med	High	Med	High
Population*, mln	42.4	39.7	40.6	37.7	40.0	35.6	39.7
Average life expectancy, both genders, years	72.2	73.9	75.0	75.3	77.1	76.7	79.1
Average population age, both genders, years	40.5	42.7	42.5	44.4	43.9	45.4	42.6
Share of working-age population, both genders, %	51.1	48.4	48.1	47.5	46.7	43.0	45.6
Number of retired per working persons, both genders, persons	0.99	1.14	1.16	1.24	1.30	1.49	1.43
Share of rural population, %	32.6	31.6	32.3	30.2	32.0	28.6	31.8

** Number of population is aligned with reported data provided by the State Statistics Service of Ukraine and does not included the annexed territory of Republic of Crimea. For the purpose of the NDC these numbers would be correspondingly adjusted.*

2.3 Energy prices projections

Comprehensive energy prices projection is as important as macroeconomic drivers or energy policy targets, as different price dynamics for different energy resources determine the price parity between energy resources and thus may affect economic viability of technologies or policy options in the future.

The International Energy Agency's forecast (World Energy Outlook 2018, New Policies Scenario, Table 2.4)[7] was used for the purposes of this analysis.

Table 2.4. Energy prices projections

Energy Source	2017	2020	2025	2030	2035	2040	2045	2050
Energy Coal, EU, USD 2017/t	85	90	80	83	84	85	87	89
Brent Oil, USD 2017/barrel	52	65	88	96	105	112	121	132
Natural Gas, EU, USD 2017/ mln BTU	5.8	6.0	7.8	8.2	8.6	9.0	9.4	9.9

2.4 Carbon prices

The establishment of the scheme for GHG emission allowance trading (Emission Trading Scheme, ETS) is provided by the EU ETS Directive 2003/87/EU included to the Association Agreement between Ukraine and EU. Despite there was a firm implementation plan for this task, for the moment it is still difficult to estimate the clear timeframe when the Ukrainian ETS would be introduced. This is due to both objective political and administrative difficulties, such as the delay in introduction of a new power market model (summer 2019) and the inability to fully cover plants with an annual GHG emissions of 200 mln t CO2e in Crimea and the Donbass regions, as well as the incompleteness of the regulatory framework.

In particular, the operation of ETS system is not possible without a proper MRV system (system for monitoring, reporting and verification of emissions reports). As of today, there is no single adopted methodology for calculating GHG in Ukraine, as well as verification procedure and an appropriate authorized agency. Relevant draft law8 and Government decrees[9] were developed by the Ministry of Ecology still in autumn 2018, although have not been adopted yet.

Given the high level of uncertainty about the timing of full-fledged introduction of the ETS in Ukraine, its organizational framework and participants, it is quite difficult to estimate the prospective level of the carbon price set by the market and incorporate correspondent market conditions into the NDC2 scenarios without additional assump-

[7] IEA (2018), World Energy Outlook 2018, IEA, Paris, https://doi.org/10.1787/weo-2018-en.
[8] Draft Law of Ukraine on the Principles of Monitoring, Reporting and Verification of Greenhouse Gas Emissions http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=64881
[9] Draft Resolution of the CMU on Approval of the Procedure for Verification of the Operator's Report on Greenhouse Gas Emissions http://www.greenmind.com.ua/images/2019/proekt-postanovy-kmu-pro-modernizatsiyu-potochnoyi-veryfikatsiyi-zvilnennya-operatora-pro-vikifikatsiyu-parnykh-haziv.pdf; Draft Resolution of the CMU on Approval of Procedure for Monitoring and Reporting of Greenhouse Gas Emissions http://www.greenmind.com.ua/images/2019/proekt-postanovy-kmu-11-04-18-1.pdf; Draft Resolution of the CMU on Approval of the List of Activities Covered by the Monitoring, Reporting and Verification of Greenhouse Gas Emissions http://www.greenmind.com.ua/images/2019/proekt-postanovy-kmu.pdf

tions. Considering this, the Project team did not to include the ETS (carbon pricing) assumptions in Scenarios 2 and 3, which are based on the clearly defined targets and objectives of the effective governmental documents. Instead, the team the impact of carbon price will be evaluated within sensitivity analysis upon two options:

- Ukrainian domestic cap and trade ETS implementation with coverage based on World Bank PMR Carbon Pricing Report (2019) and carbon tax for the sectors not covered by the ETS. The emissions cap for sectors covered by ETS will be as in the Scenario 2, which is different from that adopted in the PMR report. Therefore, the explicit carbon price for ETS will be different than that used in the PMR report.

- Apply a range of carbon tax values in Scenario 2, which cover all energy users, exploring the sensitivity of the solution to GHG emission prices.

The idea of both sensitivity options is to add one more measure on top of the EE and RE measures, which are included in Scenario 2. More advanced technologies, which are available in Scenario 3, should be available for this sensitivity analysis on Scenario 2, in order to allow more flexibility to the system.

Cross-border carbon adjustment tax macroeconomic impact assessment will be carried out, based on various experts judgments of future EU policy implementation and assumptions regarding carbon intensities of sectors that would be potentially taxed by EU and using the same carbon price as in the EU ETS.

2.5 Potential of renewable energy sources

The renewable energy potential of Ukraine's applied for NDC2 scenarios was presented in the report "Transition of Ukraine to the Renewable Energy by 2050"[10], with minor updates and changes.

2.5.1 Wind potential

Ukraine has a significant natural potential for the implementation of wind energy projects. This supports government's interest in the development of this industry and attracts a large number of potential national and foreign investors. International experience proves that most efficient wind energy development is taking place in the coastal area and in the mountain and rugged mountain areas. From this point of view, Ukraine has necessary geographical potential for wind energy development zones.

According to the latest estimates of the Ukrainian Wind Energy Association (UWEA), 16 GW of WPP is a real potential of the wind energy sector of Ukraine. If capacity utilization rate is at least 40% - confirmed in practice for currently operating WPPs in

[10] "Transition of Ukraine to the Renewable Energy by 2050" / O. Diachuk, M. Chepeliev, R. Podolets, G. Trypolska and oth. ; edited by Y. Oharenko and O. Aliieva // Heinrich Boell Foundation Regional Office in Ukraine. – Kyiv: Publishing house "Art Book" Ltd., 2017. – 88 pages

Zaporizhzhia, Kherson and Mykolaiv regions - the annual power generation capacity of WPPs can amount to 56 billion kWh. This is equivalent to 29% of the total electricity production in Ukraine before the occupation of the Autonomous Republic of Crimea, city of Sevastopol by the Russian Federation and its military aggression on the territory of defined areas of Donetsk and Luhansk regions. Based on 2016 figures, 56 billion kWh equals to 34% of the total electricity production.

The potential of on-shore wind energy until 2050 applied in NDC2 scenarios is presented in Table 2.5. Under the cost optimization process of building the most optimal energy generation system to satisfy the energy consumption needs, the model will choose the level of wind energy generation that is not higher than figures in the table with Key Input Assumptions in the Summary.

Table 2.5. Wind Energy Potential, GW

	2020	2030	2035	2050
On-shore wind	1,65	8,0	16,0	24

Taking into account recent global trends of renewable energy development, including both on-shore and off-shore wind, the economically viable wind potential in Ukraine could be further considered under Scenario 3.

2.5.2 Solar energy potential

According to the State Agency on Energy Efficiency and Energy Saving of Ukraine (SAEE), the theoretically possible potential of solar energy at the territory of Ukraine is over 730 billion kWh per year, but the technically possible potential is only 34.2 billion kWh per year.

One of the main obstacles to the intensive development of renewable power is a poorly developed grid and outdated centralized approach. According to national expert assessments, renewable energy technologies in Ukraine can cover up to 80% of electricity demand taking into an account current level of technology development.

In NDC2 scenarios the following maximum solar energy potential was applied as presented in Table 2.6. Roof-top solar potential for both private households and commercial real estate, including industry and agricultural sectors were modelled under this Scenario.

Table 2.6. Solar Energy Potential, GW

	2030	2035	2050
On the ground solar panels	6	12	36
Roof-top solar panels	2	4	12

2.5.3 Bioenergy potential

According to the Bioenergy Association of Ukraine[11], the economically feasible current bioenergy potential is about 20 million toe, and it could reach 42 million toe in

[11] http://uabio.org/

2050 (Table 2.7). This is possible due to increased use of corn for biogas production, energy crops cultivation and use of biogas.

Table 2.7. Bioenergy potential

Biomass type	2015			2050
	Theoretical potential, mln t	Share available for energy sector, %	Economic potential, mln tce[12]	Economic potential, mln tce
Cereals straw	35,14	30	5,22	7,83
Rape straw	3,10	40	0,62	0,93
Corn grain production wastes (stems, cores)	30,3	40	3,31	4,97
Sunflower seed production wastes	21,2	40	1,74	1,74
Secondary agricultural wastes (sunflower husks)	1,9	41	0,39	0,39
Total agricultural potential	**91,64**		**11,28**	**15,86**
Wood biomass (firewood, logging wastes and residues, splinters)	8,8	41	1,47	2,97
Wood biomass (maintenance logging of forest bands, dead-wood)	11,0	58	2,57	1,47
Total wood	**14,80**		**3,45**	**4,44**
Biodiesel	-	-	0,27	0,27
Bioethanol	-	-	0,77	0,77
Total biofuel	**-**	**-**	**1,04**	**1,04**
Biogas from by-products of the agri-food sector (manure + food industry)	1,6 10^9 м^3 CH_4	50	0,97	3,40
Biogas from solid waste landfills	0,6 10^9 м^3 CH_4	34	0,26	0,85
Biogas from wastewater	1,0 10^9 м^3 CH_4	23	0,27	0,56
Total biogas	**3,2·10^9 м^3 CH_4**		**1,5**	**4,81**
Poplar, miscanthus, acacia, alder, willow	11,5	90	6,28	18,84
Corn (biogas)	3,3 10^9 м^3 CH_4	90	3,68	14,72
Total energy crops			**9,96**	**33,56**
TOTAL, million tce			27,63	60,10
TOTAL, million toe			**19,34**	**42,07**

Source: *data provided by the Bioenergy Association of Ukraine, 2017*

2.5.4 Hydro energy potential

Large hydropower development is limited in NDC2 scenarios, as this type of generation is recognized as unsustainable renewable energy source. Thus, only the completion of the Kakhovka HPP-2 on the basis of the existing dam is potentially considered, since serious environmental impacts are not expected in this case. Based on these assumptions, the capacity of large hydropower (HPP and PSPP) will be 6,033 MW (2015) + 250 MW (Kakhovka HPP-2), which will amount to 6,283 MW in total.

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

[12] tce stands for tons of coal equivalent

According to the Institute of Renewable Energy, NASU, the maximum capacity of small HPPs, which could be achieved by 2030 is 250 MW. That is, the additional potential to existing capacities will be 160 MW. Assuming that 50% of the new small HPPs meet all environmental criteria, the additional increase will be 80 MW. It is assumed that a significant part of this potential should be implemented as a result of modernization and increase of efficiency of the existing small HPPs. New mini-HPPs can only be constructed subject to stringent environmental criteria that need to be introduced at the legislative level.

There is bigger potential for large hydro development in Ukraine, but taking into account the increasing negative impact and further consequences of large hydro development due to climate change, large hydro could not be further considered as renewable energy source.

2.5.5 Geothermal potential

Based on the information provided on the SAEE web-site, Ukraine has some potential for geothermal energy development. At the same time, the current scientific and geological-exploration data and activities in Ukraine only consider geothermal water energy development. Based on different assessments, economically viable geothermal water source for energy is assumed at the level of up to 8,4 mln toe per year, but economically viable geothermal potential for power energy is insignificant, even though it's been incorporated and modelled in TIMES-Ukraine.

2.5.6 Power and Heat Sector

TIMES-Ukraine has comprehensive technologies list for power and heat sectors in order to evaluate the potential for GHG emissions reductions in Ukraine that is presented in Annex 2. The main sources of GHG emissions reductions comes from existing technologies enhancement, phasing-out old technologies and development of new renewables technologies with the change of the heat and power production structure, while there are opportunities for nuclear energy development as low emission technology.

Meanwhile, for the stable and reliable operation of United Energy System of Ukraine (UES), TIMES-Ukraine modelled the scenario applying the assumptions that large wind and solar energy sources will be developed in parallel with balancing energy production sources, such as accumulation and natural gas power generation technologies, since both solar and wind are unstable energy sources. The main assumption here is that for each MW of new wind or solar energy entering UES, 1 MW (10%) of accumulating energy must be built and for each MW of solar and wind energy connecting UES – 0,3 MW (30%) and 0,4 MW (40%) of new rapid start natural gas energy production facilities must be built.

Existing green tariffs system for renewable energy will be in place until 2030 only and after that all renewable sources will be competing with the rest of energy production under equal conditions.

2.6 Potential of energy efficiency improvements

Energy efficiency enhancement will be taking place in different sectors through technological improvements and replacements. Below, there is a list of energy efficient technologies selected by TIMES-Ukraine for modelling of NDC2 scenarios as cost effective. Detailed report of increasing energy efficiency potential in Ukraine by sectors could be found here[13].

2.6.1 Buildings Sector

Despite proclaiming energy efficiency as one of the main priorities of state policy and the gradual expansion of government initiatives to stimulate consumers to use energy in an efficient manner in their everyday life, the technical condition of most existing residential and non-residential buildings and related energy systems does not ensure required level of energy characteristics of buildings. Energy costs for heating amount to 250-400 kWh per m^2 per year in Ukraine, while it is 180 in Germany, 150 in Scandinavia, and 60-80 kWh per m^2 per year in buildings constructed using heat-saving technologies.[14]

Based on data of the Association of the Energy Auditors of Ukraine[15], SEVEn Energy company[16,17] the assumptions on investment needs and efficiency of measures for thermal modernization of buildings presented in Table 2.8.

Table 2.8 Assumptions on investment needs and efficiency of measures for thermal modernization of buildings

	Private residential buildings		Multi-apartment buildings		Non-residential buildings	
	investments EUR mln/PJ	savings %	investments EUR mln/PJ	savings %	investments EUR mln/PJ	savings %
Simple rehabilitation	28.9	14	31.0	14	38.8	10
Complete rehabilitation	117.0	52	125.6	46	165.0	55
Additional modernization	140.0	74	180.0	75	220.0	75

An analysis of the prospective needs for heating and the use of energy resources for other household needs has been carried out. It takes into account the assumptions of the demographic scenario, in particular living conditions of households, as well as the forecasted growth rates and structure of the service sector. Despite the forecast for further gradual reduction of the population, the growth rate of the living space in the household sector will outweigh this negative trend: the total area of residential buildings will increase by 14.5% till 2050 as compared to 2015. The average area for

[13] "Transition of Ukraine to the Renewable Energy by 2050" / O. Diachuk, M. Chepeliev, R. Podolets, G. Trypolska and oth. ; edited by Y. Oharenko and O. Aliieva // Heinrich Boell Foundation Regional Office in Ukraine. – Kyiv: Publishing house "Art Book" Ltd., 2017. – 88 pages.
[14] Ukraine on the way to independence. Achievements and perspectives // State Agency on Energy Efficiency and Energy Saving of Ukraine. – Kyiv, 2016. – 45 pages
[15] http://aea.org.ua/
[16] http://www.svn.cz
[17] Impact Assessment of the Energy Efficiency Directive (2012/27/EU) for the Energy Community, https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/3304025/0633975ADB617B9CE053C92FA8C06338.PDF

households living in multiapartment buildings will be about 60 m^2, and 90-100 m^2 in private houses.

Buildings' thermal insulation technologies have biggest potential on the housing sector, but this this not the only measure applied during the modelling. Increasing the efficiency of heating, water heating, cooling, lighting and other consumptions technologies is also important and that was modelled by TIMES-Ukraine by type of technologies and energy sources demand. The housing sector GHG emissions reductions policies and measures foresees the development of bio-, geo- and solar technologies together with other technologies that will be using centralized heat and power energy produced from renewable sources.

2.6.2 Industry

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

Table 2.9 Energy consumption subject to introduction of new technologies in industry

Sector	Current average energy consumption per ton of product[18]	Perspective energy consumption /t products[19],	Cost of technology, $/t products*****
Metallurgy	13-14 GJ/t of cast iron	from 750 to 325 kWh/t of steel (1.2-2.7 GJ)	$540-600/t of steel
Production of ammonia	35-38 GJ/t	27 GJ/t	$30-50/t
Pulp and paper	29-32 GJ/t	from 18.7 to 17.1 GJ/t	$600-800/t
Cement	Wet technology: 5.3-7.1 GJ/t; Dry technology: 3-4 GJ/t	from 3.0 to 2.5 GJ/t of cement	$90-130/t
Production of glass		10.8 GJ/t	$250-300/t

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

The development of the electric furnace steel production method in the metallurgical industry, new promising technologies (+20% of energy efficiency) in the chemical industry, new technologies in pulp and paper, cement etc. industry based on biomass, electricity and heat (in particular, electricity and thermal energy produced

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

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

from RES) can make possible transition from consumption of traditional fuel and energy resources to the use of energy from renewable sources.

2.6.3 Transport

There were 10,000 electric cars registered in Ukraine as of June 2019, according to the Ministry of Infrastructure of Ukraine.

Electric cars can be supplied with electricity from RES. In addition, increase of electric mobility could also reduce the energy demand as a whole as electric cars are more energy efficient than cars with internal combustion engines (ICEs). The CP of electric motors can be 90-98%, while the CP of ICEs is 30-45%. Main characteristics of electric and biofuels vehicles used in the TIMES-Ukraine model are presented in Table 2.10-2.11.

Table 2.10. Main characteristics of electric vehicles used in the TIMES-Ukraine model

Mode of transport	Cost, EUR thousand		Life time, years	Efficiency, km/GJ		Annual mileage, thousand km
	2015	2050		2015	2050	
Intercity buses	300	260	20	230	277	27.5
City buses	300	260	20	325	390	27.5
Cars	35	25	20	765	890	17.5
Trucks	300	175	20	235	285	22.0
Motorcycles	5.0	5.0	10	777	850	4.8

Table 2.11. Main characteristics of biofuels vehicle used in the TIMES-Ukraine model

Mode of transport	Cost, EUR thousand		Life time, years	Efficiency, km/GJ		Annual mileage, thousand km
	2015	2050		2015	2050	
Intercity buses	250	205	20	93	112	27.5
City buses	250	205	20	325	390	27.5
Cars	30	29	20	308	370	14.5
Trucks	140	135	20	125	142	22.0

Ukraine’s railway transport is 95% electrified and it is assumed that this indicator will not be decreased. Aviation and navigation transport have potential for both biofuel use and electrification in Ukraine, even though those technologies are underdeveloped in Ukraine, but there are pilot demonstration projects taking place already. The team has modelled so that existing technologies will allow to switch to 100% of biofuel by 2050 in Ukraine.

2.6.4 Power Transmission and Natural Gas Transportation

One of the measure to reduce the GHG emissions footprint from power transmission and natural gas transportation is avoiding and minimizing leakages and losses, especially under current situation when power transmission and distribution losses are accounted for 12 % of all power energy produced in Ukraine. Natural gas transportation, including to EU, requires lots of energy that is used on natural gas transportation stations and could be potentially replaced with electricity power sources that will not only increase the efficiency of natural gas transportation system, but reduce fugitive emission.

TIMES-Ukraine modelled power transmission and distribution losses reductions and avoidance measures up to 7% and switch from natural gas turbines to electric engine during natural gas transportation process that will allow reduction of up to 80% of energy per unit of natural gas transported.

2.6.5 Agriculture

Agriculture (as energy consumer) is represented in a simplified form in the TIMES-Ukraine model. Five sub-sectors are identified in this sector: crop growing, livestock breeding, local transport, non-energy consumption and other needs. In addition, energy consumption for the autonomous production of electricity and heat is included not in this but in the energy sector. The model assumes that each demand in agriculture can be met with the technologies using biofuels (biomass) and electricity and heat form renewables.

SECTION 3. SCENARIOS OF GHG EMISSIONS PATHWAYS FOR UKRAINE

3.1 Overall modelling results

Overall modelling results under Scenario 1 projects that GHG emissions will be increasing starting from 2020, while the level of absorption in LULUCF sector will be going down. Overall GHG emissions under Scenario 1 could reach 408,734 kt CO_2-eq. in 2030 and 523,573 kt CO_2-eq. in 2050, that will represent 44% and 55% of 1990 GHG emissions level respectively, and 10.1 and 14.2 t CO_2-eq. emission per capita respectively.

Scenario 2 forecasts that GHG emissions will be relatively stable during the period of 2020-2050 - 240-267 Mt CO_2-eq., that represents 27-30% of 1990 level of GHG emissions. GHG emission per capita during 2020-2035 will be at the level of 6.1-6.3 t CO_2-eq. and will start increasing after 2035 reaching up to 7.3 t CO_2-eq. per capita in 2050 that is higher than the level of 2015. LULUCF sector absorption level will reach up to 12 Mt CO_2-eq. in 2030 and over 24 Mt CO_2-eq. in 2050.

GHG emissions level under Scenario 3 will be decreasing continuously, reaching 241.1 Mt CO_2-eq. or 27% from 1990 level in 2030 and 56.5 Mt CO_2-eq. or 6% in 2050. Under Scenario 3 the GHG emissions per capita will be at the level of 6.0 t CO_2-eq. in 2030 that in comparable with Scenario 2 level and 1.5 t CO_2-eq. per capita in 2050, that is comparable with reaching global temperature goal of 1.5°C. Under Scenario 3 LULUCF sector absorption potential will reach the level of 18 Mt CO_2-eq. in 2030 and over 36 Mt CO_2-eq. in 2050. Moreover, Bioenergy Power and Heat Plants (BECCS) technology implementation could increase the level of absorption by 2.3 Mt CO_2-eq. in 2050 (BECCS technology affordability for Ukraine will be considered after 2030).

Under Scenario 3 the share of GHG emissions in Energy and Industrial Processes Sectors will be 89% in 2030 and 101% in 2050, share of Agriculture will be 15% and 59% respectively, the share of Waste sector - 3% and 4% respectively. LULUCF absorption level will be 8% in 2030 and 64% in 2050.

The carbon intensity of the economy under all three Scenarios will be going down, including Scenario 1 as the GHG emissions reduction trends will be lower than economy growth trends. Carbon intensity of the economy under Scenario 2 and 3 will decrease reaching the level of 0. 0.48 and 0.46 toe / 1000 USD GDP PPP in 2030 respectively, and 0.02 and 0.06 toe / 1000 USD GDP PPP in 2050 respectively.

3.1.1 Overall scenario results on total GHG emissions

Table 3.1. Total GHG emission in Ukraine by Scenario 1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Base year(1)	Historical data*, kt CO_2-eq.						Projections, kt CO_2-eq.						
		1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Total (net emissions)(1)	879311	879311	505076	379881	410741	375758	310490	316525	364745	408734	416700	456385	486947	523573
1+2. Energy + Industrial processes and product use	843307	843307	489363	378488	395735	360866	267283	273586	318532	359242	364409	402225	430914	465787
3. Agriculture	83372	83372	57987	35659	32355	31817	37278	39005	39713	39983	40227	40214	40194	40125
4. Land use, land-use change and forestry(1)	-59292	-59292	-53822	-45655	-29343	-29345	-6281	-8286	-5909	-3234	-1075	386	1787	3039
5. Waste	11924	11924	11548	11389	11995	12420	12210	12220	12409	12743	13139	13560	14052	14622

* Ukraine's Greenhouse gas inventory 1990-2017 available from https://unfccc.int/documents/195605

Table 3.2. Total GHG emission in Ukraine by Scenario 2

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Base year(1)	Historical data*, kt CO_2-eq.						Projections, kt CO_2-eq.						
		1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Total (net emissions)(1)	879311	879311	505076	379881	410741	375758	310490	261854	258876	252647	239397	255112	255902	267104
1+2. Energy + Industrial processes and product use	843307	843307	489363	378488	395735	360866	267283	221589	220060	216966	208716	228630	233553	248790
3. Agriculture	83372	83372	57987	35659	32355	31817	37278	38683	38585	38052	37491	37155	36813	36431
4. Land use, land-use change and forestry(1)	-59292	-59292	-53822	-45655	-29343	-29345	-6281	-10274	-10679	-12182	-15753	-18736	-21623	-24220
5. Waste	11924	11924	11548	11389	11995	12420	12210	11856	10910	9811	8943	8063	7159	6103

* Ukraine's Greenhouse gas inventory 1990-2017 available from https://unfccc.int/documents/195605

Table 3.3. Total GHG emission in Ukraine by Scenario 3

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Base year(1)	Historical data*, kt CO_2-eq.						Projections, kt CO_2-eq.						
		1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Total (net emissions)(1)	879311	879311	505076	379881	410741	375758	310490	258579	250222	241098	209321	180777	127973	56453
1+2. Energy + Industrial processes and product use	843307	843307	489363	378488	395735	360866	267283	219636	216691	214994	192347	170000	123146	57192
3. Agriculture	83372	83372	57987	35659	32355	31817	37278	38579	37811	36606	35366	34619	33867	33077
4. Land use, land-use change and forestry(1)	-59292	-59292	-53822	-45655	-29343	-29345	-6281	-11129	-14138	-18284	-24535	-28539	-32448	-36070
5. Waste	11924	11924	11548	11389	11995	12420	12210	11493	9858	7782	6143	4697	3408	2254

* Ukraine's Greenhouse gas inventory 1990-2017 available from https://unfccc.int/documents/195605

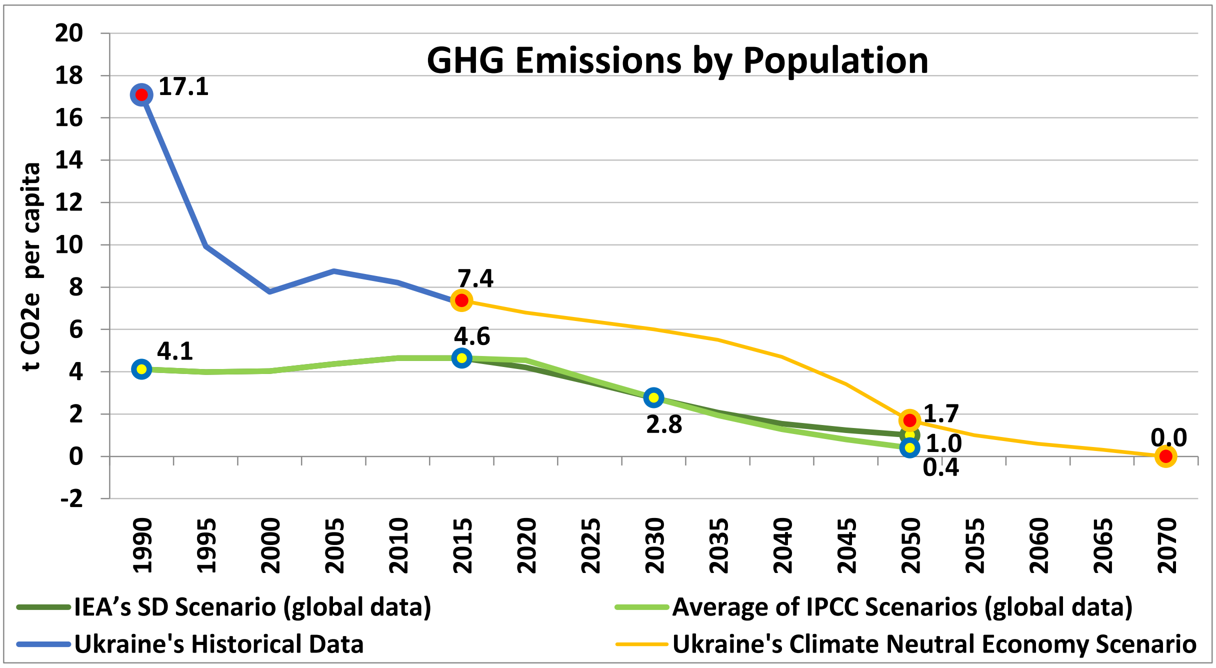

Figure 3.1. Total GHG Emission by Population (input assumption for Ukraine)

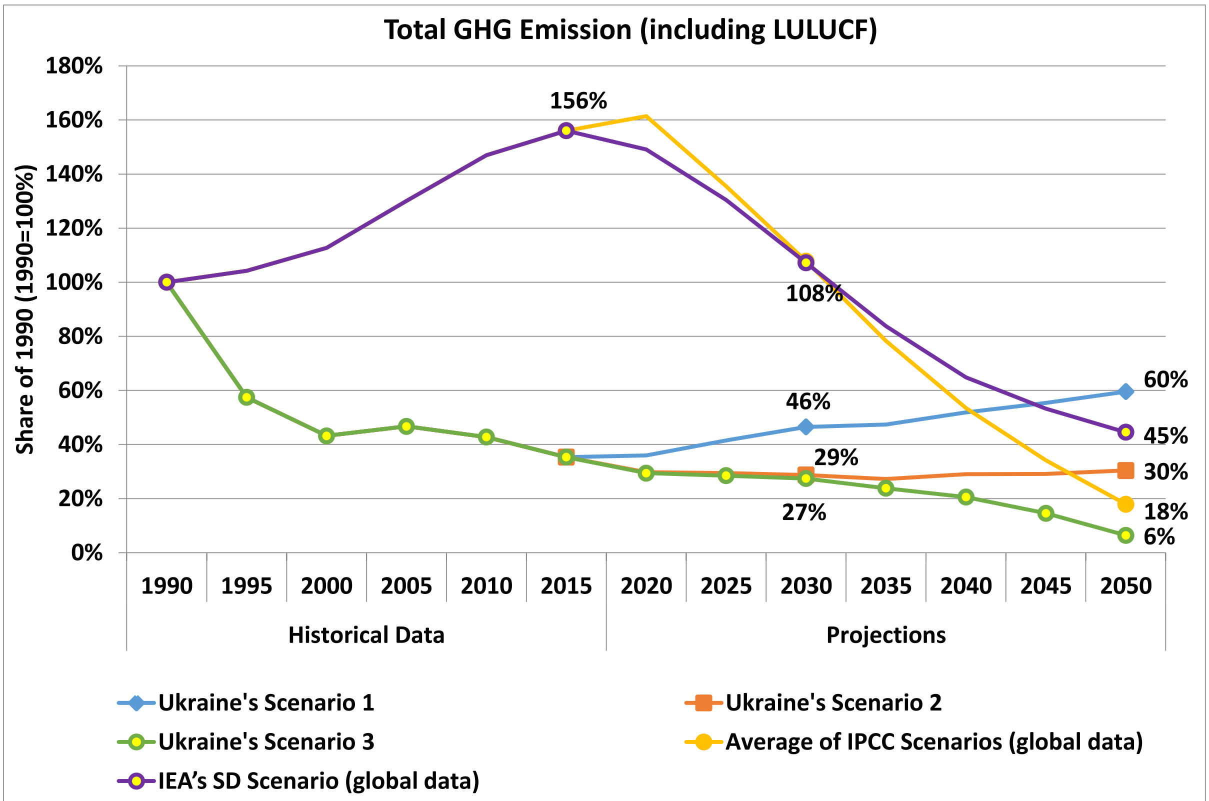

Figure 3.2. GHG Emission (incl. LULUCF) Pathways Scenarios

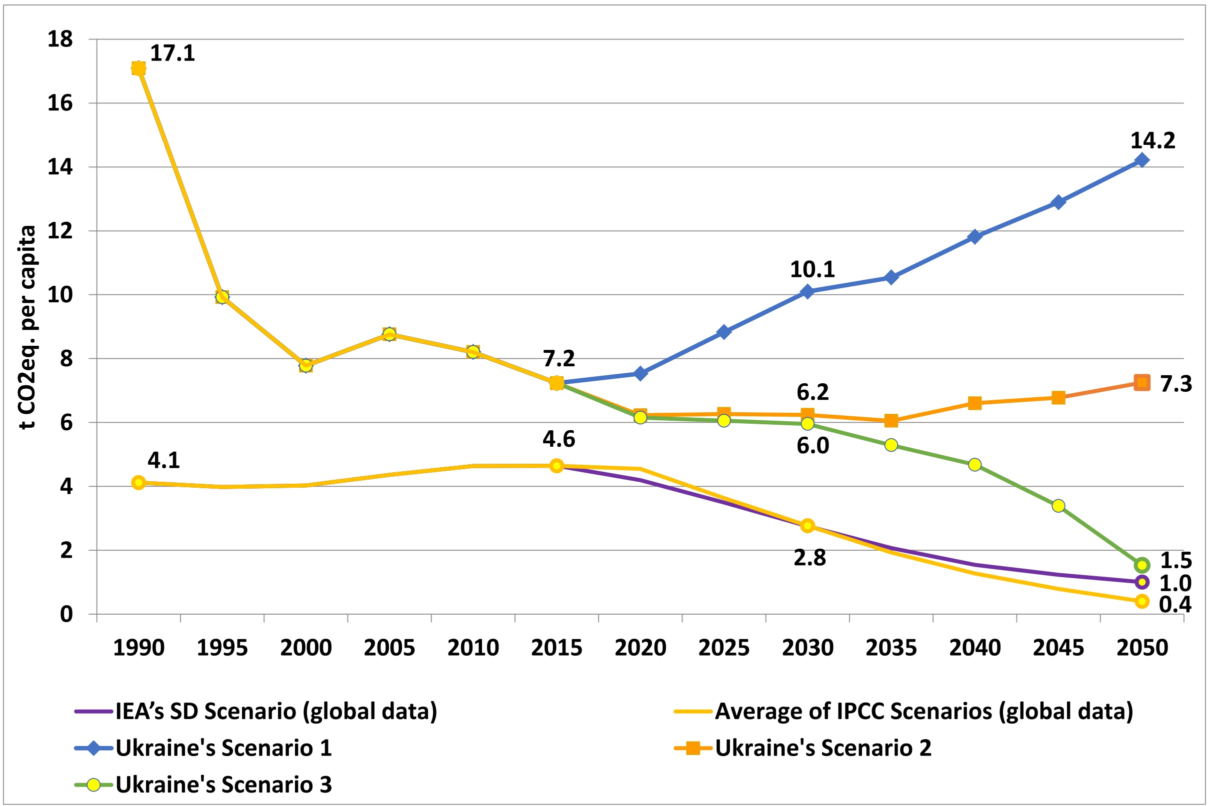

Figure 3.3. Total GHG Emission by population

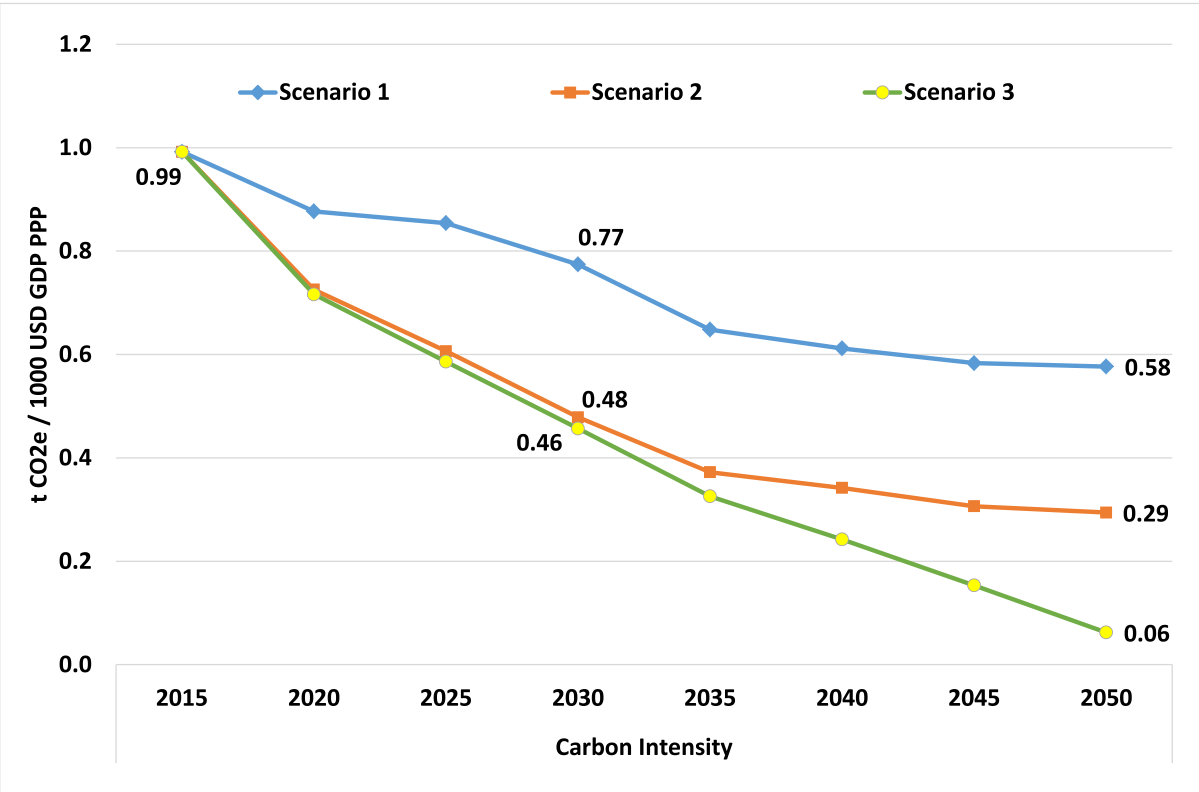

Figure 3.4. Carbon Intensive of Economy by Scenarios

3.1.2 Overall results on capital cost needs to implement scenarios in all sectors

In capital cost, needed to implement all three scenarios, share of sectors "Energy plus Industrial processes and product use" will be around 97-99%. Capital costs of Energy sector are including all investments in energy technologies and infrastructure not only in power and heat sectors, but also investments in technologies of the final energy consumption (for example, building renovation and appliances, different transport vehicles (cars, trains, ships, etc), lighting fixtures, industrial equipment's, etc.).

Table 3.4. Capital cost needed to implement all three scenarios and all sectors, billion euro

Scenarios	2020	2025	2030	2035	2040	2045	2050	TOTAL
1+2. Energy + Industrial processes and product use, billion euro								
Scenario 1	132	160	129	126	227	199	184	1,157
Scenario 2	144	196	187	236	160	196	220	1,339
Scenario 3	145	199	202	187	216	260	460	1,669
3. Agriculture + 4. Land use, land-use change and forestry								
Scenario 1	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.04
Scenario 2	1.7	2.1	2.6	3.0	3.5	3.9	4.3	21.1
Scenario 3	1.9	2.8	3.7	4.5	5.4	6.3	7.1	31.7
5. Waste, mln Euro, cumulative for 5-year period								
Scenario 1	0.04	0.21	0.23	0.25	0.27	0.30	0.32	1.6
Scenario 2	0.4	2.1	2.1	2.1	2.1	2.1	2.1	12.9
Scenario 3	0.6	2.8	2.9	2.9	2.9	2.9	2.9	17.9
TOTAL								
Scenario 1	132	160	129	126	227	199	184	1,159
Scenario 2	146	200	192	241	166	202	226	1,373
Scenario 3	148	205	209	194	224	269	470	1,719

Scenario 1 will need to raise €1,159 billion in capital cost (investments), and more than 18.5% for Scenario 2, and about 50% more for Scenario 3.

