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The economic implications of phasing out coal in Ukraine by 2030

Prepared for the Heinrich Böll Foundation, Kyiv Office - Ukraine

Research for "The economic implications of phasing out coal in Ukraine by 2030" was conducted in October 2020 - April 2021 by Aurora Energy Research on initiative and with financial support of the Heinrich Böll Foundation, Kyiv Office – Ukraine. The idea of the study is to compare economic implications of two different scenarios of power sector development, one of which assumes phasing out coal for electricity production by 2030. This report summarizes methodology used, major assumptions and key results, such as hypothetical power mix under both scenarios and corresponding economic implications (influence on job places, taxes, macroeconomic parameters, etc.).

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Executive Summary: The economic implications of phasing out coal in Ukraine

The coal sector has been an integral part of the Ukrainian electricity system for decades. But infrastructure and plants are approaching the end of their technical lifetime, and investments in the electricity sector are necessary, independent of the future composition of the power sector.

This study explores how this window of opportunity could be used to phase out coal in Ukraine and transition to a cleaner power mix for the future. We present a potential coal phase-out by 2030, reducing coal generation over the decade, while investing in new renewable power generation. Overall, the study shows the following:

> A coal phase-out is not only technically feasible, it also creates economic opportunities and new jobs, while reducing the inefficient subsidy payment.

As the current coal industry of Ukraine is projected to accumulate losses of more than a billion Euro over the next decade, a coal phase-out can reduce the burden on the state budget while simultaneously creating new jobs in the renewables industry.

The study is designed to span a 'solution space', assessing the economic impacts of an ambitious coal phase-out plan in contrast to a continuation of the status quo.

> Reflecting about Ukrainian energy transition is in line with global developments.

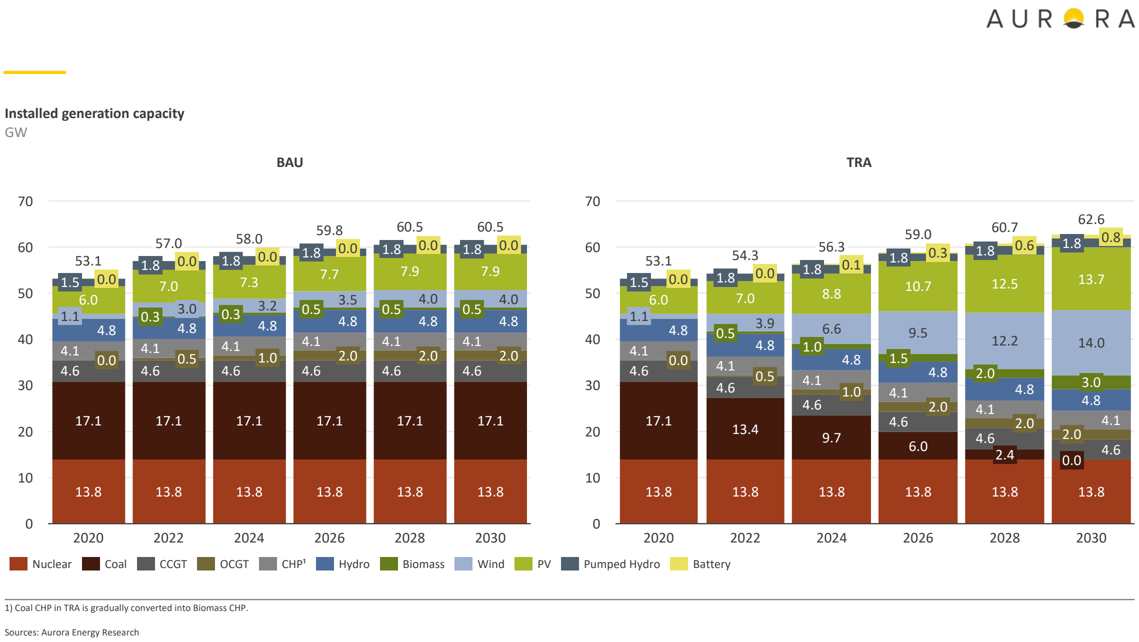
In line with their climate targets, multiple countries have announced to phase out coal-fired power generation in order to decarbonise their electricity systems. As it stands, 20 of the 27 EU member states have announced to phase out coal from their electricity mix or are already coal-free. Additionally, previous very coal dependent countries like Canada, Chile or the UK have taken concrete measures to close down their national coal plant fleet.

These announcements stem not only from climate concerns. Phasing out coal has shown to curb local pollution in NO_2, SO_2 and particulate matter which affect respiratory health. Also, economic costs associated with ongoing coal production have in many cases proven higher than building new, renewable generation capacities. Overall, the decision to phase out coal from the electricity system is part of an ongoing transition of the energy system observed across a wide range of countries.

Old, central generation is replaced by decentral, clean energy sources that operate more flexible. These globally observed developments are also mirrored in the Ukrainian discussion, with the country committing to the Paris Agreement and targeting net-zero emissions by 2060. And like in many other countries, the Ukrainian power sector is in need of modernisation.

Other studies have shown that a coal phase-out in Ukraine is technically possible. Already with the currently available technologies, enough energy is available to supply demand at all times. This study complements these analyses by complimenting detailed power sector modelling with an assessment of the economic impacts. We analyse how a feasible pathway could look like and what the impact on the state budget and the wider economy would be. Along with the coal phase-out by 2030, the study looks at the cost of decommissioning of coal mines and associated welfare payments for affected groups of workers to accompany the transition of the energy sector.

For this purpose, we have modelled a transition scenario (TRA) with a linear closure of all 17 GW coal capacity in Ukraine between 2020 and 2030. In parallel, renewable capacities in the scenario almost triple compared to current capacities, amounting to 35 GW of wind, hydro power, biomass and photovoltaic capacity in 2030. Other capacities like nuclear are held constant or altered according to current announcements for closure or commissioning. Transition scenario is compared to a business-as-usual scenario (BAU). This scenario takes into account recent announcements as well as renewable energy sources (RES) build-out as incentivised by current policies. This only amounts to a 1.5-fold increase of current capacities (see also Figure i).



1) Coal CHP in TRA is gradually converted into Biomass CHP.

Sources: Aurora Energy Research

Figure i.: Power generation capacities in BAU and TRA

In a second step, the study analyses macro-economic implications of this trajectory. Estimating the direct costs for the operation and closure of mines and coal power plants as well as indirect costs for compensation of affected actors as well as effects on job creation in emerging industries. Thirdly, the study also considers changes to the state budget, e.g. by an altered tax income (Figure v). In a last step, with the help of a CGE model, the study looks at the macro-economic spill-over effects of the energy transition and how GDP and individual sectors are impacted by the ambitious policy approach.

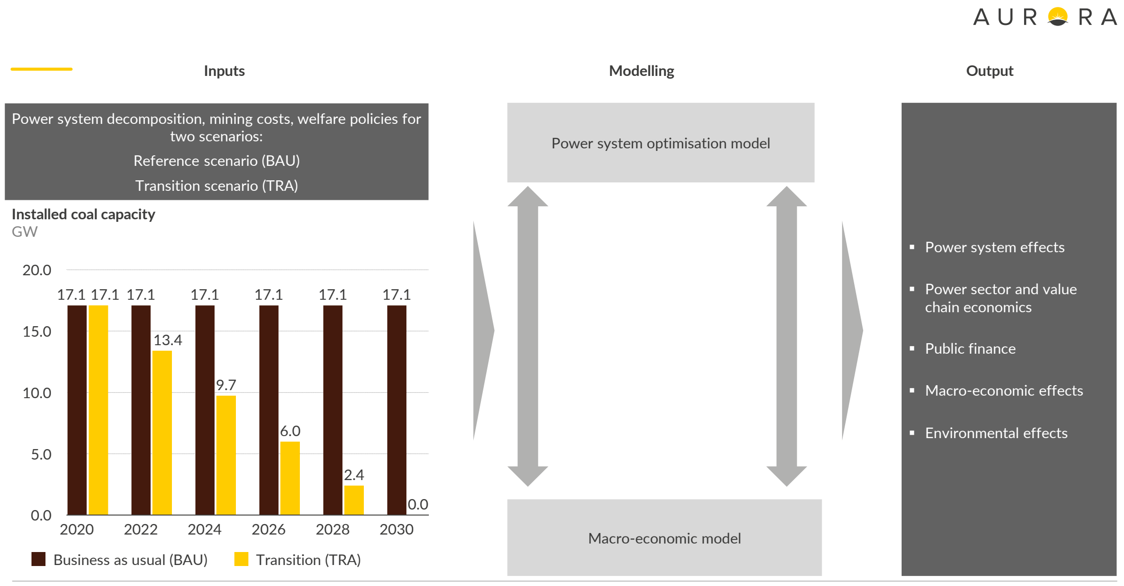


Figure ii.: Approach of the study

With this design, the study aims to show potential benefits and solutions as well as inform policy makers on aspects that have to be considered when planning a further transition of the power sector. Factors that should be considered when steering a process towards coal phase-out as well as drivers for costs and potential revenue streams become visible.

When taking a closer look on the power system modelling, two conclusions are central:

> Stable electricity supply can be guaranteed while reaching a renewable share of > 50% of power generation in 2030.

In the power sector, the assessment shows that security of supply can be guaranteed while phasing out coal. We modelled power generation on an hourly basis and see renewables taking an increasing share (see also Figure iii).

Coal generation decreases from 28% (or 40 TWh) to less than 20 TWh in the mid-twenties until its phase-out in 2030. Renewables take an increasing share in the electricity mix. In 2030, they generate more than 83 TWh, making up more than half of the total electricity mix. Generation from wind contributes the largest of all renewable sources. From 3.3 TWh in 2020, it increases to 29 TWh in 2026 and 42 TWh by 2030, making up 25% of the total generation mix. PV almost triples its share from 4% to 11% in 2030. This corresponds to an increase of over 12 TWh, from 6.2 TWh in 2020 to 18.6 TWh in 2030. By 2030, biomass generates almost 14 TWh of electricity, increasing from 1 TWh in 2020 to around 7 TWh in the middle of the decade. In the transition scenario, we also see that gas capacities are being relied on significantly more to provide the needed flexibility. Almost 9 TWh are generated by gas in 2030 in total. Notably, the old gas-powered steam turbines replace coal in mid-peak load. This points toward the second main conclusion from the analysis of the power system:

1) Coal CHP in TRA is gradually converted into Biomass CHP.

Source: Aurora Energy Research

Figure iii.: Power generation mix in BAU and TRA

Flexibility not capacity adequacy is the key challenge for the Ukrainian power system.

Currently, Ukraine has more capacity installed than it actually needs to fill its power demand. Today, there is not a single hour where 70% or more of coal capacity are used, and there are gas plants that do not need see any economic incentives to dispatch at all. This means that more than 30% of coal plants (or more than 5GW) could be phased out without any consequences for security of supply.

Our modelling has shown however that capacities that can balance intermittent generation from renewables are important. Nuclear plants with their technical limitations and the old age in Ukraine are mostly inadequate to provide this flexibility, which is why biomass, pumped hydro storage and batteries need to play an increasingly important role in a high renewable system. Here the question needs to be discussed how this flexibility can be ensured in the future in the most economical way.

Broadening the view from the power sector to its repercussions on the Ukrainian economy, five aspects deserve special mentioning.

Firstly, the analysis finds that the current operation of coal mines is hugely unprofitable.

