DOCUMENTATION

ULEAP - Ukraine's LEAP to Decarbonization

Decarbonizing Ukraine's economy requires thorough planning and stringent measures to reduce Ukraine's emissions. Modelling supports this process allowing to quantify the emission and economic impacts of alternative paths towards a carbon-neutral Ukraine. The Low Carbon Ukraine (LCU) Project implemented the well-established modelling framework "Long-range Energy Alternatives Planning system" for Ukraine (ULEAP). ULEAP models Ukraine's greenhouse gas emissions based on a detailed representation of Ukraine's energy system. In the first part, this documentation describes ULEAP's modelling approach and its underlying assumptions. The second part is dedicated to the baseline scenario describing emission paths up to the year 2050.

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0. Glossary

Base year: First year on which a scenario is based. This year represents actual emission and energy consumption values measured in the year.

Baseline: The baseline scenario depicts the development of a system if no new policies are introduced. It thus shows what would happen if everything were left to run as it does currently.

Carbon Intensity: The amount of CO_2e emitted per energy used or per US$ of GDP produced (e.g., tCO_2e/kWh or tCO_2e/US$)

CO_2e: Carbon Dioxide equivalent. The potential of gases to warm up the atmosphere is usually given in "CO2 equivalents", equating the greenhouse gas effect of a gas to that of CO2. One ton of methane for example has the same effect as appr. 25 tons of CO_2 (over the course of 100 years).

Dispatch: Managing which power plant provides how much electricity at what time. "Optimal dispatch" lowers the costs of an electricity system and causes it to emit less carbon dioxide.

Energy Economic System: This system describes the connection between classic "economic" variables like GDP and population growth and energy-relevant values such as electricity production, emissions, etc. The combination of both fields is necessary, as they are heavily entangled.

Energy Balance: Shows a country's energy supply, transformation, and consumption by energy resource and economic sector

Energy Efficiency: The amount of GDP produced per unit of energy used (e.g., US$/kWh)

Energy Industry: The industry producing energy; e.g., electricity plants, coal mines, refineries, etc.

Energy Intensity: The amount of energy used per US$ of GDP produced (e.g., kWh/US$)

Final Energy Consumption (FEC): The actual amount of energy used by final consumers. This does for example comprise the consumption of electricity, but not the amount of electricity lost during transmission, nor the amount of energy needed to produce electricity.

Non-Energy Demand for Energy Carriers: When energy carriers are used not for producing energy, but for other processes, e.g., for producing plastics, cosmetics, etc. Such usage of energy carriers can nonetheless cause emissions.

ODM: Optimal Dispatch Model, developed by LCU

Scenario-based model: A model that is able to calculate different scenarios for the future development of a system (e.g., a climate friendly scenario vs an emission-intense scenario).

Total Primary Energy Supply (TPES): The absolute and total amount of energy fed into a country's energy system over the course of a year.

1. Executive Summary

Decarbonizing Ukraine's economy requires thorough planning on the way and stringent measures to reduce Ukraine's emissions. To support this process, the Low Carbon Ukraine project (LCU) has implemented ULEAP, based on the well-established modelling framework "Long-range Energy Alternatives Planning system" (LEAP). Ukraine's LEAP model (ULEAP) allows to quantify the emission and energy consumption levels of alternative economic paths towards a carbon-free Ukraine.

ULEAP models Ukraine's greenhouse gas emissions based on a detailed representation of Ukraine's economic system. It accounts for the economic activity of Ukraine, disaggregated by sector, then calculates the resulting sectoral energy use and the sectors' emissions. Starting from a base year, changes in economic activity, energy use and emissions are modelled with underlying assumptions of population and GDP growth as well as sectoral changes in energy consumption and emission intensity per use of energy.

Importantly, ULEAP is a scenario-based energy-environment modelling tool. It allows to compare different possible trajectories of economic activity, energy use and emissions while making assumptions transparent. ULEAP can thus be used to answer questions such as:

a) How do different assumptions on population and GDP growth, sectoral economic activity, efficiency gains or fuel switching affect future emissions?

b) What sectoral emission reductions are necessary to reach different economy-wide emission reduction targets?

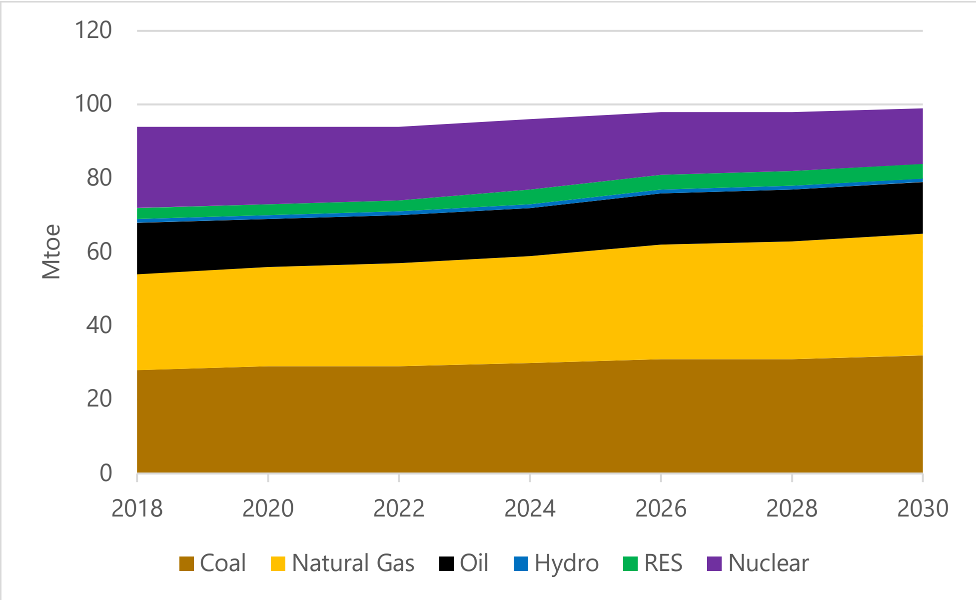
c) How can these sectoral emission reductions be achieved (fuel switching, efficiency gains, reduction of activity)?

d) Or, more concretely: How much electricity will Ukraine's steel sector consume in 2030, if it switches entirely to Electric Arc furnaces? How much electricity will be needed for hydrogen production if the steel sector switches to using only hydrogen for the reduction of iron?

In a first step, we have employed ULEAP to model a "baseline" scenario for Ukraine's emissions trajectory up until 2050. This enables us to model the effect of policies that change the energy efficiency or emission intensity in certain sectors, comparing them to the baseline scenario.

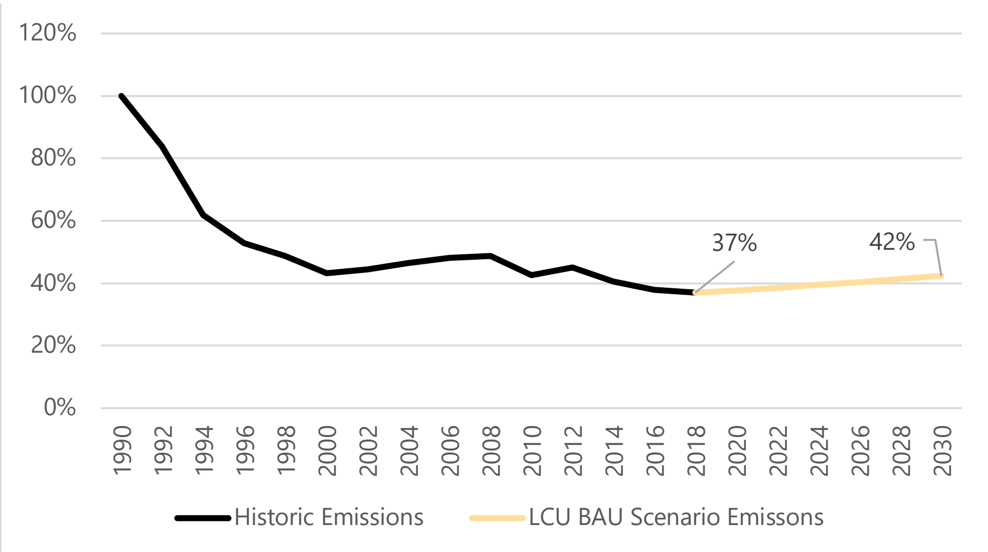
LCU's baseline scenario employs the same assumptions on projected population growth and sectoral economic development as the NASU Institute for Economic Forecasting in support of the draft second NDC. LCU's baseline therefore reaches similar results for energy consumption and emission level projections until 2030. It is thus well-grounded within the current Ukrainian policy debate. However, the LCU team then further calibrated the baseline projection through interviews with several sectoral experts in Ukraine's most important economic fields, such as the steel sector, the residential building, the electricity and the agricultural sectors. Our research culminated in the following projection of emissions and energy consumption until 2030. For a more detailed overview, please compare Figure 1, Figure 7 and chapter 5.

Figure 1: **Total Primary Energy Supply LCU BAU scenario**



Source: own calculations.

Figure 2: **Historic and future GHG emissions, projected under the LCU BAU Scenario**



Source: UNFCCC and own calculations.

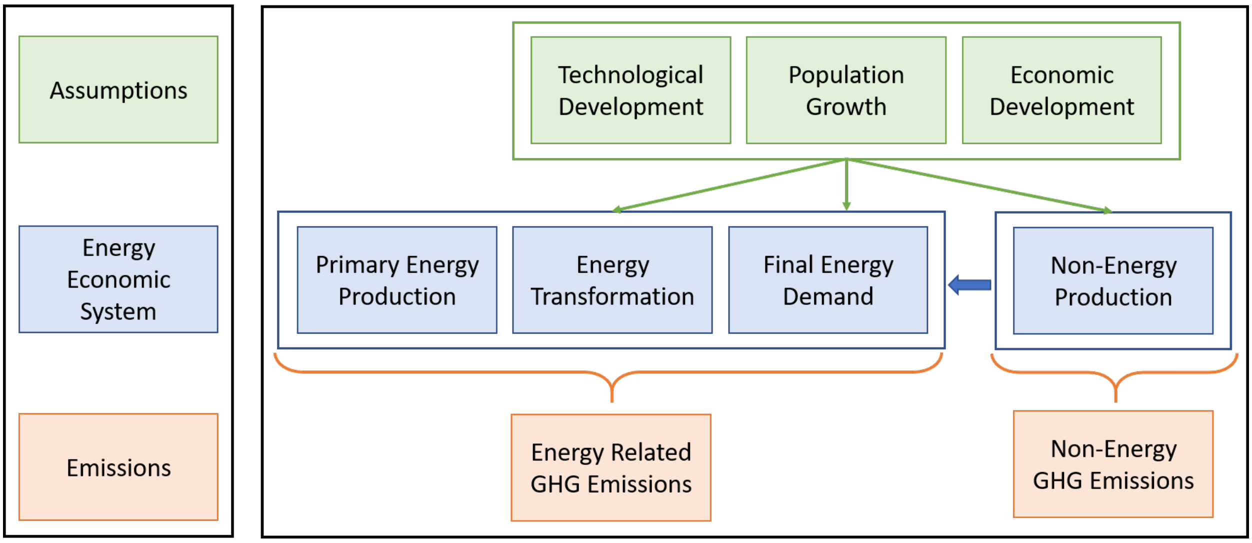
Note: Shown are historic and projected emissions of Ukraine (without temporarily occupied territories).