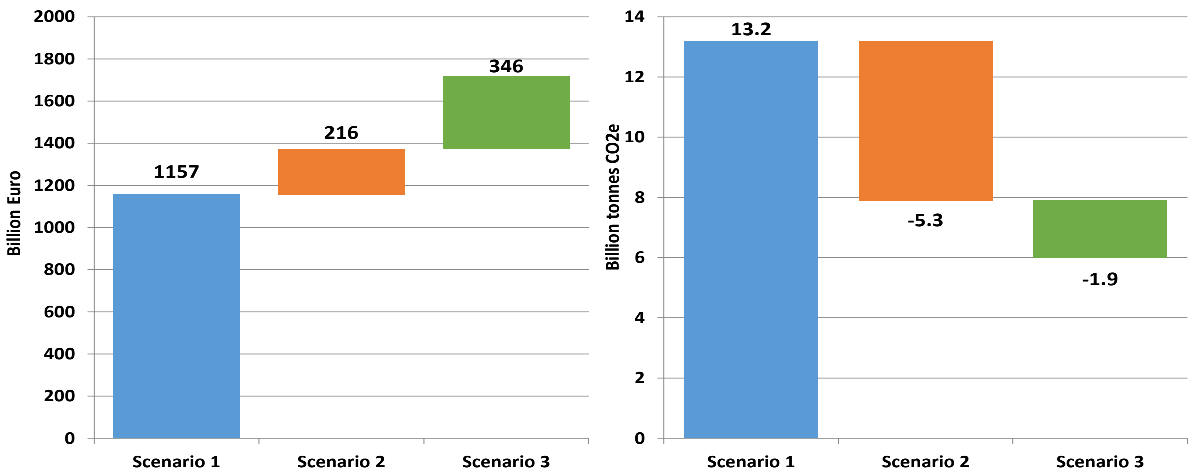

Figure 3.5. Incremental investment needs and GHG emission reduction by the period 2020-2050

3.2 Energy and industrial-process and product-use sectors

3.2.1 Key assumptions

- Limited rate of policy implementation observed in the previous years, with significant delays between policy formulation, adoption and implementation (e.g. insufficient EE, RE legislation implementation performance rate).
- The current investment conditions, including green investments and commodity markets situation.
- Most technologies will stay unchanged between 2015 and 2030 (when technology replacements take place only after the end of already prolonged multiply times equipment lifetime or for covering additional demand).

Assessing the complex impact of the existing legislation implemented on time and its entirety, and based on the legislation, policies and measures adopted in Ukraine as of September 1, 2019, including but not limited to:

- The Law of Ukraine on the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030
- Ukraine's 2050 Low Emission Development Strategy
- Energy Strategy of Ukraine till 2035
- Action Plan for the implementation of the stage "Energy Sector Reform (2020)" of the Energy Strategy of Ukraine till 2035
- National transport strategy of Ukraine for the period up to 2030
- Natural gas transportation system development plan for 2018-2027
- National Energy Efficiency Action Plan till 2020
- National Renewable Energy Action Plan till 2020
- State Heat Supply Policy Concept till 2035
- State Climate Policy Concept Implementation till 2030 and its Action Plan

Table 3.5. Key indicators in Ukraine's legislation documents (adopted) related to energy and/or climate

Indicators	2015	2016	2017	2018	2019	2020	2025	2030	2035

Indicators	2015	2016	2017	2018	2019	2020	2025	2030	2035
The Law of Ukraine on the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030[20]									
Share of renewables (incl. hydro power plants) in TPES, %	4					8	12	17	
Primary Energy Intensity, toe/$1000 GDP (PPP)	0,28					0,2	0,18	0,13	
Share of GHG emission compared to 1990,%	37,8					<76	<60	<60	
Air pollutant emissions from stationary sources, % of 2015	100					<6	<16,5	<22,5	
Electric vehicles, % of new vehicles purchased						0,1	0,5	10	
Energy Strategy of Ukraine till 2035[21]									
Primary Energy Intensity, toe/$1000 GDP (PPP) (constant 2011 US$)	0,28					0,20	0,18	0,15	0,13
Share of renewables (incl. big hydro) in TPES, %						8	12	17	25
Share of renewables (incl. hydro power plants) in power generation, %	5					7	10	>13	>25
Share of GHG emission compared to 1990,%						<60	<60	<60	<50
National transport strategy of Ukraine for the period up to 2030[22]									
GHG emission and air pollutant emissions from stationary sources, % of 1990								<60	
Share of alternatives fuels, %	10							50	
Share of electric transport in urban public transport, %								75	
National Renewable Energy Action Plan till 2020[23]									
Share of renewables in cooling and heating systems	6,7	7,7	8,9	10	11,2	12,4			
Share of renewables in electricity production	8,3	8,8	9,7	10,4	10,9	11			
Share of renewables in transport	5	6,5	7,5	8,2	9	10			
Share of renewables in Gross Final Energy Consumption (GFEC)	6,7	7,4	8,3	9,1	10,1	11			
National Energy Efficiency Action Plan till 2020[24]									
Share of retrofit residential buildings, %						25			
Share of retrofit public buildings, %						20			
net-zero energy building, % per year						3			
energy saving in 2020 from average final energy consumption in 2005-2009, %						9			
Concept of implementation of the state policy of heat supply till 2035[25]									
heat production losses, %				8					
transportation heat losses, %				12					10
Share of alternative energy in heat production, %							30		40
Indicators	**2015**	**2017**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Ukraine's 2050 Low Emission Development Strategy [26]									
Share of GHG emission compared to1990 by high ambition scenario, %	31	31	31	31	29	28	31	31	31

Additional policies and measures elaborated in other mitigation related planned and drafted legislation that has not been adopted in Ukraine, including:

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20 The Law of Ukraine on the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030. Retrieved from https://zakon.rada.gov.ua/laws/show/2697-viii

21 Energy Strategy of Ukraine till 2035. Retrieved from https://zakon0.rada.gov.ua/laws/show/605-2017-%D1%80

22 National transport strategy of Ukraine for the period up to 2030. Retrieved from https://zakon.rada.gov.ua/laws/show/430-2018-%D1%80

23 National Renewable Energy Action Plan till 2020. Retrieved from https://zakon.rada.gov.ua/laws/show/902-2014-%D1%80

24 National Energy Efficiency Action Plan till 2020. Retrieved from https://zakon.rada.gov.ua/laws/show/n0001824-15#n2

25 Concept of realization of the state policy of heat supply till 2035. Retrieved from https://zakon.rada.gov.ua/laws/show/569-2017-%D1%80

26 Ukraine's 2050 Low Emission Development Strategy. Retrieved from https://unfccc.int/sites/default/files/resource/Ukraine_LEDS_en.pdf

- Draft Strategy of sustainable development of Ukraine till 2030
- Draft Strategy for the Development of the Industrial Complex of Ukraine
- Draft targets for new National Energy Efficiency Action Plan till 2030
- The Ukrenergo draft "Report on the assessment of adequacy (sufficiency) of generating facilities"
- Draft the Transmission System Development Plan for 2019-2028

Table 3.6. Key indicators in Ukraine's strategic documents (not adopted) related to energy and/or climate

Indicators	2015	2016	2017	2018	2019	2020	2025	2030
Draft Strategy of sustainable development of Ukraine till 2030 [27]								
Share of renewables in Gross Final Energy Consumption (GFEC), %	6,7					11	14,2	17,1
Primary Energy Intensity, toe/$1000 GDP (PPP) (constant 2011 US$)	0,28					0,27	0,23	0,2
Share of GHG emission compared to 1990,%								<60
Draft Strategy for the Development of the Industrial Complex of Ukraine [28]								
Primary Energy Intensity, toe/$1000 GDP (PPP)	0,28						0,17	
Draft targets for new National Energy Efficiency Action Plan till 2030 [29]								
Final Energy Savings comparing to baseline scenario developed in current NEEAP of Ukraine till 2020, %						-20		-30
Final Energy Consumption, mtoe						55.5		57.2
Total Primary Energy Consumption, mtoe						101		109
The Ukrenergo draft "Report on the assessment of adequacy (sufficiency) of generating facilities" [30]								
Indicators	**2015**		**2025-2050**					
Share of storage capacities compared to capacities of variable renewables (wind and solar), %	0		10					
Share of gas manoeuvres (incl. fast start) capacities compared to wind power capacities, %	0		30					
Share of gas manoeuvres (incl. fast start) capacities compared to solar power capacities, %	0		40					

- Full implementation of all existing and drafted legislation plus additional policies and measures that will be in line with global efforts of holding the

[27] Draft Strategy of sustainable development of Ukraine till 2030 (based on SDGs). Retrieved from https://www.undp.org/content/dam/ukraine/docs/SDGreports/UNDP_Strategy_v06-optimized.pdf
[28] Draft Strategy for the Development of the Industrial Complex of Ukraine. http://www.me.gov.ua/Documents/Detail?lang=uk-UA&id=10ef5b65-0209-4aa1-a724-49fd0877d8d6&title=ProektRozporiadzhenniaKabinetuMinistrivUkrainiproSkhvalenniaStrategiiRozvitkuPromislovogoKompleksuUkrainiNaPeriodDo2025-Roku.
[29] FINAL DRAFT of the energy efficiency target till 2020 calculation (including perspective until 2030). - https://library.euneighbours.eu/content/final-draft-energy-efficiency-target-till-2020-calculation.
[30] The SE NPC Ukrenergo draft "Report on the assessment of adequacy (sufficiency) of generating facilities". Retrieved from https://ua.energy/wp-content/uploads/2018/11/Zvit-z-otsinky-vidpovidnosti-dostatnosti-generuyuchyh-potuzhnostej.pdf

increase of the global average temperature to well below 1.5°C of pre-industrial levels.

- Includes policies and measures of Scenario 2 plus most innovative, state-of-art, internationally and industrially proven, recognized as climate friendly policies, measures and technologies, such as carbon capture storage, power to gas, power to heat, power to fuels, fuel cells, hydrogen technologies, etc. Key assumptions of innovative technologies are presented in Annex.
- Scenario 3 GHG target for Ukraine until 2050 is in line with IEA Sustainable Development Scenario[31] and scenarios presented in IPCC Special Report[32]. Based on the Article 4 of Paris Agreement assumed in the Scenario 3, net climate neutral economy of Ukraine can be achieved by 2070 (Figure 3.1).

3.2.2 Modelling results

Based on modelling results total GHG emission in Energy and IPPU sectors in 2030 are projected be between 215 and 359 Mt CO_2e or between 25% and 43% of 1990 level (Figure 3.6).

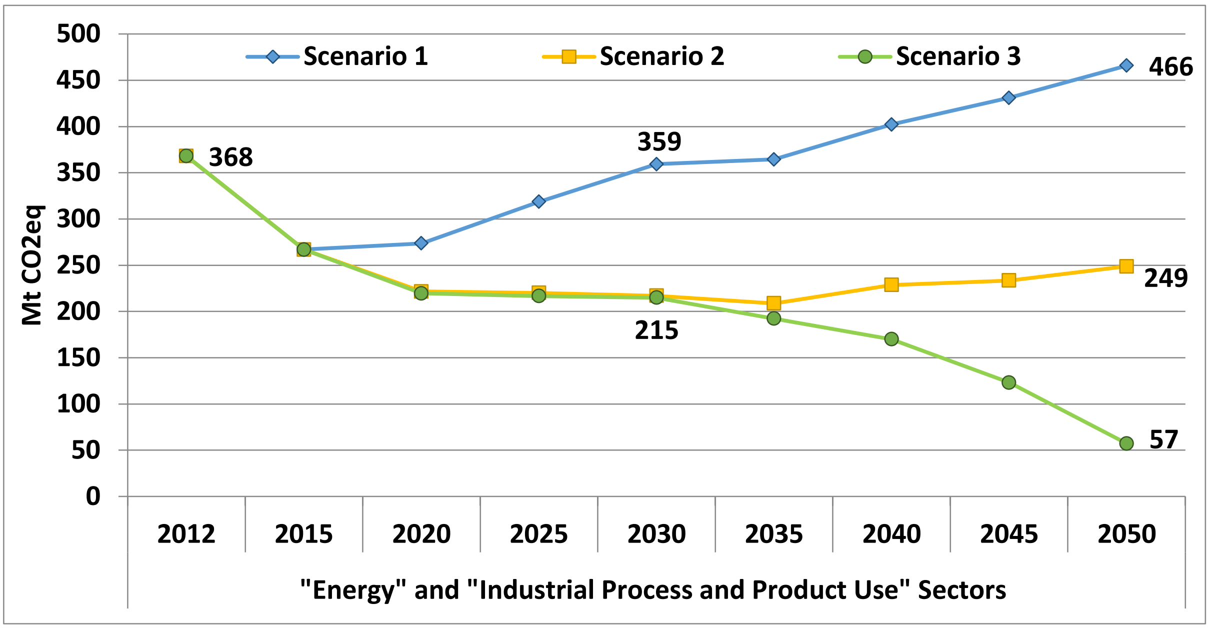

Figure 3.6. Total GHG Emission Energy and IPPU sectors by scenarios

Primary Energy Intensity in Scenarios 2 and 3 is the same by 2035, since the energy efficiency (intensity) targets were taken from the Energy Strategy till 2035 and thus are identical for these scenarios (Figure 3.7). TPES does not reduce dramatically,

[31] Sustainable Development Scenario. World Energy Outlook 2018 // International Energy Agency. – https://www.iea.org/weo/weomodel/sds/

[32] IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. – https://www.ipcc.ch/sr15/

but in Scenario 3 the share of carbon-intensive energy resources is much less comparing to Scenario 2 (Figure 3.8).

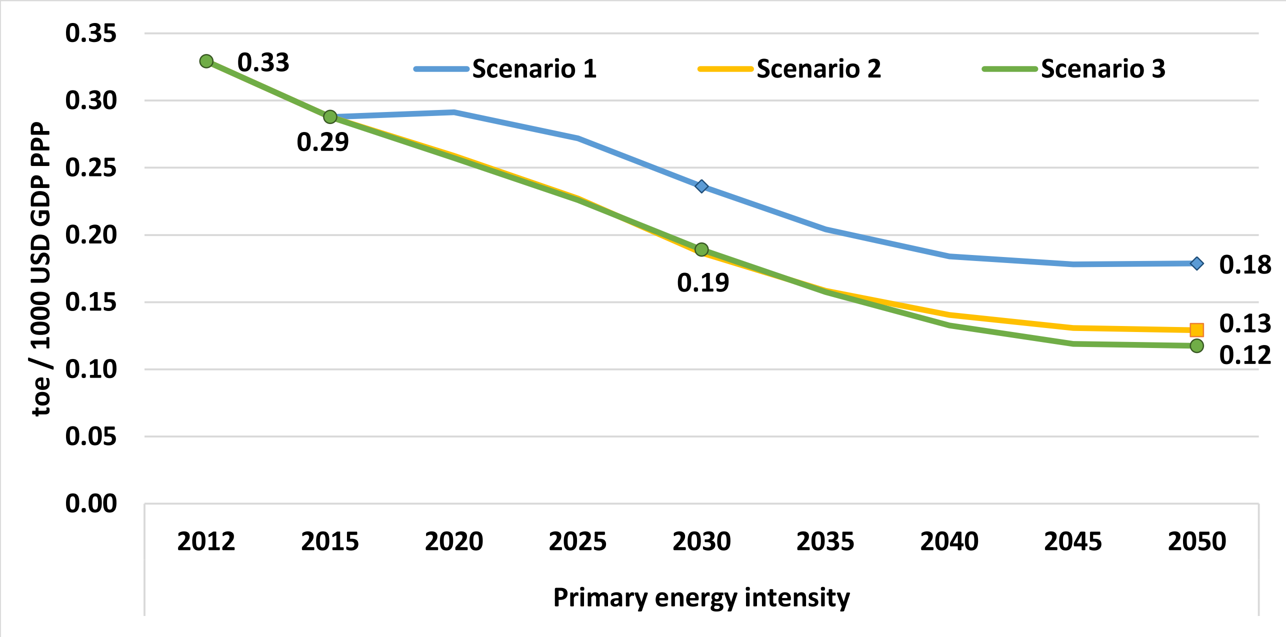

Figure 3.7. Primary Energy Intensity by Scenarios

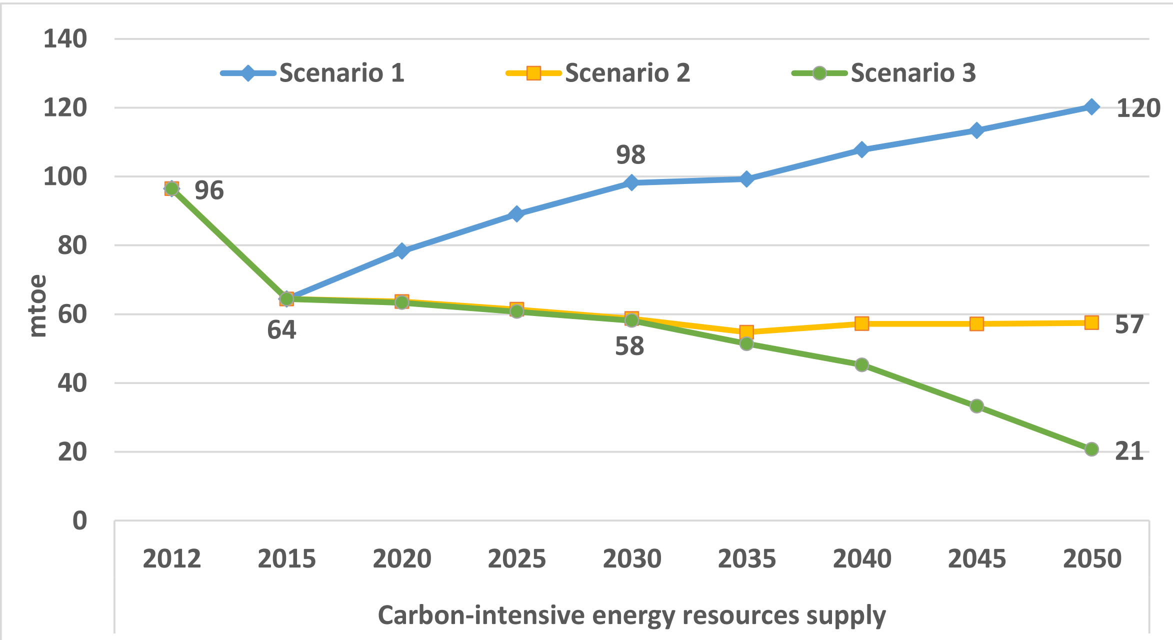

Figure 3.8. Total carbon-intensive energy resources supply

Total primary energy supply per capita in 2017 in EU-28 countries was 3.16 toe/capita and 4.10 toe/capita in OECD countries, when in Ukraine was 2.0 toe/capita. In Scenarios 2 and 3 these indicator in 2030 will be 2.4 and 2.5 toe/capita, and 3.2 and 2.9 toe/capita in 2050 respectively (Figure 3.9).

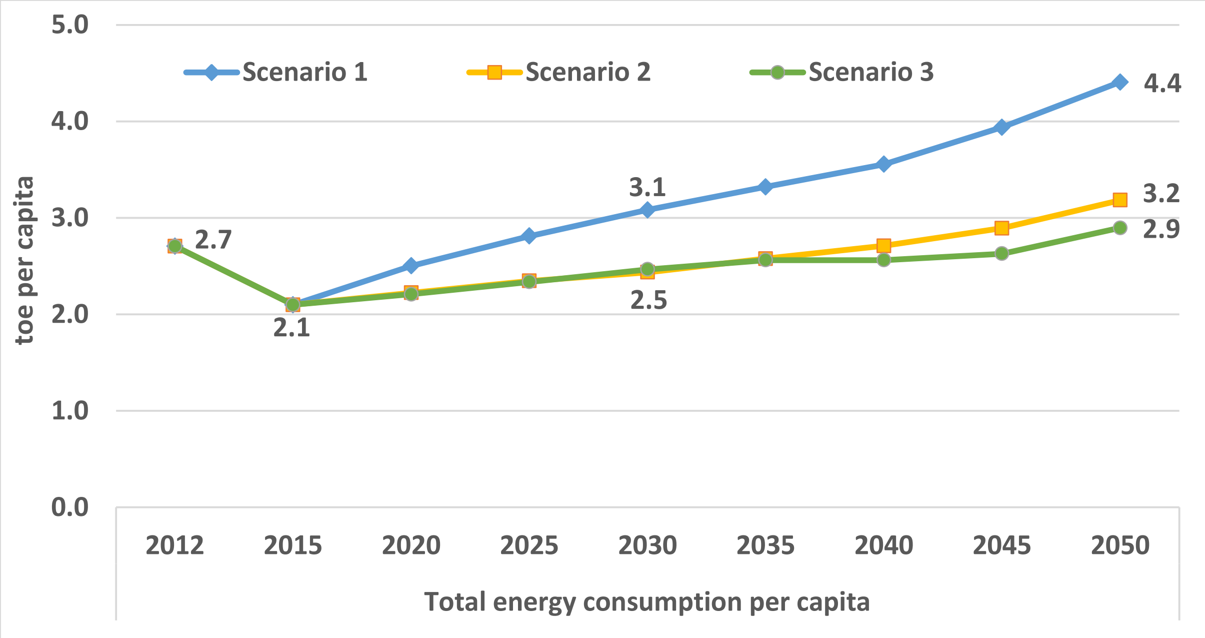

Figure 3.9. Total primary energy supply per capita

Total primary carbon-intensive energy supply (coal, oil, gas) per GDP will decrease in Scenario 2 and 3 till 2030 by 46% comparing to the 2015 level, while in Scenario 1 only by 10%. In 2050 this indicator, comparing to the 2015 level (0.21 toe / $1000 GDP PPP), decreased by 36% to 0.13, 69% to 0.06 and by 89% to 0.02 toe / $1000 GDP PPP in in Scenario 1, 2 and 3 respectively (Figure 3.10).

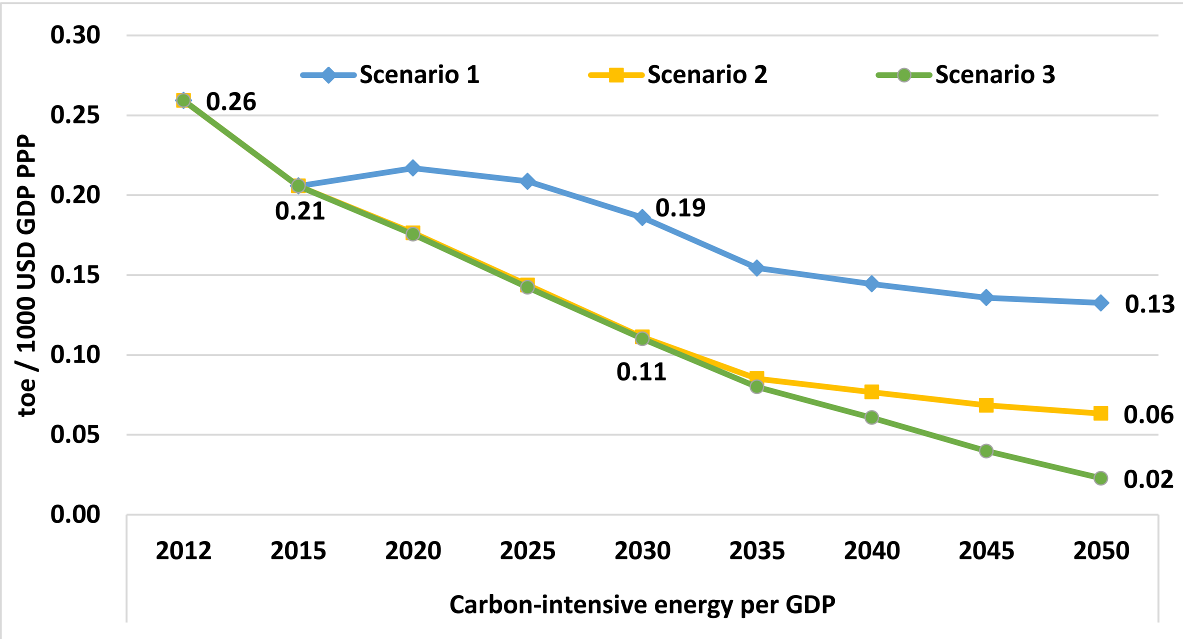

Figure 3.10. Carbon-intensive energy (coal, oil, gas) per GDP

Table 3.7 presents key TIMES-Ukraine modelling results for IPCC Energy Sector and Industrial Processes and Product Use Sector (IPPU). Scenario 1 (BAU) modelling results forecast that GHG emissions will be at the level of 43% and 55% in 2030 and 2050 respectively compared to 1990.

Implementation of all existing and drafted legislation, policies and measures under Scenario 2 can bring the GHG emissions level to 25-26% of 1990 level by 2035 primarily by achieving Energy Strategy targets. GHG emissions level could increase after 2035 due to the absence of long terms plans or strategies on GHG emissions reduction or climate/energy related strategies, if Ukraine's LEDS targets will not be achieved. But under Scenario 2 it is projected that LEDS target will be achieved.

Scenario 3 (Climate Neutral Economy Scenario) is in line with global efforts of holding the increase of the global average temperature to well below 1.5°C of pre-industrial levels. According to the modelling results of Scenario 3, the GHG emissions per capita in 2050 will be at the level of 1.7 tons (in 2050 the GHG emissions in all sectors will at the level of not exceeding 1.7 times of projected Ukraine's population). Therefore, based on the assumptions presented in the Table of Key Input Assumptions in the Summary or in Figure 3.1, the level of GHG emissions in 2050 under Scenario 3 should be not higher than 7.2% from 1990 or 61 Mt CO2e. Based on the results of the modelling, the GHG emissions in Energy and IPPU sectors in 2050 under Scenario 3 will 57 Mt CO2e, that is around 7% of 1990 level. At the same time, the share of GHG emission in 2030 under Scenario 3, compared to 1990, will be just 1% lower than in Scenario 2, due to the fact that we assumed that all innovative technologically proven climate-friendly policies, measures and technologies, such as carbon capture storage, power to gas to power, fuel cells, hydrogen technologies, will be launched for implementation starting from 2030 onwards.

It is expected that Ukraine's economy will grow, therefore it will need more energy resources. Total primary energy supply (TPES) will growth in all scenarios, but in scenarios 2 and 3 TPES will increase by 10-11% till 2030, when in Scenario 1 will increase by 29%, comparing to 2015. In 2050 TPES in Scenario 1 will increase by 80%, in Scenario 2 – by 30% and in Scenario 3 – by 20%, while the share of carbon-intensive resources in TPES will be at the level of 75%, 50% and 20% accordingly.

Decarbonisation of Energy and IPPU sectors will stimulate to use more electricity. Depending on the scenarios, electricity production will increase by 22-29% in 2030, but in 2050 differences of electricity production in Scenario 3 comparing to other scenarios will be huge. In 2050, electricity production in scenarios 1 and 2 will increase by 72-84%, while in Scenario 3 it will increase by almost 2.4 times, however share of renewables will be higher.

Based on modelling results total investments needs in Energy and IPPU sectors for the period 2020-2050 in Scenarios 1, 2 and 3 are expected to be 1.16, 1.34 and 1.67 trillion euro respectively. While overall investment needs in Scenario 3 will be more by 44% comparing to the Scenario 1, the investment needs in the power sector will be two times more.

Table 3.7. Key modelling results for Energy and IPPU Sectors

Scenarios	2012	2015	2020	2025	2030	2035	2040	2045	2050
GHG Emission, Mt CO_2eq.									
Scenario 1	368	267	274	319	359	364	402	431	466
Scenario 2	368	267	222	220	217	209	229	234	249
Scenario 3	368	267	220	217	215	192	170	123	57
Shares of 1990 level of GHG Emission, %									
Scenario 1	44%	32%	32%	38%	43%	43%	48%	51%	55%
Scenario 2	44%	32%	26%	26%	26%	25%	27%	28%	30%
Scenario 3	44%	32%	26%	26%	25%	23%	20%	15%	7%
Total primary energy supply, ktoe									
Scenario 1	122.5	90.1	105	116	125	131	137	149	162
Scenario 2	122.5	90.1	93	97	99	102	105	109	117
Scenario 3	122.5	90.1	93	97	100	101	99	99	107
Total primary energy (only carbon-intensive) resources, ktoe									
Scenario 1	96.4	64.4	78	89	98	99	108	113	120
Scenario 2	96.4	64.4	64	61	59	55	57	57	57
Scenario 3	96.4	64.4	63	61	58	51	45	33	21
Primary Energy Consumption, ktoe									
Scenario 1	116	87	100	110	118	123	128	138	150
Scenario 2	116	87	89	91	92	94	96	99	106
Scenario 3	116	87	88	91	93	93	90	89	95
Electricity production, TWh									
Scenario 1	198	163	175	196	210	218	233	255	280
Scenario 2	198	163	156	175	199	226	238	268	300
Scenario 3	198	163	155	176	208	229	242	290	389
Share of renewables (incl. big hydro energy) in electricity production, %									
Scenario 1	5.9%	5.8%	11%	12%	14%	14%	18%	18%	17%
Scenario 2	5.9%	5.8%	16%	21%	30%	40%	47%	48%	47%
Scenario 3	5.9%	5.8%	16%	26%	34%	40%	48%	55%	58%
Share of nuclear in electricity production, %									
Scenario 1	45.9%	55.0%	52%	44%	38%	44%	35%	38%	42%
Scenario 2	45.9%	56.2%	58%	53%	46%	43%	34%	37%	40%
Scenario 3	45.9%	56.2%	59%	53%	46%	48%	43%	45%	41%
Total investments needs in Energy and IPPU sectors (cumulatively for 5 years), billion Euro									
Scenario 1	–	–	132	160	129	126	227	199	184
Scenario 2	–	–	144	196	187	236	160	196	220
Scenario 3	–	–	145	199	202	187	216	260	460

3.2.3 Modelling results by Sector

The limited rates of implementation of national and municipal policies (climate, energy efficiency, renewable energy, etc.) observed in previous years and included in Scenario 1 will still have an impact on Ukraine's total GHG emissions, especially in buildings (Residential and Commercial sectors) and Power and Heat sectors, but without new or updated climate policies in Industry, Supply and Transport sectors GHG emissions will be growth rapidly (Figure 3.11).

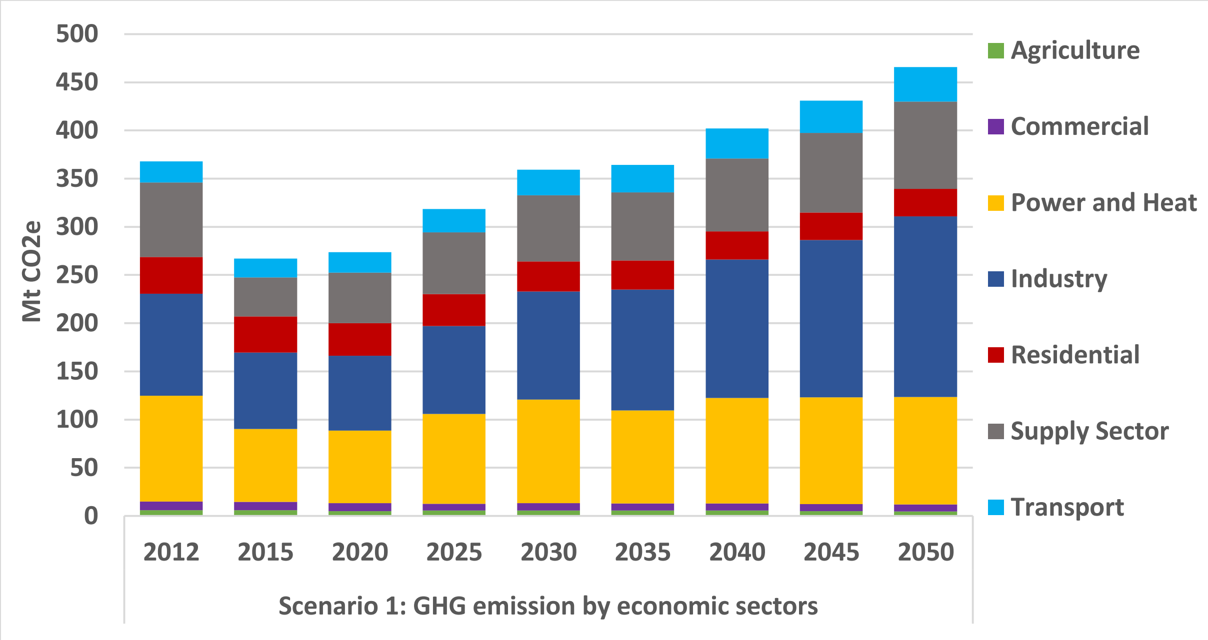

Figure 3.11. GHG Emission by Scenario 1 (Energy and IPPU sectors)

Achieving the adopted goals related with climate in different sectors of economy can reduce total GHG emissions in Energy and IPPU sectors by 19% in 2030 comparing to 2015 (Figure 3.12). In Scenario 2 GHG emissions in all sub-sectors will decreasing in 2030 and 2050, except in Industry and Supply sector, which remain the most energy-intensive economy sectors. In 2050 GHG emission reductions in the building sector can amount to -77%, in the power and heat sector -50%, transport -38% and agriculture -30% comparing to 2015, but total GHG emission reductions in 2050 will be amount to -7%.

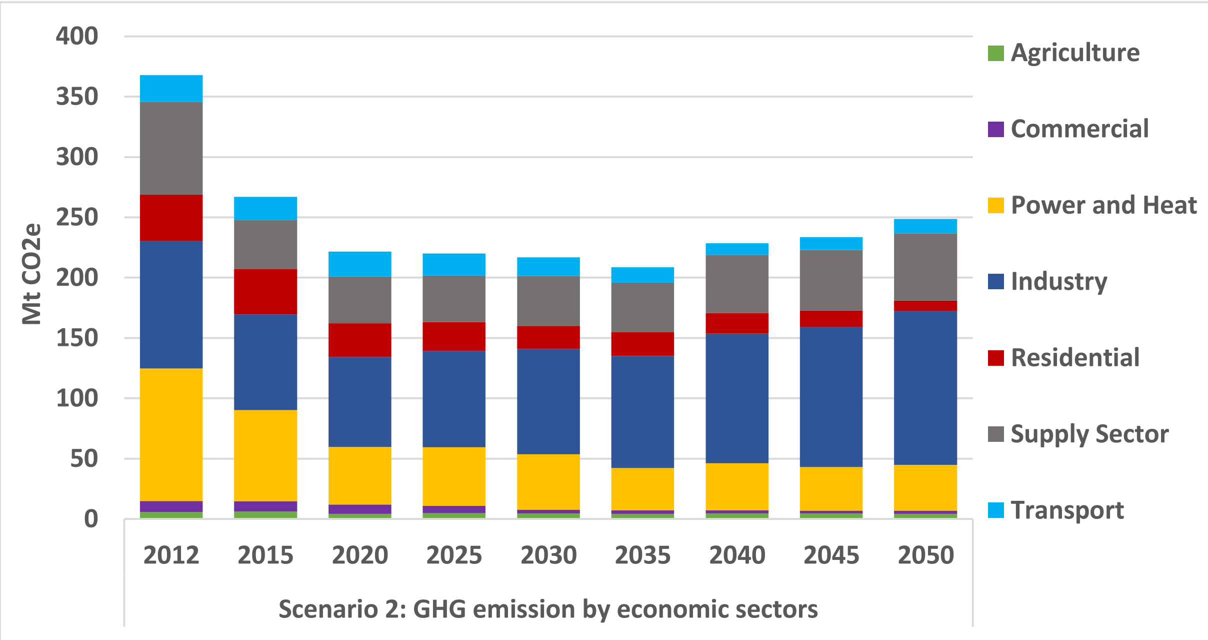

Figure 3.12. GHG Emission by Scenario 2 (Energy and IPPU sectors)

Key GHG emissions reduction policies and measures under Scenario 2 by sub-sectors (modeling results):

- ***Building sector:***
    - thermal modernization of buildings;
    - advanced electric and gas boilers for space and water heating;
    - improving centralize heat and hot water supply in the buildings;
    - solar hot water heating.
- ***Industry:***
    - Increasing energy efficiency through advanced and innovative technologies;
    - Decreasing share of carbon-intensive energy sources;
    - Increasing share of recycling of material sources;
    - Utilizing heat-waste;
    - Intensification of electrification of steel production and other process;
    - Electrification of local transport.
- ***Transport:***
    - Private and public transport fleet renovation (increasing of energy efficiency);
    - Continued stimulating to rapidly increasing share of electric vehicles in passengers transportation;
    - Continued stimulating to rapidly increasing share of LPG/LNG consumption (more cheaper, less emissions);
    - Increasing share of biofuels consumption, first of in the next 10-20 years;
    - Optimizing the structure of passenger and freight traffic in cities.
- ***Agriculture:***
    - Increasing of energy efficiency consumption;
    - Increasing local biofuels and bio-waste consumption;
    - Increasing of solar and wind energy consumption.
- ***Power and heat sector:***
    - Reduction of coal-based thermal power plants;
    - Increasing of solar and wind generations;
    - Increasing share of biomass in electricity and heat production, including a district heating productions;
    - Keeping the nuclear power generations on a 45-50% level;
    - Pollutions reduction by the large combustion plants;

- Stimulation of cogeneration of electricity and heat;
- Modernization of existing power plants;
- Keep or increase share of electricity generation at hydroelectric power plants;
- Construction of storage batteries as balancing and manoeuvring technologies.
- Stimulating of biomass in district heating productions;
- Import of electricity will not play a crucial role of electricity generation;

- ***Supply sector:***

  - Reduction of gas, electricity, heat losses;
  - Increasing of energy efficiency consumption;
  - Increasing of renewable consumptions;

Difference between GHG emission by sub-sectors in Scenario 2 and Scenario 1 presented on the Figure 3.13.

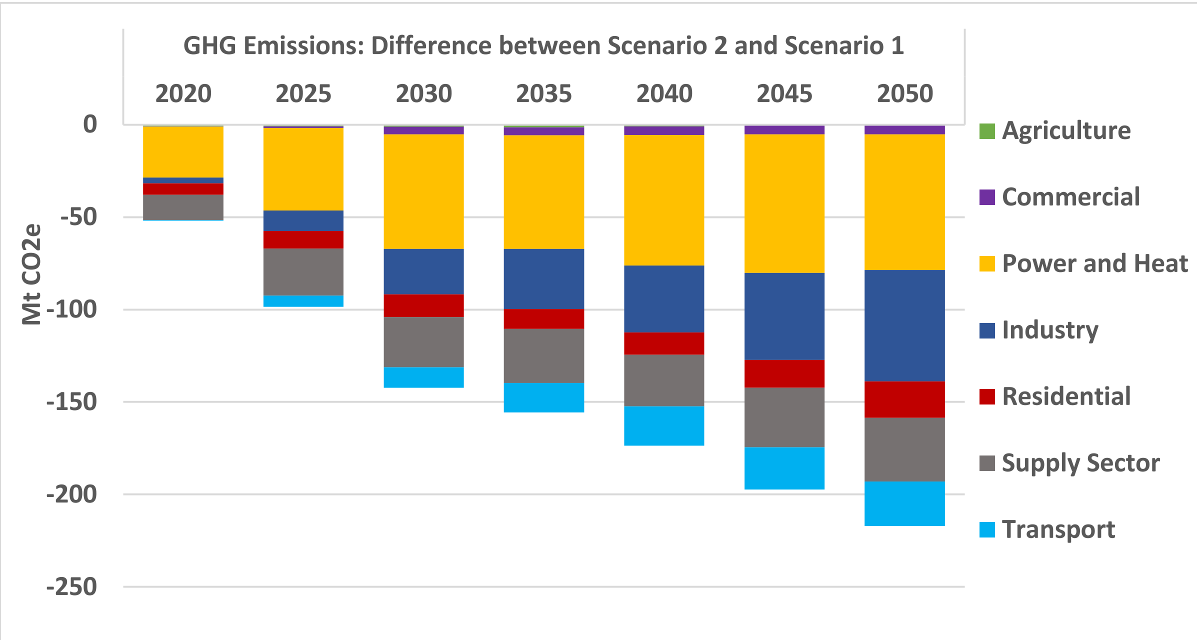

Figure 3.13. Difference in GHG Emission between Scenario 2 and Scenario 1 (Energy and Industrial Process sectors)

In additional to Scenario 2 policies and measures, Scenario 3 foresees the implementation of the following policies and measures for GHG emissions reductions by 2050:

- ***Building sector:***

  - Additional increasing share of renewables consumption;
  - Available hydrogen for consumption for space heating;

- Solar-gas (natural and hydrogen) and solar-electricity systems for hot water and space heating.
- Using geothermal energy for space heating;

- ***Industry:***
  - Additional increasing energy efficiency through advanced and innovative technologies;
  - Additional electrification of industrial process;
  - Additional decreasing of carbon-intensive energy sources consumptions;
  - Decarbonization of accompanying (accessory, non-specified) processes;
  - Available carbon and capture storage (CCS) technologies in metallurgy, chemistry, cement production and others.
- ***Transport:***
  - Fully decarbonizing through electric, bio- and hydrogen vehicles in passenger and freight transport;
  - Using biofuels in aviation and navigation transports;
- ***Agriculture:***
  - Fully substitute carbon-intensive energy sources by local biofuels and bio-waste;
  - More solar and wind in energy consumption.
- ***Power and heat sector:***
  - Fully decarbonizing of electricity production;
  - More solar, wind and geothermal electricity generation;
  - More cogeneration of electricity and heat;
  - Using carbon and capture storage (CCS) technologies;
  - Using carbon and capture storage (CCS) technologies for biofuels power plants;
  - Using Fuel Cells (FC) technologies
  - Constructing small nuclear reactors.