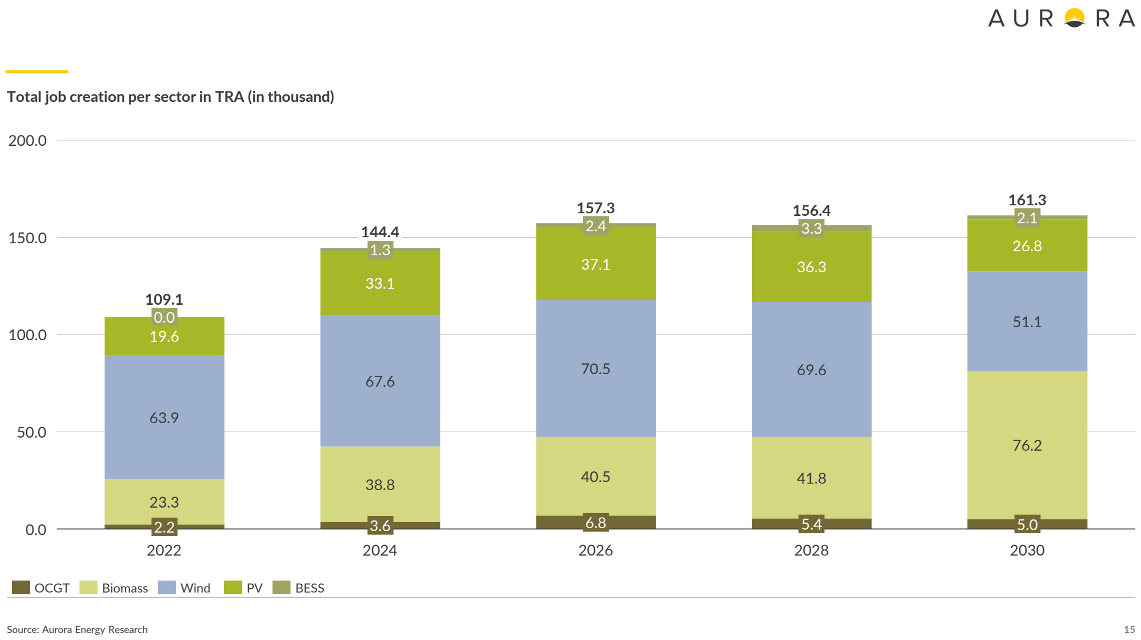
More than a billion Euro would be necessary to sustain the state-owned coal mines in the coming 10 years.

State-owned coal mines register losses of up to 230 € per ton of coal extracted. Shutting down these mines reduces mine-related costs by 35% for the state, even when accounting for decommissioning costs of these mines and compensation for workforce.

From mining companies' data, we assess that around 55 000 jobs in mining and power generation will be lost.

While 55 000 jobs will be lost with phasing out coal, the energy transition also creates the potential for up to 160 000 new jobs.

Photovoltaic, wind and biomass power generation assets can also be produced in Ukraine. This would create new jobs (see Figure iv).



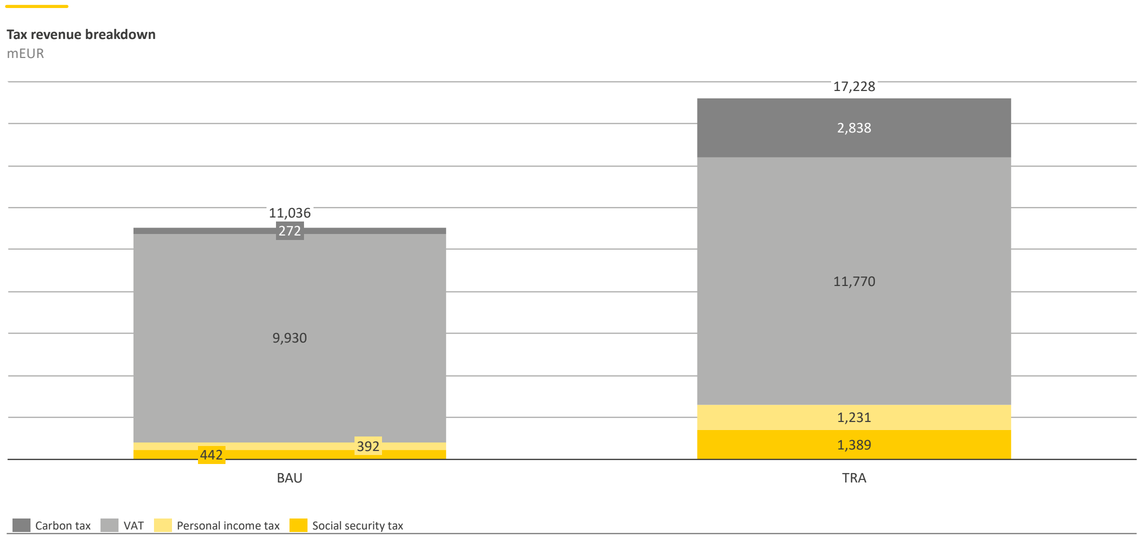
Total job creation per sector in TRA (in thousand)

Source: Aurora Energy Research

Figure iv.: Job creation in TRA

Changes in employment have implications for the state budget: The creation of new jobs impacts the state revenue via the income tax. We further analysed economic impacts of the energy transition on four components to the state budget: Income tax, social security tax, value-added tax (VAT) and carbon tax:

The transition scenario has a positive impact on public budgets, creating >50% higher tax revenues over the coming 10 years.



Note: Net present value with the 10% ROR

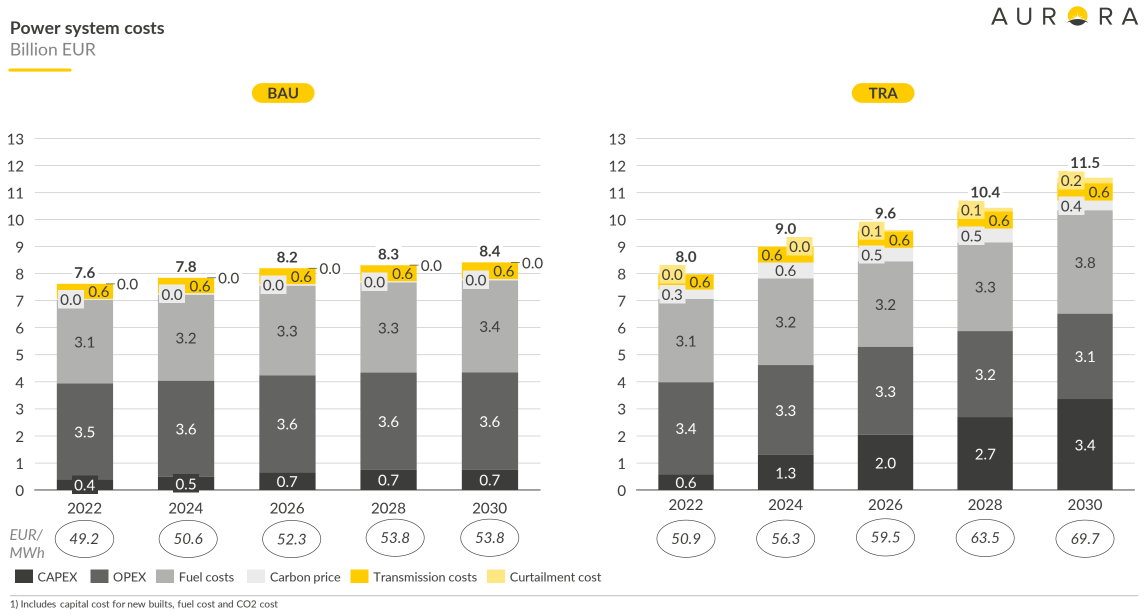
Source: Aurora Energy Research

Figure v.: Net present value of tax revenues in BAU and TRA

The transition and build-out of new generation assets requires investments and creates additional cost. Looking at the total system cost over the next decade, the analysis show:

The energy transition leads to higher power sector cost of on average EUR 1.6 bn.

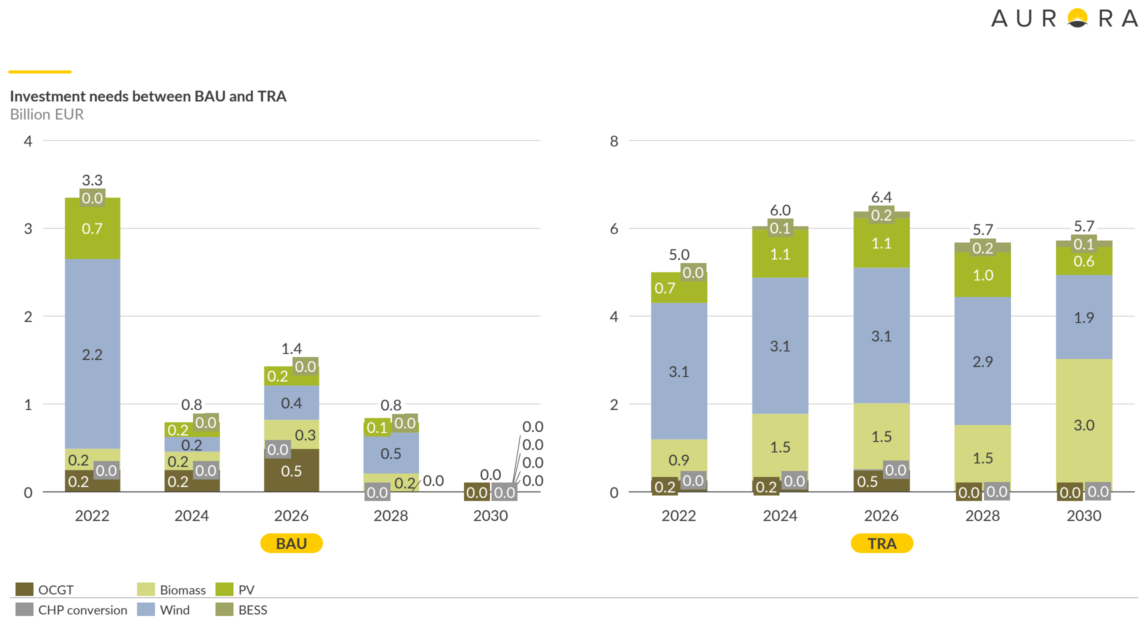
Here it is noteworthy that new investments in the sector are necessary under any circumstances in the medium and that an accelerated transition can help to target these replacements. The additional investments made have the potential to create jobs and stimulate economic growth (see Figure vii for an overview of investment needs).



1) Includes capital cost for new builts, fuel cost and CO2 cost

Source: Aurora Energy Research

Figure vi.: Power system costs



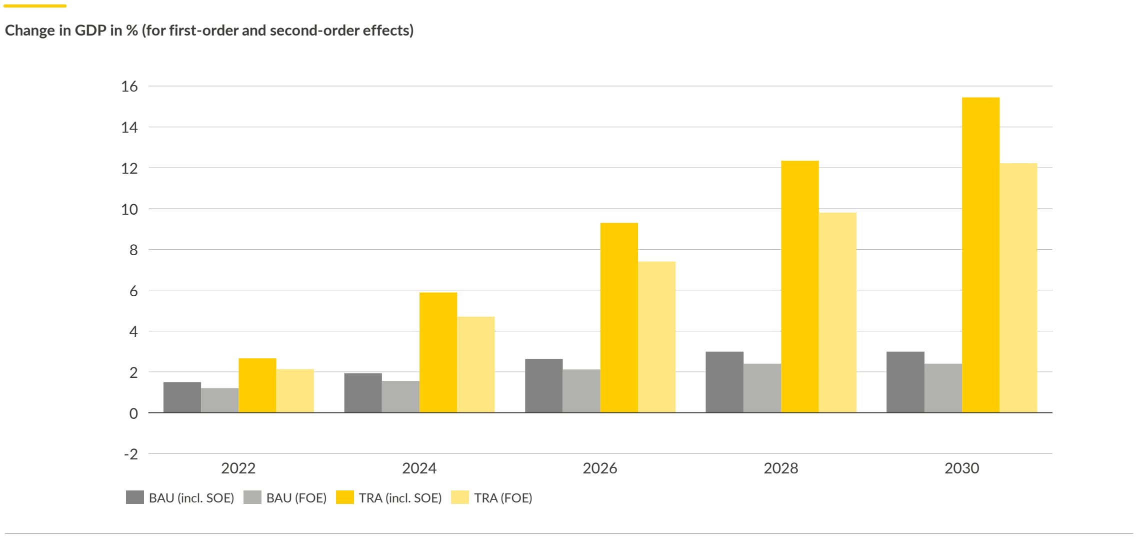
Source: Aurora Energy Research

Figure vii.: Investment needs under BAU and TRA

Lastly, the study assesses the wider macroeconomic impacts of the transition scenario (via a CGE model).

The analysis shows that the TRA scenario through the mobilised investments has a positive effect on gross domestic product (GDP). In comparison to the 2018 equilibrium, the analysis shows for TRA in 2030 that direct investment amounts to +12 % GDP and induces a total GDP growth of 15% (second-order effects of 3%). In comparison, direct investments under BAU amount to 2% of GDP, inducing a 3% growth (second-order effect of 1%).

These findings suggest that the positive direct impacts can cause further positive spill-over effects in the wider economy (also see Figure viii). The assessment of the impacts on individual sectors shows that certain sectors benefit, while others are negatively affected.