2. Overview

Ukraine LEAP (ULEAP) is a scenario-based energy-environment modelling tool.[1] Depicting the rich interdependences of Ukraine's energy system, it comprehensively accounts how energy is produced, transformed, and consumed. Energy consumption together with emission factors – differentiated by energy source and economic activity – determine greenhouse gas (GHG) emissions. ULEAP's base year is 2018 and its results reproduce observed official energy, emissions, and economic statistics of the Ukrainian economy. Emissions are then projected into the future based on assumptions on the population growth, economic development, and technological development.

Figure 3 provides an overview of the modelling approach. The heart of ULEAP is the model of the energy economic system (blue layer). Given energy demand and technological characteristics of the supply side, ULEAP determines the energy production and transformation.

Figure 3: ULEAP Modelling Approach



Source: Own depiction.

Note: Assumptions (green) impact the future energy economic system (blue) and thereby greenhouse gas emissions (orange).

Ukraine's electricity plants, resource producers and importers supply all the energy demanded by Ukraine's economy. To calculate the energy demand of the economy, ULEAP first assesses the economic activity of all sectors. The economic activity together with each sectors' energy efficiency and intensity determines final demand. ULEAP then calculates the level of energy production equating demand and supply. Some energy is lost in production processes or during transport. ULEAP calculates energy demand on an annual level.

[1] ULEAP is a variant of the LEAP model (SEI, 2005).

Energy supply is modelled by primary energy production including extraction and imports and its transformation to secondary energy. Due to the large share of electricity sector emissions in Ukraine's total GHG emissions and due to the central role of electricity to decarbonize the economy, ULEAP's transformation step puts a special focus on electricity generation. ULEAP's electricity generation therefore relies on LCU's detailed electricity sector model ODM (Meißner, 2020). ODM models all power plants for each hour in a given year taking into account technical flexibility restrictions as well as constraints imposed by the electricity transmission grid.

The emissions layer (orange) calculates GHG emissions based on the results of the energy economic system. For this ULEAP closely follows the IPCC Guidelines applying emission factors differentiated by energy resource and economic activity. Providing a holistic view on Ukraine's GHG emissions, ULEAP also includes non-energy GHG emissions such as methane emissions from agriculture and process emissions of industries.

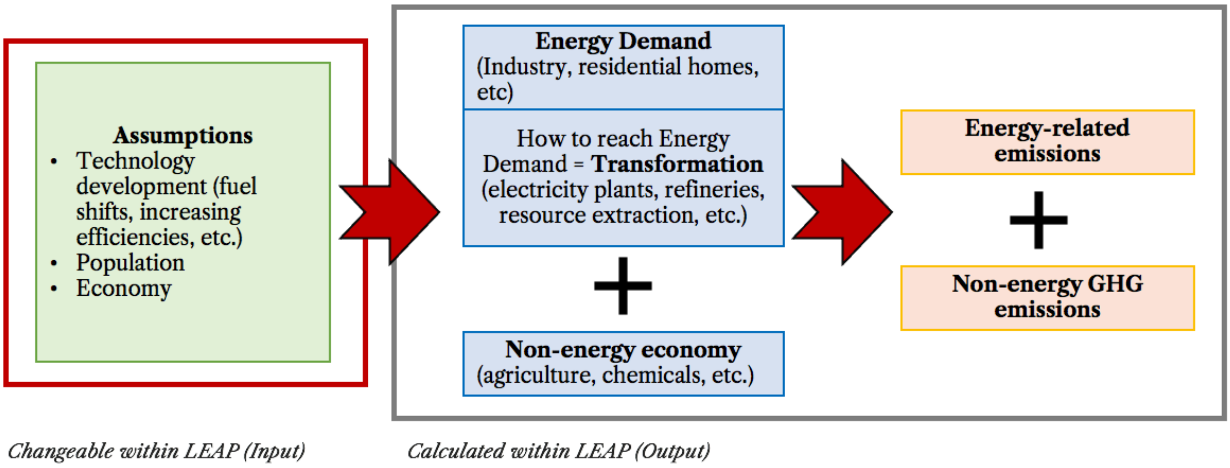
The assumptions layer (green) determines ULEAP's future emissions' projections. Whereas the core model reproduces official energy, emissions, and economic statistics of the year 2018, further exogenous assumptions are needed to project possible emission pathways up to the year 2050. These assumptions come in three categories: Population, economics, and technological development.

Population growth determines Ukraine's future population size. Population size directly drives energy demand through the residential sector. If the population increases, energy demand for heating and cooking as well as for private transportation increases as well. Likewise increasing population, also indirectly drives energy demand by increasing the demand for non-energy products and, in turn, non-energy sector's energy demand. The development of the population thus impacts emission development through energy demand changes as well as through changes in non-energy GHG emissions.

We consider two major classes of assumptions on economic development: Growth of the Gross Domestic Production (GDP) as well as the allocation of domestic production across economic sectors. Like population growth, development of GDP affects energy demand directly as well as indirectly through non-energy sector activities. An increase in GDP increases disposable income and, thus, increases demand for energy and non-energy products leading to an increase of GHG emissions. Assumptions on the allocation of total production across sectors determine how different sectors are affected by the change in GDP.

Technological development drives energy and emission development in two major ways: energy efficiency and carbon intensity assumptions. Energy efficiency assumptions determine how the production activities translate into energy demand. If energy efficiency increases, energy demand and, thus, emissions decrease for a given level of production. Carbon intensity assumptions reduce emission for a given energy demand. This occurs through a switch of production technologies towards low or carbon free energy sources, e.g., transitioning towards renewable energies for electricity production.

Figure 4: LEAP input vs. output



In the remainder of this documentation, we describe each of the layers of the ULEAP model in detail. We begin with an in-depth description of ULEAP's core energy, emissions, and economic system. This includes on the one hand a transparent exposition of the modelling approach. On the other hand, we describe ULEAP's base year results, i.e., Ukraine's energy production and demand along with GHG emission in the year 2018. This description of the base year is followed by transparently explaining our approach to project Ukraine's emissions into the future. This contains a discussion of our assumptions for the baseline development up to 2050 as well as the presentation of energy and emission development along the implied baseline path.

3. Energy Economic System

3.1 Overview

ULEAP relies on three main building blocks: Resources, transformation, and demand. The resource block determines primary and secondary energy sources used in the model together with their availability in the form of reserves and international trade capacities. The transformation block describes technologies to convert primary to secondary energy sources. The demand block specifies the activity of industry and residential demand and, thereby, the demand for energy products.

Before providing a detailed description of the modelling of each of these building blocks in the subsequent subchapters, we provide an overview over the main data sources. Modelling the energy, emissions, and economic system in ULEAP requires specifying the economic activity level of residential and industrial sectors, their energy efficiency as well as the carbon intensity of energy transformation, in particular electricity generation. We measure these variables based on several main data sources:

- *Energy balance*: Measures energy supply, transformation, and consumption by energy resource and economic sector (UKRSTAT, 2018b).

- *Common Reporting Format*: Ukraine's emissions reported to the UNFCCC. This reports GHG emissions by activity and fuel source (UNFCCC, 2020). It is based on the energy balance but also provides further (dis)aggregation useful to replicate Ukraine's official emission accounts.
- *Input-output table*: Measures economic activities by industrial sector in monetary values (million UHA) (Ukrstat, 2018a).
- *Transport statistics*: Measure private and industrial transport activities in terms of person and tonne kilometres by transport mode (Ukrstat, 2018c).

3.2 Resources

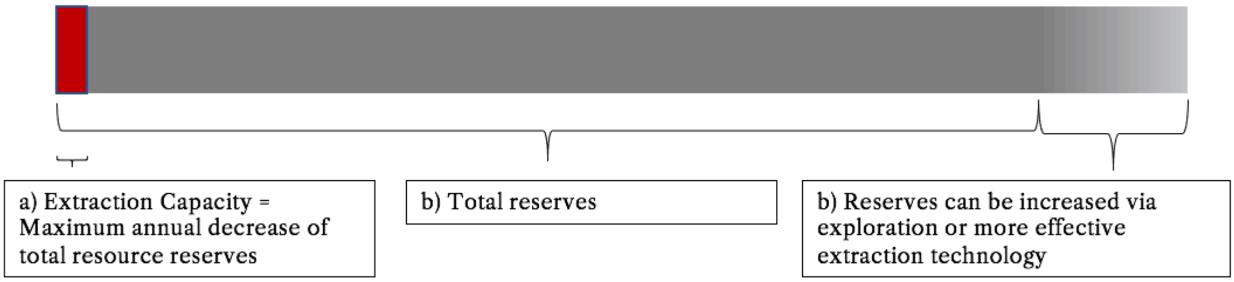
ULEAP includes eight primary energy sources including three fossil (coal, crude oil, and natural gas), four renewable sources (biomass, hydro, solar, and wind) and nuclear energy (see Table 1). Apart from electricity and heat, secondary energy sources include four types of refined oils. Diesel, gasoline and liquefied petroleum gas (LPG) are used in transportation and *oil* signifies other refined oils.

Table 1: Energy Resources in ULEAP

Primary Energy Sources		Secondary Energy Sources	
Fossil Fuels	Coal	Diesel	Refined Oils
	Crude Oil	Gasoline	
	Natural Gas	Liquefied Petroleum Gas (LPG)	
	Nuclear	Oil	
Renew-ables	Biogas	Hydrogen	
	Biomass	Heat	
	Hydro	Electricity	
	Solar		
	Wind		

Modelling primary energy supply requires imposing production capacities as well as rules for the case of capacity shortages. For fossil fuel resources, nuclear, and biomass energy, we assume extraction and production capacities to equal domestic production observed in the base year 2018 energy balance (see Table 3). ULEAP also accounts for Ukraine's currently available reserves for coal, oil, uranium and natural gas, which are depleted over time in a forward-looking scenario. Moreover, if capacity is not sufficient to meet demand, imports satisfy the demand shortfall. Primary energy resource production is thus limited by a) total capacity which can be extracted over time and b) the annual production capacity of Ukraine's resource extraction facilities. a) describes the totally available resources in Ukraine and changes over time when resources are extracted or new sources discovered. b) is measured in annual terms and only changes when new facilities are being constructed or old ones destroyed.

Figure 5: **Resource Extraction Example**



Supply of renewable resources (hydro, solar, and wind power) is unlimited in capacity but restricted by installed transformation capacities (e.g., hydro, wind, and solar power plants, see subsequent section).

Secondary energy is either imported or supplied by domestically transforming primary energy. ULEAP relies on imports once the domestic transformation capacities are exhausted (see subsequent section).

3.3 Transformation

ULEAP's transformation block describes the domestic transformation of primary to secondary energy sources. It consists of three subcategories. Electricity generation, heat generation, and refineries. As a fourth category we also include losses and statistical differences in the transformation block, following the Energy Balance.