Based on modeling results in Scenario 3 GHG emission in 2030 will decrease by 37% in agriculture, by 60% in commercial sector, by 45% in residential, by 43% in power and heat sector, and by 13% in transport, but in 2050 GHG emission in this sectors can be near zero, moreover GHG emission in power and heat sector can be negative as a result of bio CCS technologies application (Figure 3.14). In this scenario GHG emission in industry and supply sector in 2030 can be on the 2015 level, but in 2050 can be less by 50% or more.

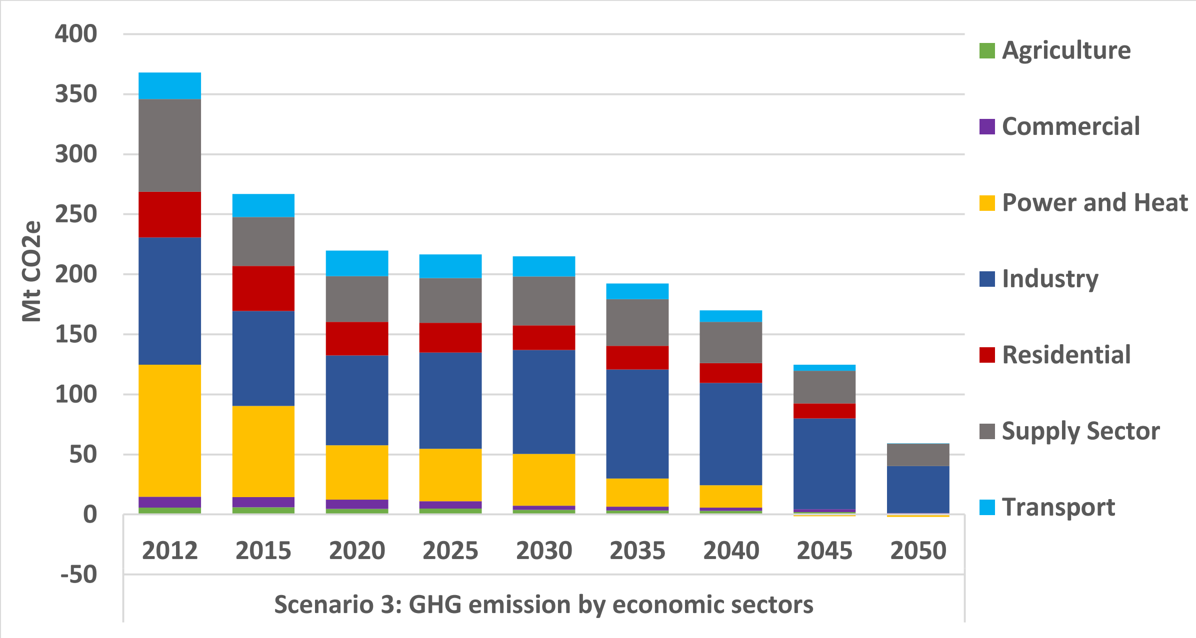

Figure 3.14. GHG Emission by Scenario 3 (Energy and Industrial Process sectors)

Difference between GHG emission by sub-sectors in Scenario 3 and Scenario 1 presented on the Figure 3.15.

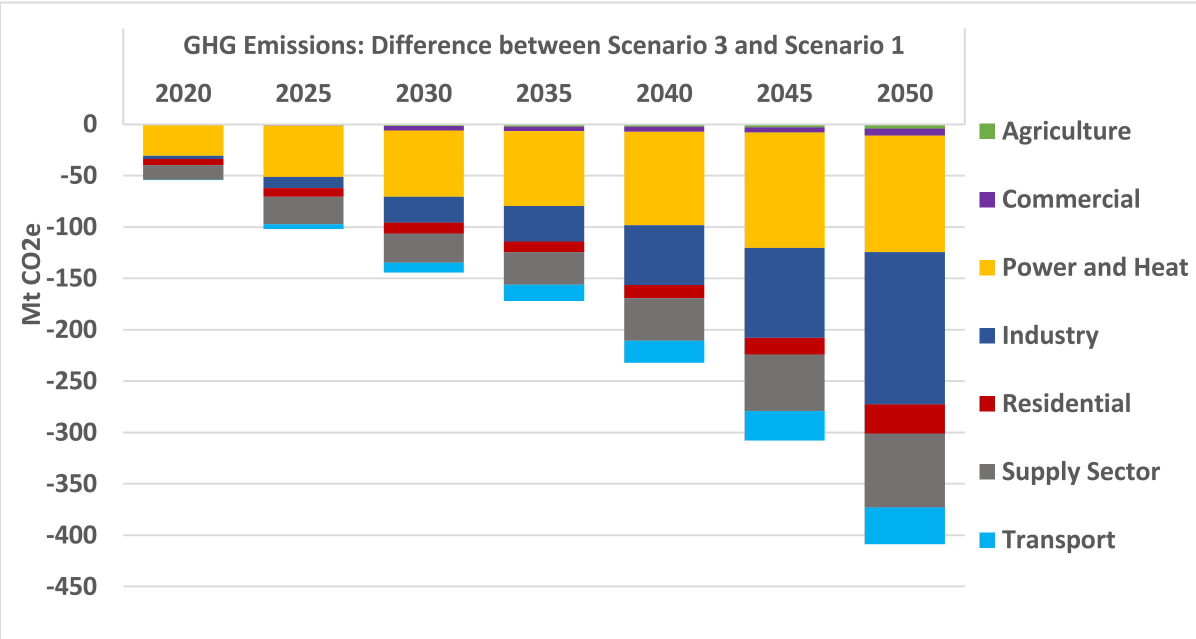

Figure 3.15. Difference in GHG Emission between Scenario 3 and Scenario 1 (Energy and IPPU sectors)

3.2.4 Focus on the Electricity Generation Sector

3.2.4.1 Sector Trends

According to modelling results of Scenario 1, coal and nuclear will be dominated in power generation and share of renewables will be no more 20% (Fig. 3.16).

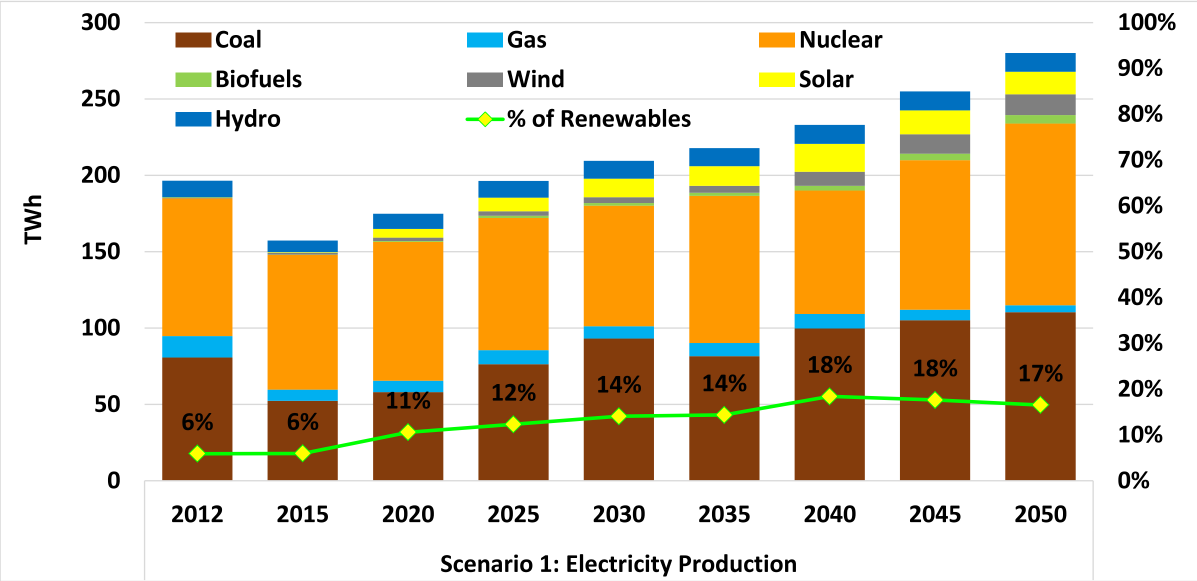

Figure 3.16. Electricity Generation by Scenario 1

Implementing policies and measures from Scenario 2, coal will decrease till 12-17% starting from 2030 (Fig. 3.17). Nuclear electricity generation can be more till 2035 and the same after 2035 comparing to Scenario 1. Share of renewables will growth twice till 2030 and will be 40% in 2035 and around 46-48% in 2040-2050. Share of nuclear will decrease in 2020-2040 from 58% till 34% and increase in 2050 till 40%.

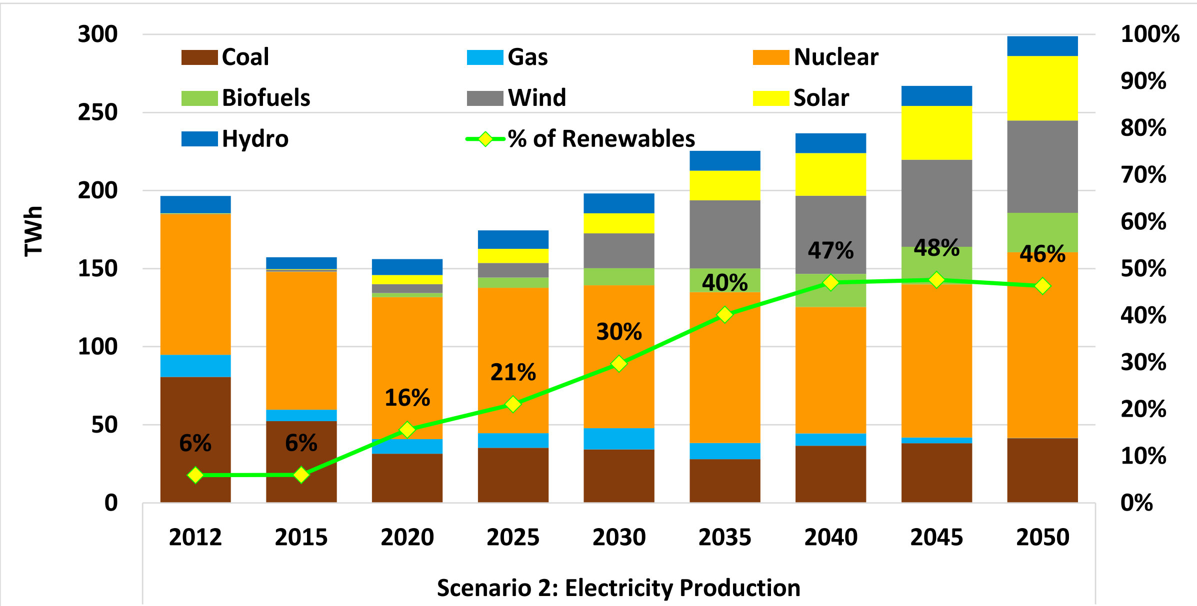

Figure 3.17. Electricity Generation by Scenario 2

Additional measures from the Scenario 3 will play crucial role for coal generation, which should be zero starting from 2045 (Fig. 3.18). At the same time, will growth the shares of renewable and nuclear production.

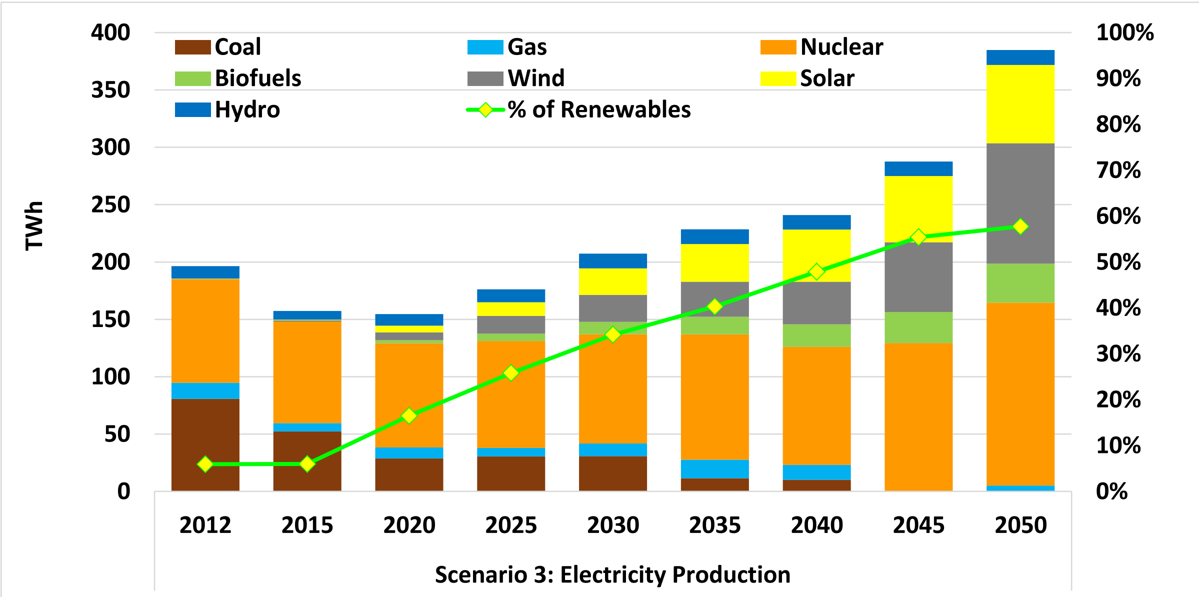

Figure 3.18. Electricity Generation by Scenario 3

3.2.5 Capital cost needed to implement the scenarios in energy, industrial processes and product-use sectors

For achieving targets of Scenario 2 and Scenario 3, for example for power sector, should be plus 36% and twice total investments comparing to the Scenario 1 respectively (Fig. 3.19). The greatest need for investment will be in 2040-2050 (Fig. 3.20).

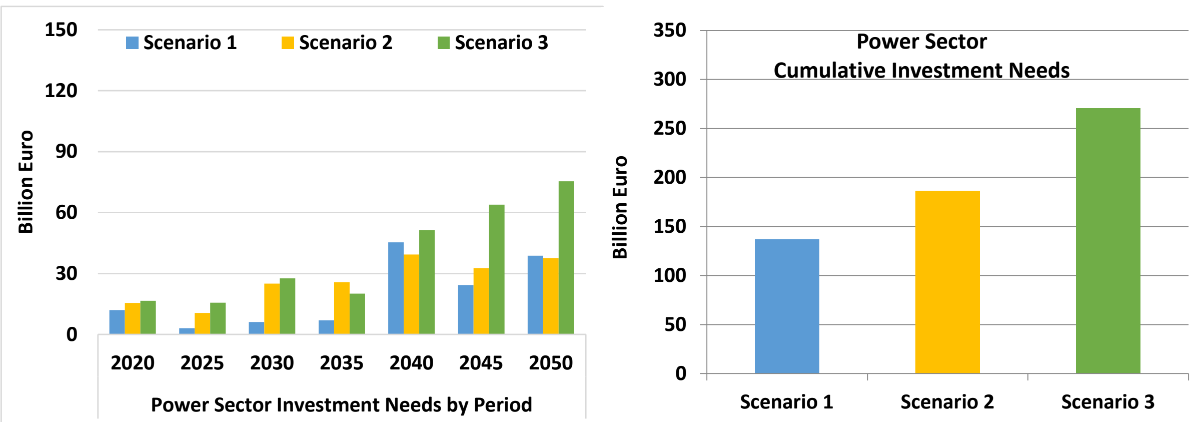

Figure 3.19. Power Sector Investment Needs

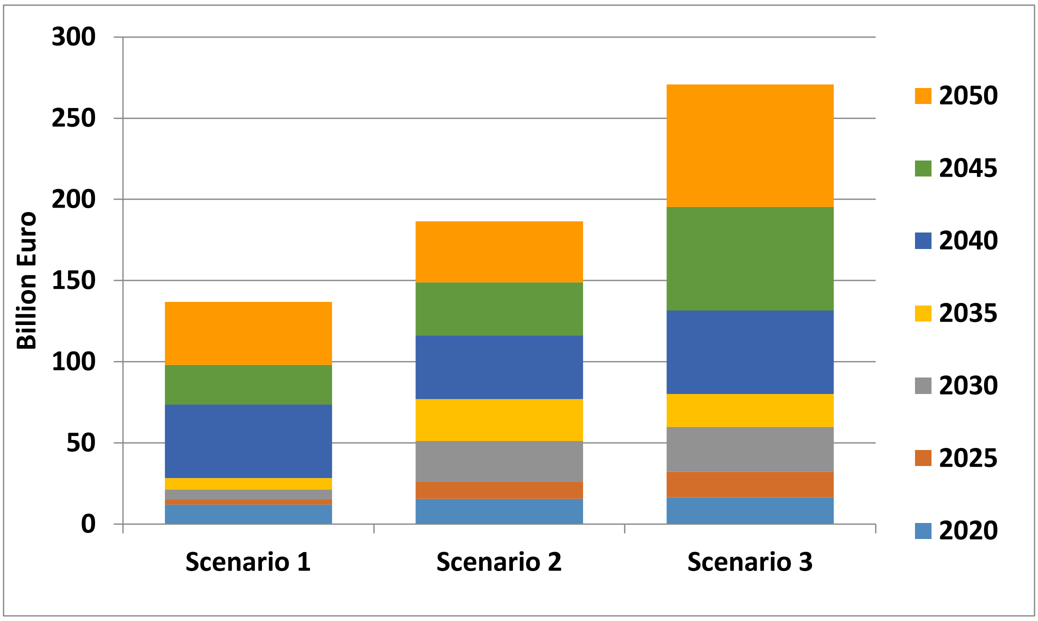

Figure 3.20. Power Sector Investment Needs by periods

The total capital cost needed will more by 15% in Scenario 2 and more by 43% in Scenario 2 comparing to the Scenario 1 (Fig. 3.21).

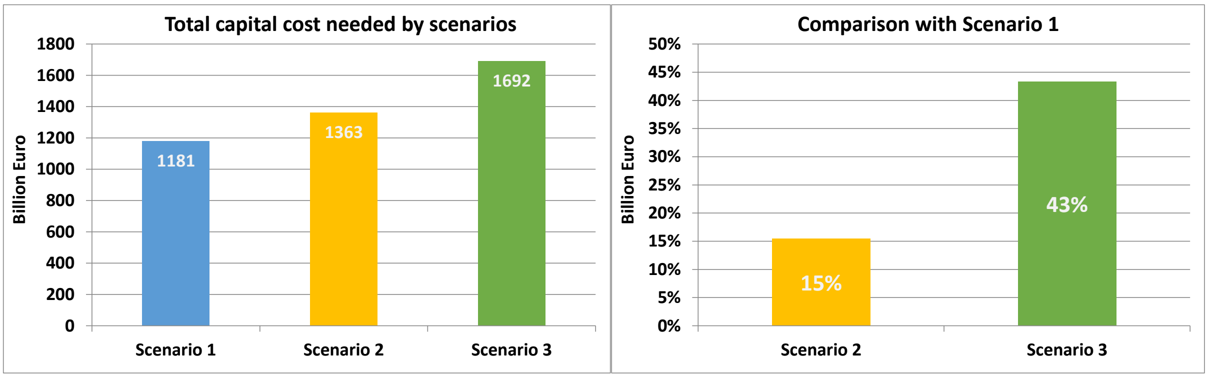

Figure 3.21. Total capital cost needed by scenarios

3.3 Agriculture and LULUCF sectors

3.3.1 Key assumptions

For the purpose of second NDC we applied the UNFCCC/IPCC definitions of sectors, and thus activities covered by them. This is beneficial for comparability with current reporting on GHG emissions and removals, however creates some contradictions of measures between sectors (when a reduction in Agriculture sector leads to emission increase in LULUCF and vice versa). Nevertheless, total effect was estimated to the extent possible. For the projections in forestry, no major changes in ownership structure was projected. That means that current structure of forest managing agencies and entities is maintained.

Wood harvest is foreseen to further increase in the future. Based on the data from the State Forest Agency Ukraine uses around 60 % of its annual wood increment. At the same time, such countries as Sweden, Austria and Switzerland use around 80-90 % of its annual wood growth still keeping its area with high forest cover, and paying big attention to sustainability of forestry management. Thus, it is assumed that harvest of wood will increase to around 28 mln m^3 in 2050.

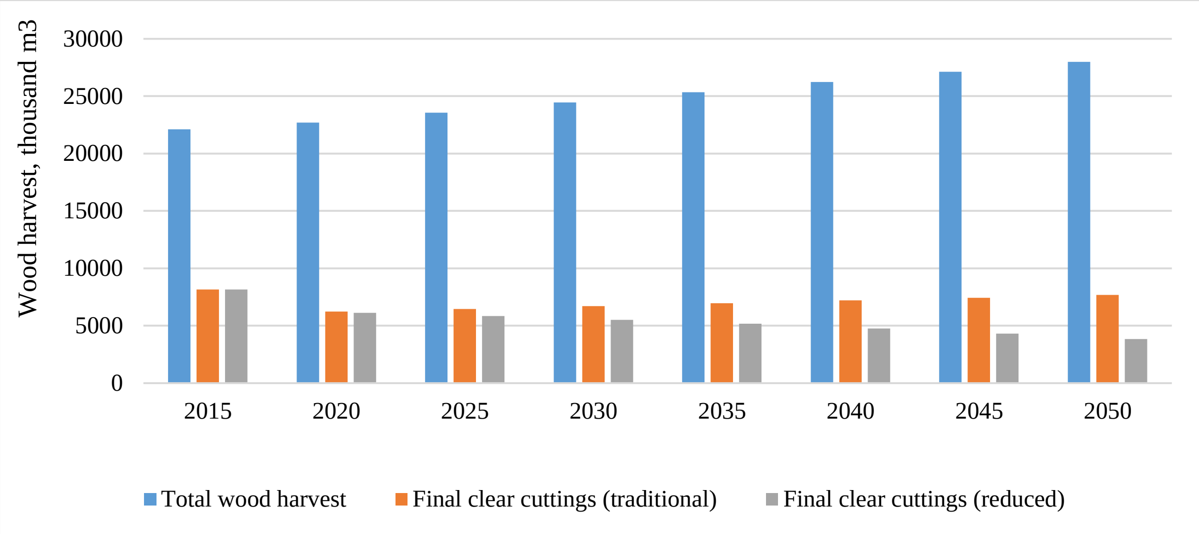

Figure 3.22. Wood harvest projection

For the Agriculture sector one of the main data sets is livestock population. For the purpose of comparability of modelling results, population of livestock projections was assumed the same across all scenarios.

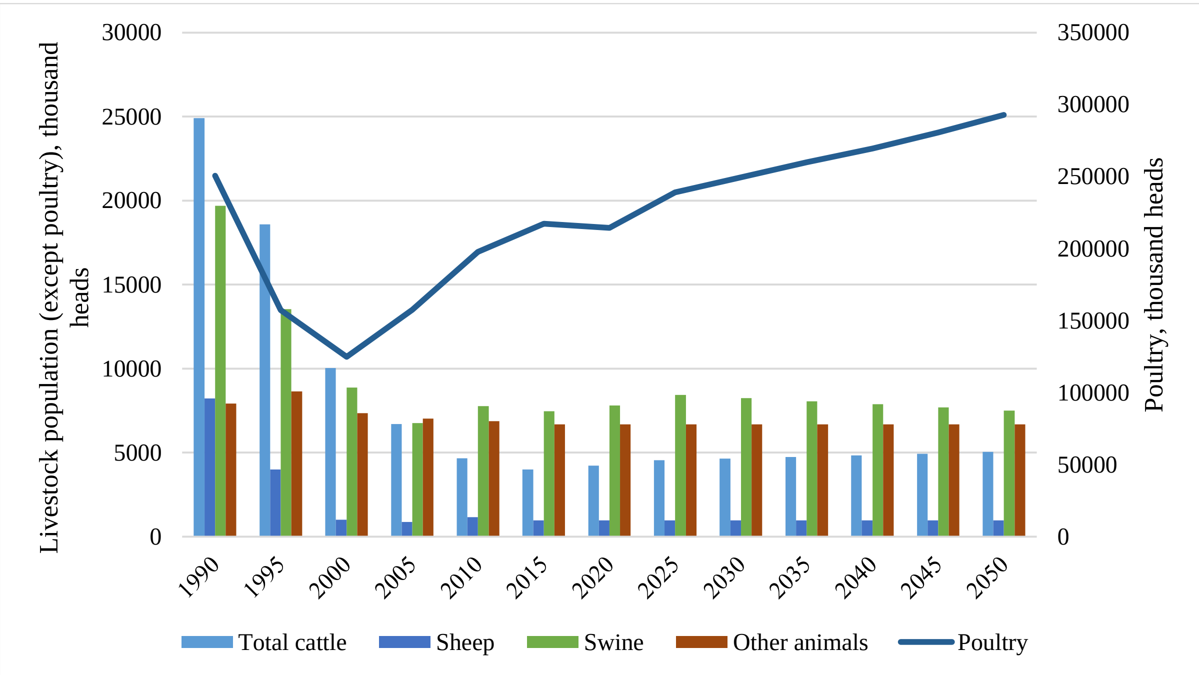

Figure. 3.23. Livestock population dynamics

Scenario 1 (Business As Usual Scenario) is based on previous and current trends of agriculture and forestry development. Moreover, future climate change and correspondent impacts in these sectors are included (for example, increase of negative effects in forests from natural disturbances, crop harvest change and others).

In the forestry, further increase of wood harvest is expected due to increasing demand, as described above. Current practice of harvesting will be maintained, according to which around half of wood is removed by final clear cuttings (referenced to “traditional” in Figure 3.22).

In the “State Ecology Strategy until 2030” increase of forest cover is planned, however due to lack of clear mechanisms of organization and financing of these measures, BAU scenario foresees increase forest cover to 16,5 % in 2050, which corresponds to current rates of afforestation.

In agriculture, BAU scenario is based on current trends of consumption, import and export of meat and milk and current number of livestock population. For the purpose of projection, population used the data from statistics on meat and milk production, import and export, and relative consumption by population. Due to war started in 2014 and drop in wealth of population, the consumption dropped. In the projection, recover in meat and milk consumption is foreseen as the average value before 2014. This results in different trends for different animal groups: increase in cattle and poultry population, stable number of sheep and other animals and decrease of swine (Figure 3.22).

In the “State Ecology Strategy until 2030” it is planned to increase the area of grasslands to 15,8 %, but for BAU scenario it was assumed, that area increase will be dependent on demand for moving and grazing.

Scenario 2 (Reference Scenario) includes the same trends and processes, as in BAU, however, this scenario includes full implementation of national policies and strategies, like “Ukraine 2050 Low Emission Development Strategy” (ULEDS), “State Ecology Strategy until 2030”. Some implementation of technologies identified in the Technology needs assessment is also foreseen.

For the forestry sector implementation of the “State Ecology Strategy until 2030” in the part of forest cover increase is expected to be implemented fully in 2030 with further grow to 19 % in 2050. The goal from ecology strategy is considered to be included into calculations, since ULEDS contains less ambitious goal for afforestation and forest cover increase.

Higher area of protected forests is planned in the ULEDS and ecology strategy, thus the share of main clear cuts was designed to be lower, as mentioned in the strategy, with increased share of selective cuts. Particularly, starting from 2020 gradual decrease of final clear cuts is foreseen, reaching 50% of wood removal in final cuts in 2050 to be done by selective methods (referenced to “reduced” in fig. 3.22).

In agriculture, according to the “State Ecology Strategy until 2030,” there will be an increase of grassland area is also expected to be fulfilled in 2030 with the same tendency of area increase until 2050.

For the crop production, ULEDS includes GHG emissions reduction from more efficient use of Nitrogen mineral fertilizers, but additional technology assessment is needed, in order to understand if current technologies might reach 20 % reduction of this measure. Moreover, alternative Scenario 2 foresees new technologies development and scaling up in crop production. Among them, new information and telecommunication technologies can contribute up to 10 % higher nitrogen fertilizers efficiency, conservation tillage technologies (no-till, low-till) can reduce the GHG emissions reductions on the area of around 5 mln hectares, and organic crop production may be scaled up to 2 mln ha.

For livestock sector, implementation of technologies for biogas production from manure is included in this scenario, which will allow not only to replace fossil fuel use for energy purposes, but is expected to reduce GHG emissions in agriculture by 25 % until 2050.

Scenario 3 (Climate Neutral Economy Scenario), is based on implementation of all measures and activities, described for Scenario 2. Moreover, extended scope of implementation of technologies, identified by experts within the project of technology needs assessment as high priority technologies is foreseen. On top of that, new technologies and approaches are needed to gain very high ambitions in GHG emission reduction and removals increase, like use of promising technologies, currently not in the commercial use due to its insufficient overall mitigating effect, lack of knowledge and very high costs.

In the forestry Scenario 3 includes the same measures and activities, as planned in Scenario 2. With the aim of mitigate negative effects of climate change enhancement of preventive measures of pest and disease losses are planned, as well as activities for more fast forest fire recognition. With this aim, measures of increase of fire watching towers, extended fire preventive measures on ground and use of promising tools, like drones, was considered. It was assumed, that this would allow to reduce GHG emissions from negative effects of natural disturbances by 50 % in comparison with previous scenarios.

In the future, land availability for forestry will have increased competition from agriculture. While technological barriers might be overcome by new approaches currently under focus (for example, use of remote instruments, new mechanisation and automation in forestry), actual lands for forestry will be in larger focus. Agriculture as a major component of food security cannot be opted by increase of forests. Nevertheless, comprehensive landscape planning is essential to support decisions on appropriateness of particular land use in particular conditions.

For the crop production GHG emissions reduction activities from Scenario 2 is included. These includes reduction of emissions from N-fertilizers planned by LEDS, new information and telecommunication technologies in agriculture, conservation tillage technologies, organic crop production and increased efficiency of N-input by mineral fertilizers. Increased scale of implementation of these technologies is foreseen to be reached in Scenario 3.

For livestock sector, implementation of technologies for biogas production from manure is included in this scenario, which will allow not only to replace fossil fuel use for energy purposes, but is expected to reduce GHG emissions in agriculture categories of manure management by 50 % until 2050.

There are some promising technologies currently not in commercial use, like use of algae in industry, waste and agriculture sector for Carbon uptake, which may also contribute to GHG emission reduction. However, current knowledge of its potential, commercial viability and economical effect is not researched.

3.3.2 Modelling results

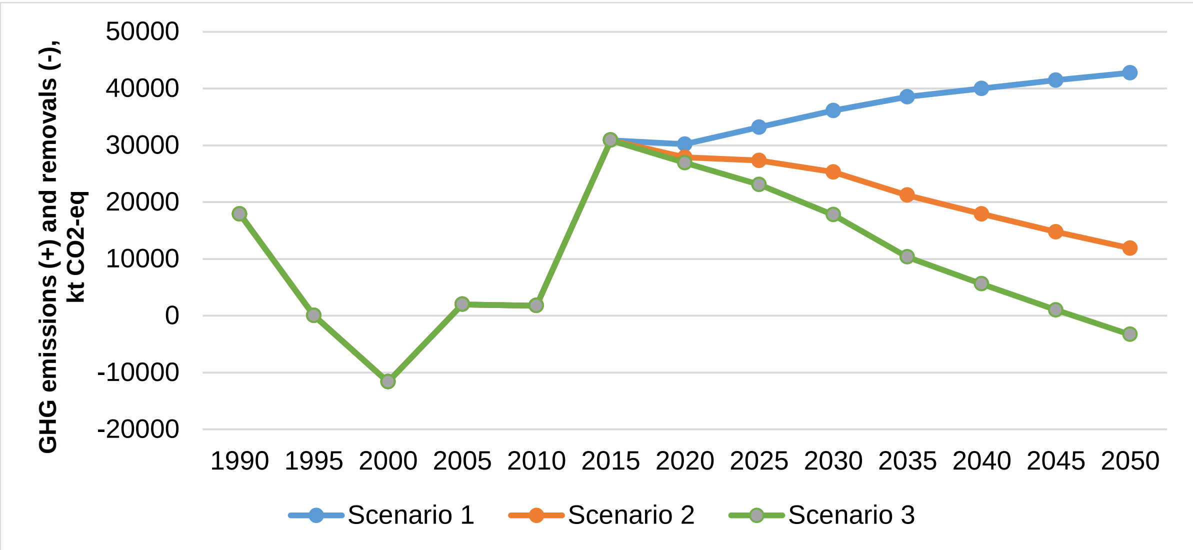

Figure. 3.24. Total GHG emissions in Agriculture and LULUCF sectors

In the Scenario 1 LULUCF sector will become net source of emissions in 2050, still being net sink in 2030. This is caused by two main drivers: net removals in Forest land, and net emissions in Cropland and Grassland categories.

Forest Land continues to be total sink. However, due to increase of area of cuttings and increase of wood losses due to natural disturbances Carbon removals will decrease. Thus in 2030 GHG removals in the category will reach 70 % of 1990 level, and in 2050 – around 63 %. In the Cropland and Grassland category GHG emissions will occur. Moreover, its growth is driven by continuation of current tendencies of low organic fertilizers application with a background of increase of areas of crop harvest. In 2030 emissions in this category will be higher than in 1990 by around 5 times.

In the Agriculture sector GHG emissions will be lower than in 1990 by almost half, but comparing with current levels, emissions will rise on around 7%. Particularly, decrease of GHG emissions from Enteric Fermentation will reach around 20 % from 1990. Similar tendency is observed in the Manure Management category – emissions will be on the level of 30 % of 1990. This is related to livestock population decrease compared to the base year. Emissions from agricultural soils will increase compared with current emissions due to increase of cropland areas, but still will be lower than in the base year. In 2030 emissions from this category is expected to be 93 % of 1990, and 95 % in 2050.

In the Scenario 2 LULUCF sector is expected to be a net sink, keeping removals from forests higher than emissions from crop grow. This will allow to increase net removals by almost 2 times as in 2015. In the Forest Land category higher rates of GHG removals are expected compared to reference scenario. Particularly, in 2030 removals are estimated to be on the level of 77 % of 1990, and in 2050 – around 92 %. This is connected to higher afforestation areas and change in age structure due to change of cutting patterns, which are aimed in wood harvest. In the categories of Cropland and Grassland measures for GHG emission reduction in the forms of increased efficiency of Nitrogen fertilizers application, use of conservation tillage technologies and increase of organic agriculture areas will have positive influence as reduced GHG emissions by 10 % in 2030 and by 15 % in 2050 compared to current levels.

In the Agriculture sector in all categories GHG emissions decrease are expected. This is foreseen to be the results of GHG emissions reduction from mineral fertilizers application, reduction of mineralization of agricultural soils and enhancement of equipment use for biogas production from manure, as well as use of feed supplements. Consequently in the Agriculture sector GHG emissions reduction is expected compared with 1990 by 49 % in 2030 and by 47% in 2050 correspondingly.

In the Scenario 3 LULUCF sector is expected to have higher removals than in Scenario 2. Particularly, in 2030 it foresees to have 3 times more GHG removals than in 2015.

In the Forest Land category GHG removals will occur, which will be larger, than in the Scenario 2. Particularly, this is connected to emissions reduction from implementation of measures for mitigation of natural disturbances impacts. Consequently it is expected, that in 2030 GHG removals will be lower by 12 % than in 1990, and in 2050 – only 5 % lower than in 1990. In the Cropland and Grassland categories wider scope of implementation of activities, identified in the technology needs assessment project, will allow to mitigate GHG emissions by 23 % 2030 and 38 % in 2050 compared to current levels.

According to the Scenario 3 in the Agriculture sector there will be further GHG emissions reduction compared to Scenario 2. Particularly, that is the result of implementation of activities, included into Scenario 2, but in a wider extent, as it is estimated in the technology needs assessment project. The highest influence will be from mineral fertilizers application efficiency increased, reduction of mineralization of agricultural soils and enhancement of equipment use for biogas production from manure. Thus, GHG emission reductions will be on the level of 47 % of 1990 in 2030 and 42 % in 2050.

Totally two sectors have big potential for GHG emission reduction and removals increase. According to already adopted or developed policy goals and measures, Ukraine may decrease its emissions in these sectors in 2030 by around 10 Mt CO_2-eq. with further reduction in 2050. Putting even higher efforts, projected in Scenario 3 presents that net removals might be reached in 2050.

Table 3.8. Modelling results of GHG emissions and removals

Emissions (+) and removals (-), kt CO_2 eq.	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest Land													
Scenario 1	-68129	-61729	-62837	-55743	-52271	-51534	-51881	-50027	-47950	-46339	-44988	-43698	-42555
Scenario 2	-68129	-61729	-62837	-55743	-52271	-51534	-52308	-51663	-52182	-54705	-57477	-60152	-62537
Scenario 3	-68129	-61729	-62837	-55743	-52271	-51534	-52493	-52158	-52985	-55817	-58898	-61881	-64575
Cropland and Grassland													
Scenario 1	-8163	3633	13549	23085	21768	41786	41023	41557	42106	42655	42765	42875	42985
Scenario 2	-8163	3633	13549	23085	21768	41786	39461	38423	37390	36342	36131	35919	35707
Scenario 3	-8163	3633	13549	23085	21768	41786	38792	35458	32091	28672	27749	26823	25895
Wetlands													
Scenario 1	12267	785	244	273	276	349	225	214	263	263	263	263	263
Scenario 2	12267	785	244	273	276	349	225	214	263	263	263	263	263
Scenario 3	12267	785	244	273	276	349	225	214	263	263	263	263	263
Other emissions													
Scenario 1	4732	3489	3388	3042	882	3117	2347	2347	2347	2347	2347	2347	2347
Scenario 2	4732	3489	3388	3042	882	3117	2347	2347	2347	2347	2347	2347	2347
Scenario 3	4732	3489	3388	3042	882	3117	2347	2347	2347	2347	2347	2347	2347
Total LULUCF sector													
Scenario 1	***-59292***	***-53823***	***-45656***	***-29344***	***-29345***	***-6281***	***-8286***	***-5909***	***-3234***	***-1075***	***386***	***1787***	***3039***
Scenario 2	***-59292***	***-53823***	***-45656***	***-29344***	***-29345***	***-6281***	***-10274***	***-10679***	***-12182***	***-15753***	***-18736***	***-21623***	***-24220***
Scenario 3	***-59292***	***-53823***	***-45656***	***-29344***	***-29345***	***-6281***	***-11129***	***-14138***	***-18284***	***-24535***	***-28539***	***-32448***	***-36070***
Enteric Fermentation													
Scenario 1	39139	29801	17312	12963	9785	8747	8191	8413	8400	8368	8315	8257	8167
Scenario 2	39139	29801	17312	12963	9785	8747	7957	7772	7360	6933	6810	6684	6533
Scenario 3	39139	29801	17312	12963	9785	8747	7957	7772	7360	6933	6810	6684	6533
Manure Management													
Scenario 1	6573	4153	2235	1904	2060	1936	1971	2105	2105	2100	2090	2078	2058
Scenario 2	6573	4153	2235	1904	2060	1936	1901	1905	1779	1650	1617	1583	1543
Scenario 3	6573	4153	2235	1904	2060	1936	1798	1611	1301	990	923	857	788
Agricultural Soils													
Scenario 1	31508	19930	14489	16481	19277	26505	28843	29194	29478	29760	29810	29859	29900
Scenario 2	31508	19930	14489	16481	19277	26505	28825	28908	28913	28907	28728	28546	28355
Scenario 3	31508	19930	14489	16481	19277	26505	28825	28427	27945	27442	26886	26325	25755
Total Agriculture sector													
Scenario 1	***77220***	***53884***	***34036***	***31348***	***31122***	***37188***	***39005***	***39713***	***39983***	***40227***	***40214***	***40194***	***40125***
Scenario 2	***77220***	***53884***	***34036***	***31348***	***31122***	***37188***	***38683***	***38585***	***38052***	***37491***	***37155***	***36813***	***36431***
Scenario 3	***77220***	***53884***	***34036***	***31348***	***31122***	***37188***	***38579***	***37811***	***36606***	***35366***	***34619***	***33867***	***33077***

Inter-linkages between LULUCF and Agricultural Sector with other Sectors

There are weak interlinkages between Agriculture and LULUCF with Energy and Industrial Processes sectors. The only linkage is in the use of biomass from crop residues and wood for combustion with energy purposes. However, since GHG emissions in Energy from biomass use is not summarized in total emissions, because it is considered as a source of renewable energy, there is no double counting or underestimation of emissions.