Source: Aurora Energy Research

Figure viii.: Impact on GDP in % of first-order (FOE) and second-order effects (SOE)

Key policy considerations

The investment necessity in the Ukrainian electricity sector opens a window of opportunity to steer the decarbonisation of the power sector, induce economic growth and create new job opportunities.

There are **six key policy areas** that need to be considered:

1. How can a **decarbonised power sector** in Ukraine look like? How can flexibility be ensured?
2. How can **investments** into the renewables and flexible asset be attracted?
3. What is the political economic behind the energy transition? Who are the **key actors** in the process that can facilitate change?

4. Which **processes** can facilitate the energy transition? What are formats (e.g. expert commissions, stakeholder consultations etc.) that enable this transition?
5. How can a **just transition** be designed? How can structurally affected regions and workers be best supported? How can vulnerable households be protected against rising power prices?
6. What **industrial policy** can complement the energy transition? Which existing sectors are negatively impacted by the transition process and might need support, what emerging industries can be attracted and build up for the future?

Peer-review of the study results

To ensure adequacy of the study's methodology, input data and assumptions and results, the Macroeconomic modelling center of Kyiv School of Economics was invited for peer-review as a well-known and trusted Ukrainian institution. Below is the peer-reviewer conclusion.

"The study "The economic implications of phasing out coal in Ukraine by 2030" is of crucial importance as it fills the gap on assessment the required changes at energy sector and coal mining in order to greatly increase efficiency of these sectors. It uses substantial level of data detalization and state-of-art approaches (such as computable general equilibrium model), creating evidence-based picture of the changes at economy level. The study indeed proves that the transition to phasing out the coal is possible and required. The value of the study is amplified by recent economic developments. The Ukrainian economy is hampered by chronic problems and most recently was being struck by COVID crisis. The public investment needs in fact are ultimately high. At the same time, the government has to support a lot of its unprofitable enterprises, where coal mines are of the worst performance.

It is worth to appreciate the efforts on collected data given its volume and quality. Input data consists of several detailed datasets, which allows to achieve high assessment precision. While the Ukrainian statistics in general tends to be highly aggregated, the microdata are very important in order to ensure the quality of study. And it is worth to note the collected dataset about the mining sector, which makes it is possible to show separate effects for each year of the mines shutdown process.

The study is balanced in arguments and ways of economic effects evaluation, applying bottom-up and general equilibrium approaches. The first one allows to show in a plain manner potential losses and gains for the labor market, government budget, while the second one makes possible to understand the overall economic effect in terms of gross domestic product as well as to show the sectoral impact. The level of details is sufficient and creates a distinct picture of the steps required at the transition scenario. The scenarios also reflect costs to the government in two cases of mines shutting down, namely, conservative and progressive, which gives understanding of what the government should do to balance between reforms needs and level of social tensions. Historical perspective demonstrates a decrease of miners by almost 7 times from 2002 to 2020. The large number of workers were able to get new qualifications and thus jobs. It gives hope to sort out the lay off issues in a civilised manner and hence to animate economically depressed regions. Social consequences are important since it is one of the main political reasons to keep mines in operation.

While the assumption on VAT increase can be taken as highly probable, there is an uncertainty about actual outcome of PIT and social security contributions. It doesn't make any major argument against the results, as these effects cannot be directly estimated from data and most of alternative assumptions may be a subject to critics. However the report may clearly state that the calculated increase of the mentioned taxes is valid mostly under the assumption of attracting the free labor market resources (unemployed persons etc.) as labor force reallocation between sectors can affect the results. In the latter case, tax increase will be slightly smaller and largely will be explained by wage differential. Elaborating of mentioned above assumptions on labor force, it is assumed in the study that loss or gain of the labor force is coming as newly created or destroyed. Still there are high probability that there will be a mix of changes, for example, since only part of the miners and heat power generation stations workers will retire after closing the mines, still the difference between scenarios will be kept.

The report shows around EUR 14.2 billion are required to fulfil the transition case, which is around EUR 1.5 billion invested annually under assumption of linearly distributed payments. The foreign direct investment over the last few years increased to USD 4-5 billion per year, which makes the assumption quite realistic. Important result is that while investment in the transition scenario exceeds business-as-usual scenario level fourfold, the total costs are higher by only one quarter. The investment flow is a main driving force behind the GDP growth in a transition scenario, which should be stressed on when delivering results to other stakeholders especially to the government institutions.

The study uses the simulations with a developed in-house computable general equilibrium model (CGE) aimed to increase validity of the results. The developed CGE model contains features to reflect the energy reform. The production factors are labor, capital and fossils, where the latter is important for changes in coal mining, otherwise largely being quite standard. It is based on 2018 input-output tables for Ukrainian economy and other data on national accounts. The important and unorthodox model feature, added specifically for the simulation, is decomposition of the electricity generation sector by generation type (coal power, renewables, and others) which substantially increases simulation accuracy. The other valuable feature of the simulation is constraints on coal price as well as simultaneous decrease of labor force in mining and coal mining itself. While this is probably correct in the short-term, the longer perspective may turn into employment of the part of former miners. And finally electricity prices might be fixed which helps to evaluate spillover effects. The simulation is able to show substantial shifts in labor force between the sectors (besides the coal mining) mostly driven by investment shock. Obviously, there are a number of assumptions which are theoretically correct but dot not fully cover stylized facts of the economy. For instance, labor force mobility between sectors in Ukraine currently is quite limited.

The model simulations show strong preference for a transition scenario which generates roughly 12% increase in GDP. Our own simulation with CGE model which aimed to replicate results assuming targeted decrease in coal supply and given investment flow generates slightly lower but close values. However we assume slightly different model specification, which may explain the difference in the results.

In overall, the study provides deep analysis of technical specification of electricity generation in Ukraine assuming phasing out coal generation as well as highly reliable and promising economic effects assessment. It confirms not only the possibility but indeed required transition from coal generation to renewable energy.”

Head of the Macroeconomic modelling center of Kyiv School of Economics,

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Introduction

The year 2020 has been marked by the pandemic of COVID-19 and the ensuing economic downturn. While the economic downturn has led to a sudden fall in emissions, these are likely to be temporary on a global scale. Energy consumption in Ukraine merely fell, which translated itself into lower demand for domestic coal. High coal consumption and large energy inefficiencies have generally placed Ukraine above the highest emitters from the EU per unit of GDP[1]. While Ukraine has pledged in the Paris Agreement to reduce its carbon emissions by 40% compared to the 1990 baseline, emissions have already decreased by 64% between 1990 and 2020. The biggest reduction by 48%[2] came from the economic collapse of the Soviet Union in the early 1990s.

The power sector plays a critical role in Ukrainian emissions, emitting around 58 Mt of carbon dioxide[3] (CO_2) in 2019 (excluding heat plants). In 2019, renewable power accounted for 13.5%[4] (including big hydro) of overall installed power capacity. According to its Energy Strategy until 2035[5], the Ukrainian government aims to increase the share of renewable power in the overall power generation to 13% (including big hydro) by 2030. Yet, several commentators have noted that Ukraine is already at 7.3%[6] (wind, solar, biomass) and that the goals therefore are essentially a continuation of the status-quo.

During the first lockdown in 2020, power demand in Ukraine declined by 5.9%[7]. As a result, three of the 15 nuclear blocks stopped generation for more than two months in line with a forecasted reduction in electricity demand. Sharp drops in March and April forced other nuclear reactors to reduce generation. These reductions are expected to account for a decrease of 8.6%[8] from the initially projected share of nuclear in power production in 2020.

At the same time, the coal sector witnessed tumultuous times during the COVID-19 pandemic. Salaries remained unpaid for several months and consequently workers in several mines refused to work[9]. Simultaneously, the state enterprise “Centerenergo” was accused of buying coal from the Russian Federation instead of buying from domestic suppliers[10]. The Ministry of Energy stepped in to resolve the situation in June 2020.

In addition, mining workers were promised repayment of debts from earlier before and during the pandemic as well as comprehensive discussions of the future of mining regions and so-called

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[1] World Bank Data: CO2 emissions (kg per 2017 PPP$ of GDP) – Ukraine, European Union, OECD members, Germany, Russian Federation

[2] World Bank Data: CO2 emissions - Ukraine

[3] UNFCCC, May 2020

[4] IEA data; hydro not included

[5] OECD, 2020

[6] Ukrenergo; not including hydro

[7] Українська енергетика, Jul. 2020

[8] World Nuclear Association, Feb. 2021

[9] Ministry of Energy of Ukraine, Jun. 2020

[10] Ministry of Energy of Ukraine, Jul. 2020

mono-cities (relying economically solely on coal mining). However, salary payments were further delayed until November 2020. The crisis seems to be resolved for the moment due to special aid of about 0.5 bn EUR[11] dedicated to salaries in the mining industry. This situation proves once again that coal mining sector remains a burden for the State Budget of Ukraine. At the same time research[12] shows an ineffective use of public money spent for support and restructuring of coal mining sector.

On the other hand, Ukraine has committed at the highest level to follow principles of the European Green Deal. This means that decarbonisation should become a core principle of its overall economic development. It has been already reflected in the latest statements and policy amendments. For example, the government of Ukraine is in the process of developing the Concept and respective State program for the transformation of Ukraine's coal mining regions until 2030 and the Concept for a coal sector reform until 2030. These documents are expected to foresee the closure of some coal mines and to decrease the share of coal in the energy mix. At the same time DTEK company – the biggest Ukrainian private coal mining and coal power generating company – announced[13] in 2020 the goal to become climate neutral in 2040 and close all coal facilities by that time.

Regardless of these plans and announcements, the Ukrainian power sector remains the most carbon intensive sector of the economy. Thus, the report focuses on the power sector and its decarbonization potential. It is generally considered the easiest sector to decarbonise with economically competitive and technically feasible low carbon solutions available. It furthermore considered to be instrumental in electrifying and decarbonising other sectors. The scientists of the Intergovernmental Panel on Climate Change (IPCC) agree [14] that to globally avoid catastrophic impacts from climate change, greenhouse gas emissions should be drastically reduced before 2030, not after. **Therefore, this report is aimed at assessing whether a substitution of coal power generation with renewables is feasible in Ukraine by 2030. The report asks how this alternative can satisfy future electricity demand and how this will influence CO_2 emissions. Furthermore, the report also assesses how the economic costs of a continuation of coal mining and coal power generation compared to the economics of a new renewables-based power system.**

Thus, the report zooms in on the power-sector and the potential of a coal phase-out combined with big investments in renewable energy sources and their subsequent impact on the wider economy in comparison to a continuation of business-as-usual.

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[11] Ministry of Energy of Ukraine, Nov. 2020

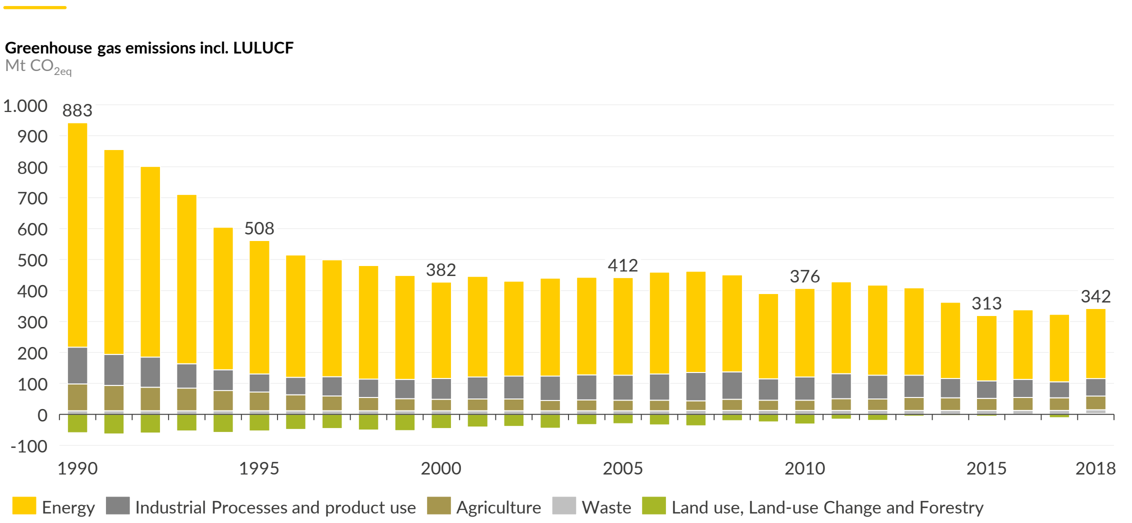
[12] DixiGroup, 2020

[13] DTEK, November

[14] IPCC, Mar. 2020

1 Brief description of the Ukrainian power sector

The energy sector is crucial when it comes to the decarbonisation of Ukrainian's economy. As Figure 1 shows, emissions have decreased rapidly after the collapse of the Soviet Union, but stagnated in the current century.