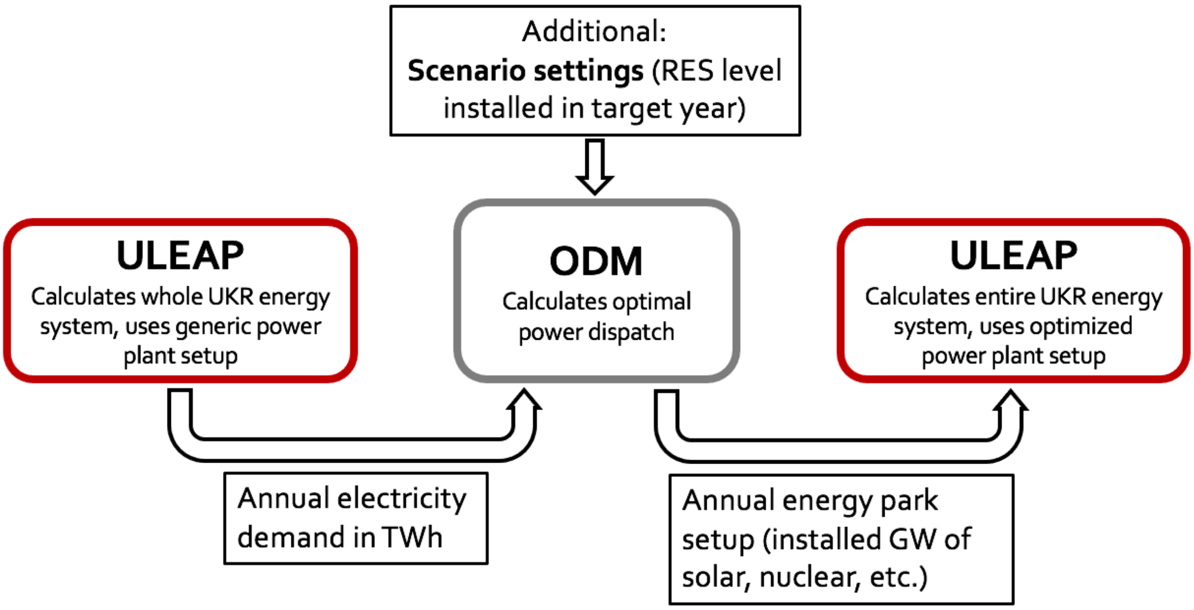
3.3.1 Electricity Generation

Electricity generation is of major importance to decarbonize Ukraine's economy; not only because of the high share of coal generation but also because of the need for electrification to decarbonize industries and transportation. We rely on LCU's Optimal Dispatch Model (ODM) to model electricity generation. ODM is a detailed electricity market model. As a unit-commitment model, it models all power plants in the Ukrainian market in detail including technical flexibility restrictions. Furthermore, ODM uses a cascading hydro approach for hydro power. Using a direct-current load-flow approximation, ODM also includes electricity grid constraints.

We integrate ODM into ULEAP by soft-coupling the two models in three steps. First and already using Ukraine's installed generation capacities, we solve ULEAP to determine annual electricity demand. Second, we pass annual demand to the ODM, to scale it with an existing hourly load profile for Ukraine. ODM determines the optimal dispatch of power plants. We pass the share of annual demand satisfied by the respective generation technology (coal, gas, nuclear, or renewable generation) back to ULEAP. In the third step, we do a final run of ULEAP using these shares to determine the demand for energy source and, thus, emissions of the power sector. Note that in this second ULEAP run demand remains at the level as in the first run but the composition of electricity generation and therefore fuel and emissions demand changes.

The ODM model description (Meißner, 2020) describes the electricity system model in detail. It also provides data sources for the electricity supply side, as well as for hourly electricity demand. Annual electricity demand in LEAP is endogenously derived based on the different demand blocks (see subsequent section) and calibrated based on Ukraine's energy balance and the UNFCCC Common Reporting Format. To determine fuel demand and emissions, we need to determine the efficiency of the different generation technologies. Whereas ODM relies on disaggregated power plants, LEAP models technologies. We therefore average ODM's efficiencies over plants within a technology class to determine the efficiencies for ULEAP. Provided fuel demand, applying UNFCCC's emission factors then yields the electricity sector's emissions.

Figure 6: LEAP-ODM Link



3.3.2 Heat Generation

ULEAP allows for two major classes of heat production: Pure heat plants and Combined Heat and Power (CHP) production. The heat demand stemming from the demand module (see subsequent section), is served by CHP and heat plants. For modelling purposes, we introduce a CHP capacity which is dispatched first, while the rest of the heat demand is served by heat plants. For this purpose, heat plants have unlimited capacity.

Once supply by power plant class is determined, we specify the supply per energy resource using the percentage shares of the energy balance. The energy balance allows calculating the shares of burning coal, gas, oil, biomass, and nuclear fuel in either pure heat or CHP plants. For CHP plants, we also need to account for electricity as a by-product. We derive this by-product efficiency also using the energy balance. Using UNFCCC's emission factors, we then determine the emissions of heat production by class and technology.

3.3.3 Refineries

Refineries transform crude oil inputs into different refined oils, including transport fuels (diesel, gasoline, and LPG), and other forms of oil.

In order to calculate the total possible output of the refineries in terms of refined oils, we use the maximum average annual output over the last years. The transformation efficiency, i.e., the amount of the crude oil needed to provide one unit of refined oil is parameterized based on the energy balance. Thus, we receive the crude oil demand by refineries. The output is differentiated into gasoline, LPG and oil products ("oil" in ULEAP). The country's diesel demand is served to 100% by imports.

Deriving GHG emissions of refineries is a complicated process and we therefore cannot simply rely on UNFCCC emission factors. Instead, we calibrate our aggregated refinery emission factors to meet emissions as reported in the UNFCCC CRF data.

3.3.4 Transmission Losses, Energy Sectors Own Demand, and Statistical Differences

Transmitting energy causes losses. We include these losses for primary and secondary energy sources determined as percentage share of the respective resource supply (e.g., 8% of all supplied electricity is lost). For this we derive losses as share of the respective transmission sectors' output based on the energy balance. These percentage shares for losses are calibrated to produce losses observed in the energy balance.

Natural gas transportation losses due to pipeline leakage cause significant GHG emissions, for which we account. According to the U.S. Department of Energy (2015), natural gas lost into the atmosphere consists of 98% methane and 0.5% CO_2.

Besides supplying energy, the transformation sector also consumes energy sources. We include the energy sectors' own demand by determining the total energy demand of the Ukrainian energy industry and splitting it into different fuels, following the energy balance.[2]

To resemble Ukraine's energy balance in the base year as close as possible, we include reported statistical differences. These differences, which are anyways rather small, are only included in the base year and assumed to fade-out afterwards. We follow the same approach for transfers as reported in the energy balance. Both, statistical differences as well as transfers, are assumed to be emission-neutral.

3.4 Demand

ULEAP's demand modeling approach requires specifying the activity level for each agent, i.e., sector. Given the demand level, energy efficiency together with fuel composition assumptions determines the demand for energy sources.

We distinguish four main demand categories. Industry and residential energy, transport energy demand, and non-energy demand.

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[2] For technical reasons, own demand of the energy industry is implemented in LEAP's demand side. We decided to include it in this section of the documentation, as it is traditionally reported in the transformation section of energy balances.

3.4.1 Industries

ULEAP includes twelve industry sectors and an additional sector for activities not further specified. During the development, the selection of industries was guided by data availability. As we determine industries activity level in monetary units but energy demand and emissions in physical units, the selection of industries constitutes the intersection of sectors provided in the national accounting system, the energy balance, and the UNFCCC CRF.

Table 2: **ULEAPS's industry sectors**

Sector	GDP Share	Sector	GDP Share
Agriculture and Forestry	10.5%	Non-Ferrous Metals	0.6%
Chemical and Petrochemicals	3.1%	Non-Metallic Mineral	0.8%
Commercial and Public Services	54.4%	Paper, Pulp, and Printing	1.0%
Construction	2.9%	Textile and Leather	1.1%
Food and Tobacco	8.6%	Transport Equipment	1.6%
Iron and Steel	2.0%	Wood and Wood Products	1.0%
Machinery	0.9%	Not Further Specified	1.8%
Mining and Quarrying	6.5%		

Notes: Own calculations based on Ukrstat (2018a). Upper part is implemented in ULEAP's industry class, lower part in other sectors. Numbers do not add up to 100 as GDP share of energy sectors is not listed.

For each industry we derive the share in GDP in 2018 using the input-output table at basic prices. Applying these shares to total GDP (3'560 billion UAH in constant 2010 UAH) we derive each sectors activity level in monetary units. To derive sectors' energy intensity, we divide total energy demand as provided by the energy balance by the sector activity level. The demand for each energy resources is then calculated again based on the energy balancing using demand for each fuel divided by total energy demand. Once energy demand by fuel resource is determined, UNFCCC emission factors are used to determine GHG emissions.

3.4.2 Residential

We observe residential energy demand in the energy balance as well as energy demand for each energy source. This allows us to determine the energy resource composition. ULEAP measures the residential activity level in population.

3.4.3 Transportation

ULEAP distinguishes three major classes of transportation: Private and freight transportation and natural gas transportation using pipelines.

We measure private and road transportation in passenger- and ton-kilometre, respectively. For private transportation, ULEAP includes four transport modes: Individual transport using cars and public transport in the form of buses, trains, and domestic aviation.[3] ULEAP's freight transportation module covers freight transportation using roads, rails, or inland waterways.[4]

Whereas we have detailed information about the activity level of private and freight transportation, we lack data on disaggregated energy demand. The detailed energy balance by product provides demand for different refined oils (diesel, gasoline, and LPG) and electricity by transport model. However, we have no information about the share of these demand dedicated to private and freight transportation. As navigation (inland waterways) demand is fully dedicated to freight (private) transportation, we only have to split demand by road and rail transportation. Rail transportation uses mainly electricity and a minor share of diesel which we assume to be freight transportation. Using efficiency factors provided by (Pagenkopf et al., 2019), we convert diesel demand to ton-kilometres and deduct this demand from the total freight activity level. Electricity demand is then allocated across private and freight transportation transforming activity data into energy demand using named efficiency factors and finally splitting electricity demand proportionally between freight and passenger transport.

Splitting road transport's energy demand across cars, public road transport, and freight transport follows a similar approach. According to the energy balance by product, road transport consumes diesel, gasoline and LPG. We assume that public road transport, i.e., busses, and freight transport exclusively run on diesel, leaving gasoline and LPG for private cars. Given efficiencies of Pagenkopf et al. (2019), we derive diesel demand for busses and freight transport. Deducting these values from total diesel demand by road transport, the residual share is allocated to private cars. For all transport modes, we use IPCCC's default emission factors to derive GHG emissions.

According to the energy balance, pipeline transport mainly consumes natural gas and a minor amount of electricity and refined oils. We use these observations to model the fuel composition of energy demand of pipeline transport. We do not observe how many cubic meters of natural gas have been transported. Thus, we use total Ukrainian natural gas demand as a proxy for the pipeline activity.

3.4.4 Non-Energy Demand

Non-energy demand signifies the demand for energy resources that is not used for combustion but as a process input. ULEAP couples these demands to the activity level of the respective industry. The energy balance provides the demand for energy resources. As these demands are not used as combustion fuel, we do not associate emissions with it.