Interlinkages between Agriculture sector and LULUCF are rather strong. There are several activity data sets and factors, flowing between these sectors and used in the different stages of calculation: amount of manure produced by livestock, amount of crop residues produced and left for decay on the fields, amount of Nitrogen fertilizers applied on the fields. Consequently, results of modelling of these data or factors influence both sectors. Nevertheless, there is a clear guidance on where emissions and removals should be reported according to the UNFCCC to avoid omissions and double counting, which was followed in the modelling.

Interlinkage between Agriculture and LULUCF with Waste sector is weak. It is related to biomass products after the end of lifetime and direct biomass waste. If these products are not used for energy generation purposes (discussed above), they are considered in Waste sector, subject for combustion without energy generation, recycling or disposal.

3.3.3 Capital cost needed to implement scenarios in Agriculture and LULUCF sectors

Table below contains investment needs. Scenario 1 contains investments needed in order to maintain the current level of afforestation. Investments under scenarios 2 and 3 reflects funds needed to reach certain level of management in forestry and agriculture, which was selected for modelling.

The costs on afforestation are based on typical measures in the past, which the forest enterprises had to undertake to successfully establish new forests. It included expenditures on change of legal status of lands determined for afforestation, costs of planting and initial treatment.

In light of cancelling the moratorium on trade and strong support to establish market of agricultural lands by the Parliament and Government of Ukraine, it is worth to mention that the costs of afforestation might be significantly affected by this. Particularly important for future possibility and costs of establishment of new forests is the mechanism of determination of lands for afforestation. It might include direct purchase of lands by the Government in land owners for afforestation on the market, compensation for the land by other values or other.

Table 3.9. Assessment of investments needed for implementation of activities, included into different scenarios, thousand euro

	2020	2025	2030	2035	2040	2045	2050
Scenario 1	4686	4686	4686	4686	4686	4686	4686
Forest Land	4686	4686	4686	4686	4686	4686	4686
Scenario 2	1693305	2136528	2583132	3034048	3468853	3905646	4344421
Forest Land	19400	19730	36905	55260	55458	55599	55676
Crop Production	1542289	1656165	1756578	1860124	1965716	2073354	2183036
Livestock	131616	460633	789649	1118664	1447679	1776693	2105708
Scenario 3	1896208	2810573	3673989	4543757	5399458	6259194	7122957
Forest Land	20007	21768	40249	59910	61413	62860	64242
Crop Production	1612985	1867571	2054492	2246583	2442766	2643041	2847406
Livestock	263216	921233	1579249	2237264	2895279	3553293	4211308

3.4 Waste sector

3.4.1 Key assumptions

Modelling for all three Scenarios was carried out based on GHG emissions in 2017, the latest available historical year provided in Ukraine's GHG Inventory Report. All the methodologies to estimate GHG emissions are in line with the latest Ukraine's GHG Inventory. List of potential waste treatment practices and available technologies was identified based on Technology Needs Assessment in Ukraine (Mitigation) report[33] finalized and published in 2019. The following indicators and trends were used for GHG emission modelling in Waste sector by categories, where sector-specific indicators are marked in *italics*:

Solid waste disposal: population, *MSW per capita generation, waste treatment practice (share of disposal, reuse, recycling, composting, incineration, landfilling), coverage of population by centralized waste collecting system, construction of new sanitary (deep managed) landfills, MSW composition, share of landfill methane flaring and recovery*.

Schematically MSW mass balance model is illustrated for better transparency in Figure 3.25, showing the following.

1. The total amount of MSW generation is equal to sum of MSW generation covered by centralized collecting system and MSW not covered[34] by it. Input data for MSW generation are: population, coverage of population, per capita MSW generation.

2. When the amount of generated MSW is determined, it is split by different waste component flows derived from MSW composition. These flows are: paper and cardboard, food waste, garden waste, wood, nappies, rubber and leather, textiles

[33] Technology Needs Assessment Report. Mitigation. Technology Prioritization. Output of the Technology Needs Assessment project, funded by the Global Environment Facility (GEF) and implemented by the United Nations Environment Programme (UN Environment) and the UNEP DTU Partnership (UDP) in collaboration with University of Cape Town. – Kyiv. – 2019. – 119 pp. Available at: https://tech-action.unepdtu.org/wp-content/uploads/sites/2/2019/08/tna-01-mitigation-ua-final-190731.pdf

[34] Unspecified practice (such home composting, recycling, etc.) of MSW not covered by centralized collecting system is excluded from the mass balance because it leads to insignificant GHG emissions.

and non-biodegradable (disaggregated by ferrous metals, non-ferrous metals, glass, plastics, hazardous and other inorganics). Wherein, MSW not covered by centralized collecting system reallocates to unmanaged shallow dumps.

3. Food and garden waste components form the raw material flow for composting, being determined by the share of compositing practice.

4. Glass component forms the raw material flow for reuse, being determined by the share of reuse.

5. Paper, cardboard and non-biodegradable (e.g. plastics, glass and metals) components form the raw material flow for recycling, being determined by the share of recycling.

6. The rest part of MSW is divided into two flows: incineration and landfilling being determined by the share of incineration.

7. Distribution by types of disposal sites is determined by putting into operation of new sanitary landfills.

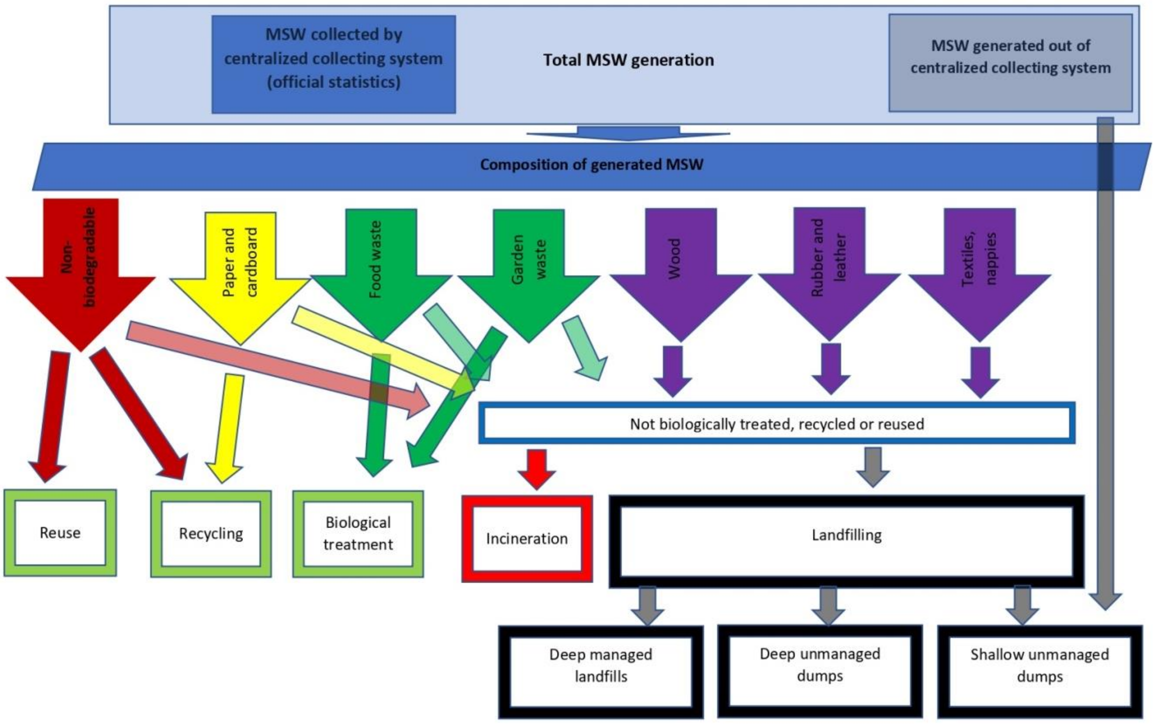

Figure 3.25. General scheme of MSW mass balance model (mass flows)

Biological treatment of solid waste: population, industry and agriculture sector development indicators, *MSW per capita generation, share of composting and technology of composting*.

Incineration and open burning of waste: GDP growth, industry sector development, category specific legislation (*prohibition of MSW incineration without energy recovery*).

Wastewater treatment and discharge: population, share of urban and rural inhabitants, sectors development indicators (energy, ferrous metallurgy, agriculture, food etc.), *share of wastewater purification and discharge; meat, milk and fruits consumption per capita, technology development, share of wastewater methane flaring and recovery*.

Scenario 1 (Business as Usual or Barrier Scenario)

Scenario 1 is based on existing waste management practice in Ukraine as for 2017 and on general, cross sectoral macroeconomic and socio-demographic projections. This scenario implies that significant infrastructural changes in waste sector would not be implemented, and the main waste management indicators would be similar to 1991-2017 period, namely: about 95% of officially generated municipal solid waste (MSW) would be landfilled, waste water treatment facilities wouldn't be modernized, share of landfill methane recovery and flaring (less than 5%) would be constant.

Scenario 2 (Reference Scenario)

Scenario 2 (Reference Scenario) is based on the assumption that all targets set in existing legislation (laws, strategies, plans, concepts, programs) would be achieved successfully. The core legislation acts on waste management system would be fully implemented, namely: National Waste Management Strategy up to 2030 and National Waste Management Plan up to 2030. Also, this scenario is based on the assumptions that key concepts for policies and measures defined in Ukraine's 2050 Low Emission Development Strategy would be implemented, as well as sustainable development goals defined for Ukraine by the Ministry of Economic Development and Trade of Ukraine would be achieved as well, among which are: decreasing of share regarding contaminated discharge water, per capita food consumption increasing, decreasing of water supply intensity for GDP etc. The current rate of efficiency of successful EU countries' waste management systems was taken into account, when defining key indicators. This scenario implies that MSW landfilling would be reduced to 30% by 2030 and 20% in 2050; landfill methane utilization would be increased to 23% in 2030 and 36% in 2050; new composting facilities with lower CH_4 and N_2O emission factors would be operated; per capita N_2O emissions from protein consumption would reach typical EU values; wastewater methane utilization would reach 41% in 2030 and 70% in 2050; water supply intensity for GDP would be decreased to 0.5 in 2050 compared to 2015.

Scenario 3 (Climate Neutral Economy Scenario)

Scenario 3 (Climate Neutral Economy Scenario) is based on the assumption that all targets set in the existing legislation would be significantly over-achieved due to the wide implementation of modern technologies and best international practices (after the example of Germany, Sweden etc.) in Ukraine's waste management system, including most innovative internationally proven and recognized as climate friendly policies, measures and technologies, such as minimization of landfilling as much as it possible; wide dissemination of composting, incineration, recycling and reuse technologies; deep utilization (recovery and flaring) of methane generated from organic matter degradation, significant water supply intensity decreasing etc.

It is expected that this would lead to best existing standards for EU countries in waste management system by 2050. This scenario implies that MSW landfilling would be reduced to 20% by 2030 and 5 % in 2050; landfill methane utilization would be increased to 30% in 2030 and 63% in 2050; new composting facilities with very low CH_4 and N_2O emission factors would be operated; per capita N_2O emissions from protein consumption would correspond to the best practice of EU countries; waste water methane utilization would reach 66% in 2030 and 95% in 2050; water supply intensity for GDP would be decreased to 0.35 in 2050 compared to 2015.

General waste generation and treatment trends for Scenarios 1, 2 and 3. It is expected that annual per capita MSW generation rate will be at the level of 1 %. Thus, it will increase from 0.347 t/cap /yr in 2017[35] to 0.480 in 2050 that corresponds with recent average value for EU countries. Food consumption in 2017 was equal to 51 kg/cap/yr for meat, 210 kg/cap/yr for milk and 51 kg/cap/yr for fruits and it's expecting to increase by 80, 380 and 90 kg/cap/yr respectively by 2030[36]. Coverage of population by centralized MSW collection system in 2017 was equal to 77 %, being constant for all the projecting years for Scenario 1 and it will reach 100 % under Scenarios 2 and 3 by 2030[37]. The share of MSW disposed at deep managed landfills in 2017 is equal to 26.2%, 42.2 % for deep unmanaged landfills and 31.6 % for shallows unmanaged landfills, being constant for all the projecting years under Scenario 1, while under Scenarios 2 and 3 all the MSW disposal will occur only at deep managed landfills starting 2030[38]. Under Scenario 1 the level of illegally dumped MSW is estimated at the level of 2017 and being equal to 10 % for all the projecting years. Under Scenarios 2 and 3 illegal dumping will not occur starting from 2030[38].

Share of contaminated discharge water is at the level of 2017 for Scenario 1 being equal to 15.7 % for all the projecting years, for Scenarios 2 and 3 it will decrease to 2.5 % by 2030[38]. Key Scenarios' specific indicators on GHG emissions forecasts in Waste sector are provided in Table 3.10 below.

[35] Includes officially collected MSW covered by centralized collecting system, generated waste which is not covered by centralized collecting system and evaluated data on temporarily occupied territories (GHG inventory methodology). Estimations are based data from on the Ministry of Regional Development, Construction and Housing statistics on 2017 (estimated on mass indicators), also see: http://www.minregion.gov.ua/napryamki-diyalnosti/zhkh/terretory/stan-sferi-povodzhennya-z-pobutovimi-vidhodami-v-ukrayini-za-2017-rik/; assumption that amount of illegally dumped MSW is equal to 10 % of officially collected one; amount of generated MSW at the temporarily occupied territories is proportional to population living at this area.

[36] Sustainable Development Goals: Ukraine. Ministry of Economic Development and Trade of Ukraine.– 176 pp. – Kyiv. – 2017.

[37] Based on Waste Management Strategy.

[38] Includes recycling and composting.

Table 3.10. Key indicators comparison for scenarios 1, 2 and 3 (marked with green – newly illustrated or revised data)

Indicator		Unit	2030 Scenario 1	2030 Scenario 2	2030 Scenario 3	2050 Scenario 1	2050 Scenario 2	2050 Scenario 3
MSW treatment practice	Reuse	%	0.00[39]	10[40]	10	0.00	10	10
	Processing[38]	%	4.11[38]	50[41]	55	4.11	55	60
	Recycling	%	*4.10*[38]	*34*[41]	*37*	*4.10*	*35*	*40*
	Composting	%	*0.01*[38]	*16*[41]	*18*	*0.01*	*20*	*20*
	Incineration	%	2.49[38]	10[41]	15	2.49	15	25
	Landfilling	%	93.4	30[41]	20[42]	93.4	20[43]	5[44]
MSW composition (after sorting and recycling)[45]	Paper & cardboard	%	14.3	11.0	5.8	14.3	12.1	9.4
	Textile	%	4.2	9.5	12.6	4.2	10.8	12.6
	Food waste	%	34.5	41.8	43.7	34.5	37.5	43.7
	Wood	%	1.9	4.3	5.7	1.9	4.9	5.7
	Park waste	%	3.9	4.8	5.0	3.9	4.3	5.0
	Nappies	%	1.5	3.3	4.5	1.5	3.8	4.5
	Rubber & leather	%	2.0	4.5	6.0	2.0	5.2	6.0
	Plastics	%	13.4	8.5	2.2	13.4	9.5	6.7
	Glass	%	6.7	1.3	0.2	6.7	1.5	0.3
	Iron	%	2.0	0.5	0.7	2.0	0.6	0.1
	Colored metals	%	0.4	0.1	0.2	0.4	0.2	0.0
	Hazardous waste	%	0.6	0.1	0.2	0.6	0.1	0.1
	Other inorganics	%	14.6	10.2	13.1	14.6	9.5	5.8
Landfill methane utilization[46]		%	4.48	23[47]	30[48]	4.48	36[48]	63[48]
Flaring		%	*0.01*	*6*[47]	*8*[48]	*0.01*	*6*[48]	*16*[48]
Recovery		%	*4.47*	*17*[47]	*22*[48]	*4.47*	*30*[48]	*47*[48]
Biological treatment, implied emission factor, CH_4[49]		g/kg	4.00	2.00	0.50	4.00	1.00	0.03
Biological treatment, implied emission factor, N_2O[49]		g/kg	0.30	0.15	0.09	0.30	0.07	0.03
Reference N_2O emissions from consumed protein per capita[50]		g/cap/yr.	78	66	42	78	55	17
Wastewater methane utilization[46]		%	0	41[51]	66[51]	0	70[51]	95[51]
Flaring		%	*0*	*0*[51]	*5*[51]	*0*	*5*[51]	*10*[51]
Recovery		%	*0*	*41*[51]	*61*[51]	*0*	*65*[51]	*85*[51]
Water supply intensity for GDP[52]		index to 2015	1.00	0.70	0.60	1.00	0.50	0.35

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[39] Based on Ministry of Regional Development, Construction and Housing statistics on 2017 (estimated on mass indicators), also see: http://www.minregion.gov.ua/napryamki-diyalnosti/zhkh/terretory/stan-sferi-povodzhennya-z-pobutovimi-vidhodami-v-ukrayini-za-2017-rik/; assumption that amount of illegally dumped MSW is equal to 10 % of officially collected one; amount of generated MSW at the temporarily occupied territories is proportional to population living at this area.

[40] Based on the Waste Management Strategy

[41] Waste Management Strategy does not provide concrete data on MSW processing, e.g. recycling and composting targets, nevertheless it includes target for the overall waste processing share equal to 50 %. Moreover, historical data provided for waste processing corresponds to statistics on MSW treatment. Accordingly MSW processing target for projections was defined based on overall waste determined target. To split MSW processing value by recycling and composting, the average value typical for EU countries was used which is equal to 16 % for 2017, also see Eurostat waste database (footnote "a").

[42] According to Scenario 3 it's expected that the level of MSW disposal in 2030 will be similar to MSW treatment practice in United Kingdom and France as for 2015.

[43] According to Scenario 2 it's expected that the level of MSW disposal in 2050 will be similar to MSW treatment practice in Great Britain and France as for 2015.

[44] According to scenario 3 it's expected that the level of MSW disposal in 2050 will be similar to MSW treatment practice in Sweden and Denmark as for 2015.

[45] MSW composition changes take into account implemented and/or expended modern treatment practices based on Waste Management Strategy targets which typically are used on certain fraction; for example, reuse is mostly focused on glass, recycling – on paper and cardboard, metals, metals, composting – on food and park waste.

[46] Utilization includes recovery and flaring.

[47] Methane recovery facilities are much more efficient if they are planned to be put into operation at the design stage of the landfill. Methane recovery was assumed to be proportional to trend of the new modern regional landfills, which are determined to be constructed by 2030 according to Waste Management Strategy (50 new regional well-managed landfills by 2030). Landfill gas flaring will is assumed not to be occurred because of green tariff stimulus.

[48] EU countries' landfill gas recovery/flaring common practice for 2017 was taken into account to identify national attainable/feasible targets for 2050, also see EU's GHG Inventory, available at: https://unfccc.int/documents/194946. Value for flaring in 2030 reflects sanitary requirements for landfill operation.

[49] Lower implied emission factors will be in place due to implementation of well-organized waste composting facilities.

[50] Technology level development influencing N2O emission reduction from protein consumption was considered through statistical analysis of EU countries' GHG Inventories (Poland, Sweden, Spain, Germany, France).

[51] There're no quantitatively determined targets in Ukraine's strategies, plans, concepts or other national development documents. EU countries' wastewater biogas recovery/flaring common practice for 2017 was taken into account to identify national attainable/feasible targets for 2050, also see EU's GHG Inventory (Poland, Sweden, Spain, Germany, France), available at: https://unfccc.int/documents/194946.

[52] Water supply intensity by 2030 corresponds to Ukraine's Sustainable Development Goals. It's expected to reach the values of 0.60 and 0.35 for scenarios 2 and 3 by 2050 based on general trends of new technology implementation.

3.4.2 Modelling results

Detailed GHG emission modelling results by each scenario are presented in Table 3.11, and also illustrated in absolute units in Figure 3.26, as well as relative ones in Figure 3.27.

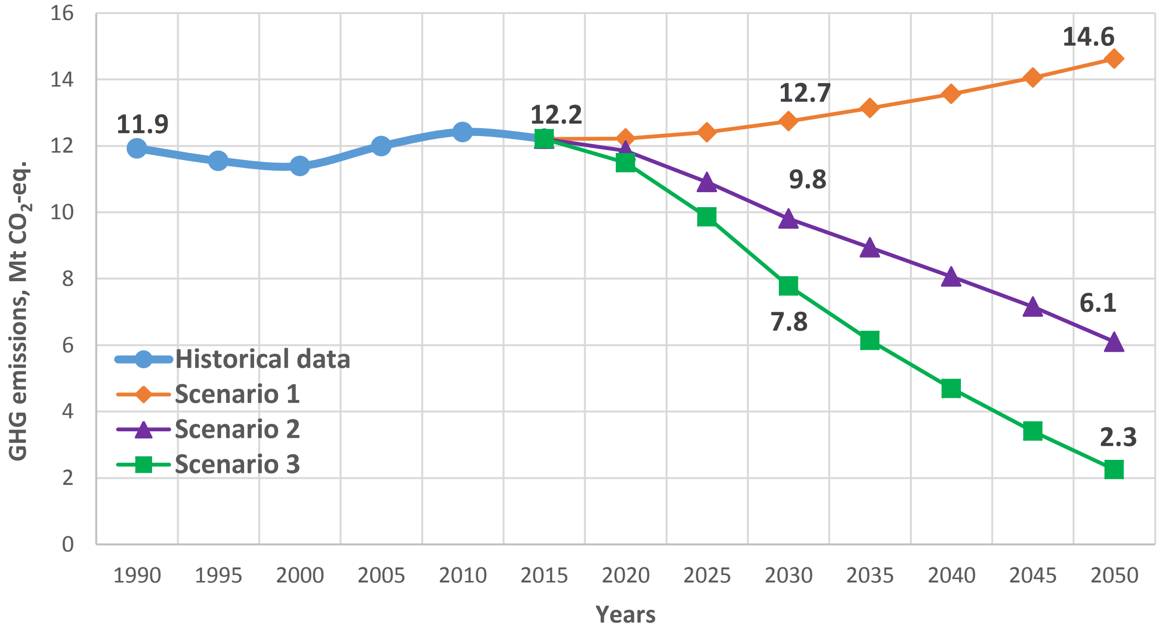

Figure 3.26. Total GHG emissions in Waste sector up to 2050

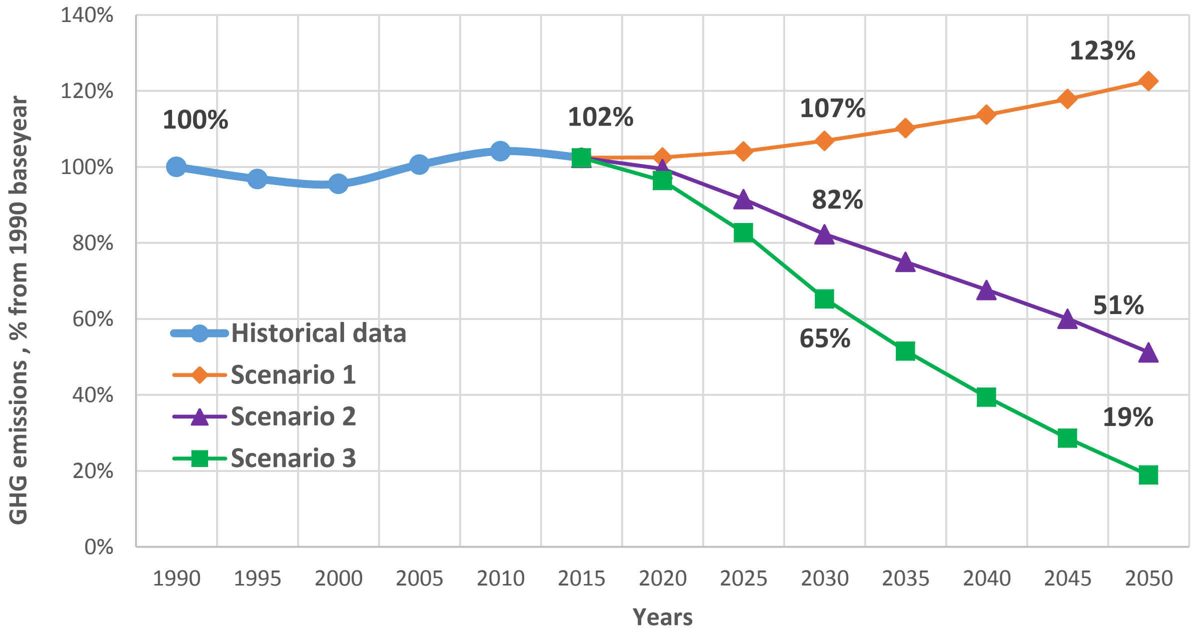

Figure 3.27. Total GHG emissions changes in Waste sector up to 2050, compared to 1990 base year

Table 3.11. GHG emissions in Waste sector by categories, 1990-2050

Emissions (+) and removals (-)	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Solid Waste Disposal, *Mt CO_2e*													
Scenario 1	6.5	7.3	7.4	7.6	8.0	8.1	8.1	8.2	8.4	8.5	8.7	8.9	9.1
Scenario 2							7.9	7.1	6.2	5.7	5.1	4.6	4.2
Scenario 3							7.7	6.7	5.4	4.2	3.2	2.3	1.6
Biological Treatment of Solid Waste, *kt CO_2e*													
Scenario 1	34	23	10	5	3	39	28	31	36	42	47	52	59
Scenario 2							107	213	268	256	238	215	185
Scenario 3							108	176	124	118	110	101	90
Incineration and Open Burning of Waste, *kt CO_2e*													
Scenario 1	36	31	40	57	59	12	12	14	16	19	22	23	29
Scenario 2							11	13	17	20	23	26	28
Scenario 3							11	13	17	20	23	26	28
Wastewater Treatment and Discharge, *Mt CO_2e*													
Scenario 1	5.3	4.2	4.0	4.3	4.3	4.0	4.0	4.1	4.3	4.5	4.8	5.1	5.4
Scenario 2							3.9	3.6	3.3	3.0	2.7	2.3	1.7
Scenario 3							3.6	2.9	2.2	1.8	1.4	1.0	0.6
Total Waste sector, *Mt CO_2e*													
Scenario 1	11.9	11.5	11.4	12.0	12.4	12.2	12.2	12.4	12.7	13.1	13.6	14.1	14.6
Scenario 2							11.9	10.9	9.8	8.9	8.1	7.2	6.1
Scenario 3							11.5	9.9	7.8	6.1	4.7	3.4	2.3

It's expected under **Scenario 1** that GHG emissions in Waste sector would increase by 6.9 % in 2030 compared to 1990, reaching the value of 12.74 Mt CO_2-eq., and increase by 22.6 % in 2050 being equal to14.62 Mt CO_2-eq. Such an uptrend would be occurred mainly due to the increase of per capita waste generation, as well as industrial wastewater generation caused by the overall economy growth.

GHG emission structure by IPCC categories under Scenario 1 is illustrated in figure 3.24. Share of GHG emissions from solid waste disposal was equal to 55 % in 1990 and 67 % in 2015 of total Waste sector emissions, expected to reach 66 % in 2030 and 62 % in 2050; for wastewater treatment and discharge: 45 % in 1990, 33 % in 2015, 34 % in 2030 and 37 % in 2050. Other sources are negligible through all the time series.

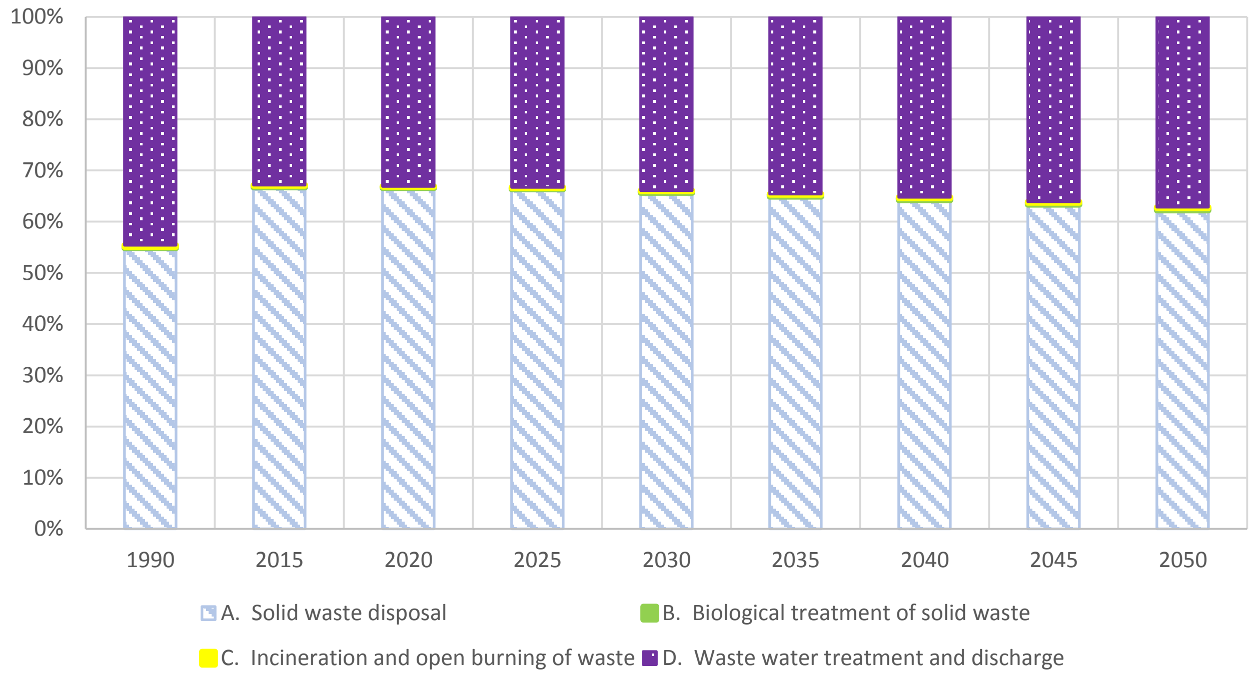

Figure 3.28. GHG emission structure by IPCC categories. Scenario 1

It is expected under **Scenario 2** that GHG emissions in Waste sector would decrease by 17.7 % in 2030 and 48.8 % in 2050, compared to 1990. Such a downtrend would be occurred mainly due to the rapid reduction of MSW landfilling from 93.4 % to 20 % in 2050, wide dissemination of methane utilization/recovery technologies in waste sector both for solid and liquid waste. Wherein, methane utilization at wastewater treatment plants will increase from 0.0 % in 2017 to 70 % in 2050. As for landfill methane utilization, its share will increase from 4.48 % in 2017 to 36 % in 2050 being stimulated by the modern regional landfills construction.

GHG emission structure by IPCC categories under Scenario 2 is illustrated in figure 3.25. Share of GHG emissions from solid waste disposal was equal to 55 % in 1990 and 67 % in 2015 of total Waste sector emissions, expected to reach 64 % in 2030 and 68 % in 2050; for wastewater treatment and discharge: 45 % in 1990, 33 % in 2015, 34 % in 2030 and 28 % in 2050. GHG emissions from biological treatment will reach 3 % by 2050, emissions from incineration and open burning will be negligible.

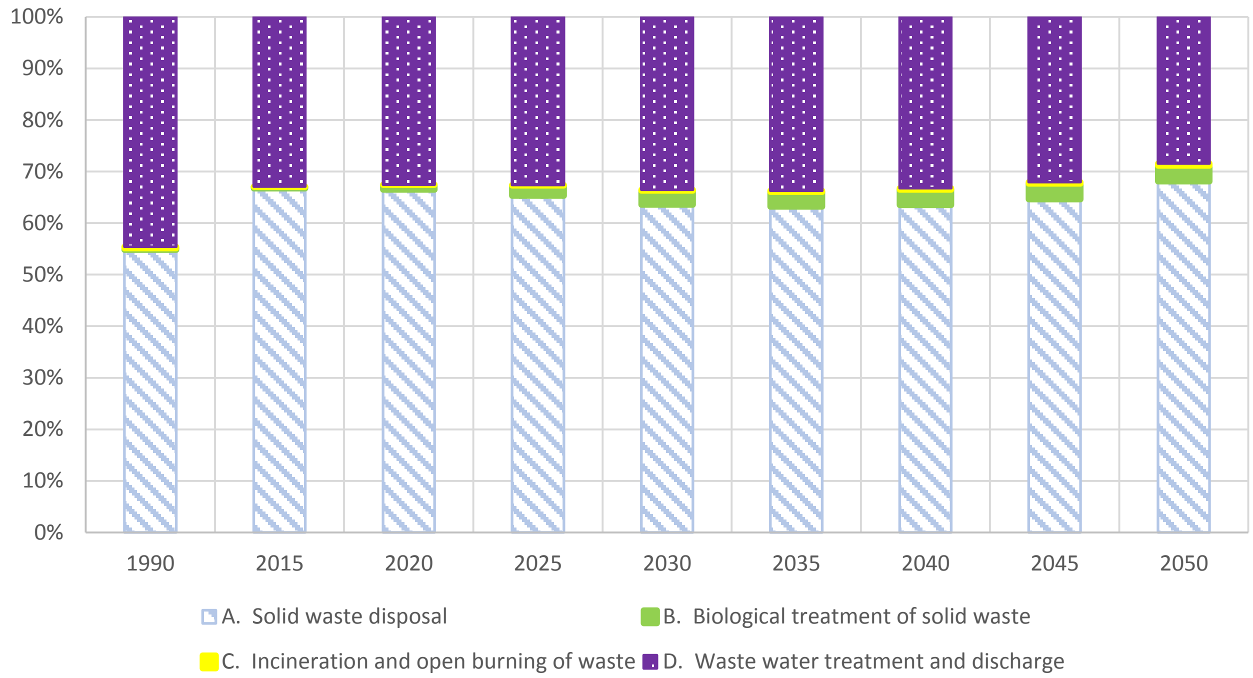

Figure 3.29. GHG emission structure by IPCC categories. Scenario 2.

It's expected under **Scenario 3** that GHG emissions in Waste sector would decrease by 34.7 % in 2030 and 81.1 % in 2050 compared to 1990. Such an ambitious downtrend would be occurred mainly due to the rapid and physically available reduction of MSW landfilling to 5 % in 2050, ubiquitous technically available dissemination of methane utilization/recovery technologies in waste sector both for solid and liquid waste. Wherein, methane recovery at wastewater treatment plants will increase from 0.0 % in 2017 to 95 % in 2050. Implementation of modern composting facilities with very low CH_4 and N_2O emission factors will make significantly lower the upward GHG emission trend caused by the multiply increase of waste composting volumes that is an alternative to waste landfilling. As for landfill methane utilization, its share will increase from 4.48 % in 2017 to 63 % in 2050 being stimulated not only by the modern regional landfills construction, but also by CH_4 recovery and flaring at all middle- and large size landfills in Ukraine. Further increasing of CH_4 recovery/flaring is not physically available being limited by capacity of biogas collection at old landfills.

GHG emission structure by IPCC categories under scenario 3 is illustrated in figure 3.26. Share of GHG emissions from solid waste disposal was equal to 55 % in 1990 and 67 % in 2015 of total Waste sector emissions, expected to reach 70 % in 2030, as well as 70 % in 2050; for wastewater treatment and discharge: 45 % in 1990, 33 % in 2015, 28 % in 2030 and 25 % in 2050. GHG emissions from biological treatment will reach 4 % by 2050, emissions from incineration and open burning – 1 %.

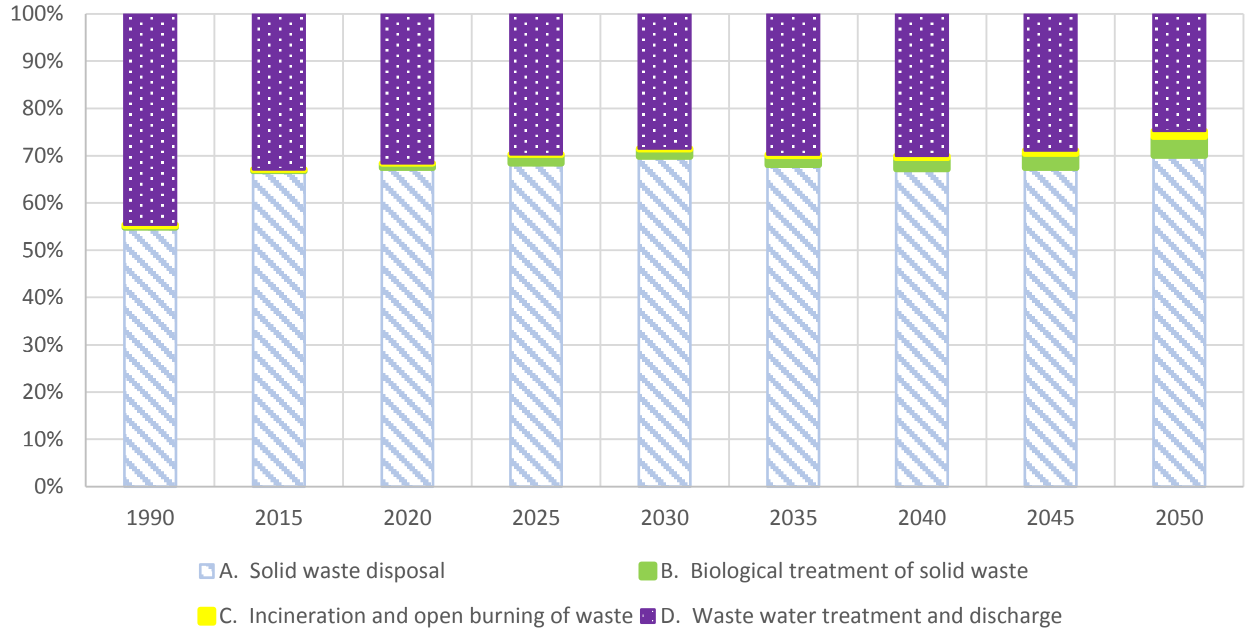

Figure 3.30. GHG emission structure by IPCC categories. Scenario 3

3.4.3 Capital cost needed to implement scenarios in Waste sector

Capital costs needed to implement Scenarios 1, 2 and 3 were estimated based on the findings of Technology Needs Assessment in Ukraine (Mitigation) report. In its Annex II "Technology Factsheets for selected technologies (Waste). Waste technologies" for each type of proposed available waste treatment technology, the cost evaluation is provided taking into account Ukraine's country specific conditions. The overall cost needs for scenarios implementation were estimated taking into account level of each technology application, among which are:

- Methane capture at landfills and waste dumps for energy production.
- The closure of old waste dumps with methane destruction (flaring, biocovers, passive vent etc.).
- The construction of new regional sanitary MSW landfills.
- Waste sorting (the sorting of valuable components of MSW with the subsequent treatment of waste residual by other technologies.
- Aerobic biological treatment (composting) of food and green residuals.
- The mechanical-biological treatment of waste with biogas and energy production (the anaerobic digestion of organic fraction of MSW).
- The mechanical-biological treatment of waste with alternative fuel (SRF) production for cement industry.
- The mechanical-biological treatment of waste with alternative fuel (RDF/SRF) for district heating and/or electricity production.
- The combustion of residual municipal solid waste for district heating and/or electricity production.
- Gasification/pyrolysis of MSW for large-scale electricity/heat applications.