1) Energy includes energy industries, manufacturing industries and construction, transport, fugitive emissions from fuels and other

Sources: Aurora Energy Research, UNFCCC Emissions Inventory

Figure 1: Historic carbon emissions

However, the energy sector still takes the biggest share of all emission, and the power sector makes up almost a third of the carbon footprint of it.

Throughout the history of its independence, Ukraine has covered its electricity needs through the use of nuclear, coal and gas-fired, and hydro power plants. In the last 10 year, renewables like solar, wind and biomass have started to provide an increasing share.

In 1990, electricity generation stood at nearly 299 TWh[15]. The next decades saw a gradual decline in generation, with a minor uptick from 2000 to 2012. In 2020, nearly 150 TWh of electricity were generated. For more detailed information see Figure 2. The reasons for the changes varied following economic and political developments.

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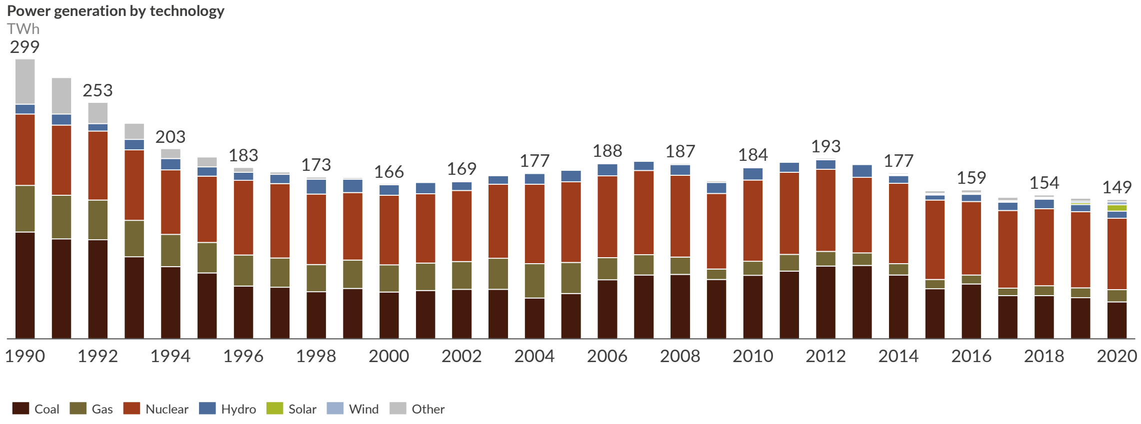
[15] IEA Data



Power generation by technology

Sources: Aurora Energy Research; UKRStat, Ukenergo, Minergy

Figure 2: Electricity generation in Ukraine, 1990-2020

According to the Ministry of Energy[16], in 2020 51.2% of Ukraine electricity was produced by nuclear power plants, 35.2% by thermal power plants (dedicated power plants and cogeneration combined), 5.1% by hydro power and pumped-storage plants. This was on a par with previous years, with general fluctuations of about 1-2%. Renewables (solar, wind, biomass) accounted for 7.3%, which presents more than doubling of its share in 2019 (3.6%).

For more detailed information on Ukraine electricity mix containing information from 1990 to 2020 see Figure 3[17] and Figure 4[18].

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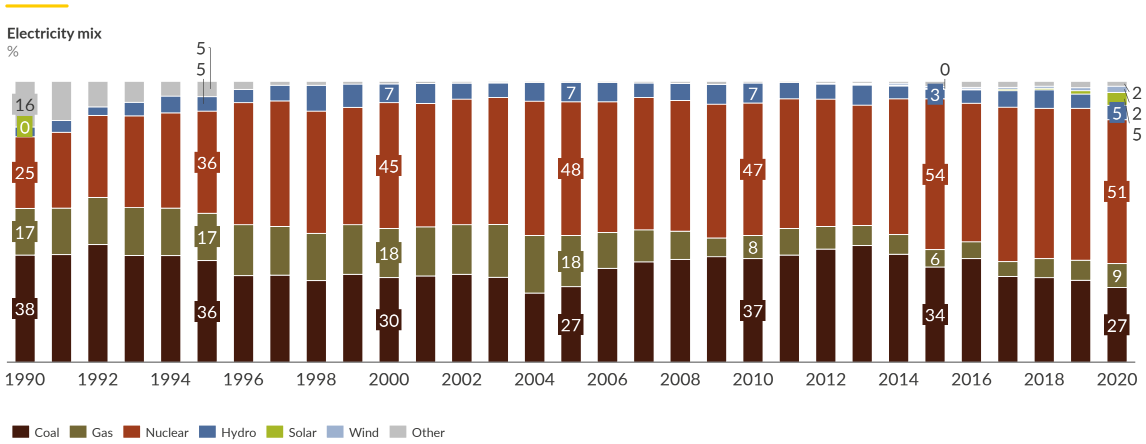
[16] Ministry of Energy of Ukraine, 2020

[17] State Statistics Service of Ukraine, NEC Ukrenergo, Ministry of Energy of Ukraine

[18] Ministry of Energy of Ukraine



Sources: Aurora Energy Research; UKRStat, Ukenergo, Minergy

Figure 3: Electricity mix 1990-2020

As for the electricity consumption by sectors, according to the Ministry of Energy[19] industry accounted for 41.8% in 2020. Population placed second with 31%, while utility consumers accounted for 12%. Other non-industrial consumers amounted to 6.3%, transport 4.8%, agricultural consumers 3.2% and construction 0.8%.

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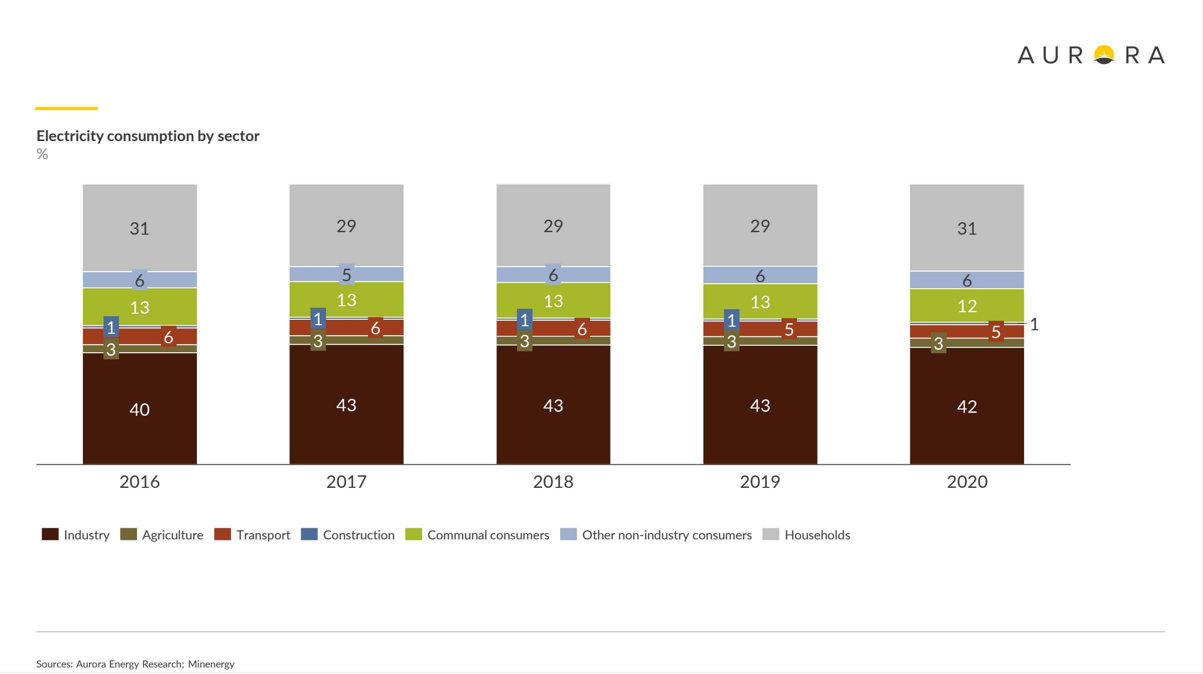
[19] Ministry of Energy of Ukraine



Sources: Aurora Energy Research; Minenergy

Figure 4: Electricity consumption per sector

Despite a big share of nuclear generation (with little direct CO_2 emissions), the Ukrainian electricity sector shows significant carbon emissions. Between 2012-2015, the CO_2 emission factor for the electricity grid was estimated in the range 0.74 tCO_2[20] per MWh. High amount of transmission losses add between 0.02 and 0.13 tCO_2 per MWh on the top of emissions associated with electricity production. The emissions largely stem from the burning of fossil fuels, primarily coal. The IPCC has assessed the hard coal to amount to 0.8 t CO_2-equivalent per MWh. Due to ageing plants with low efficiencies, emission factors range from 0.9 to 1.6 t per MWh[21] in the Ukrainian coal fleet. The Ukrainian power sector includes several other technologies with lower emissions. Gas-fired power generation is assessed to emit around 0.5 tCO2-equivalent per MWh of electricity (depending on plant), whereas hydropower, nuclear, wind and solar lie significantly below 0.01 t CO_2 equivalent per MWh of electricity generated[22] (for hydropower the emission intensity depends on the setup of the reservoir).

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20 European Investment Bank, July 2020

21 KT-Energy LLC, Mykola Shlapak, 2017a

22 IPCC, 2014

2 Research methodology

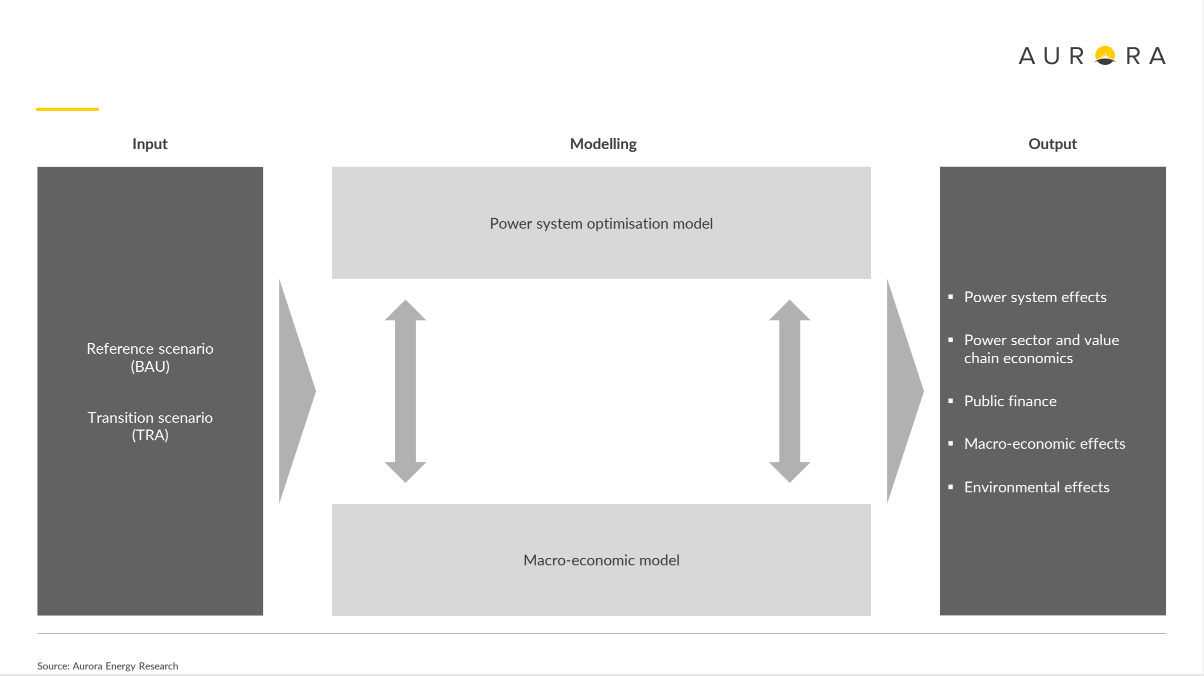
The main objective of this report is to assess the impact of a potential coal phase-out until 2030 on the power system and the wider economy. Hence, the report compares the overall system cost, dispatch decisions, generation mix, CO_2 emissions as well as wider economic impacts under two scenarios.