[3] Train transportation includes private transport using trams and subways. Ukraine's transport statistics report a tiny share of private water transportation (~0.03%). We exclude this, to facilitate splitting of energy demand.

[4] Transport statistics report about 0.1% of freight transport using aviation. Due to the small share, we exclude this mode to facilitate the splitting of transport energy demand.

3.5 Non-Energy Emissions

ULEAP's detailed energy-economic modelling approach allows determining GHG emissions caused by fossil fuel usage. ULEAP also includes non-energy related GHG emission but in a less comprehensive way. UNFCCC CRF reports non-energy GHG emissions by economic sector. As the activity of these sectors is already included in the industry demand module, we derive emission factors for non-energy CO_2, CH_4 and N_2O emissions based on reported emissions and tie them to these activity levels.

4. Base Year: Ukraine's Energy System and Emissions in 2018

In this section we describe energy demand and supply and the resulting GHG emissions in ULEAP's base year 2018. Provided that ULEAP aims to model the Ukraine energy system as close as possible to replicate official statistics, most of the information presented replicates official statistics.

As a first overview Table 3 presents the energy balance in aggregated form. In subsequent sections, we present ULEAP's base year results of each part of the energy balance, i.e., supply, transformation, and demand, in greater detail.

Table 3: **Ukraine's Energy Balance in 2018**

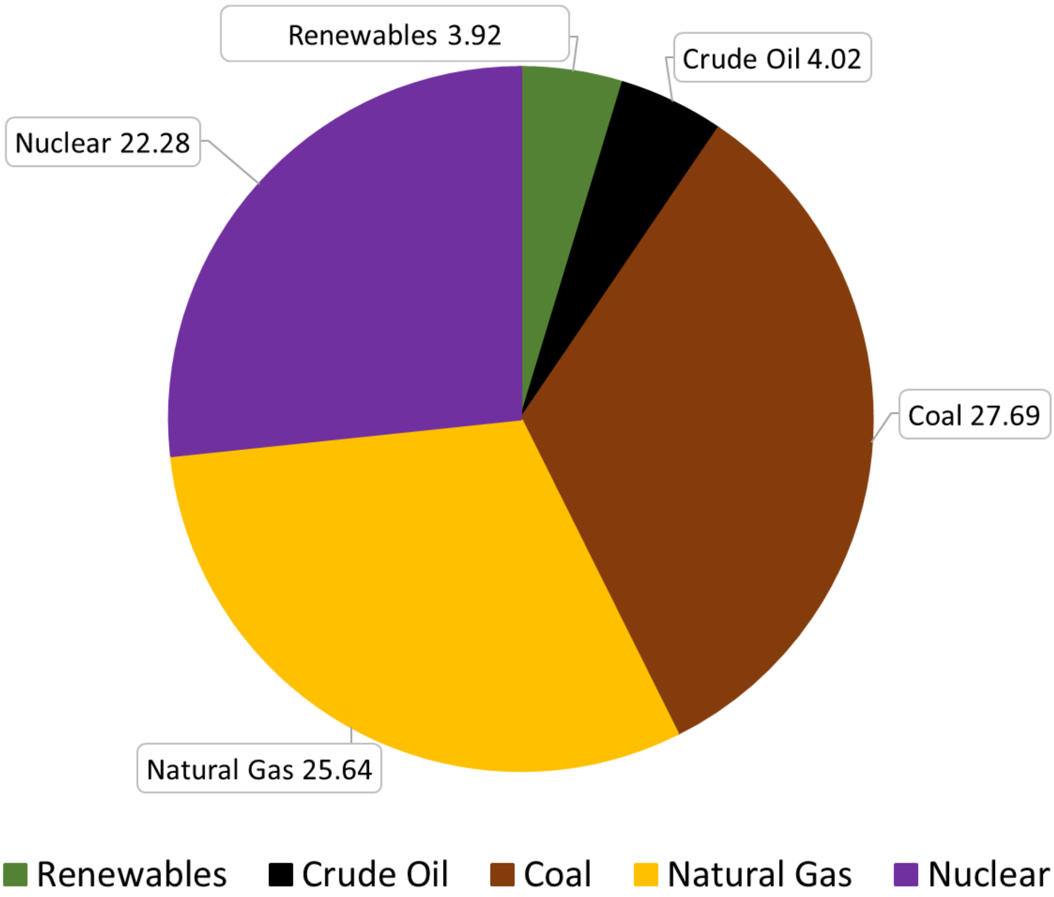
	Natural Gas	Coal	Crude Oil	Oil	Nuclear	Renewable	Heat	Electricity	Total
Production	16.49	14.09	2.34			4.77			37.68
Imports	9.16	13.60	1.68	10.01	22.28		0.47		57.19
Exports						-0.82		-0.52	-1.34
Stock Change				0.08		-0.03			0.06
Total Supply	25.64	27.69	4.02	10.09	22.28	3.92	0.47	-0.52	93.58
Electricity Plants	-0.22	-12.49			-22.12	-1.10		12.17	-23.76
Heat Plants	-8.54	-2.93		-0.19	-0.15	-0.91	9.29	1.31	-2.11
Refineries			-4.00	2.43					-1.57
Losses	-0.48	-0.43					-1.12	-1.43	-3.46
Energy Own Demand	0.95	0.64	0.01	0.05			1.12	1.42	4.18
Total Transformation	-8.29	-15.21	-4.00	2.28	-22.28	-2.01	9.28	13.49	-26.73
Statistical Difference	-0.29	-0.08		1.51			-		1.15
Industry	3.91	5.15		1.76		0.10	5.25	6.51	22.69
Residential	8.69	0.26		0.08		1.81	2.27	3.09	16.20
Transport	1.43			7.59				0.51	9.54
Non-energy demand	1.71	5.87	0.01	1.34					8.92
Total Demand	15.74	11.28	0.01	10.77		1.91	7.52	10.11	57.35

Notes: Source: ULEAP outcome for the year 2018 replicating Ukrstat's official energy balance table. Renewables include hydro, wind and solar power, biomass and other renewables. Oil includes all refined oils.

4.1 Primary Energy Supply

Figure 7 depicts Ukraine's primary energy supply. Ukraine relies on coal, natural gas and nuclear power to roughly the same parts. Renewables only play a minor role.

Figure 7: Primary Energy Supply [Million toe]



Notes: Source: ULEAP outcome for the year 2018 replicating Ukrstat's official energy balance table. Renewables include hydro, wind and solar power, biomass and other renewables.

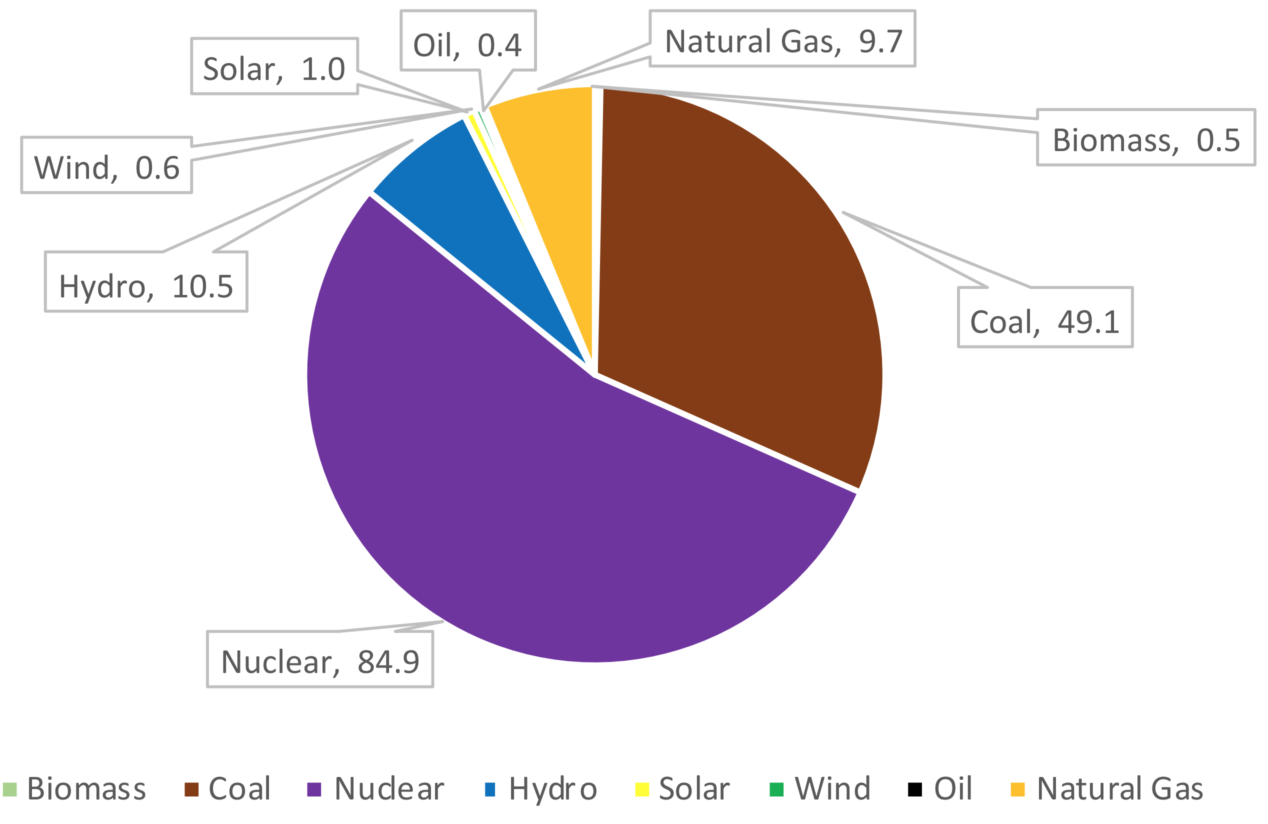
Concerning the supply structure, the energy balance (Table 3) shows that Ukraine domestically produces about two thirds of its natural gas and crude oil consumption and about half of its consumed coal. However, import dependency is high for nuclear power and refined oils.

4.2 Transformation

4.2.1 Electricity and heat generation

Ukraine's electricity generation primarily relies on nuclear and coal power (Figure 8). In 2018, 157 TWh of electricity have been produced with 54% nuclear and 28% coal power. With 10%, combined heat and power (CHP) production plays a significant role. CHP plants mainly rely on gas power (59%) followed by coal (36% of total CHP generation). Remaining electricity supply is mainly supplied by hydro power (7%). Other renewable energies, i.e., wind and solar power as well as biomass, did not play a significant role. According to the energy balance (Table 3), Ukraine mostly relies on domestic electricity production. About 6 TWh or 4% of electricity production were exported.

Figure 8: Electricity Generation 2018 [TWh]



Notes: Source: ULEAP outcome for the year 2018.

Ukraine domestically produced 108 TWh of heat in 2018. 72 TWh with pure heat plants and 36 TWh with CHP plants. Pure heat plants mostly rely on natural gas (~75%) followed by biomass (11%) and coal (10%).

Relying mainly on nuclear and coal power, the electricity and heat sector is the only consumer of nuclear fuels and consumes about two third of total coal supply. Natural gas mainly plays a role in the production of electricity within. In total, heat plants including CHP plants consume about 30% of total natural gas supply.