- The biological stabilization of Municipal Solid Waste.
- Anaerobic treatment (digestion) of sewage sludge.

Results of cost needs estimations for each scenario cumulatively for 5-year period up to 2050 are provided in Table 3.12.

Table 3.12. Capital cost needed to implement all scenarios in Waste sector, million Euro

Scenarios	2020*	2025	2030	2035	2040	2045	2050	TOTAL
Waste sector								
Scenario 1	37	206	229	251	273	295	316	1,606
Scenario 2	408	2,056	2,080	2,093	2,099	2,104	2,107	12,947
Scenario 3	564	2,845	2,881	2,900	2,910	2,914	2,912	17,925

* for 2020

SECTION 4. ECONOMIC IMPACT ASSESSMENT ANALYSIS

Humanity's pressure on the Planet Earth has crossed safe operating boundaries in several directions.[53] One of such dimensions includes climate change, with both advanced and transition economies facing challenges of the low carbon development. In this context, the adoption of the Paris Climate Agreement has become a symbolic decision for the world community.[54] It will have a significant impact on the development of world economy and energy, as well as particular countries, since it aims to keep the average temperature rise on the planet well below 2°C (compared to the pre-industrial levels). In the case of developing countries, this task can be even more complicated than for the advanced economies, as governments need to provide an additional catching-up economic growth and social equity improvements. In this context, an economic impact is the key criteria to prioritize environmental policies, as their implementation should primarily be aimed at the increase of energy efficiency and greenhouse gas (GHG) emissions reduction, but in an economically and socially acceptable way.

While transition economies often face much more significant environmental challenges than the developed countries, their initial position often provides much better opportunities for environmental, social and economic development. In some country cases there are even prerequisites for reaching the "double dividends" effect,[55] by improving both environmental and economic parts. As discussed in the previous sections of this report, in the case of Ukraine, implementation of low emission development pathways (Scenario 2 and Scenario 3 in the Report) would require significant additional investments, ranging from around $200 billion to $500 billion, depending on the pathway.

Major transformations in the domestic energy system, required to reach ambitious emission reduction targets, would also need corresponding price signals to ensure such changes. Increasing prices of energy could impact production and consumption costs with a potential to slow down economic growth. On the other hand, with a current state of the low energy efficiency and high carbon intensity, Ukrainian energy sector could significantly benefit from additional investments and serve as a driver of economic growth. According to the World Bank,[56] Ukraine has 5th highest GDP carbon intensity in the world, while Ukraine's share of renewables in the total final energy consumption was only 4.2% in 2014, almost five times lower than world average share of 20%.[57]

[53] Steffen, W., et al. 2015. Planetary boundaries: guiding human development on a changing planet. Science 347: 736–746.
[54] United Nations Framework Convention on Climate Change (UNFCC). 2017. Communication of long-term strategies. http://unfccc.int/focus/long-term_strategies/items/9971.php
[55] Parry, I., Bento, A. 2000. Tax Reductions, Environmental Policy, and the "Double Dividend" Hypothesis. Journal of Environmental Economics and Management. Vol. 39, Issue 1: 67-96.
[56] The World Bank (WB). 2017. CO2 emission (kg per PPP $ of GDP). https://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD?view=map&year_high_desc=true
[57] International Energy Agency (IEA). 2018. Statistics. http://www.iea.org/statistics/

In this Section, **we explore the possibilities of reaching "double dividend" effect in Ukraine, looking for the pathways and policy options that could lead to such outcomes.** In this context, we provide an economic assessment of two energy policy scenarios i.e. Scenario 2 and 3, discussed in the previous sections of this report. The soft-linkage of the TIMES-Ukraine and Ukrainian computable general equilibrium (UGEM) models is used to estimate economy wide and sectoral implications of policies under consideration.

This Section is organized as follows. First, we provide an overview of some of the existing studies that estimate economic impacts of the low emissions development pathway in different countries and regions. We then provide a description of the methodological framework, including the UGEM model and database, as well as approach that we use to link the UGEM and TIMES-Ukraine models. We follow up with the description of the policy scenarios under consideration. Finally, we provide an overview of the key macroeconomic and sectoral implications of the implemented scenarios, under different policy options.

4.1 Economic Impact Assessment of the Low Carbon Development Policies: An Overview of the Existing Literature

Numerous studies have provided economic assessment of the low emission development scenarios in general and Nationally Determined Contributions (NDCs) in particular. While varying in regional coverage, timeframe and level of carbon reduction targets, most studies conclude that there would be negative impacts on GDP and welfare following implementation of the mitigation policies.

Gurgel et al. (2019)[58] explore the cost of mitigation policies consistent with the Brazilian NDC target to reduce carbon emissions by 43% in 2030 and by 50% in 2050 (relative to 2005 levels).[59] They show that under the domestic cap-and-trade system on emissions (uniform carbon tax across all sectors), GDP would fall by 0.5% in 2035 and by 3.3% by 2050, while corresponding carbon taxes would be \$3/ton CO_2-eq. by 2030 and \$103/ton CO_2-eq. by 2050.

Rajbhandari et al. (2019)[60] explore a number of NDC-consistent pathways for Thailand using computable general equilibrium (CGE) model. A uniform carbon tax is used to reach the GHG emission reduction targets, while revenue from the carbon tax is redistributed to households. Authors show that to reach the emission reduction target of 25% in 2030 (relative to baseline path) a carbon price of \$54.6/ton CO_2-eq. would be required and GDP would decline by around 2.5%. At the same time, to

[58] Gurgel, A.C., S. Paltsev and G.V. Breviglieri (2019): The Impacts of the Brazilian NDC and their contribution to the Paris Agreement on Climate Change. Energy and Development Economics, 1-18 (doi:10.1017/S1355770X1900007X)

[59] According to the baseline scenario, 2030 GHG emissions are lower than in 2005, therefore relative to baseline, a lower reduction target is applied in 2030 (around 35% relative to 2030 baseline). 2050 reduction target is around 56% relative to the 2050 baseline emissions.

[60] Rajbhandari, S., Limmeechokchai, B. & Masui, T. 2019. The impact of different GHG reduction scenarios on the economy and social welfare of Thailand using a computable general equilibrium (CGE) model. *Energy, Sustainability and Society* **9,** 19 (2019) doi:10.1186/s13705-019-0200-9

reach a more ambitions reduction target of 50% by 2050, carbon price should reach \$91/ton CO_2-eq. in 2050, while GDP could fall by 11.9% in 2050. Even higher level of emissions reductions (90% by 2050 relative to baseline), would require carbon prices to exceed \$584/ton CO_2-eq. in 2045 and over \$33805/ton CO_2-eq. in 2050. Under such scenario, GDP could fall by 21% in 2045. The paper also shows that 40% improvement in the efficiency of technologies (in the policy scenarios relative to baseline) could reduce carbon prices by 53%-69% depending on the scenario.

Vandyck et al. (2016)[61] explore economic implications of reaching Paris pledges and 2^oC consistent scenario for a set of countries and regions. They show that at the global level, 21.6% reduction in GHG emissions in 2030 (relative to baseline) would result in -0.7% change in world GDP. At the same time, economic costs highly vary by countries, for instance in Russia, 28.4% cut in emissions leads to the 3.4% reduction in GDP in 2030, in EU 3.85% emissions reduction is associated with 0.2% loss in GDP, Central Asia and Caucasus could face 1.76% reduction in GDP following 26.7% cut in emissions by 2030. Under the 21.6% reduction in global emissions by 2030 carbon prices in the high, middle and income countries converge to the level of \$53/ton CO_2-eq.

Mittal et al. (2018)[62] provide assessment of the Indian NDC. They show that under 2^oC consistent scenario carbon price would increase from \$74/ton CO_2-eq. in 2030 to \$187/ton CO_2-eq. in 2050, while GDP could fall by 3.2% in 2050. If India starts implementing 2^oC scenario after 2030, then the carbon price is around \$551/ton CO_2-eq. in 2050 and GDP loss is estimated to be 5.3% (in 2050 relative to baseline path). 1.5^oC consistent scenario, implemented from the 2020, would require much higher carbon prices - \$328/ton CO_2-eq. in 2030 and \$860/ton CO_2-eq. in 2050.

Lee et al. (2018)[63] estimate economic impacts of the Japanese NDC implementation. Authors explore different scenarios of carbon tax revenue recycling, including changes in consumption tax, income tax and social security contributions. They show that to reduce emissions by around 16% in 2030 relative to baseline, would require carbon taxes in the range from \$55/ton CO_2-eq. to \$101/ton CO_2-eq., depending on the share of nuclear energy allows in the scenario. If no recycling mechanism is used, GDP falls by 0.2%-0.5% in 2030 relative to baseline. Implementation of the carbon revenue recycling allows boosting GDP growth by 0.3%-0.8% in 2030. Results suggest that the most effective method of revenue recycling in promoting GDP growth is through a reduction in the consumption tax rate.

[61] Vandyck, T., Keramidas, K., Saveyn, B., Kitous, A., Vrontisi, Z. 2016. A global stocktake of the Paris pledges: Implications for energy systems and economy. Global Environmental Change. Vol. 41, November 2016, Pages 46-23. https://doi.org/10.1016/j.gloenvcha.2016.08.006" \t "_blank" \o "Persistent link using digital object identifier"

[62] Mittal, S., Liu, J.-Y., Fujimori, S., Shukla, P.R. 2018. An Assessment of Near-to-Mid-Term Economic Impacts and Energy Transitions under “2 °C” and “1.5 °C” Scenarios for India. *Energies* 2018, *11* (9), 2213; https://doi.org/10.3390/en11092213

[63] Lee, S., Chewpreecha, U., Pollitt, H. et al. Environ Econ Policy Stud (2018) 20: 411. https://doi.org/10.1007/s10018-017-0199-0

Several studies have recently provided estimates of carbon pricing options in Ukraine. In particular, using static CGE model, Frey (2017)[64] show that the carbon tax of $3.46/ton CO_2-eq. would result in the 22% reduction in emissions. Carbon revenue recycling via consumption tax cut results in the positive macroeconomic impacts, as GDP increases by 0.1%.

A recent PMR (2019)[65] report for Ukraine shows that to achieve the 5% reduction in carbon emissions in 2030 (relative to baseline) a carbon tax of $2.68/ton CO_2-eq. is required. The report does not find any significant impacts on GDP from imposing such carbon tax, as GDP drops by less than 0.1%.

In general, there are several key points that could be summarized from the existing literature on carbon pricing in the context of current assessment. Low ambition emissions reduction targets (e.g. below 10%-20%), especially in the case of developing countries, usually have limited macroeconomic and welfare impacts, while associated carbon prices are also relatively low (do not exceed $5/ton CO_2-eq. in the case of Ukraine). In terms of carbon revenue redistribution, literature suggests that reductions in consumption taxes is the most efficient policy in terms of maximizing GDP growth. In some cases, such policies could even result in the double dividend effect (e.g. Frey, 2017 and Lee et al., 2019). High ambition carbon reduction targets (e.g. above 50%), in general, require relatively high carbon taxes even in developing countries, such as Brazil and India - $100/ton CO_2-eq. Such stringent emission reduction pathways, in most cases, result in a sizable GDP loss, exceeding 3%-5% in the long run. Energy efficiency improvements, associated with a low emissions development pathway, could result in a substantial reduction in policy costs (Rajbhandari et al., 2019).

4.2 Policy scenarios

General approach to the economic impacts assessment includes setting up of the baseline scenario (Scenario 1), which in case of the adopted approach includes calibration of the sectoral GDP growth rates, as wells replication of the baseline TIMES-Ukraine energy and emission profiles. Two emission scenarios are considered for the economic assessment, they include Scenario 2 and Scenario 3. In terms of emission reductions under policy scenarios, emissions are reduced by 40.1% in 2030 (relative to baseline – Scenario 1) under both Scenarios 2 and 3. In 2050, emissions are reduced by 46.6% under Scenario 2 (relative to Scenario 1) and by 87.8% under Scenario 3.

For each emission reduction scenario (Scenarios 2 and 3), five policy scenarios (options) are considered ((a)-(e)). Under each of them, carbon reduction target identified in the Scenarios 2 and 3 is reached **using implementation of the carbon**

[64] Frey, M. (2017). Assessing the impact of a carbon tax in Ukraine. *Climate Policy*, *17*(3), 378–396. https://doi.org/10.1080/14693062.2015.1096230

[65] Partnership for Market Readiness (PMR). 2019. Ukraine Carbon Pricing Options. Modelling Report. August 2019.

tax on all fossil fuel combustion processes, but different additional policy options are used to reach this target. Table 4.1 provides summary of the considered policy options.

Table 4.1. Policy implementation options for the economic impacts assessment

Policy option	Energy efficiency change assumptions	Carbon tax revenue redistribution assumptions	Additional assumptions
(a)	Energy efficiency changes are implemented from the TIMES-Ukraine	Carbon tax revenue is used to fund investment requirements; excessive carbon tax revenue is redistributed to households	No
(b)	Energy efficiency changes are implemented from the TIMES-Ukraine	Carbon tax revenue is used to fund investment requirements; excessive carbon tax revenue is redistributed to households	Ukrainian gas sector exports 10 million t CO_2 at a price of €20t/CO_2
(c)	Energy efficiency changes follow Scenario 1	Carbon tax revenue is used to fund investment requirements; excessive carbon tax revenue is redistributed to households	No
(d)	Energy efficiency changes follow Scenario 1	Carbon tax revenue is allocated to government	No
(e)	Energy efficiency changes follow Scenario 1	Carbon tax revenue is allocated to households	No

Source: Authors.

In the current approach, we impose uniform carbon tax on all fossil fuel combusting activities, including residential users. In terms of the assessment of economic costs, such approach could be **considered equivalent to the implementation of the emission-trading scheme (ETS)** that covers all energy users and leads to the uniform cost of carbon (carbon price) among participating agents, where government is selling emission allowances, collects and redistributes corresponding income.

In terms of the costs faced by the emitting activities, that are implicitly defined in the model (abatement cost curves), they do not change depending on the carbon reduction mechanism implementation. Differences in the (sectoral) coverage of the carbon mechanism regulations (e.g. selected industries are participating in the ETS) would change a national average cost of reduction, in general, making it higher that in the case of uniform carbon tax.

Under the policy option ***(a)***, to meet the emission reduction targets, we impose **uniform carbon taxes, carbon tax revenue is collected and redistributed to industries based on the additional investment needs estimated by TIMES-Ukraine**. In the first years of the simulation, revenue from the collected carbon taxes is lower than annual investment needs, but starting from around 2025-2030 or later, depending on scenario and policy option, collected carbon tax revenue is larger than investment needs. Once cumulative investments sourced from carbon tax revenues, exceed cumulative investment requirements, excessive carbon tax revenue is redistributed to households. If such point in time is not reached, all additional investments are redistributed to producers. Energy efficiency improvements are implemented based on TIMES-Ukraine estimates in addition to the baseline (Scenario 1) energy efficiency changes.

In the policy option ***(b)***, **we assume that Ukrainian gas extraction sector is exporting 10 million tonnes of CO_2 from the entire carbon budget of Ukraine at the price of €20/ton CO_2-eq.** We assume that the revenue from this sale is invested into gas extraction sector over the 2025-2027 timeframe. These investments are leveraged by a factor of five, which results in the total additional investments in the gas sector of €1 billion over the 2025-2027 timeframe. We assume that these investments would additionally increase the energy efficiency of the gas extraction sector by 1% per year starting from 2028.

In the policy option ***(c)***, treatment of carbon tax revenue and investments is the same as in (a), but we **exclude additional energy efficiency changes for Scenarios 2 and 3, estimated by TIMES-Ukraine**. In this policy option, we follow a conventional assumption in the economic impact assessment literature that there is **no explicit link between investment changes and energy efficiency improvements**. This does not exclude shifts in the intermediate and final consumption structure due to different relative prices of goods, but the level of technological efficiency stays at the level of baseline scenario (Scenario 1). By running such policy simulation, we are also able to decompose impacts of policy option (a) into the energy efficiency improvement part and other drivers.

Finally, in the policy options ***(d)*** and ***(e)***, we **allocate all carbon tax revenue to government and households respectively**.

4.3 Economic Impact Assessment

In this subsection we provide assessment of the economic impacts under different policy options. All impacts reported in this subsection are measured relative to the baseline case (Scenario 1). Therefore, negative numbers for changes in macroeconomic or sectoral indicators in most cases correspond to the slowdown in the growth rates, rather than reductions in value relative to the beginning of the period (2015 reference year). For instance, 11% reduction in the real value in 2050 relative to the baseline, would correspond to the annual average slowdown in the growth rate of 0.3% (for instance, instead of growing 4% per year, corresponding indicator would be growing 3.7% per year).

In our analysis, we focus on macroeconomic and sectoral impacts, as well as provide a discussion of the potential co-benefits that would be associated with the low carbon emission development pathways and that are not directly captured in our economic assessment approach.

4.3.1 Investments boost and energy efficiency improvements

Policy option “a” can be considered as the most optimistic case of the emission reduction policies implementation, both economy and environment significantly benefit from such scenario. According to our estimates, in this policy scenario GDP would grow by around 14%-16% in 2050 relative to baseline depending of scenario (Figure 4.1). Due to the higher level of investments and energy efficiency improvements, as well as relatively low cost of carbon reductions before 2035-2040, GDP is growing at a much higher pace in the Scenario 3 compared to the Scenario 2. At the same time, after around 2035, following higher level of carbon reduction ambitions and corresponding increase in the price of carbon (Annex 4), additional GDP growth rates in Scenario 3 are slowing down.

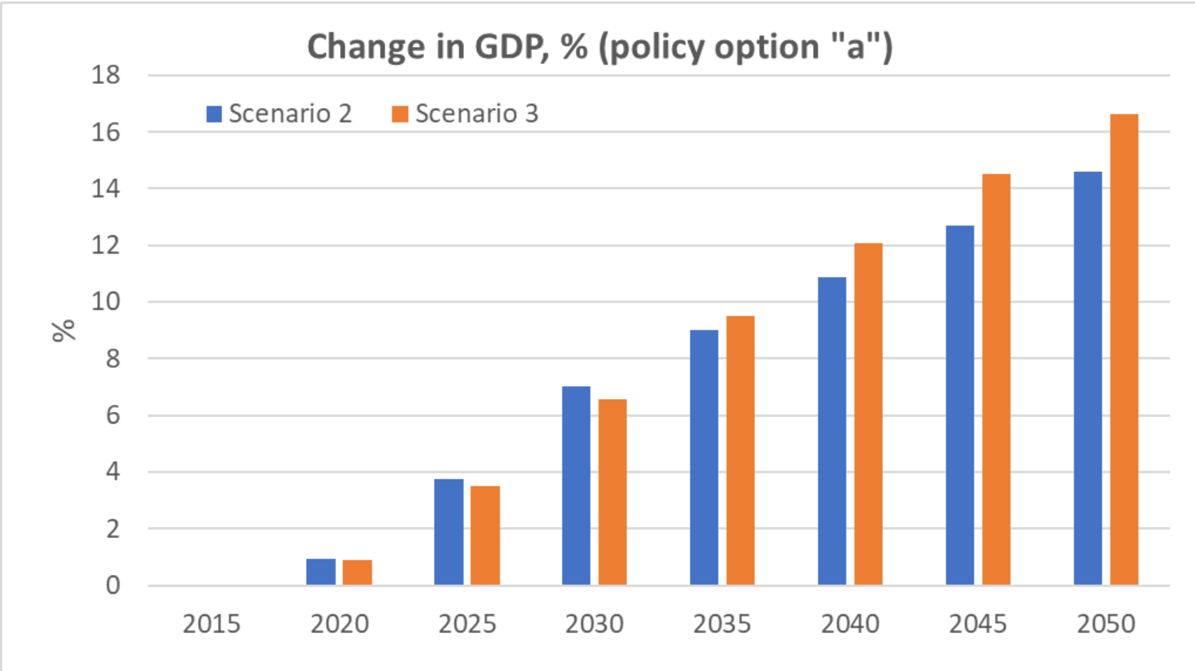

Figure 4.1. Change in GDP under policy option “a”: investment boost and energy efficiency improvements

Qualitatively, similar trend is observed for the household incomes (Figure 4.2), although in this case Scenario 2 results in a higher growth rate. Residential consumers are facing much higher carbon prices in the Scenario 3 (Annex 4), which impacts their cost of consumption. At the same time, even in the 2040-2050 timeframe, when carbon prices under Scenario 3 exceed \$100/ton CO_2-eq. and reach \$1300/ton CO_2-eq. in 2050, residential users still experience increase in real income relative to Scenario 1. As would be discussed in 4.3.3., energy efficiency improvements play a key role in making this possible, as they significantly bring down production costs and lower prices for households.

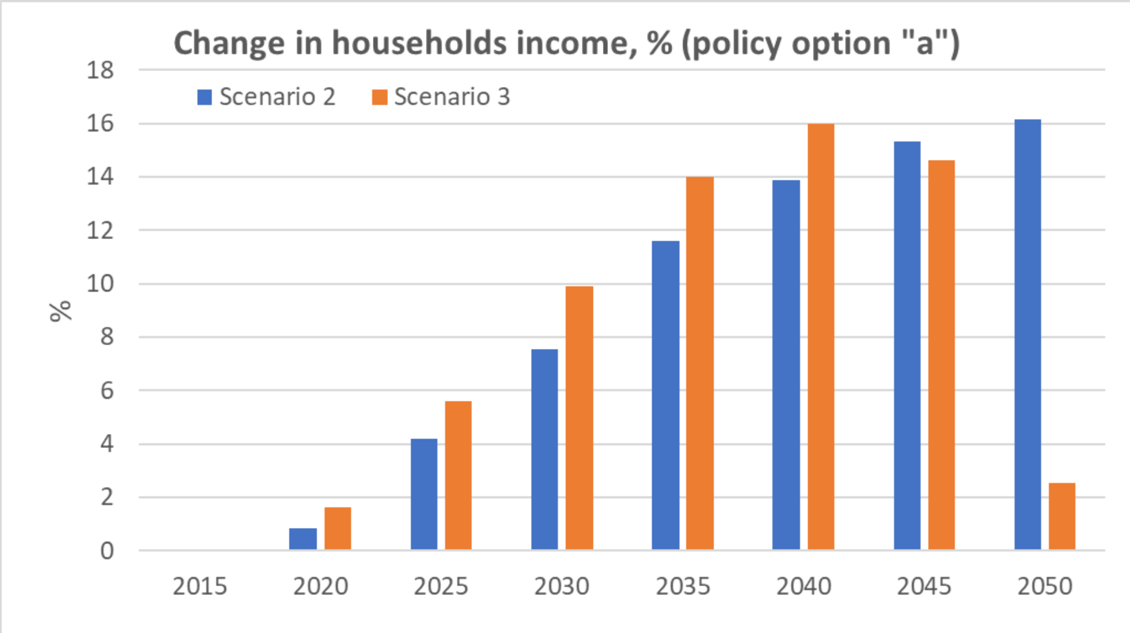

Figure 4.2. Change in real households' income under policy option "a": investment boost and energy efficiency improvements

At the sectoral level, there are significant transformations in the output structure, which results in the significant reduction of GDP carbon and energy intensity. This is especially the case for Scenario 3, where production of coke and coal fall by over 75% in 2050 relative to baseline. Other energy intensive sectors, such as basic metals production, petroleum production and utilities also significantly reduce their output under Scenario 3 (Figure 4.3).

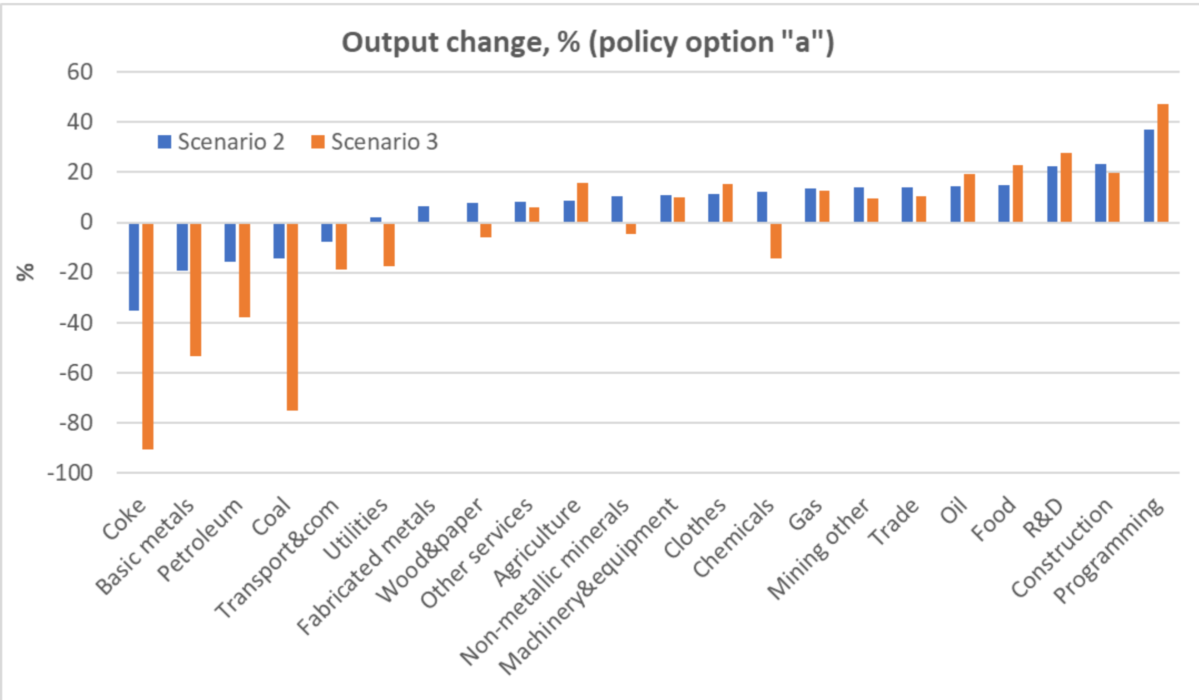

Figure 4.3. Change in sectoral output in 2050 under policy option "a": investment boost and energy efficiency improvements

At the same time, a shift towards services and sectors heavily involved into investment generation processes is observed. The latter case includes increase in output of the programming sector and research and development activities. Construction sector increases its output as a key supplier of the investment goods. Increasing output of food and agricultural sectors is driven mainly by increasing exports of these commodities. Some other final consumption goods, such as clothing and machinery and equipment experience output growth under growing final demand.

While investment-intensive pathway with investments allocated to the energy efficient technologies could be considered the most attractive from both macroeconomic and sectoral perspectives, our analysis does not capture some of the possible risks and uncertainties associated with this scenario.

In particular, it is assumed that all investments within this pathway are allocated to the domestic economy, which is one of the key sources of the observed economic growth. Impacts might not be so positive if a large share of capital goods would be purchased from abroad.

Another critical assumption is that facing increasing carbon taxes, producers and consumers not only shift their production and consumption patterns facing higher costs, but also invest into more energy efficient equipment. For instance, households not only travel less due to the higher cost of petroleum products, but they also buy a more efficient cars, than in the baseline scenario. In Section 4.3.3 we show that if this assumption does not hold, observed macroeconomic and sectoral impacts are much less positive.

Finally, we assume that required levels of investments are reached within both policy scenarios and carbon taxes serve as a source for these investments, significantly increasing the saving rate within the economy. In reality, it might not necessarily be the case and money collected from the carbon taxes might be transferred to government budget (to increase expenditures) or transferred to households. In Section 4.3.4 we explore these cases and show that there are significant risks for the long-term macroeconomic growth under these possible options.

4.3.2 Impact of the carbon permits export

Within this scenario, we assume that Ukrainian gas sector is exporting 10 million tonnes of CO_2 from the entire carbon budget of Ukraine at the price of €20/ton CO_2-eq. The revenue from this carbon permits sale is invested into gas extraction sector over the 2025-2027 timeframe. These investments are leveraged by a factor of five, which results in the total additional investments in the gas sector of €1 billion over the 2025-2027 timeframe. We also assume that these investments additionally increase the energy efficiency of the gas extraction sector by 1% per year starting from 2028.

Our results show that there is no significant impact of limited carbon permits export. Essentially, changes in real GDP and households' income stays the same as in policy option "a", with strong positive trends (Annex 4, Figure A.4.12, Figure A.4.13). There are some minor changes at the sectoral level, in particular, somewhat higher growth rates are observed for the gas sector in Scenario 2, but the difference is around 1% in 2050.

4.3.3 The role of energy efficiency improvements

Our results suggest that additional energy efficiency improvements implemented in Scenarios 2 and 3 (policy options "a" and "b") play a key role in boosting GDP growth and real households income. If these improvements are excluded from consideration, which is a conventional approach in most CGE-based economic assessments, there would be limited benefits in terms of additional GDP growth (Figure 4.4). This would be especially true for the Scenario 3, with much higher energy efficiency improvements than under Scenario 2. By comparing policy options "a" and "c", we can see that in 2050, cumulative energy efficiency improvements contribute more than half of the additional GDP growth.

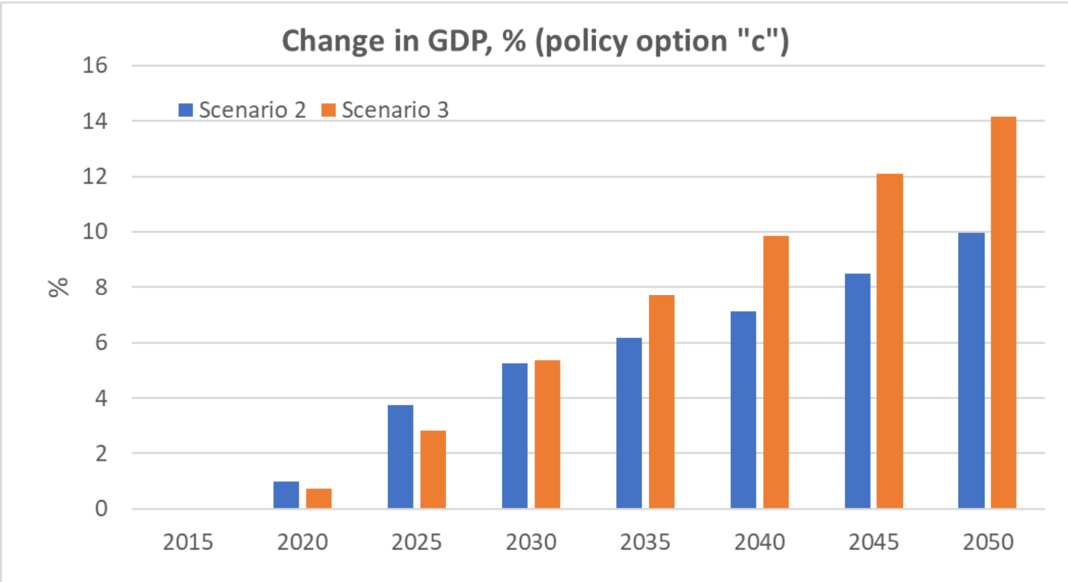

Figure 4.4. Change in GDP under policy option "c": no energy efficiency improvements

Even more important is the role of energy efficiency improvements in ensuring households income growth under Scenario 3 (Figure 4.5). As without accounting for these changes, results suggest that real households income could decrease in the long run relative to the baseline case (Scenario 1). If energy efficiency improvements are not implemented under Scenario 2, real households income stays almost the same as in the baseline scenario, with some minor increase in 2050.

Energy intensive sectors are experiencing larger output reductions if no energy efficiency changes are incorporated, same holds for the sectors that supply, transform and process fossil fuels (Annex 4, Figure A.4.15).

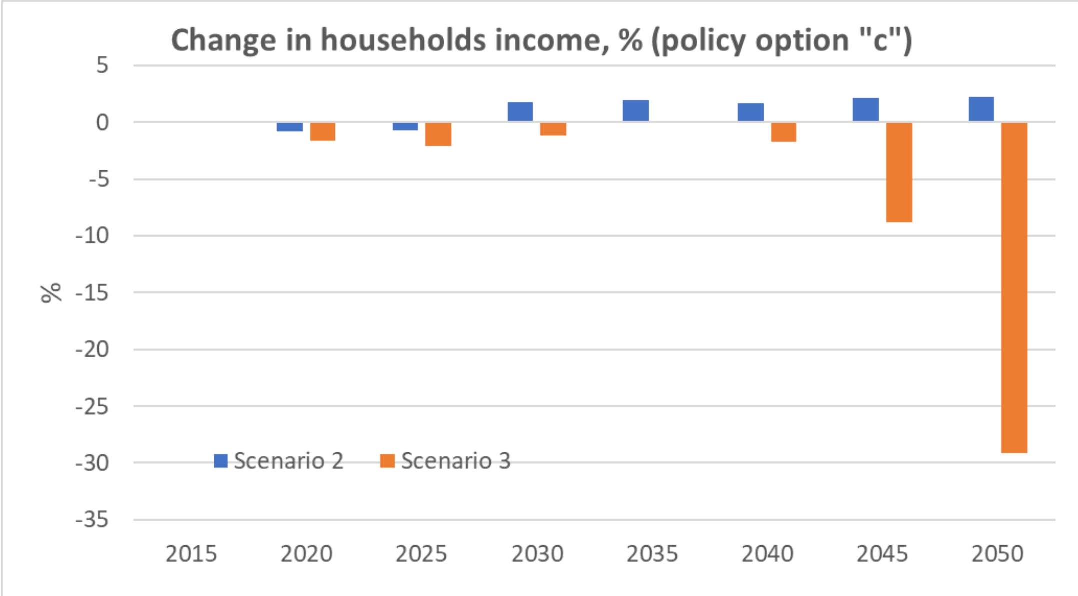

Figure 4.5. Change in real households' income under policy option "c": no energy efficiency improvements

4.3.4 Alternative cases of the carbon tax income reallocation

Apart from reinvestment of the collected carbon tax income, different other reallocation measures could be considered. In this subsection, we explore two of such options – reallocation of the collected tax income to government (option "d") and to households (option "e"). In both cases, out estimates suggest that it would lead to the negative macroeconomic and sectoral implications, with option "e" (reallocation to households), being slightly more attractive (Figures 4.6, 4.7).

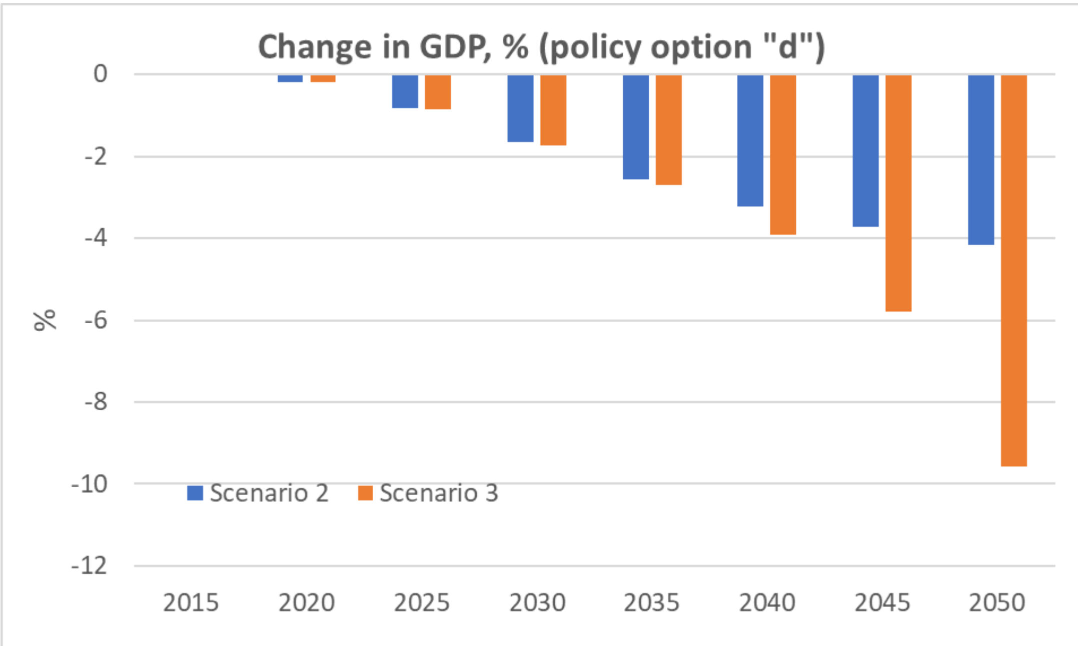

Figure 4.6. Change in GDP under policy option "d": all carbon tax revenue stays with government

At the same time, Scenario 3 results in much lower reductions in GDP growth rates relative to baseline than Scenario 2. In particular, 3.5%-4% GDP reduction in 2050 for both reallocation policy options for Scenario 2 is equivalent to the slowdown in annual GDP growth rate of around 0.1%. In the case of Scenario 3, corresponding slowdown is less than 0.3%. At the same time, we should take into account that Scenario 3 sets a very ambitious mitigation target (87% reduction in emissions in 2050 relative to baseline) and considering large co-benefits from GHG emission reductions (would be discussed in the subsection 4.3.5), these should not be considered as a high abatement cost.

Policy options “d” and “e” also lead to the reduction in households income relative to baseline (Annex 4, Figures A.4.16 and A.4.17). In general, results of the alternative carbon tax income distribution mechanisms, even more highlight the importance of ensuring investment intensive development path and the role of energy efficiency improvements.

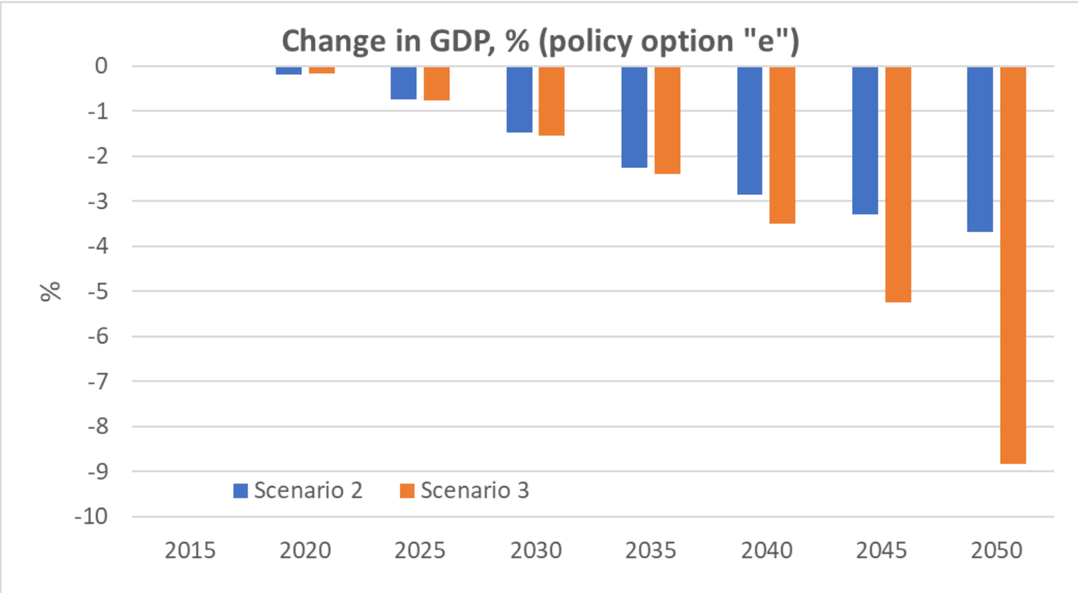

Figure 4.7. Change in GDP under policy option “e”: carbon tax revenue is reallocated to household

4.3.5 Co-benefits from emission reductions

Numerous studies have estimated that stringent climate mitigation policies are associated with significant co-benefits, including reductions in local air pollution and energy security improvement.[66] Co-benefits could be also estimated from reductions in GHG emissions, using, for instance, the social cost of carbon (SCC) approach.