2.1 General methodological approach

The analysis relies on two separate models to simulate the future evolution of the power system and the wider economy: a power system and a macro-economic model.

Firstly, a power system optimisation model simulates the dispatch in the power system for 2021-2030 based on specified inputs for both scenarios (see Section 2.3Power sector input data and assumptions). This stage shows the capacities required to guarantee a stable power supply and the overall generation mix and associated cost for both scenarios. For more details on the model, see the description of the Optimal Dispatch Model in the Section 2.1.1.

Then, the results from the power system analysis are used to a macro-economic model to simulate economy-wide outcomes based on macro-economic assumptions (see Section 2.1.2). How inputs, modelling and outputs interact can be seen in Figure 5. The study integrates a power system optimisation with a macro-economic model under two scenarios.



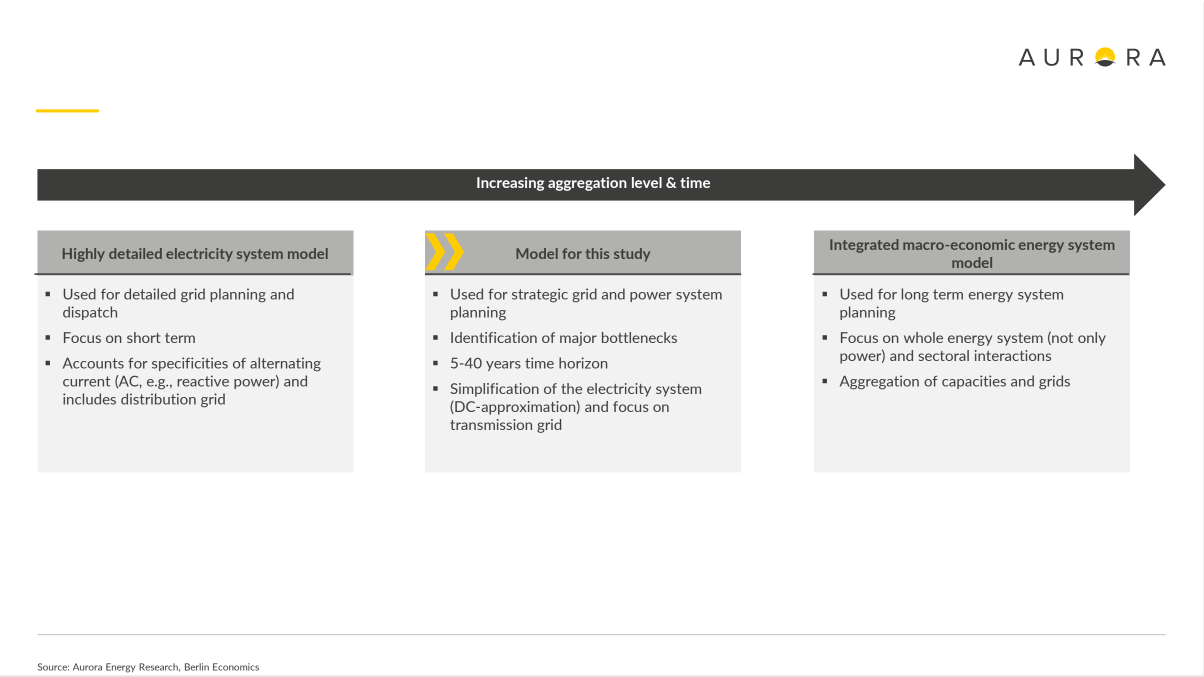
Source: Aurora Energy Research

Figure 5: Modelling approach underlying this study

2.1.1 Power sector modelling

The model analyses the cost-optimal dispatch of the Ukrainian electricity system for every hour of the year to establish which plant types/transmission capacities should be used in which region of the country. This allows to identify bottlenecks – insufficient generation or transmission capacities – and to calculate the fuel cost and emissions of the system. A sensible timeframe of analysis is five to forty years in the future, but in the context of this study we model the years 2022 to 2030. How the model compares to other models is shown in Figure 6.

The ‘optimal dispatch model’ ranks plants in terms of their short-run marginal cost of production and dispatches the cheapest sources first and adds more generation capacity until the demand is fully satisfied (for each hour). The short-run marginal cost of production of power plants is the fuel input, operations- and maintenance cost and includes other expenses, such as a levy on CO_2. Changes to generation capacity are determined ‘outside’ of the model (‘exogenously’) based on plausible scenarios of the power system (see Section 2.2).



AURORA

Increasing aggregation level & time

Highly detailed electricity system model

- Used for detailed grid planning and dispatch
- Focus on short term
- Accounts for specificities of alternating current (AC, e.g., reactive power) and includes distribution grid

Model for this study

- Used for strategic grid and power system planning
- Identification of major bottlenecks
- 5-40 years time horizon
- Simplification of the electricity system (DC-approximation) and focus on transmission grid

Integrated macro-economic energy system model

- Used for long term energy system planning
- Focus on whole energy system (not only power) and sectoral interactions
- Aggregation of capacities and grids

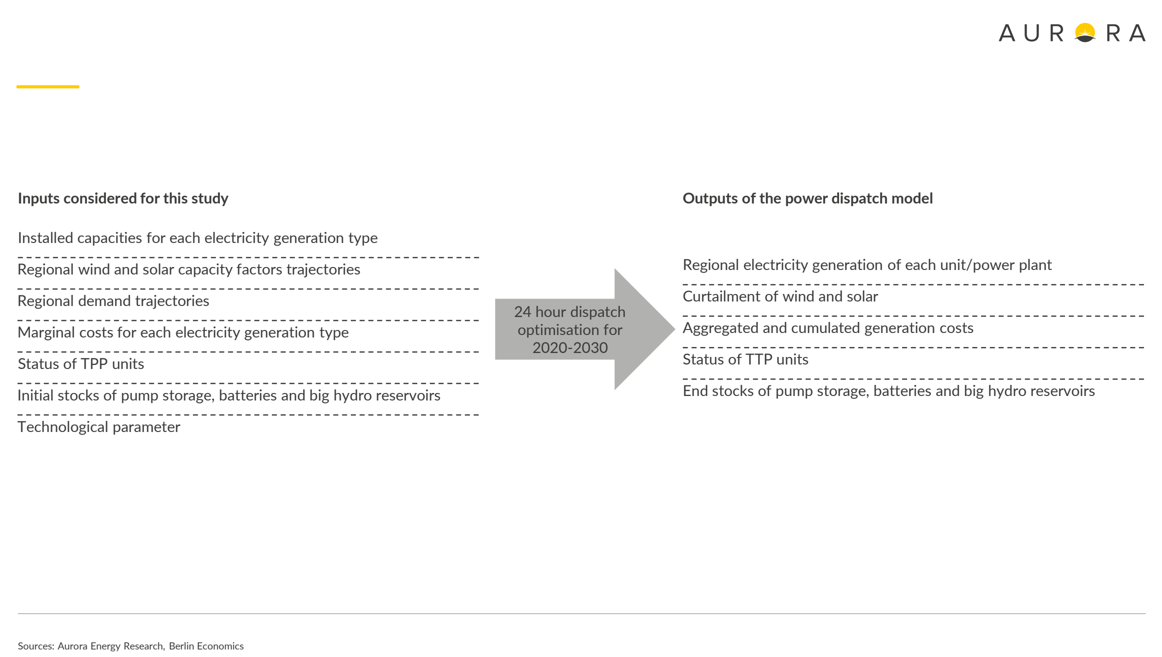
Source: Aurora Energy Research, Berlin Economics

Figure 6: Power market model used in the analysis

The following points briefly summarise the main functionalities of the model:

- **Day-ahead dispatch optimality:** The model optimizes the dispatch in a day-ahead perspective, defining stepwise the generation of installed capacities for the following hours depending on demand and weather conditions.
- **Time frame and time resolution:** The modelling is performed with hourly granularity for the whole year (8760 hours). For this report, five separate years within the 2020-2030 timeframe were modelled (2022, 2024, 2026, 2028 and 2030).

- **Technologies**: The model considers conventional power capacities such as nuclear (NPP), different types of thermal power plants (TPP), furthermore renewable sources (wind, solar, biomass and hydro) as well as storage capacities such as batteries and pump hydro capacities.
- **Power plants and units:** Existing nuclear, coal and gas thermal power plants are detailed down to single generating units, each with its own technological parameters. Thermal power plants are described on unit level and standard unit commitment. Other technologies, as well as new installations, are treated as an aggregate power plants, with general parameters and different geographical locations.
- **Technological specifics and costs:** For each electricity generation type, (different) technological parameters are considered, such as installed capacity, capacity factors, ramping constraints unit efficiency, unit fuel, fuel costs and/or minimal run-times, start-up costs of thermal power plants.
- **Power system topology:** The model assumes the Integrated Power System of Ukraine combined with Burshtyn Energy Island with no additional transmission constraints.
- **Transmission constraints:** The model considers eight Ukrainian transmission system operator (TSO) regions (energy systems described as nodes). Each two nodes are connected by no more than one transmission line. The maximum capacity of the transmission between two nodes is considered, and the balance rule at nodes. Kirchhoff laws are considered. The generation of each type is attributed to each node (region) to represent transmission constraints.
- **Cross-border trade:** The model can simulate import-export of electricity. In case of no explicit description of neighbour countries, import and export of electricity can be described as a generation types for those regions that are connected to foreign countries. For this report, cross-border trade is not included in the modelling.
- **Demand**: Fluctuating demand is defined by using the historical hourly electricity demand for each region and upscaled for future years.
- **RES:** Power generation from fluctuating renewables (wind and solar) are constrained by weather dependent capacity factors based on historical satellite data, that are considered for each of the regions.
- **Reserves and flexibility:** Reserves provision and flexibility (representing intra-day trade, not depicted in the day-ahead view) can be considered either by fixed reserve requirements or based on uncertainties resulting from RES and demand fluctuations. For this report, the fixed reserve requirement is formulated (2199 MW upward, 1040 MW downward) in line with the Ukrainian Grid Codes.
- **Curtailment:** The model considers curtailment of RES as a difference between maximum potential generation and optimised dispatch.
- **Implementation and computation**: The model is implemented in Pyomo, a Python-based, open-source optimization modelling (http://www.pyomo.org). Pyomo enables the usage of different open-source solvers (e.g. CBC, GLPK) as well as commercial solvers, such as MOSEK, GUROBI, CPLEX and further. The modelling for this report was performed using MOSEK solver.



Inputs considered for this study

- Installed capacities for each electricity generation type
- Regional wind and solar capacity factors trajectories
- Regional demand trajectories
- Marginal costs for each electricity generation type
- Status of TPP units
- Initial stocks of pump storage, batteries and big hydro reservoirs
- Technological parameter

24 hour dispatch optimisation for 2020-2030

Outputs of the power dispatch model

- Regional electricity generation of each unit/power plant
- Curtailment of wind and solar
- Aggregated and cumulated generation costs
- Status of TTP units
- End stocks of pump storage, batteries and big hydro reservoirs

Sources: Aurora Energy Research, Berlin Economics

Figure 7: Structure of inputs and outputs of the power market model

2.1.2 Macro-economic modelling

The macro-economic modelling analyses the impact of changes to the power sector on the entire economy. The study specifically analyses macro-economic and fiscal effects.

Macro-economic and fiscal effects

- Employment and net effect on jobs across the analysed value-chains. *Estimate of job impact of coal and renewable sector developments*
- Social welfare benefits payable by the state to dismissed coal-sector workers. *Based on estimates of current income and required benefits*
- Total savings and additional expenditures (e.g., through lower state subsidies for unprofitable coal mines) required, both for new capacities and decommissioning costs (TPPs) and mines separately) *Based on required investments in the power sector and estimates of decommissioning costs*
- Net effect on taxes (VAT, income tax, CO_2 tax, social security taxes): *Changes to domestic value creation, domestic jobs figures, CO_2 emissions and cost of benefits for coal-sector workers*
- Total effect on GDP, including effect on net export. *Calculation of total cost and impact of domestic value creation*

We generally distinguish between first-and second-order economic effects of the coal-phase out in Ukraine described in detail in the Section 2.4.