4.2.2 Refineries

Refiners consume almost the entire crude oil supply. ULEAP models transformation fuels in details but other refined oils as an aggregate name oil. Table 4 details the supply of oil products. Refineries convert crude oil mainly to oil and partly to gasoline and LPG. However, the major part of transportation fuels is imported, in particular diesel as the main transportation fuel is not domestically produced.

Table 4: Refined Oil Supply [Million toe]

	Crude Oil	Gasoline	Diesel	LPG	Oil
Production	2.34				
Imports	1.68	1.47	5.44	1.44	1.66
Exports					
Stock Change					0.08
Total Supply	4.02	1.47	5.44	1.44	1.74
Refineries	-4.00	0.45		0.40	1.59
Total Demand	0.01	1.92	5.44	1.84	3.33

Notes: Source: ULEAP outcome for the year 2018 replicating Ukrstat's official energy balance table. Oil is an aggregate of refined oils other than transportation fuels (diesel, gasoline, LPG).

4.3 Final demand

Table 5 details final energy demand by sector and energy resources. Natural gas is mainly used in the residential sector as well as combusted in compressors stations of the pipeline transport and in iron and steel processing. The latter is also the main final consumer of coal used in blast furnaces. Refined oils are primarily used in transportation and in smaller parts in the agriculture sector. Heat and electricity are consumed by residential consumer, services, and iron and steel manufacturing.

Overall, iron and steel manufacturing is the major industry sector with regard to energy consumption. Transportation is the major driver of oil consumption.

Table 5: **Final Energy Demand in 2018 [Million toe]**

	Natural Gas	Coal	Oil	Renew-able	Heat	Electricity
Industries	3.91	5.15	1.76	0.10	5.25	6.51
Chemicals	0.22				0.51	0.27
Construction	0.01		0.09		0.02	0.08
Food and Tobacco	0.17	0.03	0.02	0.01	0.86	0.39
Iron and Steel	1.44	4.31	0.08		1.25	1.52
Machinery	0.15		0.01	0.01	0.10	0.35
Mining	0.30	0.10	0.17		0.09	0.81
Non-ferrous Metals	0.15	0.10	0.03		0.27	0.14
Non-metallic minerals	0.43	0.55	0.04		0.07	0.22
Non specified	0.01		0.01		0.04	0.40
Pulp and paper	0.02				0.15	0.09
Textile and leather	0.01				0.02	0.03
Transport Equip.	0.02		0.01		0.05	0.08
Wood			0.01	0.01	0.10	0.07
Agriculture	0.12	0.01	1.19	0.04	0.22	0.33
Services	0.87	0.04	0.12	0.03	1.49	1.73
Transport	1.43		7.59			0.51
Pipeline Transport	1.43		0.01			0.05
Freight			3.73			0.31
Passenger			3.86			0.15
Residential	8.69	0.26	0.08	1.81	2.27	3.09

Notes: Source: ULEAP outcome for the year 2018 replicating Ukrstat's official energy balance table. Oil is an aggregate of all refined oils including transportation fuels (diesel, gasoline, LPG). Non-energy final demand is omitted but presented in the above table. Nuclear and crude oil omitted due to small values.

Given the importance of the transportation sector for energy demand and, thus, GHG emissions, ULEAP represents transportation fuels in a disaggregated manner. Table 6 presents energy demand for freight, private and pipeline transportation by energy resource. Diesel is mainly consumed by freight transportation via roads, i.e., trucks. In private transportation, gasoline and LPG are the dominant fuels of cars. Natural gas consumption of transportation is entirely caused by pipeline transport.

Table 6: Final energy demand of transportation [Million toe]

		Oil	Diesel	Gasoline	LPG	Electricity	Natural Gas
Freight	Trucks		3.56				
	Rail		0.14			0.31	
	Water		0.04				
Private	Cars		0.02	1.92	1.84		
	Buses		0.07				
	Rail					0.15	
	Dom. Aviation	0.01					
Pipeline		0.01				0.05	1.43

Notes: Source: ULEAP outcome for the year 2018. Oil represents refined oil other than transportation fuels (diesel, gasoline, LPG).

4.4 Emissions

Table 7 provides a high-level overview of Ukraine's GHG emissions in 2018. Two thirds of GHG emissions are CO_2 emissions followed by about 23% of methane, while the remainder consists of nitrous oxide emissions. The non-energy sector has the highest share of emissions followed by transformation and demand. In the remainder of this section, we analyze emissions in each of the sectors in greater detail.

Table 7: Greenhouse gas emissions by sector [Mt CO_2-equiv.]

	Demand	Transformation	Non-Energy	Total
Carbon Dioxide	88.6	81.9	54.8	225.3
Methane	1.1	37.5	40.3	78.9
Nitrous Oxide	0.8	0.3	33.0	34.1
Total	90.5	119.8	128.1	338.3

Source: ULEAP outcome for the year 2018. Data presented are in line with the national inventory report.

4.4.1 Emissions of energy demand

Ukraine's energy demand sector is the major source of carbon dioxide emissions. Table 8 reveals that energy demand by industries, residential consumers, and transportation are the major drivers of these emissions. Industries cause about 10% of total GHG emissions followed by transportation and residential consumption with 7% and 6%, respectively. Naturally, non-energy consumption of energy commodities and energy industries own demand play only a minor role.

Table 8: Demand emissions 2018 [Mt CO_2-equiv.]

GHG	Carbon Dioxide	Methane	Nitrous Oxide	Total
Industry	31.1	0.1	0.6	31.8
Residential	21.5	0.8	0.1	22.5
Transport	25.9	0.1	0.1	26.1
Non-energy consumption	5.1			5.1
Energy industry own demand	4.9			4.9
Total	88.6	1.1	0.8	90.5

Source: ULEAP outcome for the year 2018.

Table 9 provides a breakdown of GHG emissions caused by industries' energy demand. The largest amount of industry emissions is caused by the steel industry which accounts for about 5% of total GHG emissions in 2018.

Table 9: Emissions by industries' energy demand [Mt CO_2-equiv.]

GHG	Carbon Dioxide	Methane	Nitrous Oxide	Total
Agriculture, forestry and fishing	4.0		0.4	4.4
Mining	1.6		0.1	1.6
Food and tobacco	0.6			0.6
Wood and wood products				
Transport Equipment	0.1			0.1
Textile and leather				
Paper, pulp and printing	0.1			0.1
Non specified				
Non-metallic minerals	3.2			3.3
Non-ferrous metals	0.8			0.8
Chemical and petrochemical	0.5			0.5
Machinery	0.4			0.4
Iron and steel	17.0		0.1	17.1
Construction	0.3			0.3
Services	2.5			2.6
Total	31.1	0.1	0.6	31.8

Source: ULEAP outcome for the year 2018.

Within the transport sector, both freight and private transport emit about 11 Mt CO_2 followed by pipeline transport which emits about 3.3 Mt CO_2. For both private and freight transportation these emissions are mainly caused by road transportation, i.e., private cars and trucks.

Agriculture here refers to the energy-consuming parts of the agricultural sector. Non-Energy Emissions like from manure management are covered under "Non-Energy Demand".

4.4.2 Transformation sector emissions

Ukraine's transformation causes a high share of GHG emissions, in particular CO_2 emissions. Relying on coal power in electricity generation and gas-fired plants for heat production, these plants cause the major part of carbon dioxide emissions. In total, these sectors caused about one quarter of Ukraine's total GHG emissions in 2018.

Table 10: **Transformation emissions 2018 [Mt CO_2-equiv.]**

	Carbon Dioxide	Methane	Nitrous Oxide	Total
Electricity Plants	49.0		0.2	49.2
Heat Plants	30.7		0.1	30.8
Crude Oil Extraction	0.2	1.5		1.7
Gas Extraction	1.8	22.2		23.9
Coal Extraction		13.8		13.8
Oil Refineries	0.4			0.4
Total	81.9	37.5	0.3	119.8

Source: ULEAP outcome for the year 2018.

Extraction activities, in particular gas and coal extraction, are an important source of methane emissions. With 28% (17%) of total methane emissions, gas (coal) extraction is the major source of CH_4, accounting for about 6.5% (4%) of total GHG emissions.

The extraction of coal, natural gas and oil causes emissions due to leaks of methane. The amount of extracted fossil fuel in LEAP depends on Ukraine's extraction capacity and the demand for the respective resource in the country. If not enough resources can be extracted, ULEAP counts the necessary rest as imported.

The coal extraction capacity for 2018 is modelled on the previous 5 years average extraction levels: 14.5 Mtoe. Emission levels per extracted ton of coal are modelled on the UNFCCC's emission values for Ukraine.

The gas extraction capacity for 2018 is modelled on the previous 5 years average extraction levels: 16.5 Mtoe. Emission levels per extracted cubic meter of natural gas are modelled on the UNFCCC's emission values for Ukraine.

The oil extraction capacity for 2018 is modelled on the previous 5 years average extraction levels: 2.8 Mtoe. Emission levels per extracted cubic meter of natural gas are modelled on the UNFCCC's emission values for Ukraine.

The capacity of Ukrainian refineries to process crude oil for 2018 is modelled on the previous 5 years average processing levels: 2.4 Mtoe. Emission levels per extracted cubic meter of natural gas are modelled on the UNFCCC's emission values for Ukraine.

4.4.3 Non-energy emissions

Non-energy emissions play an important role in Ukraine's GHG emissions statistics. On the one hand, the metal industry is responsible for a large share of non-energy CO_2 emissions (Table 11). On the other hand, agriculture and land use changes cause a major part of CH_4 and N_20 emissions. Waste and pipeline losses are important sources of methane emissions both causing about 15% of total methane emissions (4% of total GHG emission).

Natural gas in its transport form consists of 98% methane and 0.5% CO_2[5]. With these values, LEAP calculates the CO2-equivalent emissions of exhaust natural gas.

Table 11: Non-energy emission in 2018 [Mt CO_2-equiv.]

	Carbon Dioxide	Methane	Nitrous Oxide	Total
International Bunkers	1.6			1.6
Pipeline Losses		12.0		12.0
Waste		13.3	1.0	14.3
Agriculture/LULUCF	2.8	11.3	30.8	44.9
Metal Industry	41.9	0.6		42.5
Chemical Industry	2.2	3.1	1.2	6.5
Mineral Industry	6.4			6.4
Total	54.8	40.3	33.0	128.1

Source: ULEAP outcome for the year 2018.

5. Baseline Assumptions

Baseline assumptions are categorized in three major strands. Population growth, GDP growth, and development of technologies. Population and GDP growth determine the size of the economy and, therefore, activity levels of industries, the residential sector, and transportation. Technology development impacts energy intensity per production and carbon intensities per energy consumption. Thereby, technology developments together with activity developments determine energy demand and GHG emissions.

Our LEAP model encompasses two baseline scenarios.

1. The first one takes into account own assumptions on the baseline development of the Ukrainian energy system, based on expert discussions and further research[6].
2. The second one reproduces the NDC baseline scenario developed by the Institute for Economic Forecasting in Kyiv (NASU, 2020).

Both scenarios feature the same core economic and demographic trend but differ in sectoral details.