[66] Nemet, G.F.; Holloway, T.; Meier, P. Implications of incorporating air-quality co-benefits into climate change policymaking. *Environ. Res. Lett.* 2010, *5*.
Mittal, S., Liu, J.-Y., Fujimori, S., Shukla, P.R. 2018. An Assessment of Near-to-Mid-Term Economic Impacts and Energy Transitions under “2 °C” and “1.5 °C” Scenarios for India. *Energies* 2018, *11* (9), 2213; https://doi.org/10.3390/en11092213

In the case of energy security changes, there are several approaches available in the literature that are used to measure this indicator, including diversification of energy sources, improving energy efficiency, market competitiveness level etc.[67] In this report, we use the Shannon-Wiener index to compare changes in primary energy supply mix:

$$H = -\sum_i p_i \ln(p_i)$$

Where p_i is the share of the primary energy supply source *i* in the total primary energy supply. The higher the H, the more diverse in the fuel mix, which is better from the energy security perspective. This index measures only one dimension of energy security, namely, primary energy supply diversification. There is number of limitations that should be taken into consideration when interpreting this indicator. First, as the focus is put on the primary energy supply, imports and domestic supply are treated aggregately. Therefore, two scenarios with different domestic/import split, but same primary energy supply mix would have same level of Shannon-Wiener index. Second, primary energy supply of fossil fuels and renewables are treated equivalently, meaning there is no prioritization of renewables towards fossil fuels in the primary energy supply mix.

Results show that in 2050 in the baseline (Scenario 1), the value of H is 1.54, and it increases to 1.79 under Scenario 2. Somewhat lower increase is observed under Scenario 3, where H equals 1.66, mainly due to the lower share of coal and gas supply and higher share of renewables and nuclear power. At the same time, both Scenario 2 and Scenario 3 result in substantial improvements in national energy security based on the increased diversity of the primary energy supply mix.

To monetize the damage (benefits) from changes in CO_2 emissions notion of the social cost of carbon (SCC) is widely applied in the literature.[68] SCC represents the average global damage from 1 ton of CO_2 emission. We use a central value of \$35/ton CO_2 (IMF, 2015).[69] We assume SCC value is growing by 3% annually. Following evidence from SCC meta-analysis and review of other studies reported in (van den Bergh and Botzen, 2014),[70] we use a lower bound of \$15/ton CO_2 and upper bound of \$55/ton CO_2.

Our results suggest that in the case of Scenario 2 in 2050 monetized benefits from carbon emissions reduction, following application of the SCC values, would be between \$9.2 billion and \$33.6 billion, with a central value of \$21.4 billion. In the

[67] Kruyt, B.; van Vuuren, D.P.; de Vries, H.J.M.; Groenenberg, H. Indicators for energy security. *Energy Policy* 2009, *37*, 2166–2181

[68] van den Bergh, J.C.J.M and Botzen, W.J.W. 2014. A lower bound to the social cost of CO_2 emissions. *Nature Climate Change* volume 4, pages 253–258. https://www.nature.com/articles/nclimate2135

[69] International Monetary Fund (IMF). 2015. Energy Subsidies Template. http://www.imf.org/external/np/fad/subsidies/

[70] van den Bergh, J.C.J.M and Botzen, W.J.W. 2014. A lower bound to the social cost of CO_2 emissions. *Nature Climate Change* volume 4, pages 253–258. https://www.nature.com/articles/nclimate2135

case of Scenario 3, larger emission reductions would result in a much higher gain – between $17.1 billion and $62.9 billion in 2050.

Several studies show that high levels of the outdoor air pollution could result in significant economic losses, due to the increased mortality, morbidity and productivity. For instance, OECD (2016)[71] study looks at the long-term costs of air pollution. It applies OECD's ENV-Linkages CGE model to provide projections of economic activities from 2015 to 2060, estimates PM2.5 and ozone concentration changes and links them to impacts on number of lost working days, hospital admissions and agricultural productivity. Each health end point is further attributed a monetary value.

Authors conclude that total annual market costs of outdoor air pollution are projected to rise from 0.3% of global GDP in 2015 to 1.0% in 2060. Some studies also show that there are significant co-benefits from GHG emission reductions associated with lower air pollution levels and that in some cases, such benefits could overweight climate policy implementation costs.[72]

IMF (2015) study[73] estimates that in Ukraine cost of the outdoor air pollution was around $68 billion in 2014. Pollution from coal combustion is the main contributor to this number (accounts for over 97% of these costs). In the reference case (Scenario 1), primary supply of coal increases over time, thus leading to the higher level of pollution, assuming no major changes in emission factors. In the case of Scenario 2, coal primary energy supply is over 51% lower than in the reference case, already bringing significant health benefits through reductions in pollution levels. Even more benefits from the air quality improvements should be expected in Scenario 3, where coal use is almost eliminated by 2050. Even assuming that cost of outdoor air pollution in Ukraine does not change over time (relative to the 2014 levels), Scenario 3 would bring additional benefits of around $68 billion in 2050 relative to the reference case and over half of this number (around $34 billion) relative to the Scenario 2.

[71] Organisation for Economic Co-operation and Development (OECD). 2016. The economic consequences of outdoor air pollution. https://www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf

[72] Vandyck, T., Keramidas, K., Kitous, A. *et al.* Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges. *Nat Commun* **9,** 4939 (2018) doi:10.1038/s41467-018-06885-9

[73] International Monetary Fund (IMF). 2015. Energy Subsidies Template. http://www.imf.org/external/np/fad/subsidies/

SECTION 5. SENSITIVITY ANALYSIS FOR UKRAINE'S SECOND NDC SCENARIOS

5.1 Overview

Modelling results presented in Section 3 have shown that up to 2030 the imposed cap, which is aligned with IPCC's conclusion of the desired pathway to guarantee the global warming less 1.5 °C (Scenario 3), does not substantively affect the trajectory of GHG emissions risen from the existing policies and targets (Scenario 2). **This confirms that focusing in the near-term on full implementation of existing and planned short-term policies and measures is critical**, while as expected, new innovative energy technologies became commercially available after 2030 will allow the possibility for Ukraine to enhance ambitions in a long-term.

Full implementation of existing strategies and extrapolation of correspondent targets by 2050 is already an ambitious task and will require fold increase of investments in energy sector from today's level to the volumes, comparable to the best examples of intensively developing economies. Meanwhile even such long-term extension of policies with current level of ambitions would still not be enough to stabilize emissions that start moderately growing after 2035.

Although Scenarios 2 and 3 are closely aligned up to 2030, thus may already provide some indicative information in the scope of the 2nd NDC preparation process, both Scenario 2 and 3 need further sensitivity analysis against longer-term variables.

For this reason, the Project team will carry out the sensitivity analysis as outlined in this document and **will present result in the Report 4**. The main purpose of thee sensitivity analysis is **to test additional technological and policy options that were not taken into consideration in the original Scenarios 2 and 3, while providing**:

i) **reduction of the overall GHG emissions with a reasonable cost increase** (applied on Scenario 2);

ii) **reduction of required overall investments to acceptable level** (applied on Scenario 3, although such options will also cheapen Scenario 2, thus if needed for correct comparison they will be applied on Scenario 2).

In addition, the sensitivity analysis also aims **to test the robustness of original Scenarios, in case different key macroeconomic and technological assumptions are applied.**

In order to conduct the sensitivity analysis, the Project team determined the most critical factors/variables (see Fig. 5.1 with sensitivity scenarios matrix below) that could affect future GHG emission pathways. By altering these variables to a range, the results will illustrate to what extend such changes affect the overall GHG emissions or corresponding system costs throughout the projected time-period. The results of model re-run on altered variables will inform whether certain additional policy or technological options are critical or not, and thus require more thorough policy analysis and recommendations (for Report 4).

Variable	Assumptions/ Variables Tested	Name	S2	S3	Notes
A	Optimistic macroeconomic	S2A S3A	X	X	To be applied later on combined sensitivity scenario (B-G)
B	ETS	S2B	X		Conducted under the model used for economic impact assessment scenario analysis
C	Carbon Tax	S2C	X		
D	New trajectory of GHG limits	S2D	X		Sensitivity run on S2 with ultimate CO2 constraint in line with Scenario 3, but of different levels over the period
E	No new large nuclear	S3E		X	
F	Other nuclear options	S2F S3F	X	X	Sensitivity analysis on S2 may be needed later in the stage, but not at this stage
	No new or modernized coal				A sensitivity analysis for Scenario 3 is not needed as it already does not choose any coal.
G	Balancing capacities	S2G S3G	X	X	Sensitivity run on S2 with ultimate CO2 constraint in line with Scenario 3, but of different levels over the period
H	Limited implementation of waste sector policy inputs	S3H		X	
I	Implications of the EU border carbon adjustment taxes	S2I S3I	X	X	

Figure 5.1. Sensitivity Scenarios Matrix

The team proposes to finalize sensitivity analysis with a composition of the combined sensitivity scenario, which will include all sensitivity options with notable positive effect on emissions and required investments.

NOTE: *For adequate comparison of sensitivity cases, original Scenario 2 described in Section 3 and 4 of this Report is supplemented with new technology options available in Scenario 3. Penetration of new technologies in original Scenario 2 is very limited, thus this option does not provide any notable changes there, although assumptions of sensitivity could increase the need for new technologies.*

5.2 Rationale of proposed sensitivity scenarios

This section explains why the certain sensitivity analysis is run on either Scenario 2 or Scenario 3 only or both.

Scenarios S2A & S3A: Macroeconomic sensitivity analysis

Unless the economic composition of Ukraine decouples with GHG emissions in the near future, most likely higher GDP growth will result in higher GHG emissions, which will affect both Scenarios 2 and 3. For this reason, it would be important to test how sensitive both Scenario 2 and 3 will be in case Ukraine's economic trajectory significantly changes, compared to the current macroeconomic projection used for our analysis.

The most recent projections provided by the Ministry of Economy is based on more optimistic figures, therefore in order to understand how higher economic growth can alter/affect future GHG emissions, and what policy/measure considerations need to be taken into account for such possibility, it would be necessary to run the sensitivity analysis on both Scenario 2 and 3, as:

i) for Scenario 2, it will test whether the GHG emission will significantly grow up to 2050 with higher GDP growth projections; whereas

ii) for Scenario 3, it will illustrate how more costly it would be to achieve the same level of GHG emission reduction by 2050, in case the technological options the model chooses differs.

Meanwhile further growth of GHG emissions in Scenario 2, as well as further increase of system cost in Scenario 3 do not provide sufficient information to identify optimal pathway to guarantee the global warming by not more than 1.5 °C. For this reason, we propose to apply optimistic macroeconomic scenario on the combined sensitivity scenario, **which will be defined after the initial analysis of other sensitivity options is finalised.**

This sensitivity will in addition inform the new indicative level of GHG emissions in 2030, which is important in the context of informing the target for the 2nd NDC.

Scenario S2B & S2C: Carbon prices and carbon markets

The model used to develop Scenario 2 and 3 is a dynamic model, but **as CO_2 constraint is not imposed in Scenario 2, it requires the carbon cost to be provided as an input.** Based on this input, the model will illustrate the GHG emissions trajectory from the time the cost is imposed until 2050. **For Scenario 3, were CO_2 cap is pre-defined, the model already estimated the marginal CO_2 price** that could be considered as Carbon Tax or carbon price based on ETS.

Thus, application of Carbon Tax/ETS on Scenario 2 is important to better inform our policy recommendation for Report 4, while adding Carbon Tax/ETS in Scenario 3 could negligibly change technological solution if its level is higher than estimated marginal CO2 price.

Scenario S2D: New trajectory of GHG limits, but carbon neutrality by 2070

This analysis was proposed by the Ministry of Energy and Environment, considering the significantly concentrated increase of investment needs projected for the last decade in Scenario 3.

Scenario S3E: No new large nuclear reactors

Current scenarios allow the option of choosing new nuclear and model calculations confirm its important role for reaching ambitious GHG targets, however due to other social environmental reasons, nuclear may not become a viable option as result of change in policy. **As Scenario 2 does not impose any policy targets after 2030, it may be underestimating the levels of GHG emissions in case new nuclear no longer becomes an option.**

For Scenario 3, GHG emissions limits are imposed, so the model already presents the cost-optimal technological options. Any new nuclear option will need to be replaced with other carbon-free technological solutions that will increase investment costs and electricity marginal price. However, a sensitivity analysis will inform whether there is enough potential of renewables and other technologies to compensate for the model rejecting to choose new cost-optimal nuclear power plants as an option.

Scenarios S2F & S3F: Other nuclear option, applying: 1) EU capex; 2) lower availability factor; 3) extension of existing nuclear units)

Combination of nuclear technology/policy options, where options 1 and 2 reduce competitiveness of nuclear, while option 3 will increase competitiveness of nuclear on power market, will effect GHG emissions in Scenario 2 and technological changes in Scenario 2 and 3.

N/A: No new or modernized coal units

Coal-based thermal power generation shades off after 2040 in Scenario 3 because of the strict GHG emission constrain, while less ambitious Scenario 2 targets provide a chance to the coal units to keep in operation on about 2020 level. Meanwhile, if additional environmental targets or policies are applied to Scenario 2, such as carbon tax, coal units are also supposed to be phased out like in Scenario 3. To avoid an overlapping of policy options and their effects, the Project team concludes that there is no reason to apply this sensitivity option for Scenario 3, and it’s application on Scenario 2 or Combined Sensitivity Scenario would need further discussion on whether it is relevant.

Scenarios S2G & S3G: Balancing capacities

Combination of additional large hydro and minimization of balancing technologies (options) will effect GHG emissions in Scenario 2 and technological changes (composition of renewables) in both Scenario 2 and 3.

Scenario S3H: Limited implementation of waste sector policy

Various measures included in the National Waste Management Strategy differ by unit investments and by reduction of emissions they could achieve. Meanwhile, some of these measures could potentially lead to increase of emissions, such as: construction of new regional MSW landfills and closing of unauthorized and poorly equipped landfills, increasing the share of the population with the centralized solid waste collection system, etc.

The purpose of this sensitivity analysis is to explore whether there is a reasonable limitation of waste sector policy ambitions with respective reduction of required investments that will not sizably affect the reduction of emissions achieved in original Scenarios 3.

Scenarios S2I & S3I: Implications of the EU border carbon adjustment taxes

Economic assessment provided in Section 4 of this Report has revealed a wide uncertainty range, following the implementation of internal energy and environmental policies. And although investment-oriented pathway was identified to be the most attractive from the economic perspective, a number of risks and uncertainties associated with this scenario were discussed and explored. Corresponding assessment has shown that under certain conditions economic impacts of the low emission development scenario might be negative in the long run. At the same time, possible interactions with policies introduced by other countries, including Ukraine's key trading partners, were not explored so far. In this scenario we would focus on the set of policies that could be implemented by other counties and have a significant impact on the Ukrainian economy.

5.3 Assumptions and variables tested for sensitivity

Variable A: Macroeconomic assumptions

Unless the economic composition of Ukraine decouples with GHG emissions in the near future, most likely higher GDP growth will result in higher GHG emissions, which will affect both Scenarios 2 and 3. For this reason, it would be important to test how sensitive both Scenario 2 and 3 will be in case Ukraine's economic trajectory significantly changes, compared to the current macroeconomic projection used for our analysis. The most recent projections provided by the Ministry of Economy is based on more optimistic figures, therefore in order to understand how higher economic growth can alter/affect future GHG emissions, and what policy/measure considerations need to be taken into account for such possibility, it would be necessary to run the sensitivity analysis on both Scenario 2 and 3, as for Scenario 2, it will test whether the GHG emission will significantly grow up to 2050 with higher GDP growth projections; whereas for Scenario 3, it will illustrate how more costly it would be to achieve the same level of GHG emission reduction by 2050, in case the technological options the model chooses differs.

Analysis using new/updated **macroeconomic optimistic scenario**, in line with revised GoU Decree on Macroeconomic and Social Development Scenarios (scenario 2 of the decree), including the population growth rate change.

Variable B & C: Carbon prices and carbon markets

NOTE: *Under this sensitivity analysis, we are not making policy recommendation, but only analyzing the potential impact of "carbon price/tax" introduction for GHG emission reduction targets. Therefore, the term "carbon price/tax" used here means as "a policy instrument designated to assist with achieving climate change mitigation," and a range of values applied.*

S2B Analysis: Ukrainian domestic cap and trade ETS implementation with coverage based on World Bank PMR Carbon Pricing Report (2019) and carbon tax for the sectors not covered by the ETS. The emissions cap for sectors covered by ETS will be as in the Scenario 2, which is different from that adopted in the PMR report. Therefore the explicit carbon price for ETS will be different than that used in the PMR report.

S2C Analysis: Apply a range of carbon tax values in Scenario 2, which cover all energy users, exploring the sensitivity of the solution to GHG emission prices. For the first iteration we propose to use value of carbon tax from PMR Report ($18 or ~€15.6 per t CO_2) and extrapolate till €100 pet tone CO_2 in 2050 (Fig. 5.2.)

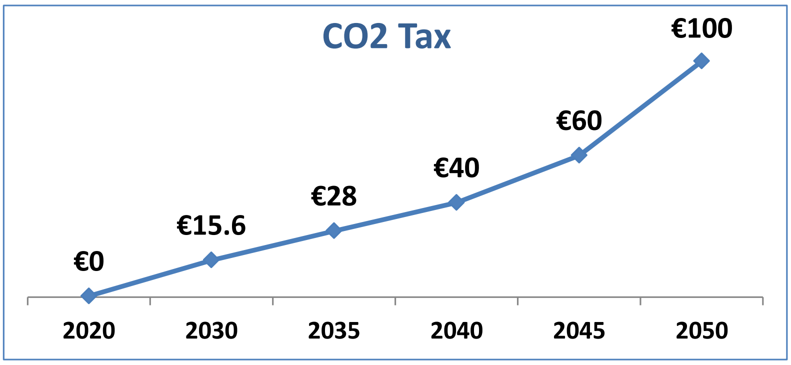

Figure 5.2. Trajectory of the carbon tax value in Scenario S2C

The idea of both sensitivity options is to add one more measure on top of the EE and RES measures, which are included in Scenario 2. In this sensitivity the more advanced technologies, which are available in Scenario 3, should be available in order to allow more flexibility to the system.

Recommendations: Cross-border carbon tax analysis with a use of energy system modelling should be done once the enforcement regulation is in place (it could be done using the same carbon price assumptions as the EU ETS).

Variable D: New trajectory of GHG limits, but carbon neutrality by 2070

This Sensitivity Scenario (incl. new trajectory of GHG limits, Fig. 5.3) composition was proposed by the Ministry considering huge increase of investment needs in the last decade in Scenario 3.

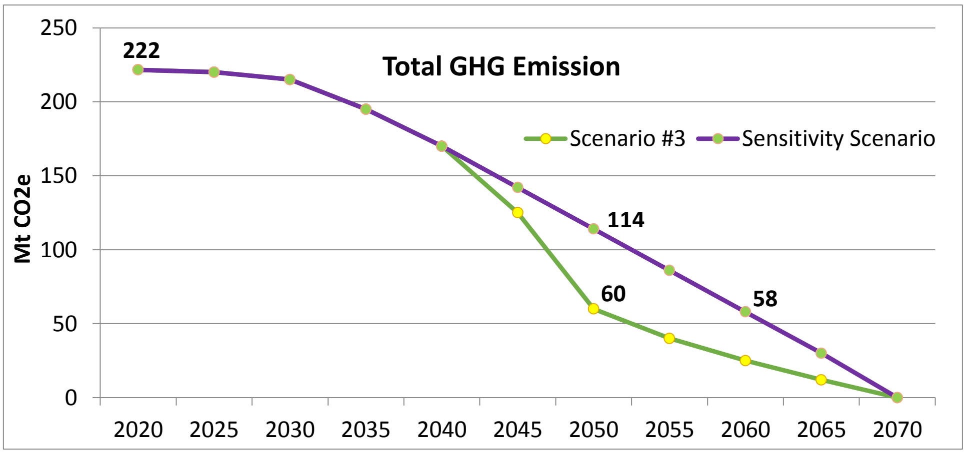

Figure 5.3. Alternative trajectory of GHG limits in Scenario S2H

Variables E & F: Nuclear power generation options

S3E Analysis: **Will assumes no new large nuclear reactors** (1000+ MW) are built in Ukraine during the period of 2020-2050

S2F & S3F Analyses: **Other nuclear option.** Will assumes building new nuclear reactors:

- ***F.1:*** With higher CAPEX based on international benchmark: large size units (incl. new units 3, 4 on Khmelnyts'ka NPP) – €5922 (~$7000) per kW (EU benchmark);
- ***F.2:*** Extension of existing nuclear reactions by additional 5-10 years: according to the information provided by NNEGC Energoatom, lifetime of existing nuclear units could be extend for additional 5-10 years (Fig. 5.4.);

Nuclear Power Plants	# Units	Capacity, MW	Date of commissioning	Current lifetime	Extension of lifetime	Potential max. operating lifetime
Rivnens'ka	1	420	22.12.1980	22.12.2010	22.12.2030	2035
	2	415	22.12.1981	22.12.2011	22.12.2031	2036
	3	1000	21.12.1986	11.12.2017	11.12.2037	2047
	4	1000	10.10.2004	07.06.2035	*planned*	2065
Pivdenno-Ukrains'ka	1	1000	31.12.1982	02.12.2013	02.12.2023	2043
	2	1000	09.01.1985	12.05.2015	31.12.2025	2035
	3	1000	20.09.1989	10.02.2020	*on process*	2050
Zaporiz'ka	1	1000	10.12.1984	23.12.2015	23.12.2025	2045
	2	1000	22.07.1985	19.02.2016	19.02.2026	2046
	3	1000	10.12.1986	05.03.2017	05.03.2027	2037
	4	1000	18.12.1987	04.04.2018	04.04.2028	2048
	5	1000	14.08.1989	27.05.2020	*on process*	2040
	6	1000	19.10.1995	21.10.2026	*planned*	2056
Khmelnyts'ka	1	1000	22.12.1987	13.12.2018	13.12.2028	2038
	2	1000	07.08.2004	07.09.2035	*planned*	2065
	3			Not completed		
	4			Not completed		

Figure 5.4. Lifetime extension of existing nuclear units in Scenarios S2E & S3E

F.3: With lower load factor in line with the current one in Ukraine based on actually observed average availability factor instead of readiness factor of 76% provided earlier by NNEGC (Fig. 5.5)

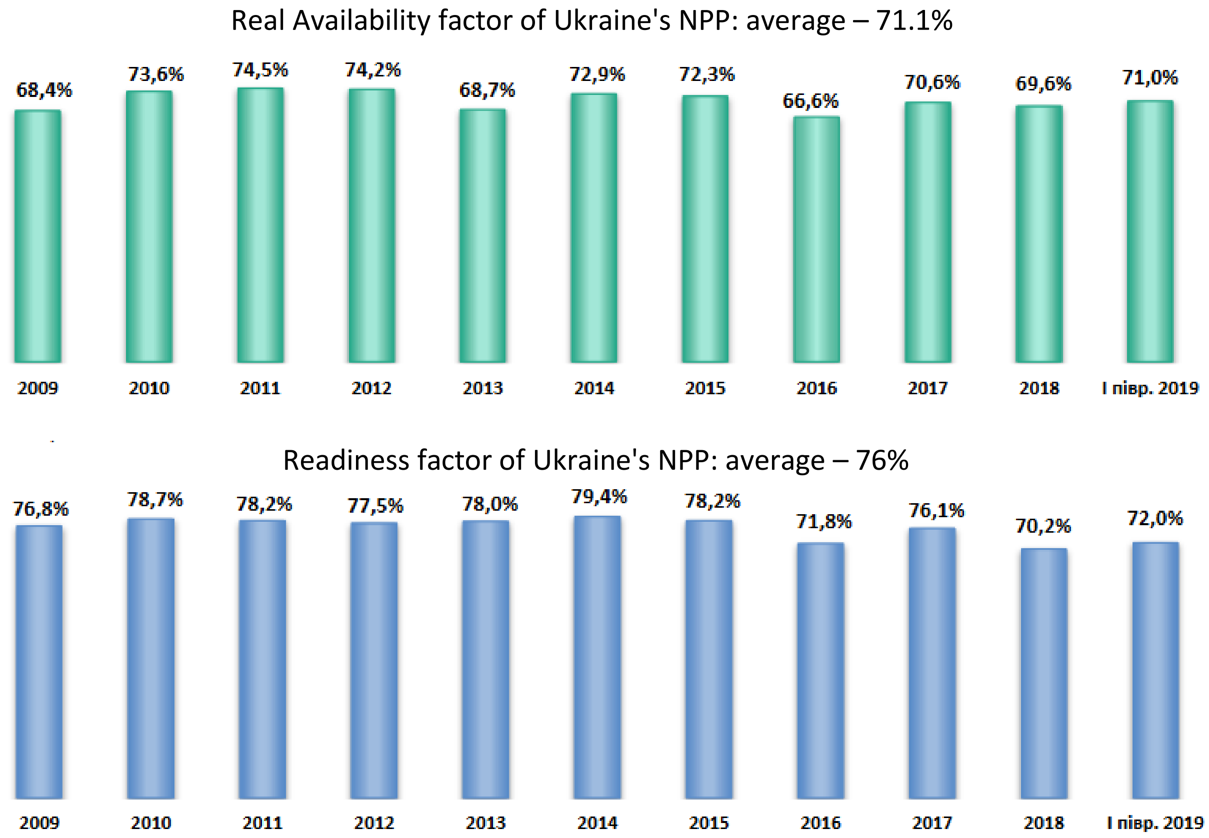

Figure 5.5. Real availability factor and readiness factor on NPPs in Ukraine

Excluding coal-fired power plants options

Will assume no new coal-fired power plant units built and/or **no modernization of existing coal-fired power plant units** take place for the period 2020-2050 for (despite the existing legislation National Plan on Large Combustion Power Plans Pollutions Reduction)

Variable G: Balancing capacities assumptions

Additional **large hydro pump storage** 1.7 GW and **lower balancing capacity requirements for VRE** (wind and solar, excl. roof panels):

- Additional 387 MW in 2020, 898 MW in 2025, 1222 MW in 2027 and 1675 MW in 2030. In the period 2031-2050 no new large HPP. Maximum additional capacities of large hydro pump storage in 2030-2050 is 1675 MW;
- reduction of minimal balancing capacity requirements for variable renewable generation (solar and wind):

- 1% in 2020 and 10% in 2050 of battery storage capacities per unit of new VRE;
- 10% in 2020 and 0% in 2050 of balancing capacities (gas, hydro, fuel cells, import) per unit of new VRE driven by endogenous technological learning and improvement of the VRE forecasting.

***Variable H: Limited implementation of existing legislation on waste management*,** applying the following assumptions for Scenario 3:

- Share of MSW landfilling in 2030, in % from generated MSW;
- Share of population covered by centralized collection MSW system in 2030, in % from total population;
- Number of new regional sanitary MSW landfills to be constructed, in units for the period of 2020-2030;
- Number of existing MSW landfills to be modernized to the level of sanitary, in units for the period of 2020-2030.

Variable I: Implications of the EU border carbon adjustment taxes

While economic impact assessment provided in Report 3 was focused on the impacts of domestic energy and environmental policies, Ukrainian economy could be also impacted by various policy options introduced by other countries, including its key trading partners. Although at this point, there is an uncertainty around the set of environmental policy options that Ukraine might face in the future, one of the possibilities that we explore in this sensitivity scenario is imposition of the border carbon adjustment tax by the EU countries on imports from Ukraine. This analysis is aimed to show possible implications of such policy for Ukrainian economy, as well as identify risks and opportunities in case such policy would be implemented. A range of possible border carbon adjustment taxes would be explored in this scenario.

ANNEXES

Annex 1. GDP projection by sector

Table A.1.1. Optimistic macroeconomic scenario: GDP growth rate by sector, 2017 = 100%

	2017	2020	2025	2030	2035	2040	2050
Agriculture, forestry and fishing	100	107.6	124.5	147.6	171.7	196.6	255.8
Mining and quarrying	100	105.7	116.5	129.4	139.5	146.6	152.5
Extraction of coal and brown coal	100	110.4	114.0	120.8	122.0	123.1	126.4
Extraction of crude oil and natural gas	100	104.9	116.6	130.2	141.4	148.9	154.0
Extraction of metal ores, other minerals and quarrying; provision of ancillary services in the field of mining and quarrying	100	105.1	117.1	131.3	143.1	151.5	159.5
Manufacturing including	100	106.6	137.5	186.8	247.3	321.2	535.9
Manufacture of food products; beverages and tobacco	100	106.5	137.8	187.8	249.4	324.8	543.9
Textile production, production of clothing, leather and other materials	100	98.4	131.4	184.9	252.1	335.4	581.4
Manufacture of wood and paper; printing and reproduction	100	100.9	121.0	150.4	183.7	221.4	322.5
Manufacture of coke and coke products	100	104.4	117.7	134.4	149.7	163.1	186.5
Manufacture of petroleum products	100	108.7	137.9	183.7	239.3	306.4	499.2
Manufacture of chemicals and chemical products	100	122.0	157.7	214.5	284.5	370.0	618.4
Manufacture of basic pharmaceutical products and pharmaceuticals	100	110.0	146.4	205.4	279.3	371.0	641.1
Manufacture of rubber and plastic products	100	108.8	146.4	207.8	285.1	381.5	666.7
Manufacture of other non-metallic mineral products	100	106.5	145.3	209.0	289.7	390.8	691.3
Metallurgical production	100	108.0	127.5	155.4	186.0	219.6	306.6
Manufacture of fabricated metal products, except machinery and equipment	100	107.0	147.2	213.4	297.5	403.2	718.2
Manufacture of computers, electronic and optical products	100	114.0	182.1	299.8	455.0	655.8	1270.2
Manufacture of electrical equipment	100	76.6	114.7	179.6	264.1	372.4	701.0
Manufacture of machinery and equipment, not elsewhere classified	100	112.3	148.4	206.7	279.5	369.5	633.8
Manufacture of motor vehicles, trailers and semi-trailers	100	102.0	152.2	237.6	348.7	491.1	923.0
Manufacture of motor vehicles, trailers and semi-trailers	100	111.3	147.6	206.4	279.8	370.8	638.4
Manufacture of furniture; other products; repair and installation of machines and equipment	100	110.7	141.9	191.4	251.9	325.6	538.7
Supply of electricity, gas, steam and air conditioning	100	106.1	118.0	132.1	143.7	151.9	158.7
Construction	100	136.7	181.8	254.9	346.3	459.8	793.9
Water supply; sewerage, waste management	100	119.3	143.1	178.0	217.6	262.4	382.3
Wholesale and retail trade; repair of motor vehicles and motorcycles	100	110.4	138.4	181.8	233.9	296.2	472.9
Transportation, warehousing	100	108.9	136.4	179.1	230.2	291.3	464.6
Postal and courier activities	100	106.9	129.6	163.4	202.4	247.2	369.5
Temporary accommodation and catering	100	112.2	150.3	212.4	290.2	386.9	672.3
Publishing activities; production of films and videos, television programs, sound recordings; radio and television broadcasting activities	100	107.0	136.1	181.7	237.1	304.1	496.2
Telecommunications	100	114.3	145.6	194.7	254.6	327.0	534.9
Computer programming, consultancy and information services	100	118.6	170.3	256.9	368.6	510.3	936.7
Financial and insurance activities	100	117.3	146.7	192.1	246.5	311.4	495.1
Real estate transactions	100	110.2	135.8	174.8	220.8	274.8	425.3
Activities in the fields of law and accounting; activity of head offices (heads-offices); management consultancy; activities in the fields of architecture and engineering; technical testing and research	100	114.4	136.1	167.5	202.7	241.8	344.8
Research and development	100	117.8	162.6	236.6	330.7	448.9	801.2
Advertising and market research; scientific and technical activities; veterinary activities	100	114.8	140.1	178.2	222.5	273.9	415.6
Administrative and support service activities	100	113.6	139.3	178.4	224.1	277.6	425.9
Public administration and defense; compulsory social insurance	100	109.8	133.4	168.5	209.2	256.1	384.3
Education	100	109.6	135.6	175.6	222.9	278.7	435.3
Health care and social assistance	100	112.0	143.7	193.9	255.3	330.0	545.6
Arts, sports, entertainment and recreation	100	101.9	138.6	198.8	274.9	370.0	652.1
Other services	100	113.2	140.0	181.1	229.7	287.1	447.8
TOTAL	100	110.2	136.3	176.2	223.4	279.3	435.9
Tax on product	100	108.5	131.6	166.1	206.0	251.9	377.3
Subsidy on product	100	136.2	147.7	166.5	180.4	187.4	232.8
GDP	100	109.9	135.5	174.6	220.8	275.1	427.2

Table A.1.2. Baseline macroeconomic scenario: GDP growth rate by sector, 2017 = 100%

	2017	2020	2025	2030	2035	2040	2050
Agriculture, forestry and fishing	100	107.6	120.7	138.6	156.5	173.1	212.0
Mining and quarrying	100	105.7	114.2	124.3	133.4	140.0	148.0
Extraction of coal and brown coal	100	110.4	112.5	114.3	118.7	120.6	119.0
Extraction of crude oil and natural gas	100	104.9	113.9	124.7	133.7	140.1	147.2
Extraction of metal ores, other minerals and quarrying; provision of ancillary services in the field of mining and quarrying	100	105.1	115.0	127.1	137.8	146.2	158.8
Manufacturing including	100	106.6	130.6	167.6	209.6	253.0	367.5
Manufacture of food products; beverages and tobacco	100	106.5	129.3	164.1	203.5	243.8	349.5
Textile production, production of clothing, leather and other materials	100	98.4	127.3	172.9	226.5	282.9	436.5
Manufacture of wood and paper; printing and reproduction	100	100.9	115.9	137.1	159.5	181.1	232.8
Manufacture of coke and coke products	100	104.4	117.2	134.5	151.8	167.6	202.0
Manufacture of petroleum products	100	108.7	132.2	168.2	208.9	250.7	360.4
Manufacture of chemicals and chemical products	100	122.0	153.8	203.6	261.2	321.4	483.4
Manufacture of basic pharmaceutical products and pharmaceuticals	100	110.0	135.5	174.8	219.7	266.2	389.3
Manufacture of rubber and plastic products	100	108.8	137.4	182.2	234.2	288.6	435.0
Manufacture of other non-metallic mineral products	100	106.5	135.7	181.5	234.8	290.7	441.9
Metallurgical production	100	108.0	125.0	149.4	175.6	201.2	263.6
Manufacture of fabricated metal products, except machinery and equipment	100	107.0	135.6	180.4	232.5	287.0	434.0
Manufacture of computers, electronic and optical products	100	114.0	153.8	217.9	294.1	375.4	599.8
Manufacture of electrical equipment	100	76.6	108.1	159.5	221.4	287.8	473.0
Manufacture of machinery and equipment, not elsewhere classified	100	112.3	141.9	188.3	242.2	298.5	450.1
Manufacture of motor vehicles, trailers and semi-trailers	100	102.0	144.1	212.8	295.5	384.4	632.2
Manufacture of motor vehicles, trailers and semi-trailers	100	111.3	137.0	176.6	221.9	268.6	392.5
Manufacture of furniture; other products; repair and installation of machines and equipment	100	110.7	138.1	180.8	230.0	281.2	418.0
Supply of electricity, gas, steam and air conditioning	100	106.1	116.0	128.3	139.2	149.2	160.6
Construction	100	136.7	168.5	217.6	273.8	331.9	486.0
Water supply; sewerage, waste management	100	117.0	136.3	164.4	194.6	224.4	298.1
Wholesale and retail trade; repair of motor vehicles and motorcycles	100	111.4	131.9	162.3	195.6	229.2	314.3
Transportation, warehousing	100	109.9	130.5	161.0	194.6	228.5	314.9
Postal and courier activities	100	104.9	121.7	146.0	172.0	197.6	260.2
Temporary accommodation and catering	100	110.1	139.4	185.1	238.1	293.6	442.9
Publishing activities; production of films and videos, television programs, sound recordings; radio and television broadcasting activities	100	105.0	127.1	160.6	198.1	236.7	337.0
Telecommunications	100	112.1	137.8	177.1	221.8	268.1	390.1
Computer programming, consultancy and information services	100	116.4	151.6	207.5	273.0	342.3	531.2
Financial and insurance activities	100	115.0	138.8	174.6	214.7	255.7	362.2
Real estate transactions	100	111.3	131.3	160.7	193.0	225.3	306.9
Activities in the fields of law and accounting; activity of head offices (heads-offices); management consultancy; activities in the fields of architecture and engineering; technical testing and research	100	115.5	133.6	159.6	187.3	214.3	280.0
Research and development	100	115.5	143.0	185.4	233.7	283.9	417.2
Advertising and market research; scientific and technical activities; veterinary activities	100	112.6	132.5	161.8	193.6	225.5	305.6
Administrative and support service activities	100	111.4	131.7	161.7	194.6	227.7	311.4
Public administration and defense; compulsory social insurance	100	107.7	126.9	155.0	185.6	216.3	293.5
Education	100	110.6	135.2	172.7	215.1	258.9	373.8
Health care and social assistance	100	113.1	138.5	177.4	221.5	267.0	386.8
Arts, sports, entertainment and recreation	100	102.9	134.8	185.4	244.9	308.0	480.1
Other services	100	111.0	132.8	165.5	201.8	238.8	333.7
TOTAL	100	110.3	130.4	160.3	193.3	226.5	313.5
Tax on product	100	108.5	127.4	155.2	185.5	215.8	291.8
Subsidy on product	100	132.3	140.3	133.9	109.6	130.3	157.5
GDP	100	109.9	129.9	159.6	192.3	225.1	308.4

Annex 2. Estimated cost of capital expenditures of the new technologies

Nuclear power plants (NPPs)

Table A.2.1. Unit №3 on Khmelnytska NPPs

Technical and economic parameters	2025-2050
CAPEX, $/ kWe	1751
Fixed Operation and Maintenance Expenses, $/ kWe	73,35
Variable Operation and Maintenance Expenses, $/MWh	1,65
Decommission Cost, % of CAPEX	10
Efficiency, %	33
Net Capacity Factor (Availability factor), %	83
Heat Rate, MWh·of heat / MWh of electricity, %	0,03
Lifetime, years	60
Period of construction, years	4
Potential year of start of operation, year	2025
Self-consumption of electricity, %	5

Source: State Enterprise "National Atomic Energy Generating Company" Energoatom"

Table A.2.2. Unit №4 on Khmelnytska NPPs

Technical and economic parameters	2030-2050
CAPEX, $/ kWe	1672
Fixed Operation and Maintenance Expenses, $/ kWe	73,35
Variable Operation and Maintenance Expenses, $/MWh	1,65
Decommission Cost, % of CAPEX	10
Efficiency, %	33
Net Capacity Factor (Availability factor), %	83
Heat Rate, MWh·of heat production / MWh of electricity production, %	0,03
Lifetime, years	60
Period of construction, years	5
Potential year of start of operation, year	2030
Self-consumption of electricity, %	5

Source: State Enterprise "National Atomic Energy Generating Company" Energoatom"

Table A.2.3. Extension of the operational life of existing units of NPPs

Technical and economic parameters	2015-2050
The cost of Extension of the operational life for 20 (30) years, *$/kWe*	300 (400)
Fixed Operation and Maintenance Expenses, $/ kWe	73,35
Variable Operation and Maintenance Expenses, $/MWh	1,65
Efficiency, %	33
Net Capacity Factor (Availability factor), %	80
Heat Rate, MWh·of heat production / MWh of electricity production, %	0,03

Source: State Enterprise "National Atomic Energy Generating Company" Energoatom"

Table A.2.4. New big units of NPPs (1000 MW)

Technical and economic parameters	2025-2100 pp.
CAPEX, $/ kWe	5250
Fixed Operation and Maintenance Expenses, $/ kWe	73,35
Variable Operation and Maintenance Expenses, $/MWh	1,65
Decommission Cost, % of CAPEX	400
Efficiency, %	33,8
Net Capacity Factor (Availability factor), %	93
Heat Rate, MWh·of heat production / MWh of electricity production, %	0,04
Lifetime, years	80
Period of construction, years	5
Potential year of start of operation, year	2031
Self-consumption of electricity, %	5

Source: State Enterprise "National Atomic Energy Generating Company" Energoatom"

Table A.2.5. New small nuclear reactors (160 MW)

Parameters	Data
Overnight Capital Cost, $/kWe	5250
Fixed Operation and Maintenance Expenses, $/ kWe.	73,35
Variable Operation and Maintenance Expenses, $/ MWh	1,65
Decommission Cost, $/kW	400
Efficiency, %	32
Net Capacity Factor (Availability factor), %	98
Lifetime, years	80
Period of construction, years	3
Potential year of start of operation, year	2025
Self-consumption of electricity, %	5

Source: State Enterprise "National Atomic Energy Generating Company" Energoatom"

Thermal Power Plants (TPPs)

Table A.2.6. Bioenergy TPPs

	2015	2020	2025	2030	2035	2040	2045	2050
	Wood biomass							
CAPEX, €/ kWe	2800	2800	2800	2600	2500	2400	2200	2000
Fixed Operation and Maintenance Expenses, €/ kWe	30							
Variable Operation and Maintenance Expenses, €/MWh	6.12							
Decommission Cost, % of CAPEX	1.5%							
Efficiency, %	24							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	30							
	Biomass from waste of agri-food complex, etc.							
CAPEX, €/ kWe	3500	2890	2800	2700	2600	2500	2300	2100
Fixed Operation and Maintenance Expenses, €/ kWe	30							
Variable Operation and Maintenance Expenses, €/MWh	6.12							
Decommission Cost, % of CAPEX	1.5%							
Efficiency, %	23							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	30							
	Biogas							
CAPEX, €/ kWe	4500	4400	4300	4200	4100	4000	3900	3800
Fixed Operation and Maintenance Expenses, €/ kWe	30							
Variable Operation and Maintenance Expenses, €/MWh	6.12							
Decommission Cost, % of CAPEX	1.5%							
Efficiency, %	42							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	30							
	Energy crops							
CAPEX, €/ kWe	3300	2900	2800	2700	2600	2500	2300	2100
Fixed Operation and Maintenance Expenses, €/ kWe	30							
Variable Operation and Maintenance Expenses, €/MWh	6.12							
Decommission Cost, % of CAPEX	1.5%							
Efficiency, %	24							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	30							
	Industrial Waste							
CAPEX, €/ kWe	3500	2890	2800	2700	2600	2500	2300	2100
Fixed Operation and Maintenance Expenses, €/ kWe	30							
Variable Operation and Maintenance Expenses, €/MWh	6.12							
Decommission Cost, % of CAPEX	1.5							
Efficiency, %	23							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	30							
Heat Rate, %	0.05							

Source: Bioenergy Association of Ukraine

Table A.2.7. Gas TPPs

	2015-2050			
	Combined Cycle	Combustion Turbine	Steam Turbine	Fast Start Internal Combustion Engine
CAPEX, €/ kWe	1000	600	920	1000
Fixed Operation and Maintenance Expenses, €/ kWe	20	11.9	16,6	20
Variable Operation and Maintenance Expenses, €/MWh	2	4.1	2,1	0.555
Decommission Cost, % of CAPEX	2	2	2	2
Efficiency, %	60	40	42	50
Net Capacity Factor (Availability factor), %	50	50	50	50 (as balancing ~1.5%)
Lifetime, years	35	30	30	35
Heat Rate, %	0.05	0.05	0.05	

Source: US EIA. Capital Cost Estimates for Utility Scale Electricity Generating Plants. November 2016, Wärtsilä Oyj Abp

Table A.2.8. Gas TPPs with CCS

	2015-2050	
	Combined Cycle + CCS	Combustion Turbine + CCS
Overnight Capital Cost, EUR/kW	2450	2050
Fixed O&M Expenses, $/ kWe..	24	14.3
Variable O&M Expenses, $/ MWh	2	4.1
Efficiency, %	51	34
Availability factor, %	50	50
Lifetime, years	35	30
Heat Rate, %	0,05	0,05

Table A.2.9. Coal TPPs

	2015-2050			
	IGCC	Supercritical parameters	Subcritical parameters	Circulating Fluidized Bed
CAPEX, €/ kWe	1800	1300	1600	1700
Fixed Operation and Maintenance Expenses, €/ kWe	63	43	30	27
Variable Operation and Maintenance Expenses, €/MWh	5.8	6	6	6
Decommission Cost, % of CAPEX	5	5	5	5
Efficiency, %	46	43	39	43
Net Capacity Factor (Availability factor), %	50	50	50	50
Lifetime, years	35	40	35	35
Heat Rate, %	0.15	0.15	0.15	0.15

Source: Projected cost of electricit 2015.