2.2 Two scenarios: Business-as-usual and Transition scenario

Scenario analysis is widely used across economics and other social sciences to assess the impact of different future development paths. These scenarios offer policy makers, utilities, and other important stakeholders a high-level view of the ramifications of different future energy system pathways. We describe two different scenarios, which are described in detail in 2.2.1 and 2.2.2:

- **Business-as-usual (BAU) scenario,** reflecting the continuation of current trends and foreseen policies.
- **Transition (TRA) scenario,** which includes an optimistic yet feasible phase-out of coal-fired power generation until 2030 and full-speed transition to renewable power (solar, wind, and biomass).

It is important to note that the BAU and transition scenario are not *predictions* of the future evolution of the power system. Rather, they describe and analyse two out of a large set of possible 'futures'.

The report is based on these two to represent two radically different visions of the future: one shaped by the continued use of coal-fired power generation (business-as-usual) and the other by a phase-out of coal and a subsequent transition to renewable energy sources (RES). The analysis intends to open a wide *possibility space*, with many possible scenarios in between.

The next two sections describe the scenarios in more detail.

2.2.1 Business-as-usual (BAU) scenario

The scenario is a continuation of current policies and the underlying structure of the power system. It assumes that carbon prices remain low, the ambition of climate policy in Ukraine remains at the baseline of the Nationally Determined Contributions (NDC) 2015 and coal-fired power generation remains a major part of the energy system.

2.2.2 Transition scenario

The scenario considers a possible development of the power sector, in which the fleet of aging and inefficient coal power plants is consecutively phased out until 2030 and replaced by wind and solar power generation and additional flexibility. The scenario rests on greater political ambition to curb CO_2 emissions and price carbon. In this scenario, coal combined-heat-and-power plants (CHPs) are refurbished and fired with biomass.

For the Transition scenario the value creation of producing and installing RES equipment is increasingly occurring domestically. As demand in Ukraine increases, imports are decreasing over time. This creates new employment opportunities along the domestic value chain.

New cost-effective non-fossil-based balancing (except of 2 GW gas high flexible capacity) and reserve capacities are deployed alongside to ensure flexibility enough to integrate additional renewables. Existing non-coal capacities are remained to provide balancing and reserves. The

Transition scenario aims to reduce the total greenhouse gas (GHG) emissions of the system significantly.

2.3 Power sector input data and assumptions

The following section set out the assumptions determining power demand and supply as well as other macro-economic variables.

In terms of power: On the demand side, critical drivers of future power demand are population growth and GDP growth (increasing demand) and improvements in energy efficiency (reducing the power demand).

2.3.1 Electricity demand development

Gross electricity demand is assumed to increase in both scenarios from 147 TWh in 2020 to 160 TWh in 2030 in line with Ukrenergo's[23] resource adequacy plan. The demand figures do not include the demand of the occupied territories of Crimea and Donetsk-Luhansk region.

Table 1: Gross power demand assumptions, BAU and TRA

Year	2020	2022	2024	2026	2028	2030
Demand [TWh]	147	154	156	157	159	160

Residential PV capacity has reached 780 MW in the end of 2020, generating 759 GWh, or 0.5% of total generation. Form the system and modelling perspective, the effect of this distributed generation is that it reduces gross demand as households and businesses consume more on-site and less from the grid. We assume that the current share of distributed generation stays constant between 2020-2030. The pre-covid gross demand profile, which includes the distributed generation effect, is scaled up for the modelling purposes.

Electricity demand is strongly linked to energy efficiency measures, electrification of transport, heat and industrial processes as well as the general development of the industrial sector. This is further contextualised in Section 2.3.2.

2.3.2 Energy intensity

While a growth in GDP and population increases power demand, energy efficiency improvements lead to lower demand as technologies and building become more efficient in their power use. While there are countless studies showing so-called 'rebound-effects' - more efficient technologies lead to lower power demand, which in turn decreases power prices, and lower prices in turn lead again to increasing power demand – these rebound effects normally do not fully offset efficiency gains. For example, projections from the Institute for Economics and Forecasting & the Böll Foundation (2017)[24], forecast the energy intensity of the Ukrainian

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[23] Ukrenergo, 2020

[24] Heinrich Böll Foundation Ukraine, 2017

economy to fall by 40% till 2030 (from 0.28 in 2020 oil equivalent (toe) per thousand 2010 USD PPP to 0.17 in 2030). Thus, energy efficiency is often considered for countries with high energy intensity of economy as additional "renewable" source of power. Although, energy efficiency measures were not deeply analysed in this study, there are studies and experience of other countries showing that energy efficiency measures can not only make energy transition easier technically, but to induce development of construction and other industries creating job places and bringing economic benefits.

2.3.3 Commodity prices

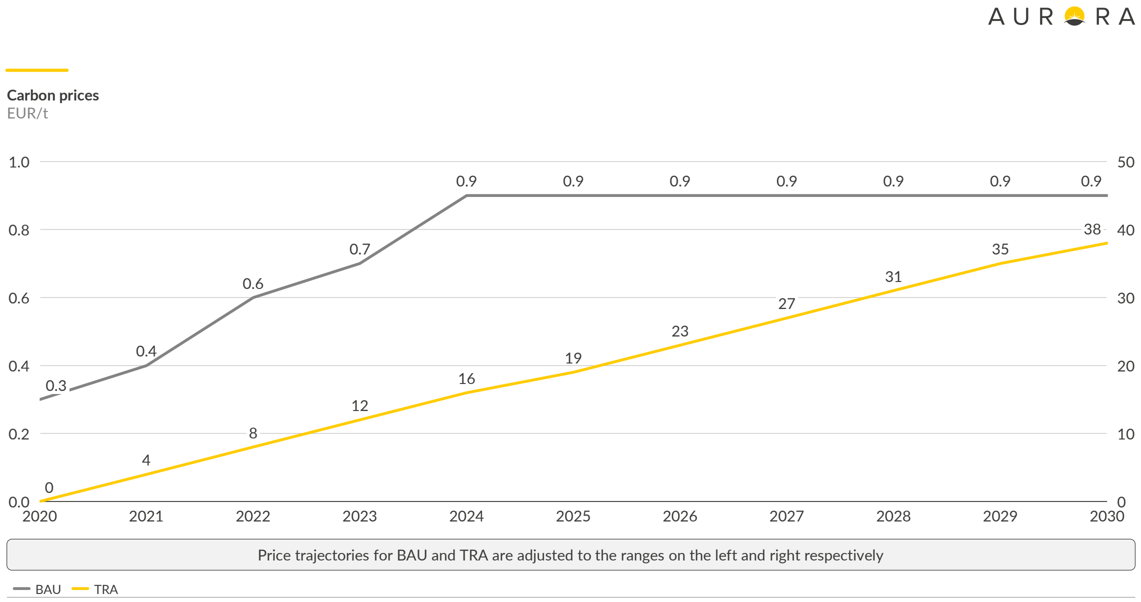
Commodity and CO_2 prices strongly influence the marginal cost of power plants, and therefore their dispatch in the power market. For instance, the recent decrease in gas prices around the world has led to a higher share of gas-fired power generation across many European countries (e.g., Germany, Greece). Similarly, changes in CO_2-prices – such as the stark increase in European Union Emissions Trading Scheme (EU ETS) prices – have led to a gradual decrease of the competitiveness of CO_2 -intensive power generation (e.g., coal) in the countries subject to such CO_2 -prices.

Table 2. Commodity price assumptions under BAU and TRA

	2022	**2024**	**2026**	**2028**	**2030**
Coal (EUR/t)	71	74	76	78	79
Gas (EUR/MWh)	20	22	25	26	27
Nuclear (EUR/MWh)	5	5	5	5	5
Biomass (EUR/MWh)	20	20	20	20	20

2.3.3.1 CO_2 tax development

Business-as-usual: Based on the draft law #4101-d, which is currently discussed in the parliament, we assume that CO_2-prices will rise from the current level of 0.3 EUR/tCO_2 (10 UAH/tonne) to 0.9 EUR/t CO_2 (30 UAH) in 2024. We assume it to remain stable until 2030.



Source: Aurora Energy Research

Figure 8: Carbon price assumptions under BAU and TRA

Transition scenario: Through a gradual increase, the carbon tax in Ukraine approaches the level of forecasted EU ETS prices (at 38 €/tonne[25]) in 2030. This is broadly in line with other forecasts (e.g., E3M[26], REKK[27]).

2.3.4 Cost of renewable energy technologies

The investment cost of RES technologies is critical to understand the total cost of the power system.

Table 3: Technology costs of Wind under BAU and TRA

	2020	**2022**	**2024**	**2026**	**2028**	**2030**
CAPEX (EUR/kW)	1150	1137	1100	1087	1071	1054
OPEX (EUR/kW)	25	29	30	31	32	33

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[25] Based on Aurora's of EU ETS price projections.

[26] E3Modelling – E3MLabh, Mar. 2020

[27] RAP, May 2020

Table 4: Technology costs of Solar, BAU and TRA

	2020	**2022**	**2024**	**2026**	**2028**	**2030**
CAPEX (EUR/kW)	750	710	641	583	534	492
OPEX (EUR/kW)	22	18	15	13	12	10

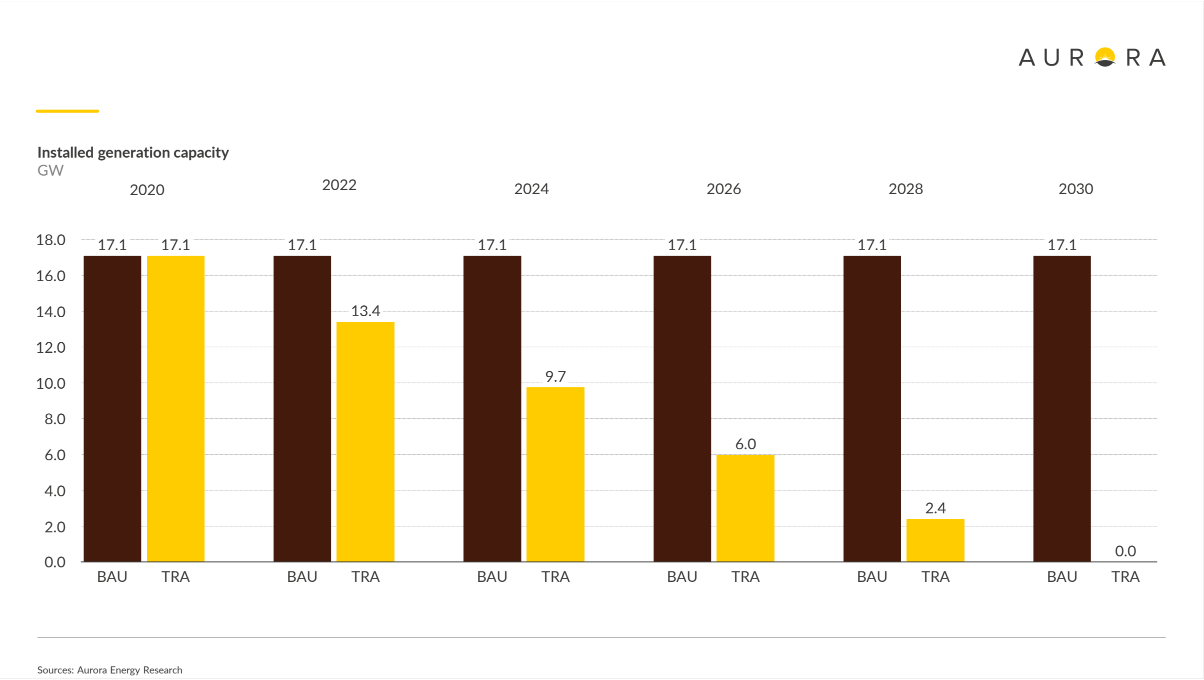
Both scenarios

- We use current capital costs (CAPEX) and operational costs (OPEX) values from Ukraine (provided by Association of Solar Energy of Ukraine and Ukrainian Wind Energy Association) for both technologies and apply Aurora's global technology learning rates.
- Cost assumptions for additional technologies can be found in the Annex.

2.3.5 Development of power generation capacities

2.3.5.1Coal

The BAU scenario assumes no changes to Ukraine's installed coal capacities. It does not take into consideration plans under the National Emissions Reduction Plan as politically difficult to enforce. In turn, TRA assumes a linear phase-out of coal capacities until 2030, based on the age of the generation blocks (see Annex for detailed list). As the costs arising from decommissioning of these blocks are unavoidable in both scenarios in the medium term, the difference in this part of expenditure between them is not considered in this study.