The main differences of the NDC and the LCU BAU scenario can be summed up as follows:

1. The steel sector does not grow, in contrast to the NDC BAU scenario's steel sector. Based on the current challenging situation of the Ukrainian iron and steel sector, hampered by old infrastructure and a looming European carbon border mechanism, this sector does not grow in the coming years. Thus,

[5] Bradbury, James et al., 2015

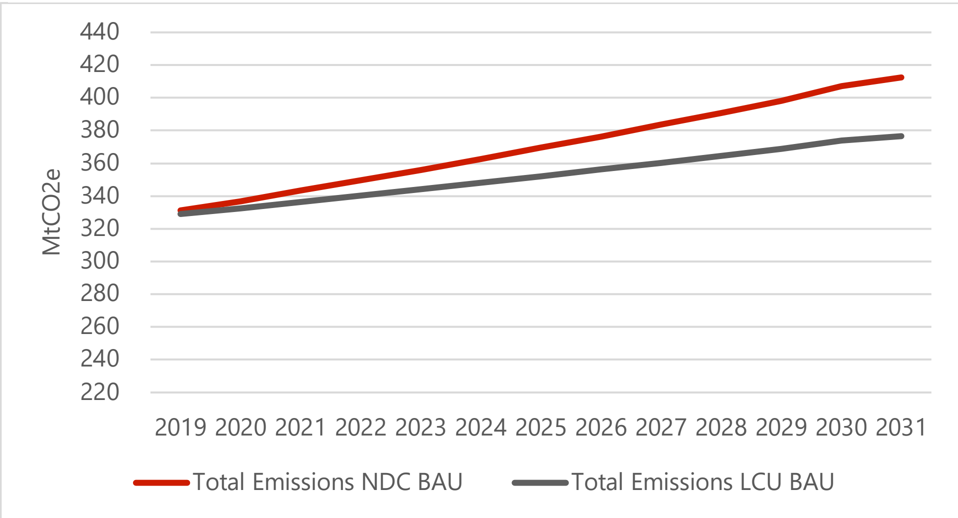
[6] Among the contacted experts are members of the Ukrainian Agribusiness Alliance, DiXi think-tank researchers, business leaders from the private sector, and members of international consultancies and organisations.

energy demand and emission levels will not grow either. The saved final energy consumption amounts to 11.4 Mtoe in 2030, of which 1.5 Mtoe are saved in electricity and natural gas each, 6.9 Mtoe in coal. Another 1.5 Mtoe coal and 1.2 Mtoe nuclear energy are saved in electricity production.

2. Agriculture output grows like in the NDC BAU scenario, but in contrast to the NDC its non-energy emission intensity does not make up for this activity level growth. Thus, LCU's BAU scenario features higher agricultural emissions than LEAP's NDC BAU scenario.

The resulting differences between the scenarios can be seen in Figure 9 and Figure 17.

Figure 9: Total Emissions in LCU's BAU scenario are lower by ca. 33 MtCO2e in 2030



Notes: Figure shows the different emission development of the NDC and the LCU BAU scenarios; Source: ULEAP calculations.

5.1 Population Growth

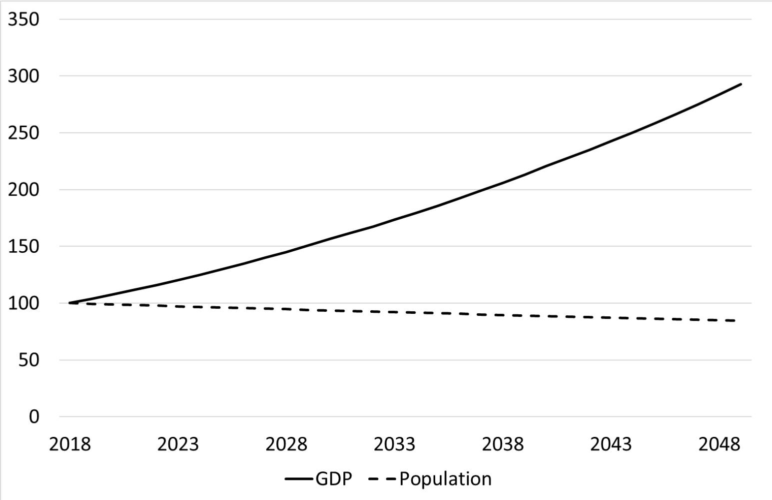
Population is assumed to decrease from about 42.2 million people in the base year 2018 to 35.6 million in 2050. This implies an annual population decrease of 0.53% (see *Figure 10*). With this, ULEAP's population development is in line with the assumptions of the modelling underlying the Nationally Determined Contributions of Ukraine. With 38.9 million people, Ukraine's Low Emissions Development Strategy 2050 assumes a slightly higher population in 2050 (KYIV, 2017).

5.2 Sectoral Developments

5.2.1 General Growth

In both baseline scenarios, we assume a general growth trend. If not specified differently, we assume sectors' output grows with general trend. General growth follows the assumptions made in the NDC baseline scenario by the Institute for Economic Forecasting. Total economic output increases by 3.8% annually until 2030, then by 3.5% until 2040, then by 3.2% until 2050 (please compare Figure 10).

Figure 10: Population and GDP Development



Source: Own calculations. Shown is GDP and population with relative to base year 2018. Base GDP 3'560 billion UAH, population 42.2 million people (Ukrstat, 2018a).

While GDP and population growth are important to understand the broad trajectory of Ukraine's emission and energy consumption trajectories, the individual sectoral development of technologies, energy intensity and emission levels are also relevant. They will be presented in the next chapters.

5.2.2 Industry

The most important sub-sectors of industry in Ukraine are portrayed in the following paragraphs. Generally, both baseline scenarios' output grows with GDP.

5.2.3 Iron and steel

LEAP's NDC BAU scenario assumes the sector to grow rapidly with 3.5% annually until 2030. It also features a modest improvement of energy intensity. The share of different energy carriers consumed stays constant.

LCU's own BAU differs, in that it assumes the iron & steel sector's output not to grow over time.

Table 12*:* **Baseline assumptions iron & steel sector, NDC BAU vs LCU BAU**

Iron and Steel	NDC BAU	LCU BAU
Activity Level	Iron and steel output grows by 3,5% annually until 2030, by 3,2% annually until 2040 and by 2,9% annually after.	Does not grow
Energy Intensity	**Final Energy Intensity** decreases annually by 0.4% until 2030, then by 0.7% (This decrease in energy intensity is the same across the Ukrainian energy demand side.)	
Emission Intensity	No change over time.	
Fuel Switch	No switch over time.	

Notes: Change and growth assumptions from NASU (2020) and own calculations, LCU BAU activity level assumptions from expert interviews

5.2.4 Agriculture and forestry

In LEAP, the industry's agricultural sector describes the emissions caused by energy-consuming machines and processes in Ukraine's agriculture. Most predominantly among them are of course trucks, grain drying, etc.

Table 13: **Baseline assumptions agriculture & forestry, NDC BAU vs LCU BAU**

Agriculture & Forestry	NDC BAU	LCU BAU
Activity Level	Agriculture output grows by 2.2% annually until 2040, and by 3,2% annually until 2050.	
Energy Intensity	**Final Energy Intensity** decreases annually by 0.4% until 2030, then by 0.7% (This decrease in energy intensity is the same across the Ukrainian energy demand side.)	
Emission Intensity	No change over time.	
Fuel Switch	After 2030, biomass replaces Diesel (whose share decreases from 62 to 54%)	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.2.5 Other industries

These "other" sectors, including the services sector, as well as the production of mineral and chemical products, roughly produce three quarters of Ukraine's general output However, they only consume 20% of the final energy demand.

Table 14: Baseline assumptions other industries, NDC BAU vs LCU BAU

Other industries	NDC BAU	LCU BAU
Activity Level	Until 2031, output grows with 3.8% per annum. Afterwards growth continues at a lower rate of 3.5% until 2041 and 3.2% until 2050.	
Energy Intensity	**Final Energy Intensity** decreases annually by 0.4% until 2030, then by 0.7% (This decrease in energy intensity is the same across the Ukrainian energy demand side.) For services the energy efficiency improvement is more optimistic in the beginning, but slightly less ambitious after: Following the NDC, it increases by 1.5% until 2030 and 0.3% thereafter	
Emission Intensity	No change over time.	
Fuel Switch	Services' and public buildings also switch from natural gas (2020: 20 □ 2030: 10%) to more biomass (1% -> 7%) and district heating (35% -> 39%)	

Notes: Change and growth assumptions from NASU (2020) and own calculations

4.2.6 Residential

The residential area per person in Ukraine is assumed to grow over the next decades, leading to an increase of 14% in the total residential area that needs to be heated in Ukraine until 2050. Simultaneously, houses and apartments are getting renovated and insulated, leading to reductions in the energy consumption per square meter. Additionally, the renewal of heating systems drives out biomass (wood) and replaces it by more modern energy sources like natural gas and central heating.

Table 15: Baseline assumptions residential sector, NDC BAU vs LCU BAU

Residential	NDC BAU	LCU BAU
Activity Level	The amount of residential area increases by 14% from 2018 until 2050.	
Energy Intensity	**Final Energy Intensity** decreases annually by 1.5% until 2030, and by 0.3% afterwards.	
Emission Intensity	No change over time.	
Fuel Switch	Biomass (wood) gets replaced by central heat: wood's share decreases from 11% to 1.5% until 2030; heat increases from 14% to 21%)	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.2.6 Transport

Transport's three key subsectors are portrayed separately here: passenger transport, freight transport and pipeline transport. Pipeline transport denotes the forwarding of natural gas in pipelines and refers to the energy consumption and emissions in the pumps required to channel the gas through the pipes.

In the baseline, passenger transport changes with Ukraine's population, while freight transport grows with GDP. Pipeline transport is proportional to natural gas demand.

Table 16: Baseline assumptions passenger transport, NDC BAU vs LCU BAU

Transport: Passenger	NDC BAU	LCU BAU
Activity Level	Slightly shrinks with population. The transport mode stays the same over time (41% of passenger km are passed in cars, 45% by rail, 6% in buses and 6% on planes)	
Energy Intensity	Final Energy Intensity decreases annually by 0.4% until 2030, then by 0.7% (This decrease in energy intensity is the same across the Ukrainian energy demand side.)	
Emission Intensity	No change over time.	
Fuel Switch	• Cars: 1% electric until 2030, 3% until 2050; rest LPG and oil • Rail: 100% electric • Buses: 1% electric until 2030, 3% until 2050; rest LPG and oil • Rail & Planes: no change (rail: 100% electric, 30% diesel), Planes: 100% oil	

Notes: Change and growth assumptions from NASU (2020) and own calculations

Table 17: Baseline assumptions freight transport, NDC BAU vs LCU BAU

Transport: Freight	NDC BAU	LCU BAU
Activity Level	Grows with GDP. The transport mode stays the same over time (18% of freight km are passed in trucks, 80% by rail and 1% on ships).	
Energy Intensity	Final Energy Intensity decreases annually by 0.4% until 2030, then by 0.7% (This decrease in energy intensity is the same across the Ukrainian energy demand side.)	
Emission Intensity	No change over time.	
Fuel Switch	• Trucks: 1% electric until 2030, 3% until 2050 • Rail & Maritime: no change ○ rail: 70% electric, 30% diesel ○ Maritime: 100% diesel	

Notes: Change and growth assumptions from NASU (2020) and own calculations

Table 18: Baseline assumptions pipeline transport, NDC BAU vs LCU BAU

Pipeline Transport	NDC BAU	LCU BAU
Activity Level	Grows with natural gas usage in the economy	
Energy Intensity	Final Energy Intensity decreases annually by 0.4% until 2030, then by 0.7% (This decrease in energy intensity is the same across the Ukrainian energy demand side.)	
Emission Intensity	No change over time.	
Fuel Switch	Natural gas compressor technology slowly gets replaced by electric compressors (from 3% to 13% in 2030, to 30% in 2050).	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.3 Transformation sectors

5.3.1 Electricity generation

We rely on LCU's Optimal Dispatch Model (ODM) to model electricity generation (Meißner, 2020). ODM is a detailed electricity market model. As a unit-commitment model, it models all power plants in the Ukrainian market in detail including technical flexibility restrictions.