Table A.2.10. Extension of the operational life of existing Coal TPPs

	2015-2050
CAPEX, €/ kWe	950
Fixed Operation and Maintenance Expenses, €/ kWe	33
Variable Operation and Maintenance Expenses, €/MWh	18
Decommission Cost, % of CAPEX	5
Efficiency, %	33-40
Net Capacity Factor (Availability factor), %	34-62
Lifetime, years	30
Heat Rate, %	0.04

Source: national data.

Table A.2.11. Coal TPPs with CCS

	2015-2050			
	IGCC	Supercritical parameters	Subcritical parameters	Circulating Fluidized Bed
CAPEX, €/ kWe	4400	3900	4650	4300
Fixed Operation and Maintenance Expenses, €/ kWe	75	52	36	34
Variable Operation and Maintenance Expenses, €/MWh	5.8	6	6	6

Decommission Cost, % of CAPEX	5	5	5	5
Efficiency, %	39	37	33	36
Net Capacity Factor (Availability factor), %	50	50	50	50
Lifetime, years	35	35	35	35
Heat Rate, %	0.15	0.15	0.15	0.15

Cogeneration or combined heat and power (CHP)

Table A.2.12. Bioenergy CHPs

	2015	2020	2025	2030	2035	2040	2045	2050
	Wood biomass							
CAPEX, €/ kWe	3500	3400	3300	3200	3100	3000	2900	2800
Fixed Operation and Maintenance Expenses, €/ kWe	50							
Variable Operation and Maintenance Expenses, €/MWh	6							
Decommission Cost, % of CAPEX	1.5							
Efficiency, %	20							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	35							
	Biomass from waste of agri-food complex, etc.							
CAPEX, €/ kWe	3500	3400	3200	3100	2900	2900	2800	2800
Fixed Operation and Maintenance Expenses, €/ kWe	56							
Variable Operation and Maintenance Expenses, €/MWh	6.6							
Decommission Cost, % of CAPEX	1.5							
Efficiency, %	19							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	35							
	Biogas							
CAPEX, €/ kWe	5500	5400	5200	5100	5000	4800	4500	4500
Fixed Operation and Maintenance Expenses, €/ kWe	56							
Variable Operation and Maintenance Expenses, €/MWh	3.4							
Decommission Cost, % of CAPEX	1.5							
Efficiency, %	25							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	35							
	Energy crops							
CAPEX, €/ kWe	3500	3400	3300	3200	3100	3000	3000	3000
Fixed Operation and Maintenance Expenses, €/ kWe	50							
Variable Operation and Maintenance Expenses, €/MWh	6							
Decommission Cost, % of CAPEX	1.5							
Efficiency, %	20							
Net Capacity Factor (Availability factor), %	50							
Lifetime, years	35							

Source: Bioenergy Association of Ukraine

Table A.2.13. Gas CHPs

	2015-2050	
	Combined Cycle	**Steam Turbine**
CAPEX, €/ kWe	800	920
Fixed Operation and Maintenance Expenses, €/ kWe	42	42
Variable Operation and Maintenance Expenses, €/MWh	1.55	1.55
Decommission Cost, % of CAPEX	2.0	2.0
Efficiency, %	50	45
Net Capacity Factor (Availability factor), %*	50	50
Lifetime, years	35	30
Heat Rate, %	1.5	1.5

Source: Projected cost of electricity 2015

** Availability factor according to Projected cost of electricity 2015 is in the range from 46 - 90%*

Table A.2.14. Gas CHPs with CCS

	2015-2050	
	Combined Cycle + CCS	**Combustion Turbine + CCS**
Overnight Capital Cost, EUR/kW	2450	2050
Fixed O&M Expenses, $/ kWe..	24	14.3
Variable O&M Expenses, $/ MWh	2	4.1
Efficiency, %	51	34
Availability factor, %	50	50
Lifetime, years	35	30
Heat Rate, %	0,05	0,05

Table A.2.15. Coal CHPs

	2015-2050	
	Combined Cycle	**Steam Turbine**
CAPEX, €/ kWe	1200	1100
Fixed Operation and Maintenance Expenses, €/ kWe	52	52
Variable Operation and Maintenance Expenses, €/MWh	5.76	5.76
Decommission Cost, % of CAPEX	5.0	5.0
Efficiency, %	36	33
Net Capacity Factor (Availability factor), %	50	50
Lifetime, years	35	35
Heat Rate, %	1.5	1.5

Source: *Projected cost of electricity 2015*

Table A.2.16. Extension of the operational life of existing CHPs

	2015-2050	
	Gas	**Coal**
CAPEX, €/ kWe	280-650	880-1300
Fixed Operation and Maintenance Expenses, €/ kWe	41-51	51
Variable Operation and Maintenance Expenses, €/MWh	0.3	1.0
Decommission Cost, % of CAPEX	2.0	5.0
Efficiency, %	25-34	16-26
Net Capacity Factor (Availability factor), %*	50	50
Lifetime, years	15	15
Heat Rate, %	1.55	1.1

Source: Projected cost of electricity 2015

** Availability factor according to Projected cost of electricity 2015 is in the range from 46 - 90%*

Table A.2.17. Fuel Cells Power Plants (FCPPs)

	2025-2050	
	TPPs	**CHPs**
Overnight Capital Cost, EUR/kW	844	844
Fixed O&M Expenses, $/ kWe..	62	62
Variable O&M Expenses, $/ MWh	14	14
Efficiency, %	50	50
Availability factor, %	85	60
Lifetime, years	10	10
Heat Rate, %	–	0.64

Other power plants

Table A.2.18. Solar Power Plants

	2015	2020	2025	2030	2035	2040	2045	2050
	PV Plant size (without tracker)							
CAPEX, €/ kWe	1300	750	725	700	630	560	510	475
Fixed Operation and Maintenance Expenses, €/ kWe	15							
Net Capacity Factor (Availability factor), %	12,5							
Lifetime, years	25							

	2015	2020	2025	2030	2035	2040	2045	2050
Decommission Cost, % of CAPEX	1%							
Construction time, years	1							
	PV Plant size (with tracker)							
CAPEX, €/ kWe	1450	920	850	800	720	645	590	540
Fixed Operation and Maintenance Expenses, €/ kWe	17.3							
Net Capacity Factor (Availability factor), %	14,5							
Lifetime, years	25							
Decommission Cost, % of CAPEX	1%							
Construction time, years	1							
	PV Roof panel							
CAPEX, €/ kWe	1700	900	875	850	800	750	700	600
Fixed Operation and Maintenance Expenses, €/ kWe	12							
Net Capacity Factor (Availability factor), %	13,0							
Lifetime, years	25							
Decommission Cost, % of CAPEX	1%							
Construction time, years	1							

Source: national data and US EIA Capital cost estimates for utility scale electricity generating plants. November 2016

Table A.2.19. Wind Power Plants

	2015	2020	2025	2030	2035	2040	2045	2050
	Onshore							
CAPEX, €/ kWe	1665	1350	1350	1350	1325	1275	1225	1200
Fixed Operation and Maintenance Expenses, €/ kWe	25	25	26	28	37	40	40	40
Net Capacity Factor (Availability factor), %	36							
Lifetime, years	20							
Decommission Cost, % of CAPEX	1%							
Construction time, years	1.5							

Table A.2.20. Hydro Power Plants (HPPs)

	2015-2050		
	Large	**Pump Storage**	**Small**
CAPEX, €/ kWe	3000-3300	1500	3000-3150
Fixed Operation and Maintenance Expenses, €/ kWe	45	45	59
Decommission Cost, % of CAPEX	3.0	3.0	3.0
Net Capacity Factor (Availability factor), %	33-36	26	30
Lifetime, years	60	60	40

Table A.2.21. Geothermal Power Plants (GPPs)

	2015-2050
CAPEX, €/ kWe	3800-4000
Fixed Operation and Maintenance Expenses, €/ kWe	143.5
Decommission Cost, % of CAPEX	1.0
Net Capacity Factor (Availability factor), %	35-55
Lifetime, years	25

Table A.2.22. Storage electricity technologies

	2020	2025	2030	2035	2040	2045	2050
CAPEX, €/ kWh	600	570	542	514	489	464	441
Fixed Operation and Maintenance Expenses, €/ kWh	8,6	8,1	7,6	7,0	6,5	6,5	6,5
Variable Operation and Maintenance Expenses, €/MWh	2,50	2,20	1,91	1,61	1,32	1,32	1,32
Efficiency, %	92%						
Availability factor (8 hours per day), %	33,3						
Construction time, years	3						
Lifetime, years	10						

Supply Sector

Table A.2.23. Hydrogen technologies

Technology Description	Input	Starting Year	Fuel input level	AFA	Life-time	Capex	Fixed O&M Cost	Variable O&M Cost
	Commodities			*%*	*years*	*M€/(PJ/year)*	*M€/PJ*	*M€/PJ*
H2 Electrolyser Centralised	Electricity	2030	1.43	90	10	21.9	0.44	
H2 HT Steam Electrolyser Centralised	Electricity	2030	1.07	90	10	40.3	0.81	
	Heat		0.20					
H2 SMR Centralised	Natural Gas	2030	1.35	90	10	10.6	0.53	0.51
H2 Electrolyser De-centralised	Electricity	2030	1.43	90	10	27.3	0.55	
H2 SMR De-centralised	Natural Gas	2030	1.50	90	10	21.9	1.09	0.51
H2 Liquefaction	Hydrogen Gas	2035	1.00	75	10	9.5	0.57	
	Electricity		0.21					

Source: Cascade-Mints D1.1 Fuel cell technologies and Hydrogen prodùstion/Distribution options, DLR

Transport

Table A.2.24. Main characteristics of hydrogen transport used in the TIMES-Ukraine model

Mode of transport	Cost, EUR thousand		Life time, years	Efficiency, km/GJ		Annual mileage, thousand km
	2015	2050		2015	2050	
Intercity buses	320	280	20	277	332	27.5
City buses	320	280	20	270	324	27.5
Cars, long distance (gas)	61	41	20	900	1200	17.5
Cars, short distance (gas)	61	41	20	765	792	17.5
Cars, long distance (liquid)	59	38	20	900	1200	17.5
Cars, short distance (liquid)	59	38	20	765	792	17.5
Trucks	350	200	20	285	340	22.0

Industry

Table A.2.25. CCS technologies

Technology Description	Efficiency	AFA	Life-time	Capex	Starting
	%	*%*	*years*	*US$ / t CO_2eq.*	*year*
Iron and Steel Production	80	90	10	65-70	2031
Cement production	90	90	10	110	2031
Ammonia production	100	90	10	100	2031
Ethylene production	100	90	10	190	2031

Source: Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century / ETC, - http://www.energy-transitions.org/mission-possible; Decarbonization of industrial sectors: the next frontier // McKinsey&Company, 2018. - https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.ashx

Annex 3. **Short list of power and heat future technologies**

Technologies	*Overnight Capital Cost (CAPEX), €/ kWe* 2020 2025 2030 2035 2040 2045 2050	*Electric Efficiency, %*	*Availability factor, %*	*Lifetime, years*	*Heat Rate*
Thermal Power Plants (TPPs) and Combined Heat and Power Plants (CHP)					
Nuclear					
New Unit №3 on Khmelnytska NPPs	1481	33	85	60	0.03
New Unit №4 on Khmelnytska NPPs	1415	33	85	60	0.03
New big units of NPPs (1050-1770 MW)	4230	42	93	30	0.04
Extension of the operational life of existing units of NPPs	254	42	80	30	0.04
New small nuclear reactors (160 MW)	4230	32	98	80	0.04
Gas					
Combined cycle TPPs	1000	60	50	35	0.15
Combustion turbine TPPs	600	40	50	30	0.15
Steam turbine TPPs	920	42	50	30	0.15
Fast Start Engine TPPs (only as balancing technologies)	1000	50	1.5	35	–
Combined Cycle + Carbon Capture and Storage TPPs	2450	51	50	35	0.05
Combustion turbine + Carbon Capture and Storage TPPs	2050	34	50	30	0.05
Combined cycle CHPs	800	50	50	35	0.84
Combustion turbine CHPs	920	45	50	35	0.95
Extension of the operational life of existing CHPs	280-650	19-43	50	15	1.1-3.0
Combined Cycle + Carbon Capture and Storage CHPs	2250	45	50	35	0.84
Coal					
Integrated gasification combined cycle (IGCC) TPPs	1800	46	50	35	0.15
Supercritical parameters TPPs	1300	43	50	40	0.15
Subcritical parameters TPPs	1600	39	50	35	0.15
Circulating Fluidized Bed TPPs	1700	43	50	35	0.15
Joint combustion of coal and biomass (subcritical parameters) TPPs	2050	33	50	35	0.15
Extension of the operational life of existing Coal TPPs	950	33-40	34-62	20	0.01-0.19
IGCC + Carbon Capture and Storage TPPs	4400	39	50	35	0.15
Supercritical + Carbon Capture and Storage TPPs	3900	37	50	35	0.15
Subcritical + Carbon Capture and Storage TPPs	4650	33	50	35	0.15
Circulating Fluidized Bed + Carbon Capture and Storage TPPs	4300	28	50	35	0.15
Combined cycle CHPs	1200	40	50	35	0.84
Combustion turbine CHPs	1100	35	50	35	0.90
Combined cycle+ Carbon Capture and Storage CHPs	2650	35	50	35	0.84

Technologies	Overnight Capital Cost (CAPEX), €/ kWe							Electric Efficiency, %	Availability factor, %	Lifetime, years	Heat Rate
	2020	2025	2030	2035	2040	2045	2050				
Bioenergy											
Wood biomass TPPs	2800	2800	2600	2500	2400	2200	2000	24	50	30	–
Biomass from waste TPPs	2890	2800	2700	2600	2500	2300	2100	23	50	30	0.3
Biogas TPPs	4400	4300	4200	4100	4000	3900	3800	42	50	30	–
Energy crops TPPs	2900	2800	2700	2600	2500	2300	2100	24	50	30	–
Wood biomass+ Carbon Capture and Storage TPPs	3650							24	50	30	–
Biogas + Carbon Capture and Storage TPPs	5350							42	50	30	–
Energy crops + Carbon Capture and Storage TPPs	3750							24	50	30	–
Wood biomass CHPs	3400	3300	3200	3100	3000	2900	2800	20	50	35	2.0
Biomass from industrials waste CHPs	3400	3200	3100	2900	2900	2800	2800	19	50	35	1.9
Biomass from municipal waste CHPs	3400	5200	5100	5000	4800	4500	4500	25	50	35	1.2
Energy crops CHPs	3400	3300	3200	3100	3000	3000	3000	20	50	35	2.0
Wood biomass + Carbon Capture and Storage CHPs	4450							20	50	35	1.5
Energy crops+ Carbon Capture and Storage CHPs	4450							20	50	35	1.5
Wind											
Onshore Wind Power Plants	1350	1350	1350	1325	1275	1225	1200	–	36	20	–
Solar											
PV Plant size (without tracker)	750	725	700	630	560	510	475	–	12.5	25	–
PV Plant size (with tracker)	920	850	800	720	645	590	540	–	14.5	25	–
PV Roof panel	900	875	850	800	750	700	600	–	13.5	25	–
Geothermal											
Geothermal Power Plants	3800-4000							–	35-55	25	–
Hydro											
Small Hydro Power Plants	3000-3150							–	30	40	–
Large Hydro Power Plants	3000-3300							–	33-36	60	
Pump Storage	1500							–	26	60	–
Storage electricity technologies, EUR/kWh											
Battery Storages	600	570	540	515	490	465	440	92	33	10	–
Fuel Cells (Hydrogen)											
Fuel Cells Power Plants	2530	1125	1125	844	844	844	844	50	85	10	–
Fuel Cells Combined Heat and Power Plants	2530	1125	1125	844	844	844	844	50	60	10	0.64

Annex 4. Economic assessment with UGEM model

Dynamic Ukrainian General Equilibrium Model (UGEM)

As energy policy impacts go far beyond energy sector, there is a need for modelling approach that would provide a top-down view of the national economy. In the previous reports, we have provided analysis of the policy tools used for the economic assessment of low emission development policies, including NDC. Results of that overview suggest that CGE models should be considered as a prevalent tools for such assessment. Therefore, in this section, in addition to the TIMES-Ukraine model, which captures key energy and environmental impacts of the NDC policies, we use dynamic UGEM model to estimate a broader economic impacts. Current version of the model is based on the static model described in Chepeliev (2014),[74] dynamic mechanisms introduced in TRPC (2014)[75] and additional sectoral and energy details introduced for the current report. It is a typical single-country recursive dynamic computable general equilibrium model with producers divided into 88 sectors. Figure A.4.1 represents key circular flows in the UGEM.

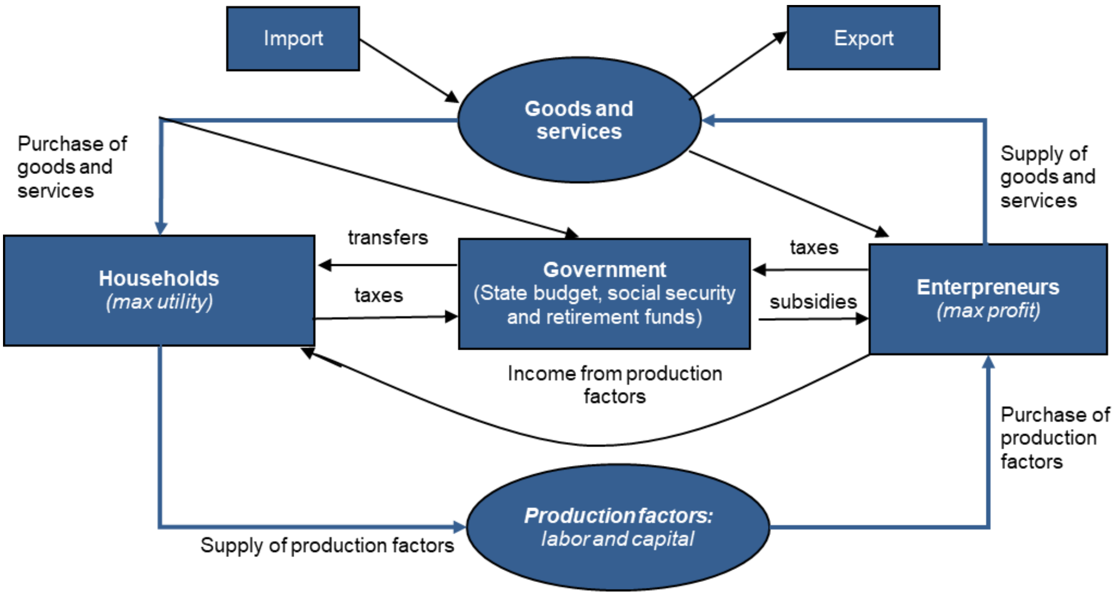

Figure A.4.1. Key flows in the UGEM model

Source: Authors.

It is assumed that producers are maximizing their profits and households are maximizing utility. Enterprises are producing goods and providing services, using capital, labor and intermediate products. Domestic producers sell their products at the national or international markets. In the domestic market, final goods and services are purchased by households, government or contribute to the gross capital formation. Households receive labor and capital payments, as well as money transfers. Government earns revenue and receives tax payments, providing transfers and subsidies to households and producers. To represent production and

[74] Chepeliev, M. 2014. Simulation and economic impact evaluation of Ukrainian electricity market tariff policy shift. Economy and forecasting, 1(1), 1-24. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2608980

[75] Thompson Reuters Point Carbon (TRPC). 2014. Improving the existing carbon charge in Ukraine as an interim policy towards emissions trading – Detailed Report. http://www.ebrdpeter.info/uploads/media/report/0001/01/9705b0af32bc096636a81554c185d9181b49d916.pdf

consumption processes in the UGEM, constant elasticity of substitution[76] (CES) production functions are used. Different nesting configurations are used for different sectors in UGEM. Figure A.4.2 depicts the production structure used in most UGEM sectors. Different production structures are used in heat generation ("hdt"), Other power generation ("othp"), Coke ("coke") and Petroleum production "petrol" – they are provided further in this Annex.

In the case of main production block, a multi-nested CES function is used, which distinguishes energy and non-energy commodities, as well as value added component. Energy nest is further split into electricity generation and other energy. Electricity generation in the current version of the UGEM is represented by seven generation technologies – coal power, gas power, nuclear power, solar power, wind power and other power (mainly includes biomass-based electricity generation). Other energy composite nest includes coal, oil, gas, coke and petroleum products. Consumption nesting structure is provided on Figure A.4.3.

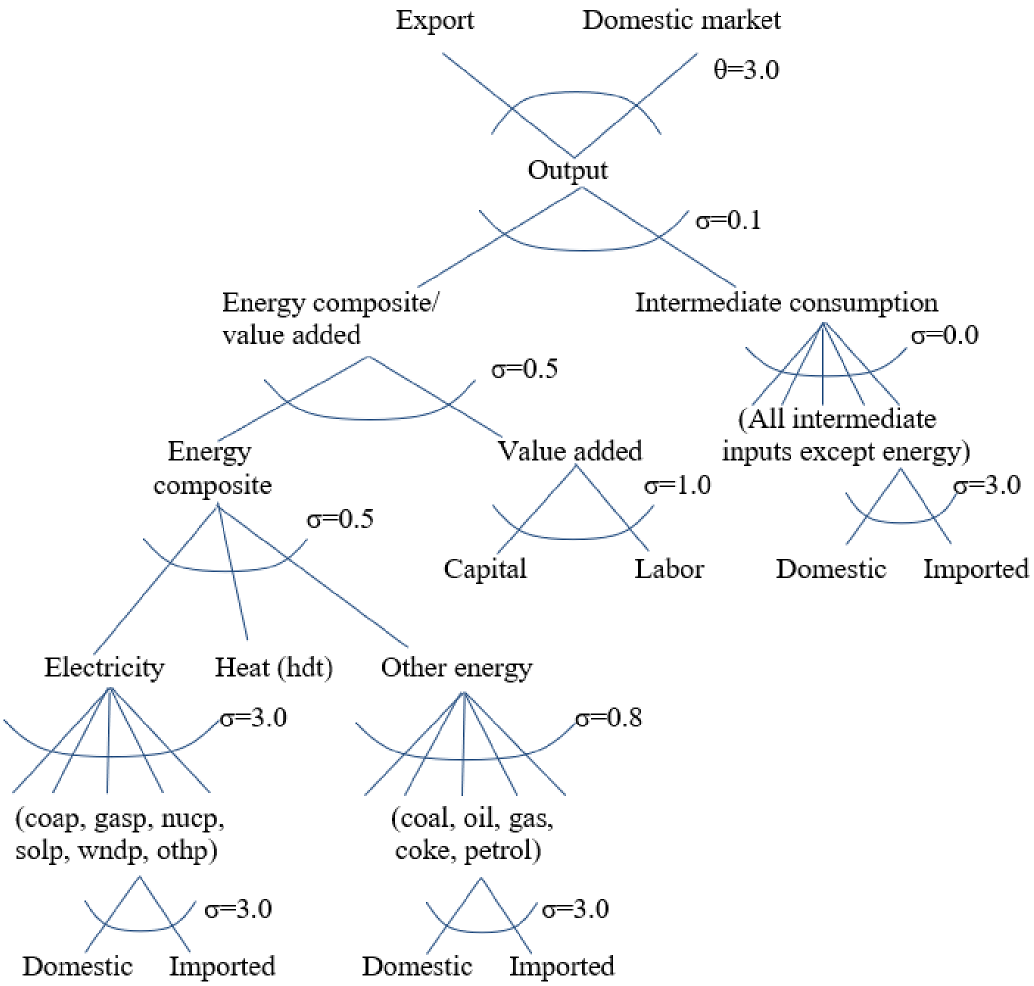

Figure A.4.2. Production nesting structure for all sectors except "hdt", "othp", "coke" and "petrol"

Source: Authors.

[76] Elasticity of substitution indicates relative consumption quantities changes resulting from the corresponding relative price changes.

Note: "σ" stands for the value of substitution elasticity in the corresponding nest; "θ" stands for the value of transformation elasticity in the corresponding nest.

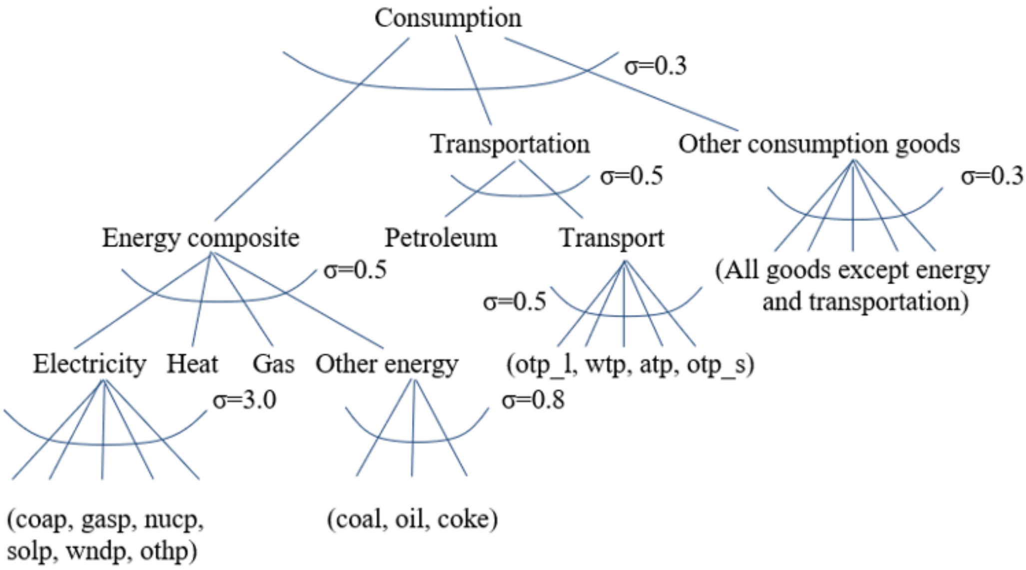

Figure A.4.3. Consumption structure for Households ("hhs") and Government ("gov") sectors

Source: Authors.
Note: "σ" stands for the value of substitution elasticity in the corresponding nest.

UGEM is formulated as a static model and solved sequentially over time. Capital stock is updated in every period with a capital accumulation equation:

$$CS_{i,t+1} = (1-\delta)CS_{i,t} + Inv_{i,t},$$

$CS_{i,t+1}$ is the value of capital stock at the beginning of the period $t+1$ in the i-th sector; δ equals depreciation rate; and $Inv_{i,t}$ is volume of investments in the i-th sector during the period t.

Key input data for the model are sourced from Input-Output tables (IOT), extended energy balances, National accounts and detailed trade data. Data inputs are organized in the form of Social Accounting Matrix[77] based on the 2015 data and reconciled using RAS and cross-entropy approaches.[78]

In particular, we start with the 2015 Ukrainian input-output table[79] with 42 sectors. A disaggregated 2005 Ukrainian IOT[80] with 79 producing sectors, is further used to split the 2015 IOT into 81 sectors. On the next step, an extended energy balance for Ukraine is integrated into the IOT. As a key source of energy data, we use Eurostat

[77] Social accounting matrix definition and examples can be found in:
Breisinger, C., Thomas, M., Thurlow, J. 2009. Social accounting matrices and multiplier analysis: An introduction with exercises. International Food Policy Research Institute. Washington D.C.

[78] For the discussion of RAS method, see:
Trinh, B., Phong, N.V. 2013. A Short Note on RAS Method. Advances in Management & Applied Economics. Vol. 3, no. 4, 133-137. http://www.scienpress.com/Upload/AMAE/Vol%203_4_12.pdf
Discussion of the cross-entropy approach can be found in:
Robinson, S., Cattaneo, A., and El-Said, M., Updating and Estimating a Social Accounting Matrix Using Cross Entropy Methods. Economic Systems Research 13, 1 (2001), 47-64.

[79] State Statistics Service of Ukraine (SSSU). 2017a. Ukrainian Input-Output Table at Basic Prices for 2015. http://www.ukrstat.gov.ua/

[80] SSSU. 2007. Ukrainian Input-Output Table at Consumer Prices for 2005 (extended program). http://www.ukrstat.gov.ua/

Energy Balance (EEB) for Ukraine (2017 edition with 2015 reference year).[81] Extended energy balance of Ukraine is mapped to the disaggregated 2015 IOT and used to further split two energy sectors. Oil and gas extraction is split into oil and gas, while electricity generation activity, represented as a single sectors in the disaggregated 2015 IOT, is split into six generation activities (Annex 5). Constructed energy and value flows and reconciled for internal consistency using cross-entropy balancing approach.

Computable general equilibrium models, like UGEM, are usually used for "What-If" type of analysis. After the input data is collected and model is calibrated to replicate the base year equilibrium, policy scenarios are designed in a way that change values of the exogenous variables of the model. As a result, an initial equilibrium is altered and a new equilibrium (or set of equilibriums in the case of dynamic model) is estimated. While UGEM model is able to assess the economy wide impacts of energy and environmental policies (e.g emission taxation), it does not represent energy sector in such a detailed way as a TIMES-Ukraine model does. To this extent an environmental policy analysis can benefit from the linkage of these two models, which we further discuss in the next sub section.

TIMES-Ukraine and UGEM MODEL LINKAGE

To provide an assessment of the NDC policies in Ukraine we use a soft-linkage of TIMES-Ukraine and UGEM models (Figure A.4.4).

On the *first step*, we calibrate both models to match the assumptions of the BaU scenario, in particular, sectoral GDP and population projections.

On the *second step*, we provide an assessment of the NDC policies using TIMES-Ukraine model. As a result, we analyze policy impacts on energy sector and estimate additional investments required to reach the energy policy targets. We also estimate specific energy consumption changes relative to the BaU scenario.

On the *third step,* we map TIMES-based changes in additional investments and specific energy consumption to the UGEM classification of economic activities. UGEM model baseline is calibrated to the TIMES-Ukraine BaU scenario. In particular, we ensure that the energy generation mix in UGEM is the same as in TIMES-Ukraine and aggregate greenhouse gas emissions (GHG) are same in both models.

[81] Eurostat. 2017. Energy balances in the MS Excel file format. https://ec.europa.eu/eurostat/web/energy/data/energy-balances

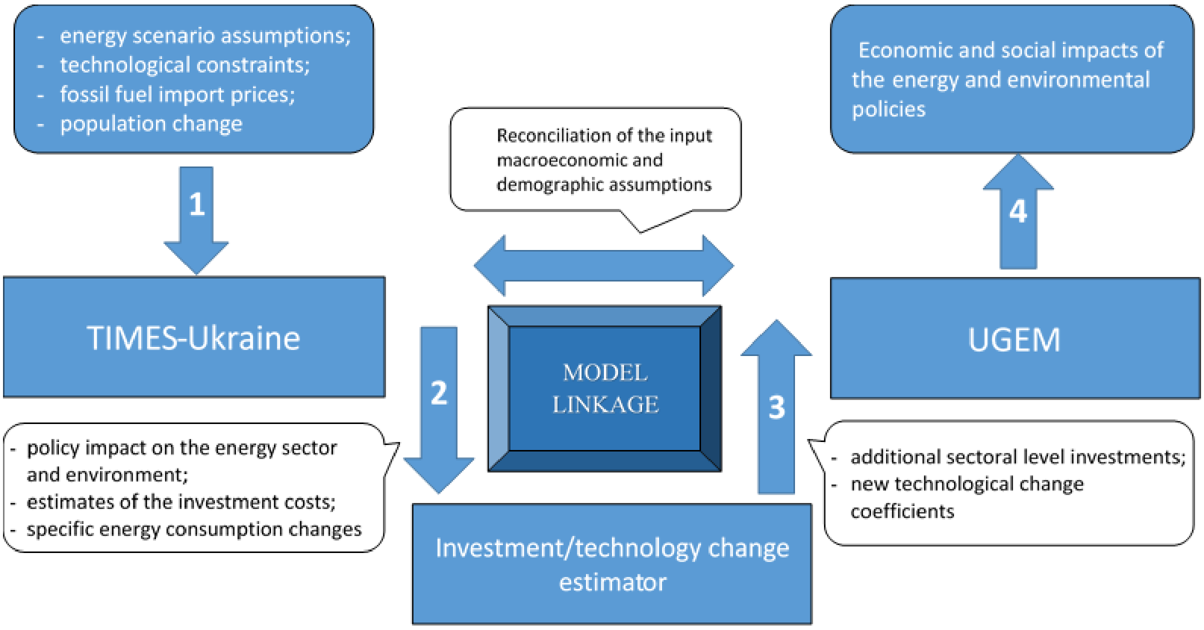

Figure A.4.4. TIMES-Ukraine and UGEM models linkage

Source: Authors.

On the *fourth step*, for each policy scenario under consideration, we implement energy efficiency improvements suggested by the TIMES-Ukraine model into the UGEM scenario runs. We impose a carbon tax in the UGEM, to match the GHG emission reductions suggested by TIMES-Ukraine. Both residential and non-residential users are subject to the introduced carbon tax. Tax revenue, collected through the imposed carbon taxes, are further allocated to industries based on the additional investment volumes estimated by TIMES-Ukraine. If carbon tax revenue exceeds required additional investments, the residual is distributed to the government.

With different approaches to the energy system representation, UGEM (top-down approach) and TIMES-Ukraine (bottom-up view) models also differ some key definitions, energy sector refinement and general framework. This creates some model linkage challenges. In particular, two modelling frameworks have different definition of investments. UGEM follows national accounts terminology and gross fixed capital formation is used to represent investments, while in TIMES-Ukraine any expenses on energy equipment or technologies are considered as investments. For instance, if household is buying a new energy efficient electric bulb or refrigerator, this is included into investments. Therefore, in the current model linkage approach, we do not include households' expenditure to the UGEM investment category, while all other investments reported by TIMES, e.g. for commercial or industrial users, are taken into account.