Installed generation capacity
GW

Sources: Aurora Energy Research

Figure 9: Coal capacities under BAU and TRA

2.3.5.2 Gas

Existing gas-fired steam turbine units totalling 4.6 GW remain online in both the BAU and the TRA scenarios. While existing units help to replace coal and to avoid building additional peak generation capacity in the TRA closer towards 2030, these aging units offer limited flexibility. Therefore, investments into 2GW of new peak generation capacities in the form of open-cycle gas turbine plants are foreseen by both scenarios.

The open-cycle gas turbines (OCGT) will be introduced to the Ukrainian power system during 2021-2026. This is based on Ukrenergo's Generation Adequacy Report (the latest draft available at the date of report preparation)[28] that deems the addition paramount for providing the required system flexibility and security of supply. The OCGTs constitute the only new investment into conventional generation to occur in the transition scenario.

2.3.5.3 Co-generation plants

Ukraine's CHP fleet of approximately 4 GW comprises a mix of coal- and gas-powered thermal power plants. In this report, we do not include effects of energy efficiency or other changes to heat demand, thus the CHP power generation remains constant for both scenarios. In BAU, we assume no changes to the existing installations. While in the transition scenario, to reduce GHG emissions, all old coal-based CHP plants are replaced with biomass units of the same generating capacity. This is also reflected in additional investment needs equal to 150 EUR/kW[29] of CHP

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[28] Укренерго, 2020

[29] Based on comparable projects across European countries

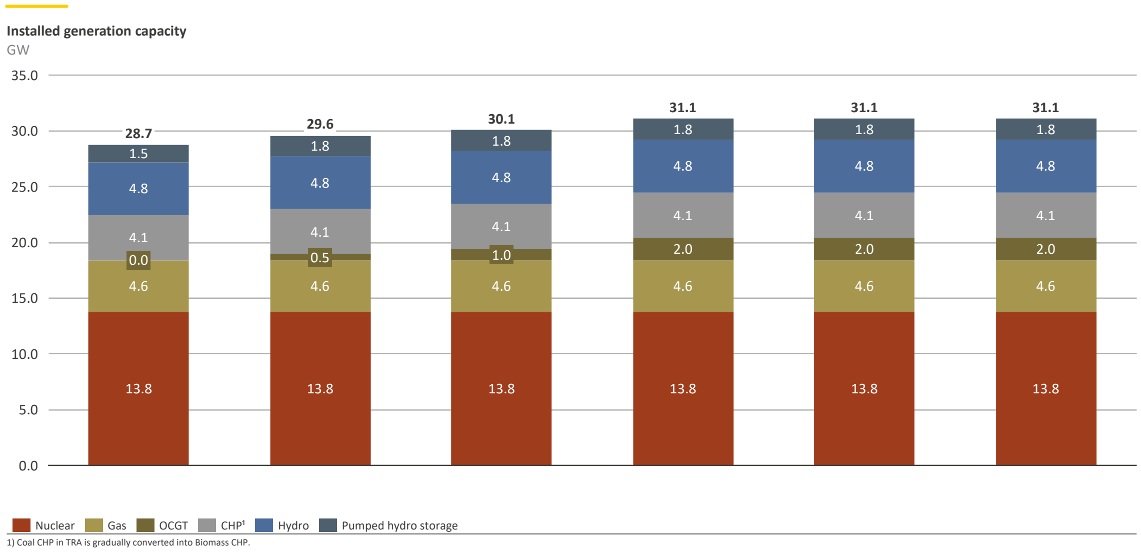
capacity. It is also noteworthy that significant capacities of small-scale CHP plants exist that are not connected to the transmission system and provide heat and electricity on-site. These are excluded from the modelling of the power system, as they have no direct effect on overall dispatch and are generally subtracted from demand.

2.3.5.4 Nuclear

We assume no changes to the installed capacities of Ukraine's nuclear fleet (until 2030) under both scenarios.

2.3.5.5 Hydropower generation and storage

For both scenarios, the installed capacities of hydro power stations and pumped hydro remain constant until 2030. The 4th unit of Dnistrovska pumped hydro station, scheduled to begin commercial operation by the end of 2021[30], is included in the model from 2022 onward. No new greenfield or brownfield projects, announced by Ukrhydroenergo and Energoatom on the different stages of development, are implemented in the model until 2030 for this report.



1) Coal CHP in TRA is gradually converted into Biomass CHP.

Source: Aurora Energy Research

Figure 10: Conventional generation capacities constant under BAU and TRA (coal excluded)

2.3.5.6 Renewable generation

For BAU, we take a conservative approach that will allow to achieve renewable power generation targets according to National Energy Strategy until 2035. We estimate the additional capacities until 2030 based on a) expert estimations for capacities which were pre-developed before introduction of the auctioning scheme and are likely to be installed during 2021-2022 as a legacy

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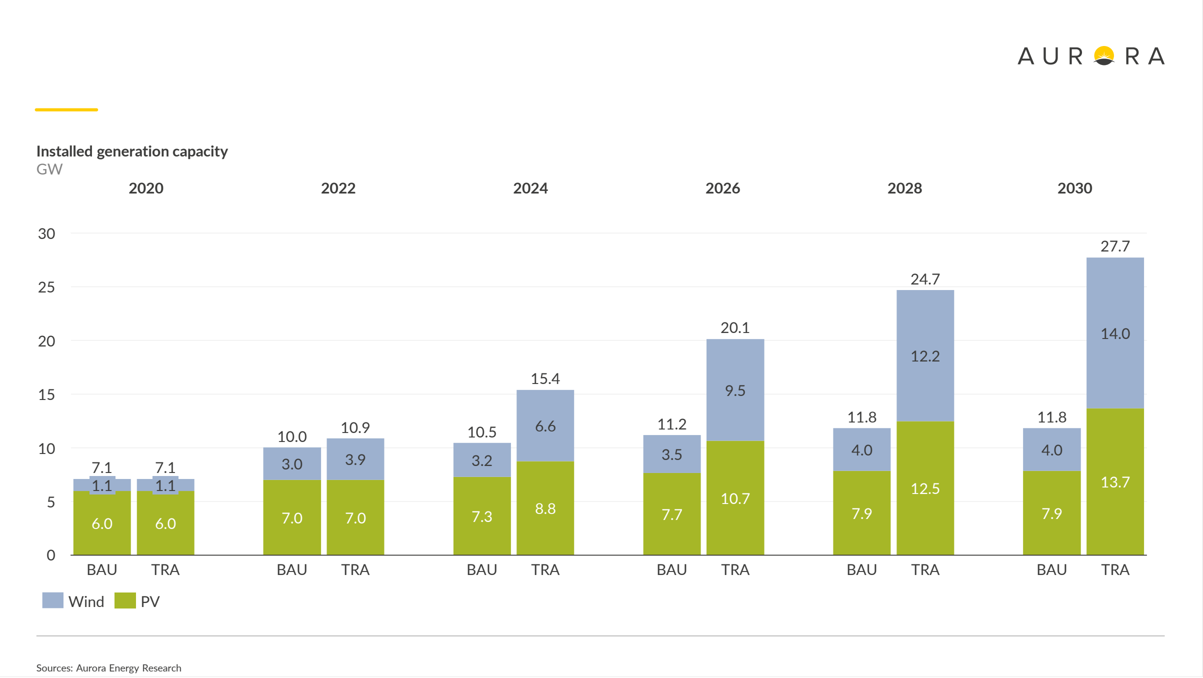
[30] Ukrhydroenergo, Mar. 2021

to feed-in tariff (FIT) scheme; b) Ministry of Energy press release with estimated auctioning quotas for the 2021-2026[31] becoming operational in 2023-2028.

In Transition scenario, the coal-powered generation is phased out and replaced mainly by renewable energy. There is no target share of RE in this scenario, it is derived from the modelling results. The built-out of RES technologies is based on cost-optimal approach. To minimize the total system costs and flexibility requirements, the new PV and Wind capacities are introduced at 60/40 ratio annually respectively. This results in almost equal installed capacity of 14 GW PV and Wind power stations in 2030. PV and Wind installations are distributed geographically equally, to avoid over-representation in the resource-reach south of Ukraine. Biomass generation units are introduced with 500 MW increase each 2 years until it reaches 3 GW in 2030.



Installed generation capacity
GW

Sources: Aurora Energy Research

Figure 11: RES capacities in BAU and TRA

2.3.5.7 Additional flexibility

To accommodate additional RES generation without investment into CO_2-emitting technologies in the transition scenario, we rely on build-out of battery storages and unlocking the existing flexibility potential.

Curtailment of intermittent PV and wind generation is used as a flexibility measure in both scenarios. The cost of curtailment is valued at weighted-average cost of feed-in tariffs for the

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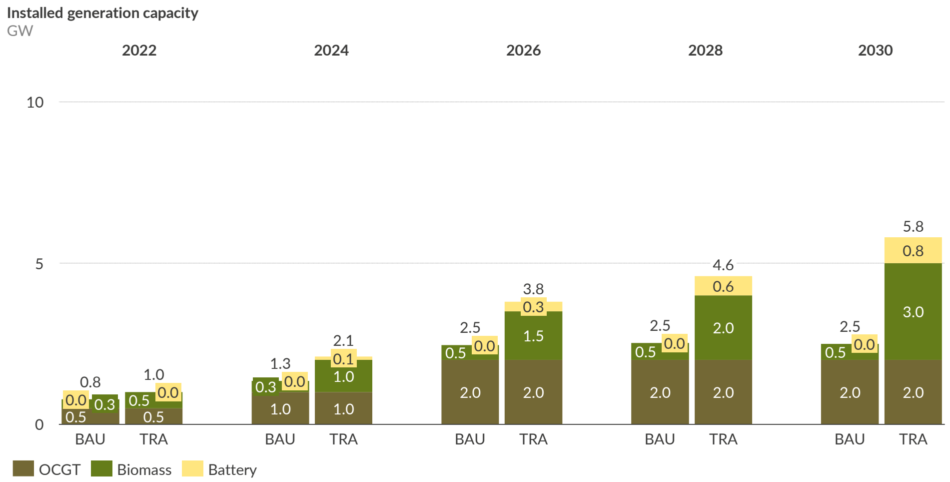
[31] Ministry of Energy of Ukraine, Dec. 2020

legacy installations and based on the levelized costs of electricity generation (LCOE) for new ones.

For transition scenario, biomass and wind generation are modelled to operate flexible from 2022. This means that biomass can now be load-following and do not produce as a “must-run” in contrast to existing approach which remains in the business-as-usual. Wind generation is modelled as providing downward reserves to the power system.

Both measures above help drastically reduce the need of new investments into flexibility measures and thus reduce the total system cost.

For transition scenario, we introduce an equivalent of li-ion battery storage technology with power-to-energy (P/E) ratio of 4 (e.g. 1 MW power output, 4 MWh energy storage volume). Combined with curtailment and flexible biomass and wind generation, the cost-optimal of solution is to install 800 MW/3,600 MWh of new battery storage until 2030.



Sources: Aurora Energy Research

Figure 12: Additional flexible capacities in BAU and TRA

2.4 Macro-economic input data and assumptions

2.4.1 GDP Growth

GDP is strongly correlated with power demand as industrial inputs, increases in consumption, and other related factors, increase the demand for power. We use the recent IMF (2020) forecast[32] for GDP growth, which also considers the effect of COVID-19 on demand growth. It assumes a real GDP decline of -7.2% (-4.0% in 2020 in Ukraine by State Statistics Committee of Ukraine) in 2020 and bouncing back to its previous trajectory. The growth rate reaches 4% in 2025. We assume that the real growth rate will continue to remain stable until 2030.

Table 5: GDP annual percentage change

Year	2020	2021	2024	After 2025
Annual GDP growth [%]	-4.0	3.0	3.8	4.0

2.4.2 First order macro-economic impacts – Excel tool

While we use a Computable General Equilibrium (CGE) model (see Section 2.4.3) for part of our analysis, we assess the direct effects of the transition scenario with Excel-based calculations of job impacts, cost of mine closures, social welfare cost, savings of subsidies and the impact on tax revenues.