To link ODM and ULEAP, we follow a three-step procedure. First, ULEAP determines annual electricity demand based on the different demand blocks (see previous section). Second, given demand, ODM calculates the optimal powerplant mix and annual dispatch in Ukraine provided fuel price developments. Third, we use ODM's annual generation shares in ULEAP to determine emissions.

Table 19: **Baseline assumptions electricity generation, NDC BAU vs LCU BAU**

Electricity Production	NDC BAU	LCU BAU
Activity Level	Depends on electricity demand development.	
Energy Efficiency	Energy efficiency improves by 2% until 2030, and by an additional 4% until 2050.	
Emission Intensity	No change over time.	
Fuel Switch	• Renewable Energy Source development (share of total electricity production) ○ Wind 0.5 -> 6% (2018 -> 2030) ○ Solar 0.5 -> 2% • Conventional capacity development (share of total electricity production) ○ Nuclear: 60 -> 38% ○ Coal: 31 -> 44% ○ Natural gas: 0.6 -> 4%	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.3.2 Heat generation

Heat is produced in both "Combined Heat and Power Plants" (CHPs) and heat-only plants. Both undergo some slight changes in the presented baselines. Mainly, some coal capacity is replaced by biomass and natural gas, while the plants get more efficient.

Table 20: **Baseline assumptions heat generation, NDC BAU vs LCU BAU**

Heat Production	NDC BAU	LCU BAU
Activity Level	Depends on heat demand development.	
Energy Efficiency	For both CHPs and heat plants, energy efficiency improves by 2 percentage points until 2030, and by 4 percentage points more until 2050.	
Emission Intensity	No change over time.	
Fuel Switch	• Heat plants ○ RES development ▪ Biomass: 11.6% -> 15% (2030) ○ Conventional capacity development ▪ Coal: 10% -> 5% (2030) ▪ Natural gas: 75 -> 80% • CHPs ○ RES development ▪ Biomass: 2% -> 10% (2030) ○ Conventional capacity development ▪ Natural gas: 60 -> 80%	

	▪ Coal: 36% -> 0%

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.4 Primary Energy Supply

5.4.1 Coal Extraction

Both scenarios assume the capacity for coal extraction to grow by 1% annually.

Table 21: Baseline assumptions coal mining, NDC BAU vs LCU BAU

Coal Extraction	NDC BAU	LCU BAU
Extraction capacity	Growth by 1% per year.	
Emission factor	No change over time.	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.4.2 Gas Extraction

The extraction of natural gas causes emissions due to leaks of methane and CO_2. The amount of extracted natural in LEAP depends on Ukraine's extraction capacity and the demand for natural gas in the country. If not enough natural gas can be extracted, ULEAP counts the necessary rest as imported.

Table 22: Baseline assumptions gas extraction, NDC BAU vs LCU BAU

Gas Extraction	NDC BAU	LCU BAU
Extraction capacity	Growth by 1% per year.	
Emission factor	No change over time.	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.5 Non-Energy

Non-energy sectors are characterised by emitting greenhouse gases without consuming energy carriers.

5.5.1 Agriculture

The non-energy emissions of agriculture are considerable and largely stem from manure management and the use of nitrogen fertilizers. The sector's output naturally grows just like the agricultural sector modelled to consume energy.

LEAP differentiates between the “energy-consuming part of agriculture” and the here presented “non-energy” part of it, in order to gain a better understanding of possible future measures to limit the emission levels in the sector.

2018 emission levels are calibrated to the UNFCCC’s “Common Reporting Format” emission values.

The NDC BAU emission levels per output decrease quickly over time, such that total emissions do not increase, although output grows. ULEAP’s own BAU does not account for such a quick improvement of emission levels per output. Therefore, emissions in LEAP’s own BAU do increase.

Table 23*:* **Baseline assumptions agriculture, NDC BAU vs LCU BAU**

Non-Energy: Agriculture	NDC BAU	LCU BAU
Activity growth	Grows like demand-side agricultural sector: grows by 2.2% annually until 2040, and by 3,2% annually until 2050.	
Emission Levels	Emission levels per output decrease by 2.1% annually until 2030, and by 1.1% after.	Emission levels per output decrease by 1.1% annually until 2030, and by 0.5% after.

Notes: Change and growth assumptions from NASU (2020) and own calculations, emission level development from expert interviews

5.5.2 Waste

Waste’s non-energy emissions stem from rotting and decaying waste in landfills. Better processing facilities could lower the amount of produced methane. In the assumed baseline scenarios, only few such facilities are built.

Table 24*:* **Baseline assumptions waste, NDC BAU vs LCU BAU**

Non-Energy: Waste	NDC BAU	LCU BAU
Activity growth	• 2020: 0.39 tons per person annually • 2050: 0.43 tons per person annually	
Emission Levels	Emission levels per ton of waste decrease by 1.9% annually until 2030. Afterwards, they stay the same.	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.5.3 Exhaustive Natural Gas Emissions from Transport Losses

In natural gas pipes and especially in pumps, natural gas escapes into the atmosphere. As it consists mainly of methane, it thus considerably contributes to global warming. The losses grow over time, as more gas is transported following the growing demand.

Table 25: **Baseline assumptions exhaustive emissions from gas transport, NDC BAU vs LCU BAU**

Non-Energy: Exhaust natural gas	NDC BAU	LCU BAU
Activity growth	No change over time: 1.9% of natural gas gets lost into the atmosphere during transport.	
Emission Levels	No change over time.	

Notes: Change and growth assumptions from NASU (2020) and own calculations

5.5.4 Chemical and Mineral Emissions

Chemical and mineral non-energy emissions also change over time. As in the agricultural sector, chemical and mineral activity grows just like their industry-side counterparts, with ca. 3% per annum.

Table 26: Baseline assumptions chemical and mineral industries, NDC BAU vs LCU BAU

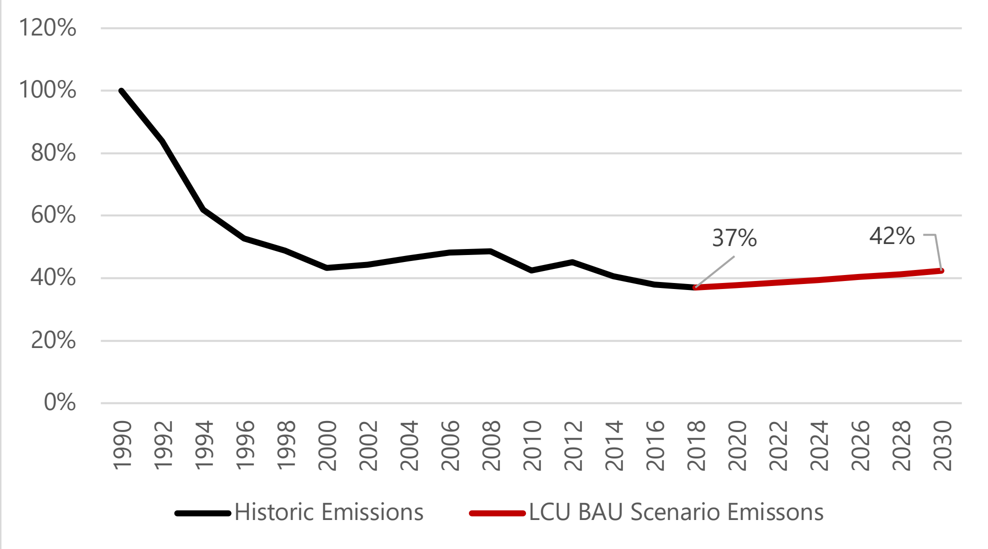
Non-Energy: chemical and mineral	LEAP's NDC BAU	LCU BAU
Activity growth	Growth like demand-side chemical and mineral sectors.	
Emission Levels	Emission intensity per output improves by 1.9% annually until 2030, then stays the same.	

Notes: Change and growth assumptions from NASU (2020) and own calculations

6. Ukraine's Energy Demand and Emissions up to 2030

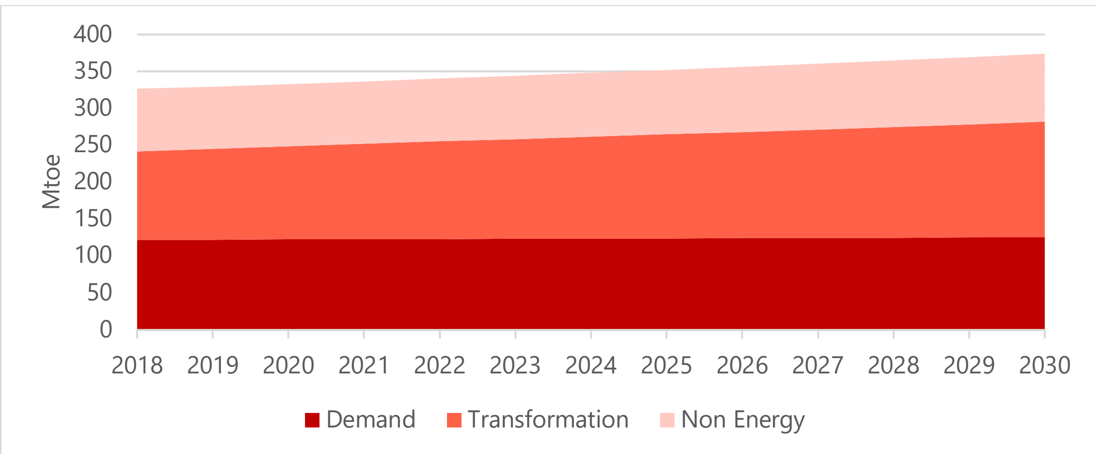
Based on the assumed output growth, the BAU scenarios envision all sectors to grow in the upcoming years, thus also projecting a growth in energy consumption and hence in emissions. The general emission growth can be seen in Figure 12. However, current emissions are low in comparison to pre-1990 levels. In 2018, Ukraine's GHG emissions were at 37% of 1990 levels (Figure 11).

Figure 11*:* **Historic and future GHG emissions, projected under the LCU BAU Scenario**



Source: UNFCCC and own calculations. Shown are historic and projected emissions of Ukraine (without temporarily occupied territories).