Models have different sectoral coverage. While UGEM covers all sectors of economy, TIMES-Ukraine provides a much more detailed coverage of the energy sectors. This creates some uncertainties in the sectoral mappings between models. In addition, some technologies represented by TIMES-Ukraine, are not explicitly

modelled in UGEM. For instance, UGEM does not have explicit representation of the carbon capture and storage (CCS) technologies, geothermal generation and electric vehicle are not considered as a separate sector (aggregated with other vehicles).
Another difference between TIMES-Ukraine and UGEM models is that TIMES chooses from the set of available technologies, so that new technologies could be introduced in the future, while UGEM operates with technologies specified in the reference year, although in the latter case, technologies could change their efficiency over time, thus mimicking introduction of new technologies or technological improvements.
Available literature suggests that in general energy system models, like TIMES-Ukraine, report lower economic costs of climate policies than CGE models, in some cases by around 60%-70%.[82]

LIST OF THE UGEM MODEL SECTORS

No.	UGEM code	ISIC rev 4 code	Description
1	crp	011, 012, 013, 015	Crop farming
2	breed	014, 017	Stockbreeding and hunting
3	breedsrv	016	Stockbreeding and hunting services
4	frs	02	Forestry
5	fsh	03	Fish farming
6	coa	05	Mining of coal and lignite
7	oil	061	Extraction of crude petroleum
8	gas	062	Extraction of natural gas
9	metore	07	Mining of metal ores
10	stone	081	Quarrying of stone; Quarrying of sand and clay
11	chmmin	0891	Mining of chemical and fertilizer minerals
12	salt	0892, 0893, 0899, 09	Production of salt; Other mining and quarrying, extraction of peat
13	cmt_omt	101	Production, processing and preserving of meat
14	fish	102	Processing and preserving of fish and fish products
15	pfv	103	Processing and preserving of fruit and vegetables
16	vol	104	Manufacture of vegetable and animal oils and fats
17	mil	105	Manufacture of dairy products
18	grain	106	Manufacture of grain mill products and starch products
19	anf	108	Manufacture of prepared animal feeds
20	ofd_bt	107, 110, 120	Manufacture of other food products, beverages and tobacco
21	tex_wap	13, 14	Manufacture of textiles and clothes
22	lea	15	Tanning and dressing of leather; luggage and footwear
23	lum	16	Manufacture of wood and of products of wood
24	pap	17, 18	Manufacture of pulp, paper and paper products
25	ppm	58-60	Publishing, printing and reproduction of recorded media
26	coke	191	Manufacture of coke oven products; nuclear fuel
27	petrol	192	Manufacture of refined petroleum products
28	bch	201	Manufacture of basic chemicals
29	agch	2021	Manufacture of pesticides and other agro-chemicals

[82] Edenhofer, O., C. Carraro, J. Kohler and M. Grubb (Ed.) (2006). Endogenous Technological Change and the Economics of Atmospheric Stabilization. The Energy Journal, Special Issue.
Timilsina, G., Pang, J., Yang, X. 2019. Linking Top-Down and Bottom-Up Models for Climate Policy Analysis: The Case of China. Policy Research Working Paper 8905. The World Bank. http://documents.worldbank.org/curated/en/426801561032910616/pdf/Linking-Top-Down-and-Bottom-UP-Models-for-Climate-Policy-Analysis-The-Case-of-China.pdf

No.	UGEM code	ISIC rev 4 code	Description
30	pvi	2022	Manufacture of paints, varnishes and similar coatings
31	pmch	21	Manufacture of pharmaceuticals, medicinal chemicals
32	och	2023, 2029	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations. Manufacturing of other chemical products
33	fib	203	Manufacture of man-made fibers
34	chem_rub	22	Manufacture of rubber and plastic products
35	glass	231	Manufacture of glass and glass products
36	cer	2391, 2392, 2393	Manufacturing of other ceramic products
37	clp	2394, 2395	Manufacture of cement, lime and plaster. Manufacture of articles of concrete, plaster and cement.
38	onmm	2396, 2399	Ornamental and building stone; other mineral products
39	bmet	24	Manufacture of basic metals
40	fmet	25	Manufacture of fabricated metal products
41	mmp	2811, 2812, 2813, 2814	Manufacture of machinery for the production and use of mechanical power
42	mgp	2815, 2816, 2817, 2819	Manufacture of other general purpose machinery
43	maf	2821	Manufacture of agricultural and forestry machinery
44	mmt	2818, 2822	Manufacture of machine tools
45	msp	2823, 2824, 2825, 2826, 2829	Manufacture of other special purpose machinery; weapons and ammunition
46	mda	27	Manufacture of electrical equipment
47	ele_nec	2610, 2620	Manufacture of office machinery and computers
48	mel	3312, 3313, 3314, 3320	Manufacture of electrical machinery and apparatus n.e.c.
49	ele_com	2630, 2640	Manufacture of radio, TV and communication equipment
50	mmpow	265, 2660, 267, 268	Manufacture of medical, precision and optical instruments, watches
51	mvh	29	Manufacture of motor vehicles, trailers and semi-trailers
52	otn	30	Manufacture of other transport equipment
53	omfm	31, 32, 3311, 3315, 3319	Manufacture of furniture; manufacturing n.e.c.
54	omfr	36-39	Recycling
55	coap	351	Coal power
56	gasp		Gas power
57	nucp		Nuclear power
58	hydp		Hydro power
59	wndp		Wind power
60	solp		Solar power
61	othp		Other power
62	gdt	352	Manufacture of gas; distribution of gaseous fuels through mains
63	hdt	353	Steam and hot water supply
64	wtr	36-39	Collection, purification and distribution of water
65	cns	41-43	Construction
66	trd	45-47	Wholesale and retail trade; repair of motor vehicles
67	accom	55-56	Hotels and restaurants
68	otp_l	49	Land transport; transport via pipelines
69	wtp	50	Water transport
70	atp	51	Air transport
71	otp_s	52	Supporting and auxiliary transport activities
72	cmnp	53	Postal and courier activities
73	telc	61	Telecommunications
74	ofi_fin	64	Financial intermediation, except insurance and pension funding
75	isr	65	Insurance and pension funding, except compulsory social

No.	UGEM code	ISIC rev 4 code	Description
			security
76	ofi_aux	66	Activities auxiliary to financial intermediation
77	rea	68	Real estate activities
78	rent	77-82	Renting of machinery and equipment without operator
79	progr	62-63	Computer and related activities
80	rnd	72	Research and development
81	legl	69-71	Legal and accounting activities
82	adve	73-75	Advertising and market research
83	govn	84	Public administration and defense; compulsory social security
84	edu	85	Education
85	healt	86-88	Health and social work
86	sew	36-39	Sewage and refuse disposal, sanitation and similar activities
87	arts	90-93	Recreational, cultural and sporting activities
88	osa	94-97	Other service activities

Production nesting structure for selected UGEM sectors

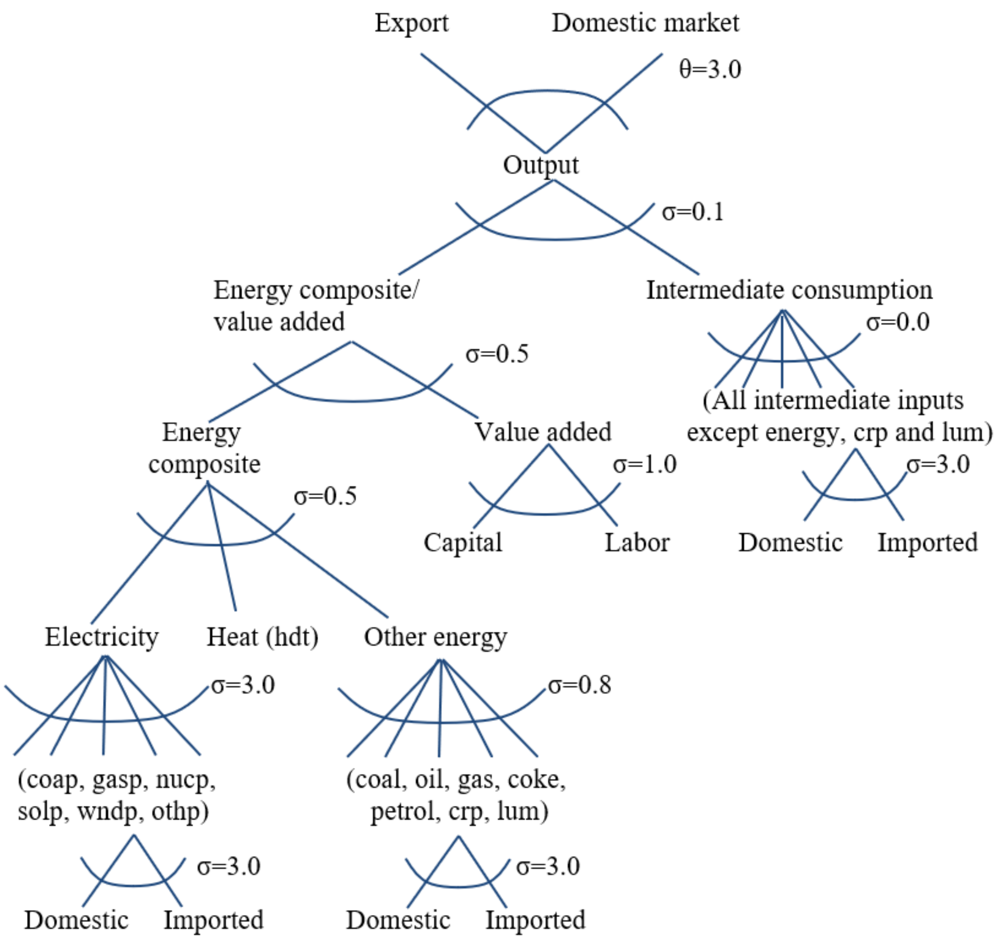

Figure A.4.5. Production nesting structure for Heat supply (“hdt”) and Other power (“othp”) sectors

Source: Authors.

Note: “σ” stands for the value of substitution elasticity in the corresponding nest; “θ” stands for the value of transformation elasticity in the corresponding nest.

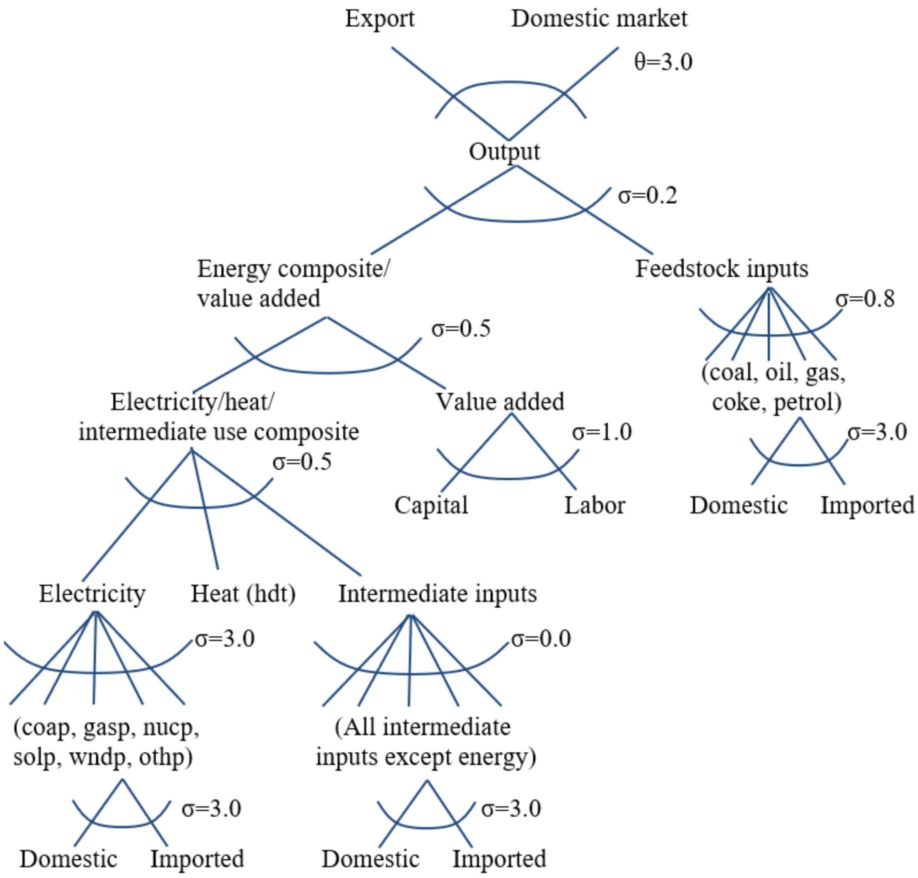

Figure A.4.6. Production nesting structure for Petroleum ("petrol") and Coke ("coke") products

Source: Authors.
Note: "σ" stands for the value of substitution elasticity in the corresponding nest; "θ" stands for the value of transformation elasticity in the corresponding nest.

Price of carbon estimated by the UGEM model under different policy options

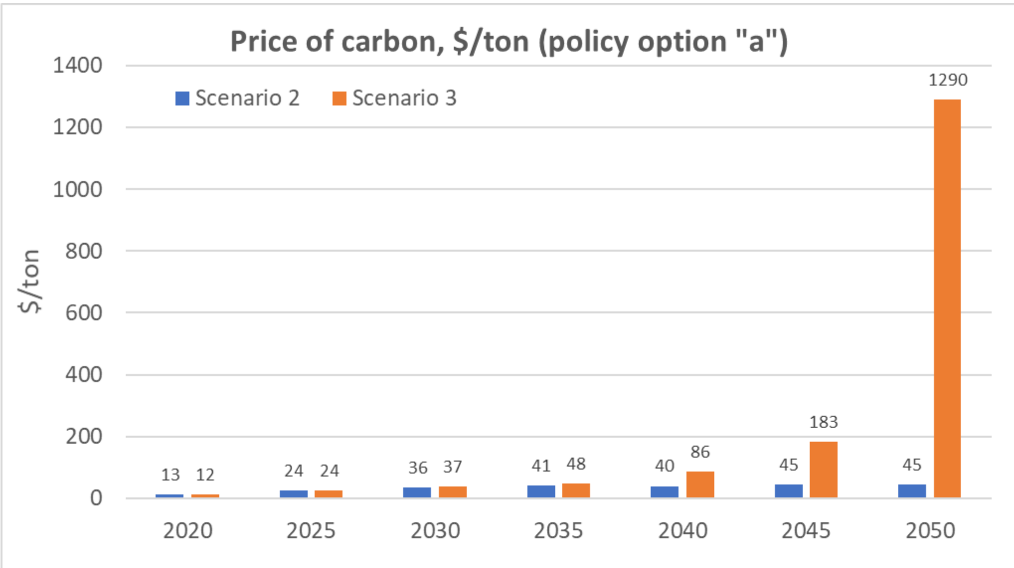

Figure A.4.7. Price of carbon under policy option "a": investment boost and energy efficiency improvements

Note: prices are reported in constant $2015.

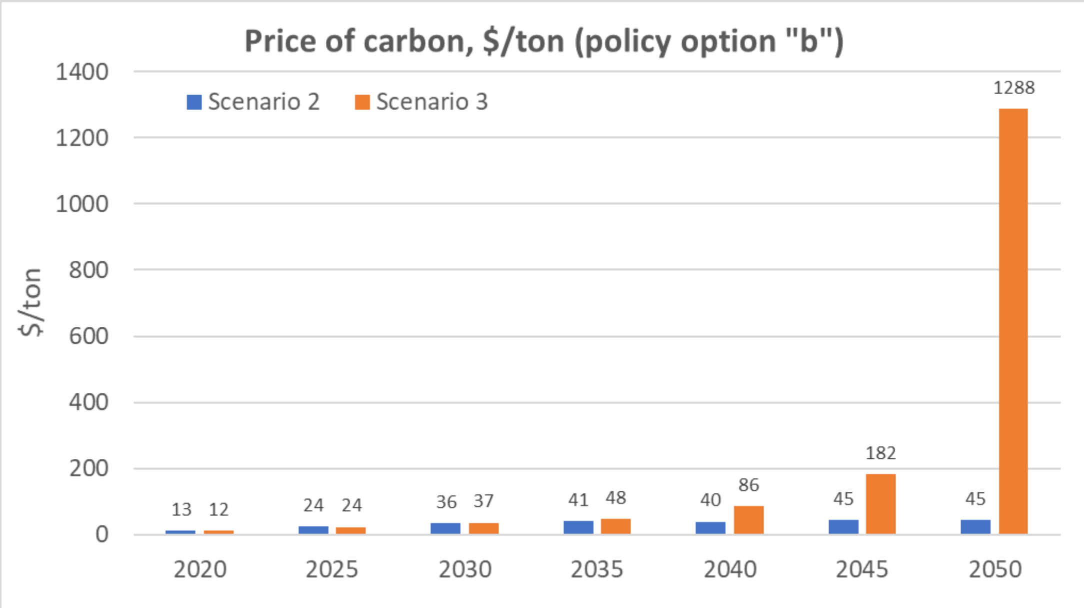

Figure A.4.8. Price of carbon under policy option “b”: impact of carbon permits export from gas sector

Note: prices are reported in constant $2015.

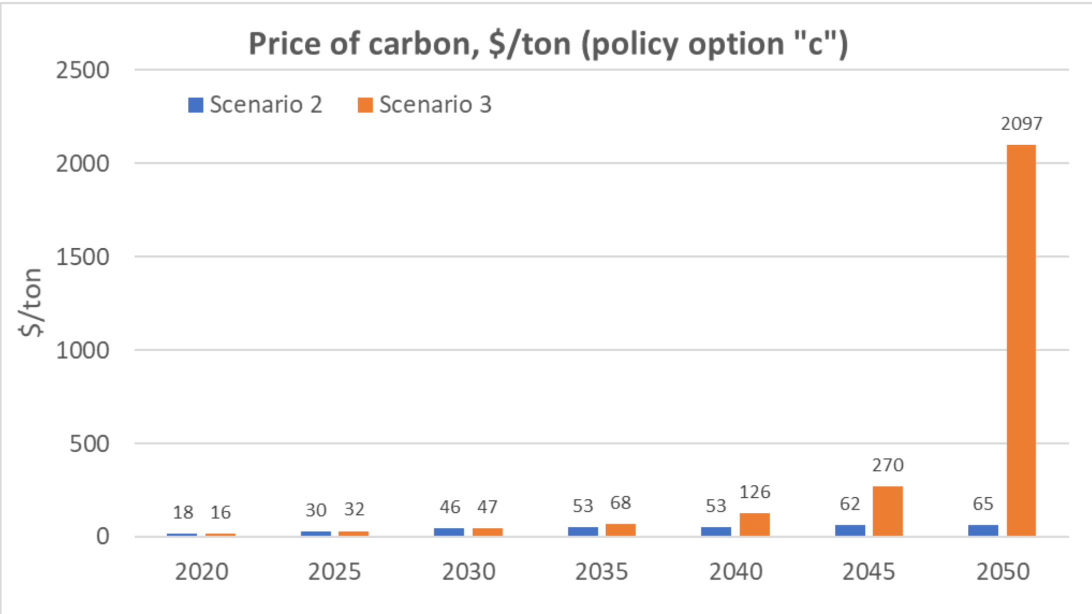

Figure A.4.9. Price of carbon under policy option “c”: no energy efficiency improvements

Note: prices are reported in constant $2015.

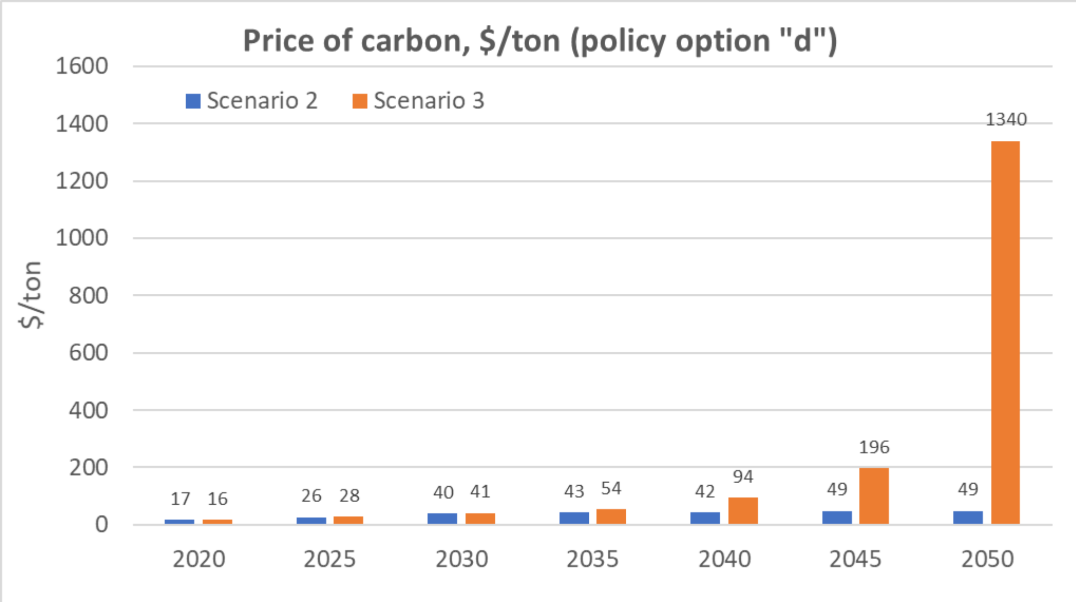

Figure A.4.10. Price of carbon under policy option "d": all carbon tax revenue stays with government

Note: prices are reported in constant $2015.

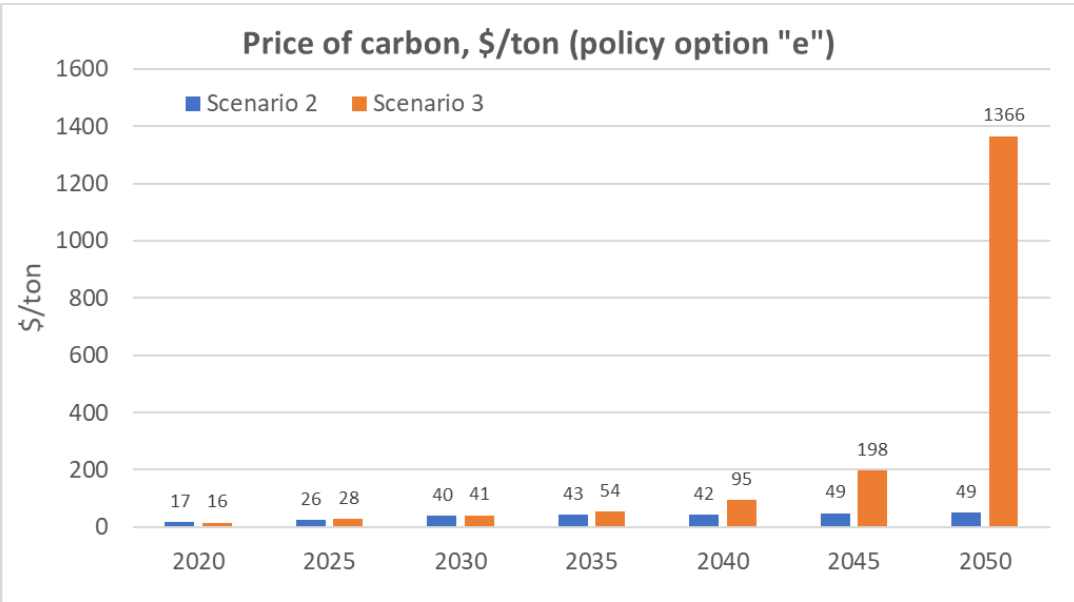

Figure A.4.11. Price of carbon under policy option "e": carbon tax revenue is reallocated to households

Note: prices are reported in constant $2015.

Additional results for the economic impact assessment

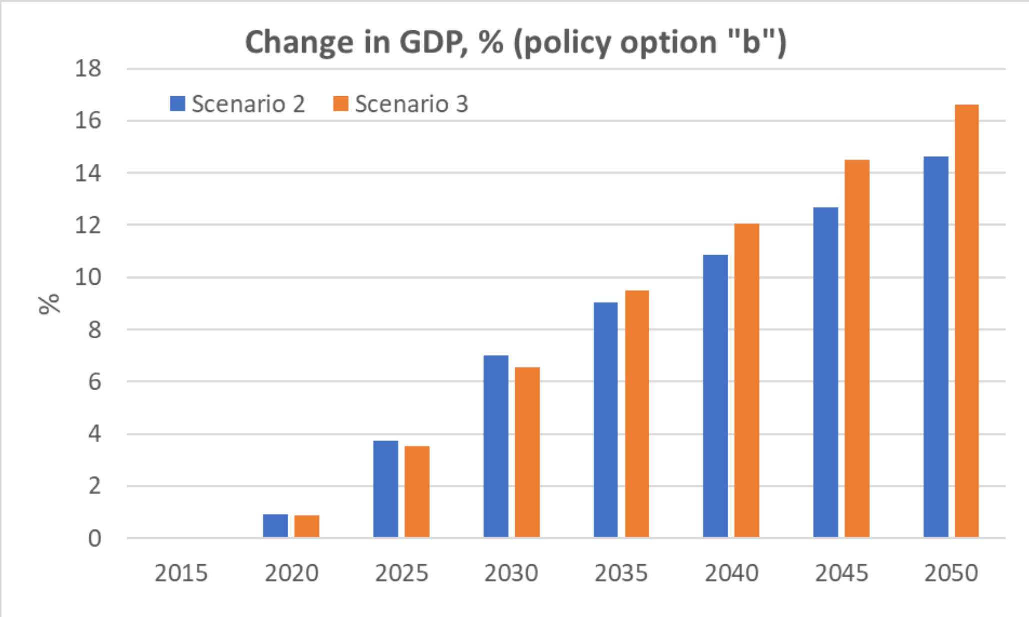

Figure A.4.12. Change in GDP under policy option "b": impact of carbon permits export from gas sector

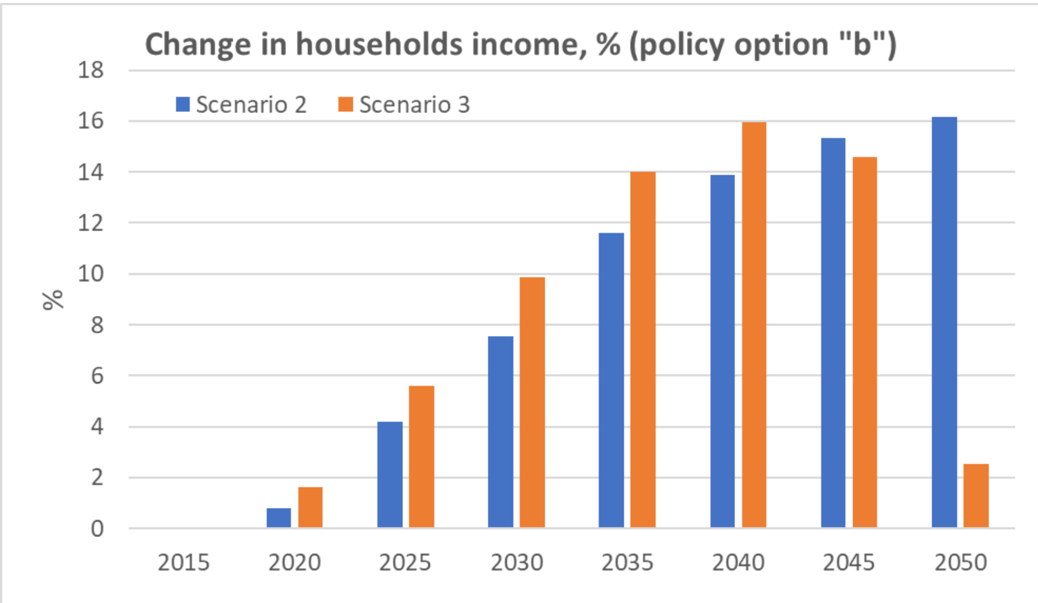

Figure A.4.13. Change in real households' income under policy option "b": impact of carbon permits export from gas sector

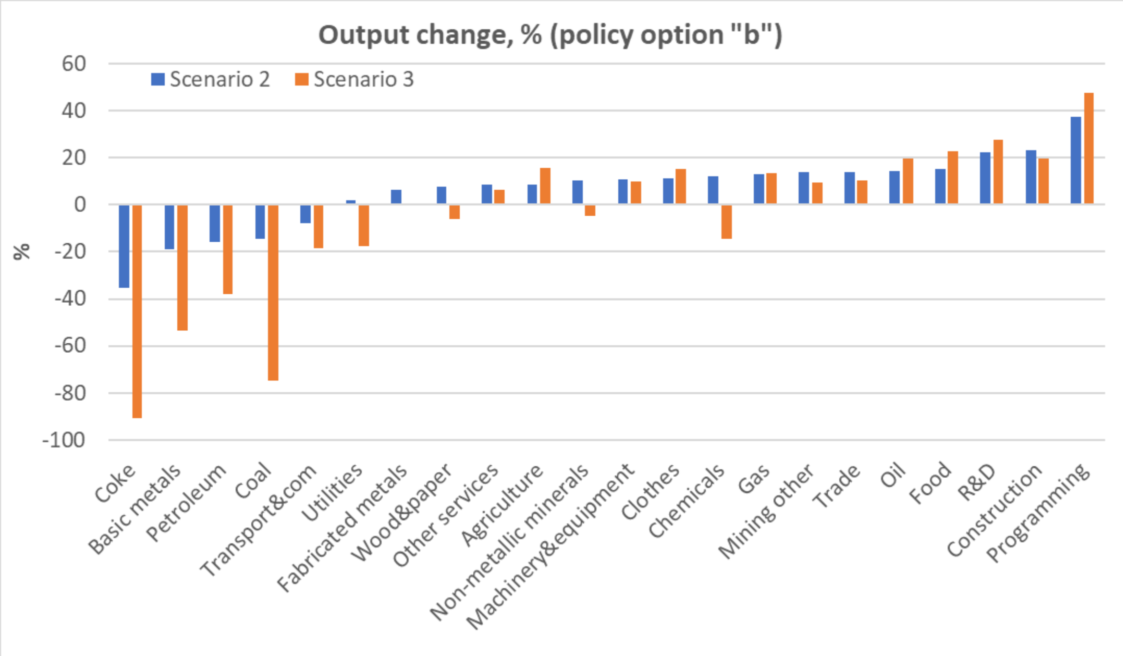

Figure A.4.14. Change in sectoral output in 2050 under policy option "b": impact of carbon permits export from gas sector

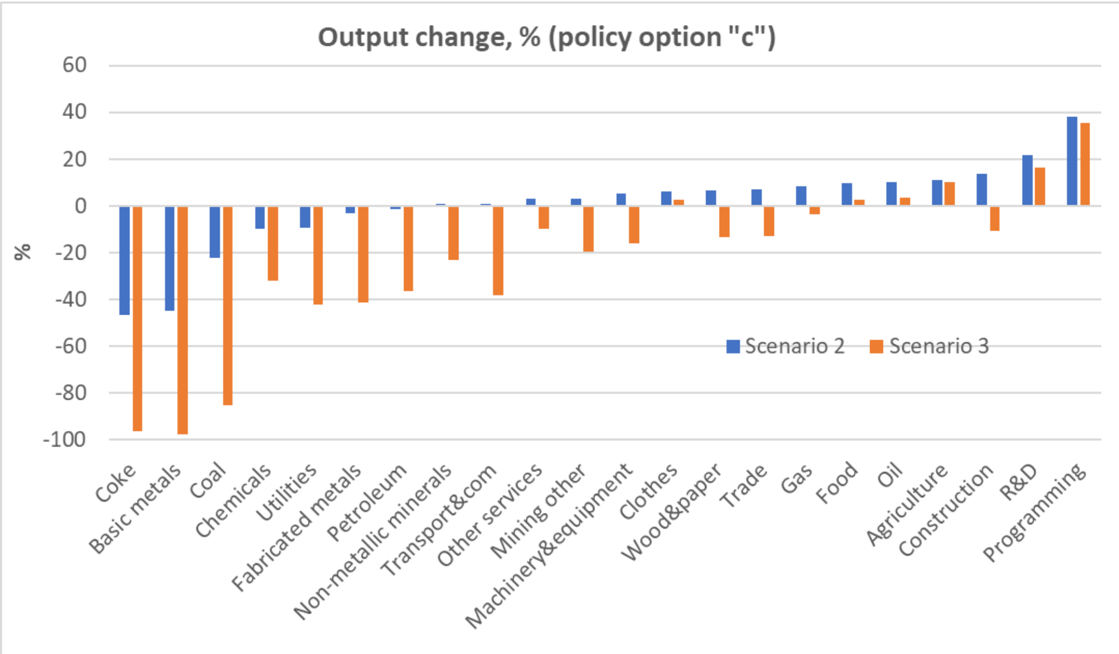

Figure A.4.15. Change in sectoral output in 2050 under policy option "c": no energy efficiency changes

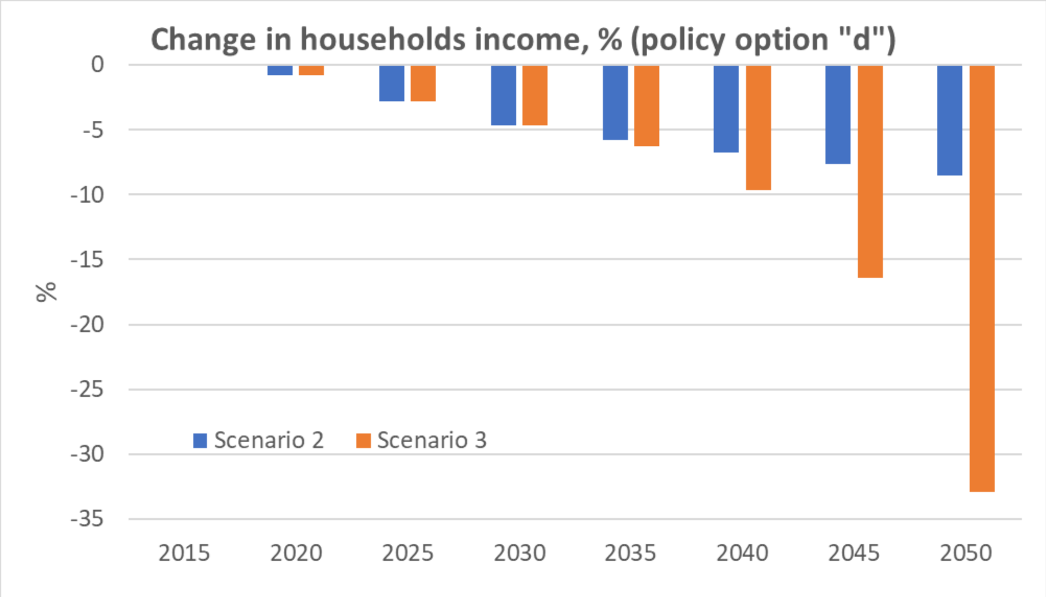

Figure A.4.16. Change in real households' income under policy option "d": all carbon tax revenue stays with government

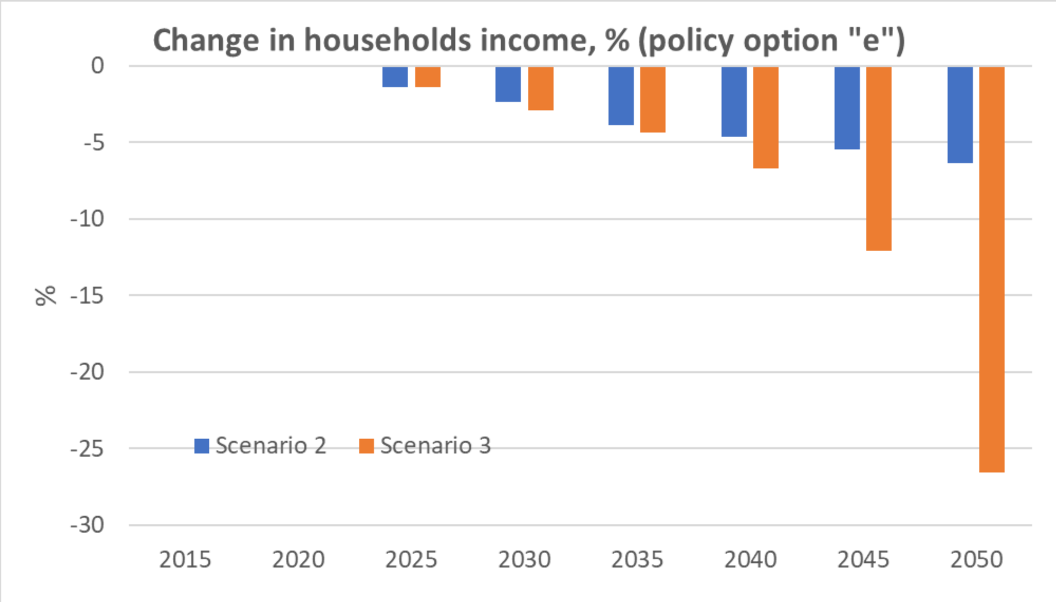

Figure A.4.17. Change in real households' income under policy option "e": carbon tax revenue is reallocated to households

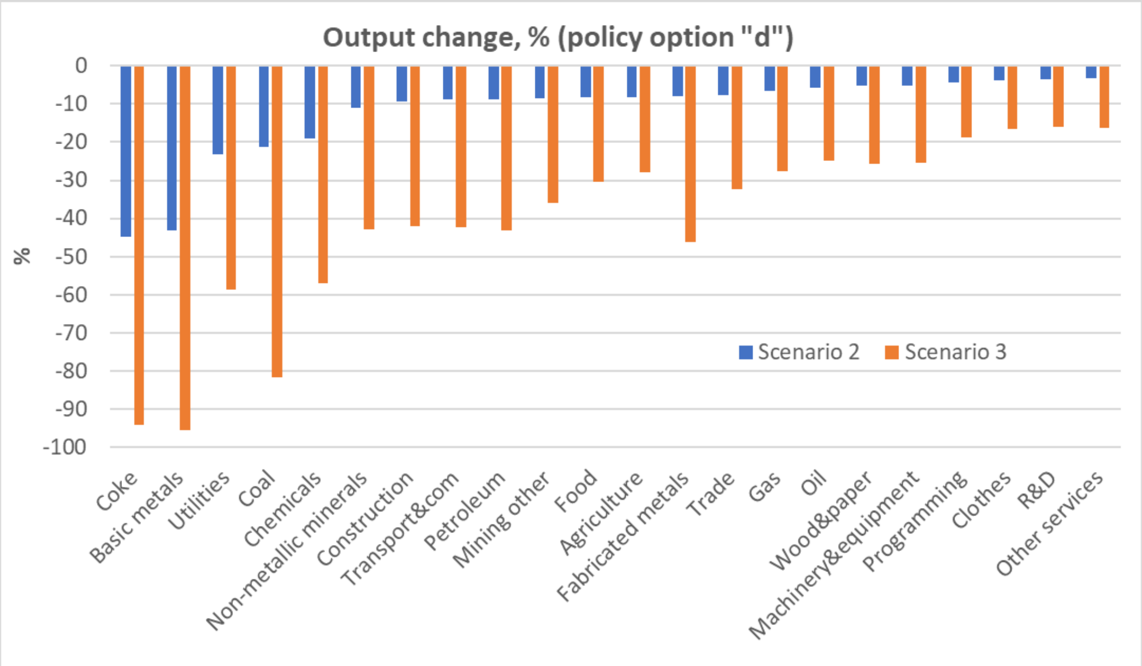

Figure A.4.18. Change in sectoral output in 2050 under policy option “d”: all carbon tax revenue stays with government

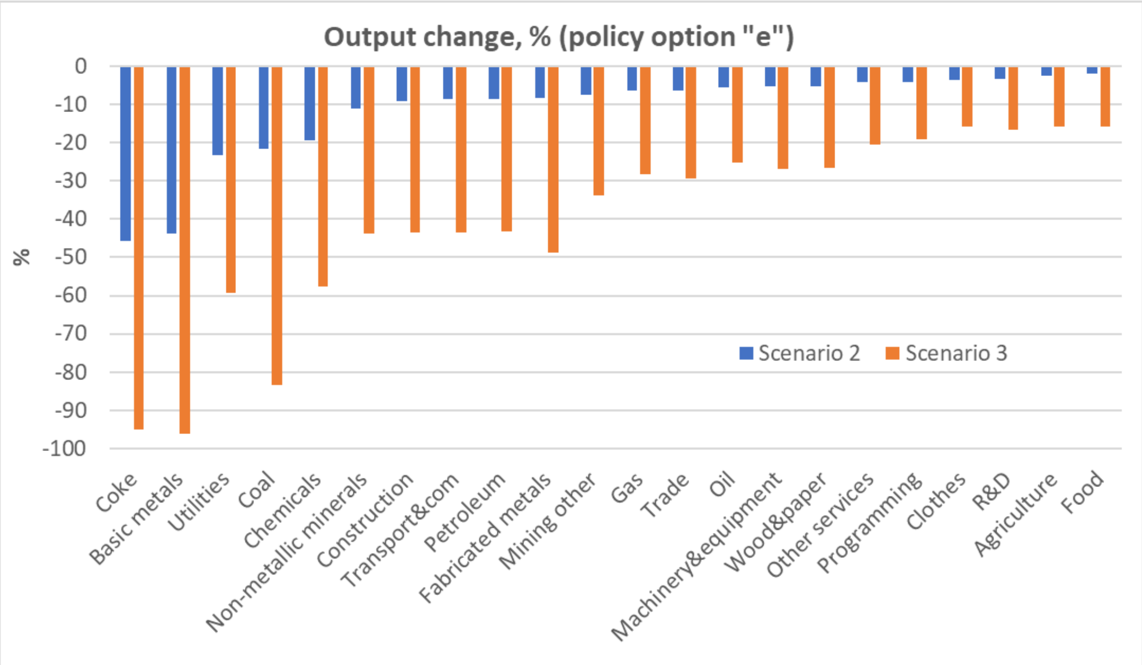

Figure A.4.19. Change in sectoral output in 2050 under policy option “e”: carbon tax revenue is reallocated to households