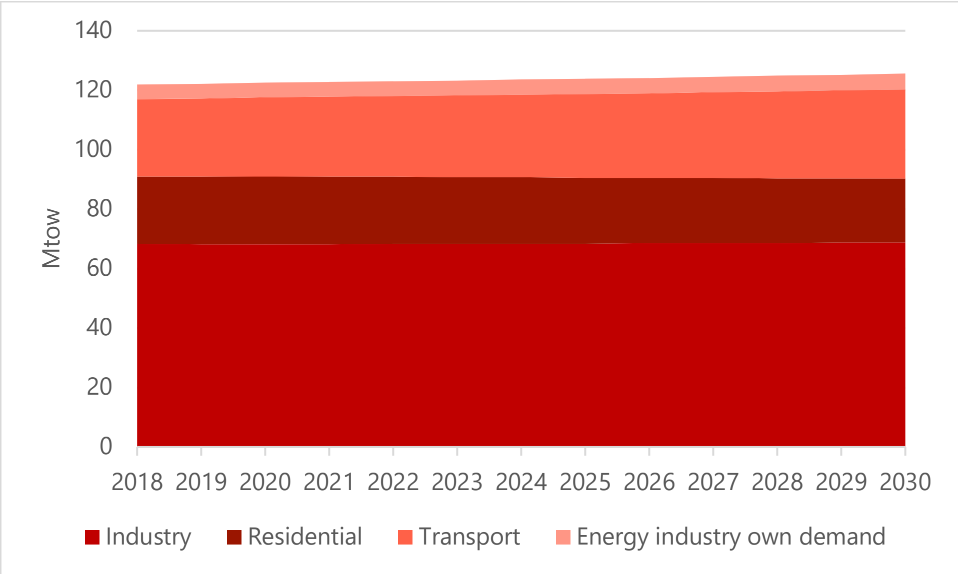
Figure 12: **LCU BAU Scenario, total emissions**



Source: own calculations. Shown are projected emissions by energy sector

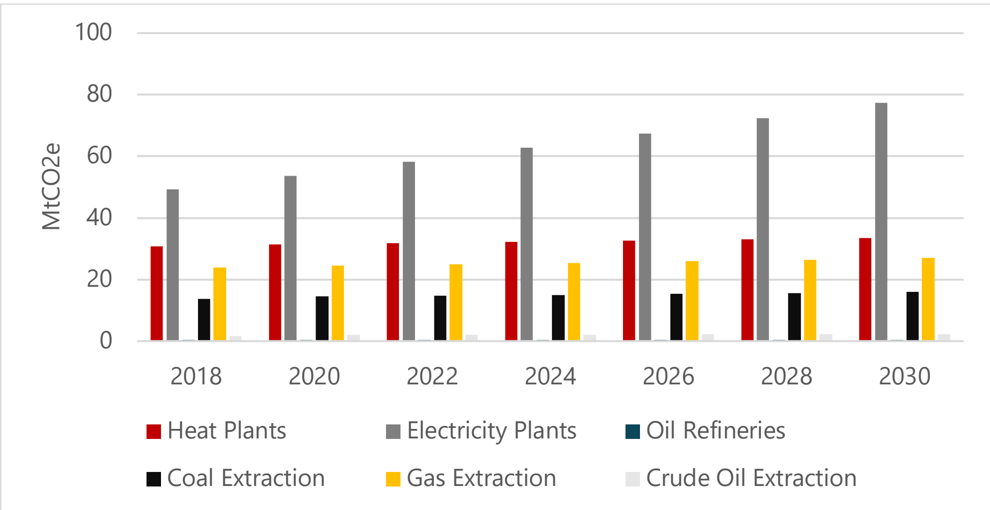
This increase in emissions is especially driven by a growth in industry production, as well as in the necessary electricity production. This electricity production is needed to keep up with the forecasted demand in the industry and residential sectors.

Figure 13: **Demand-side emissions, LCU BAU scenario**



Source: own calculations. Shown are projected demand-side emissions by sector

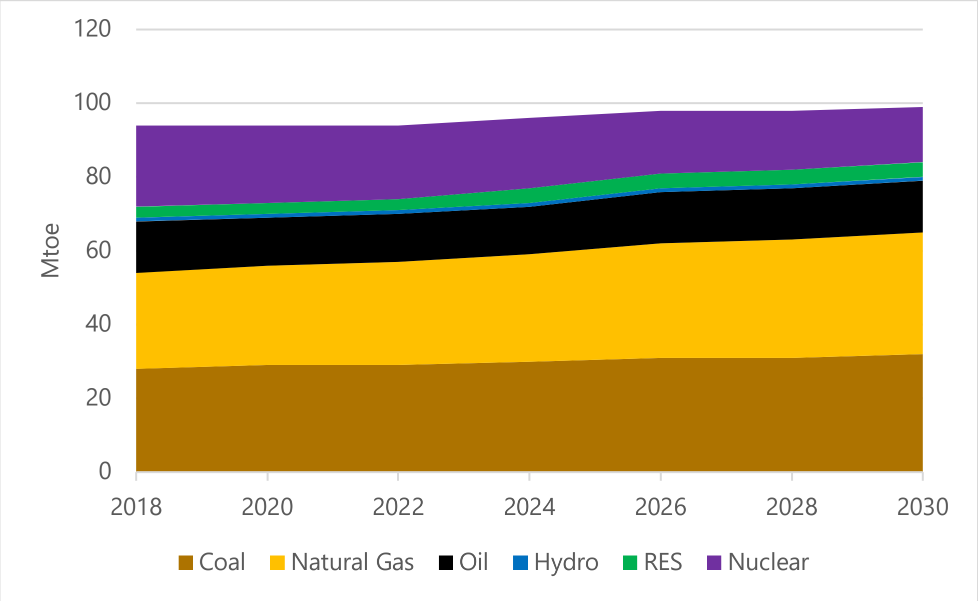
Figure 14: **Transformation emissions in the LCU BAU**



Source: own calculations. Shown are projected emissions by transformation and primary resources sector, emissions from electricity production following growth in demand for electricity

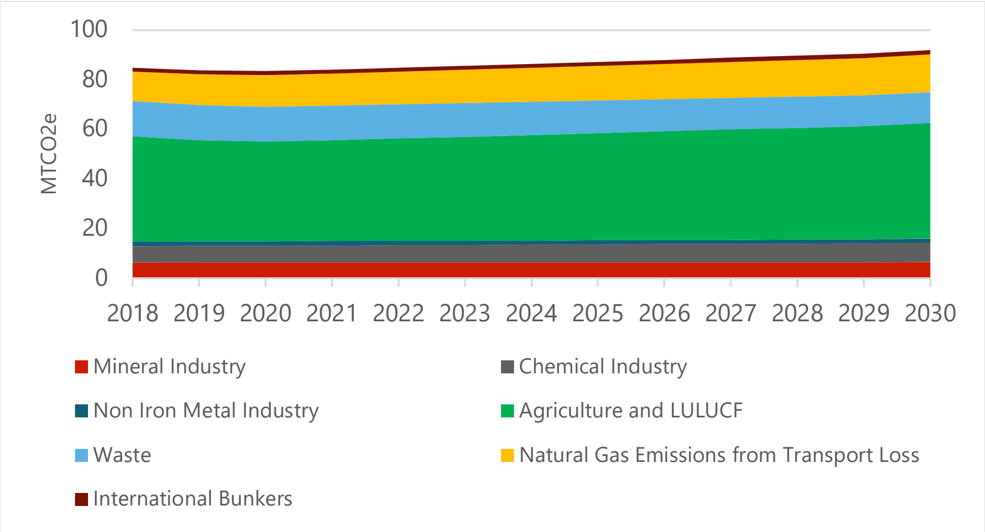
The NDC baseline scenario further does not assume major fuel switches to occur in industrial sectors. Most energy will continue to be derived from coal. As can be seen in Figure 15, the share of most energy carriers stays roughly constant over time, with natural gas taking over some of nuclear power's share.

Figure 15: Total Primary Energy Supply LCU BAU scenario



Source: own calculations. Shown is projected total energy supply by fuel in the LCU BAU Scenario.

Figure 16: LCU BAU scenario, Non-energy emissions, agricultural emissions do not grow over time in this scenario



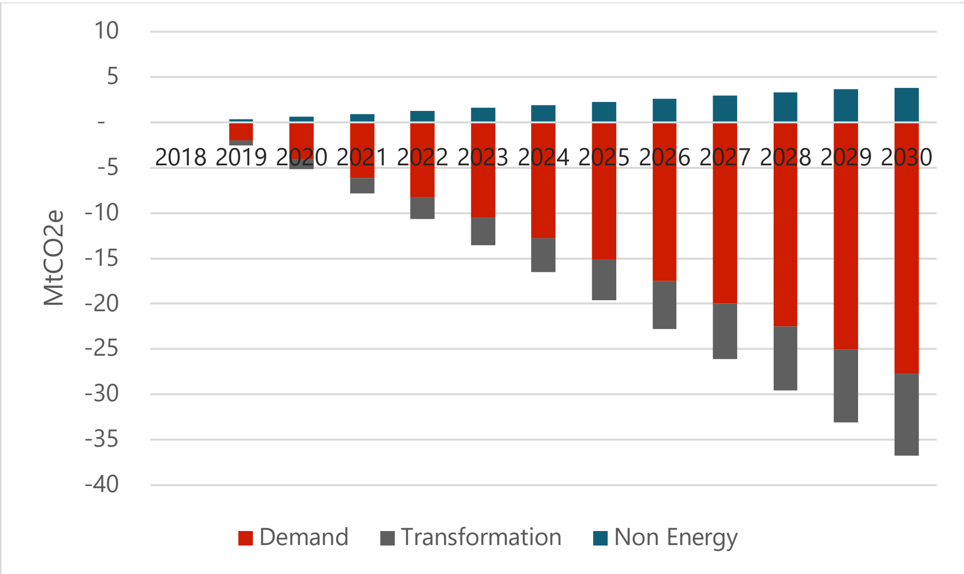
Source: own calculations. Shown are projected emissions by non-energy sector

Meanwhile, the NDC BAU scenario projects emissions derived from non-energy processes, such as the rotting of waste, the usage of fertilizers and manure management to not increase by a large margin until 2030. The main source of emissions in the non-energy segment is the agricultural sector, accounting for almost 50% of all its emissions. Agricultural emissions however do not grow in the NDC's BAU scenario, as it assumes the agricultural emission intensity per output to improve considerably over the next ten years. This means that it assumes farms to emit less CO2 per produced food. The necessary improvement rate reaches roughly 2.7% annually. This is a special case of emission intensity.

The NDC BAU Scenario also assumes other small improvements in terms of energy efficiency (energy consumed per unit of sectoral output) and in terms of general emission intensity (emission per energy used).

LCU's own BAU scenario differs in that its steel sector emissions do not grow, while agricultural emissions do grow. A detailed picture of the changes can be seen in Figure 17.

Figure 17: Differences in emissions between the two BAU scenarios



Source: own calculations. The graph shows how much higher (or lower) emissions in LCU BAU are relative to the NDC BAU scenario. The steel sector accounts for the most differences in emissions between the two BAU scenarios.

7. Literature and Data Sources

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