To facilitate transparent results, we rely on an Excel tool to compute the macroeconomic and fiscal impacts of the scenarios analysed in this study. The excel-model computes the direct job impacts based on empirical estimates from Rutovitz et al. (2015)[33], a transparent and widely used approach across academia and policymaking (see 2.4.2.1 for more details). The empirical estimates from Rutovitz are cross-checked with local employment figures provided by Ukrainian associations: Bioenergy Association of Ukraine, Ukrainian Wind Energy Association, Association of Solar Energy of Ukraine. In addition, compensation and welfare benefits to furloughed coalminers are computed using data from Ukrainian coal mines (see Table 10). The transition scenario projects a shutdown of coal mines based on profitability (e.g., the most unprofitable mines per worker they employ), while in the BAU scenario mines that did not announce plans for decommissioning (Mine 5/6, Velykomostivska, Nadiya Mine are announced for decommissioning in 2021-2022 by the Government) remain open. Yet, the shutdown plan also considers important regional factors. For instance, the shutdown of mines tries to be regionally balanced, as not to shut down all mines in one region (see 2.4.2.2).

2.4.2.1Job creation effects

There is a range of different methodologies to estimate job creation across different energy transition scenarios.[34] The two most common ones are top-down and bottom-up approaches. While top-down approaches commonly rely on input-output models[35], bottom-up analysis use analytical, value-chain and life-cycle approaches[36].

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[32] International Monetary Fund

[33] Institute for Sustainable Futures, 2015

[34] ManishRam, ArmanAghahosseini, ChristianBreyer (LUT University), Feb. 2020

[35] The World Bank, 2011

[36] Forecasting job creation from renewable energy deployment through a value-chain approach: Renew. Sust. Energ. Rev., 21 (2013), pp. 262-271, 10.1016/j.rser.2012.12.053

In the context of this study, we rely on bottom-up job estimates from IRENA (2013)[37] and Rutovitz et al. (2015)[38] which is a widely used approach to estimate job creation per additional capacity installed (so-called employment factors - EF). The bottom-up approach allows for a greater level of transparency than top-down approaches commonly used in input-output models. The EF approach does not only include estimates for new capacity additions, but also includes jobs created during decommissioning of existing power assets.

Table 6: Expected job creation per RES technology[39]

Technology	Construction / Installation (Job years/MW)	Manufacturing (Job years / MW)	Operation and maintenance (Jobs/MW)
Solar photovoltaic	13.0	6.7	0.7
Wind onshore	3.2	4.7	0.3
Biomass	14.0	2.9	1.5

The figures from Rutovitz et al. (2015) are based on a range of studies from industrialised countries (due to a lack of studies from non-industrialised countries) and therefore need to be adjusted for local conditions. As in many developing and emerging economies the cost of labour is much lower than in industrialised countries, more workers can (or have to) be employed to produce the same unit of output. As labour is cheaper (than mechanised means) and less productive on average, more people are employed. Therefore, employment estimates need to be multiplied with regional adjustments factors. The best proxy for regional adjustment factors is the average labour productivity (computed as GDP/workers). As labour productivity is set to change over time, Rutovitz et al. (2015) rely on the World Energy Outlook to compute regional job multipliers. Regionally adjusted figures were cross-checked with employment figures provided by local industry representatives. As the construction time of a solar PV facility is on average 1 year compared to the 2 years in the case of wind, number of temporary jobs in solar is halved in order to obtain annual figures.

The table below shows the regional multipliers for jobs creation of the OECD and Eastern Europe/Eurasia for 2015-2030.

Table 7: Regional job multipliers to adjust employment factors (Rutovitz et al. 2015)

	2015	2020	2030

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[37] Irena, Dec. 2013

[38] Institute for Sustainable Futures, UTS, 2015

[39] Rutovitz et al. (2015)

OECD	1	1	1
Eastern Europe / Eurasia	6.0	5.0	3.6

As technologies become more mature, fewer workers are needed for manufacturing, construction and operation and maintenance. The estimates in Table 6 are therefore already adjusted for this expected decline in employment intensity for each technology (see Table 8). Especially solar PV will see a decline in employment intensity of 41% from 2015-2030 as the technology matures, less than wind onshore (5%) and biomass (3%). Yet, solar photovoltaics already feature the highest employment factors per MW installed, therefore a decline still makes the technology highly attractive in terms of job creation (compared to onshore wind and biomass).

Table 8: Employment factor decline 2015-2030 by technology based on Rutovitz et al. (2015)

	Solar Photovoltaic	Onshore wind	Biomass
OECD	23%	5%	5%
Eastern Europe / Eurasia	41%	5%	3%

2.4.2.2 Effects on coal mines

To estimate the costs of (continued) operation for the state-owned mines, we use the 5-year average data reported in the companies' balance sheets. We set the 2018 production combined with 5-year average value as an approximation for future losses or profits. This accounts for the fact that 2020 values will likely be outliers due to the impacts of COVID-19. To determine the order of closure (see Table 9), we assume that coal mines with the highest costs per one job that they create are closed first. Another rule applied to balance employment losses in one region is that of closing no more than one company in the same year. Lvivvugillia, which employs the largest number of people, is suggested to shut operation in two phases in order to keep lay-offs distribution regionally balanced.

Table 9: Closures timeline of coal mines and companies

Closure year	BAU	TRA
2021	Mine 5/6	Mine 5/6
	Velykomostivska Mine	Velykomostivska Mine
2022		Selydivvugillia

		Volynvugillia
2023	Nadiya Coal Mine	Nadiya Coal Mine
		Myrnogradvugillya
2024		Lvivvugillia
2025		Toretskvugillia
2026		Lysychanskvugillia
		Pivdennodonbasske #1
2027		Pervomayskvugillia
2028		Imeni Surgaya
2029		Lvivvugillia
2030		Krasnolymanska

With the closure of mines, additional decommissioning costs occur. They consist of process planning and execution providing stability of the underground workings and avoiding of the formation of sinkholes or potential pollution causing health and safety risk. To assess these costs, the study uses the data available in result of closures of other mines[40]. Due to the lack of mine-specific information, the estimate is simplified to the arithmetic average of provided costs per mine. The estimate is 6.5 mEUR per mine. This approach is theoretic and adjusted to data availability. Here, the study wants to assess the overall economic implications and transition of power sector rather than provide a thorough analysis of existing coal mines in Ukraine.

Table 10: Operational data of Ukrainian coal mining companies

Coal company	Gross margin 5-year average (EUR/t)	Total profit (mEUR; 2018)	Number of employees (2020)	Absolute profit/ job (EUR)
Selydivvugillia	-300	-60	6164	-9688
Myrnogradvugillya	-82	-26	2865	-9001

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[40] Ministry of Energy

Volynvugillia	-160	-12	1358	-8704
Toretskvugillia	-88	-19	2497	-7805
Lysychanskvugillia	-206	-31	4248	-7409
Pivdennodonbasske #1	-34	-13	2207	-5874
Pervomayskvugillia	-126	-19	4285	-4405
Imeni Surgaya	-24	-6	2434	-2439
Nadiya Coal Mine	-4	-1	663	-920
Lvivvugillia	-17	-4	6361	-646
Krasnolymanska	-7	-0.2	1074	-0.3

Source: Respective company's financial statement

2.4.2.3 Compensation & welfare benefits

Whereas many jobs can potentially be created with the establishment of a RES industry under TRA, jobs in the traditional mining sector will be lost. The loss of jobs will be particularly challenging in towns in Ukraine, where most people are employed in the local coal mine and their families often rely on their income (so-called 'mono-towns'). Countries with similar conditions have decided to pay compensation for affected workers to avoid economic hardship and to facilitate a just transition. As the focus of this study are the *economic* effects of a coal phase-out by 2030, we will focus on an estimation of costs. For concrete measures and their fair allocation between regions and social groups consult for example World Bank or European Commission[41] and other stakeholders engaging in the "Just transition" discourse.

In this study, we aim at providing an estimate for a broad solution space. Therefore, we assume two different policy options in terms of cost:

- Conservative policy option (only legally required payments (e.g., one-time payments, 6 months unemployment benefits paid);
- Progressive policy option (dedicated 1-year re-employment benefits and structural support, based on the discussion on *just transition* and experiences in other countries like Germany and Canada).

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[41] European Commission, Nov. 2020

The World Bank Group, Oct. 2020

The World Bank Group, Oct. 2020

Table 11: Overview on welfare benefits between the two policy options

	Conservative	*Progressive*
Monthly retirement payments	3 years	3 years
One-off payments upon retirement	No	Yes
Unemployment benefits	6 months	12 months
One-off payment upon lay-off	No	Yes
Upskilling	No	Yes

Laid-off workforce is eligible to receive unemployment benefits for up to two years upon lay-off if the State Employment Service does not provide employment. In Ukraine they cover 50% of the previous salary. Upskilling means the re-training of laid-off workers. In the progressive policy option, we estimate that all workforce from coal mining will be offered re-training. As coal mining is usually concentrated in the so-called monotowns and mono-regions, employment opportunities beyond mining are scarce. Mine workers are usually neither directly qualified to get hired in power generation sector nor ready to resettle for work. Hence, we assume re-skilling to be necessary. Per worker, we estimate costs of re-skilling equal to the overall average annual salary in Ukraine. In contrast, we assume skill sets of power plant workers' to be easier to transfer to the RES or other sectors.[42]

The conservative policy option constitutes the lower level of compensation upon termination of workplaces with no additional training.

The progressive policy option contains more advanced support schemes. Additional to a prolonged payment of unemployment benefits, we assume that re-training and up-skilling courses are available to people from the coal sector. We assume that all workers below 50 years old receive welfare benefits for 1 year and receive retraining, for which we estimate costs 4,350 EUR per worker. For workers within the range between 50 and 55 years of age, we assume that they receive one-off welfare benefits and then receive a pension of 3,980 EUR/year. Termination of employment is in their case counted as preliminary with average duration of retirement payments of 3 years, whereas workers who are 56+ years old are considered as regular terminations. Regular terminations are not counted into the cost of transition as these costs would apply even if the mines continued operating. One-off payment amounts differ between age groups. Retired workers receive severance payment and one-off payment equal to their previous salary level times three, while laid-off workers receive severance payment equal to one previously earned salary.

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[42] Retraining Investment for U.S. Transition from Coal to Solar Photovoltaic Employment; Edward P. Louie1 and Joshua M. Pearce; *Energy Economics*. (2016)

2.4.2.4 Net effect on taxes

To calculate the effect of the BAU and transition scenario on tax revenues, we are considering the below factors:

1. Value-added tax on energy products (based on total energy cost)
2. Income tax ((Income_New – Income_Lost)*Income tax)
3. Social security tax ((Income_New – Income_Lost)*Social security tax))
4. CO_2-tax (Generation of power * CO_2-intensity *CO_2-tax)

Table 12: Taxes considered in this study

Tax item	*Rate*	*Purpose*	*Deducted from*
VAT	20.0%	Tax on consumption	Final consumers' energy purchases
Individual income tax	18%	Physical person's contribution to the public budget	Gross income in power generation/ coal mining
Military tax	1.5%	Physical person's contribution to the public budget on military needs	Gross income in power generation/ coal mining
Social security charges	22.0%	Social safety net contribution by employer	Gross income in power generation/ coal mining
Carbon tax (in 2030, see 2.3.3 for more details)	0.9 EUR/t (BAU) 38 EUR/t (TRA)	Internalise costs of climate change	Emissions, e.g. from power generation

VAT

Value added tax in the analysis is deducted from the final cost of power. This estimation suggests that VAT on power production is paid either in the process or by final consumer in the form of capital and operational cost including fuel, carbon and transmission cost.

Personal income, military and social security tax

The income and military tax as well as the social security is calculated by multiplication of current income tax rate and the net change in estimated accumulated salaries in the affected sectors (RES industry and coal mines and power plants). We assume average salary of 415[43] EUR/ month in mining and 553[44] EUR/ month in power generation industry.

Carbon tax

Carbon tax is collected from carbon emitters in line with the amount of carbon they emit in the process of electricity generation. The rate of tax differs between scenarios. Transition scenario suggests that Ukraine will align its carbon pricing with the EU ETS. For year-specific figures consult Figure 8 in the Section 2.3.3.1.

2.4.2.5 Discount rate applied

To assess the net present value of individual options and be able to compare results over time, we apply a discount rate of 10%.

2.4.3 Second order effects - Computable General Equilibrium (CGE) model

To capture further effects on macro-economic conditions (including GDP and impacts on other sectors of the economy), we utilise a general computable equilibrium model.

There are various modelling strategies that researchers use to study the impact of changes to an economic system – such as a coal phase-out – on its macro-economic equilibrium state. The two most prominent approaches are Computable General Equilibrium (CGE) and Dynamic Stochastic General Equilibrium (DSGE) models. CGE models have a long history in macro-economics and work by comparing different static equilibrium states. These equilibrium states are subject to certain constraints, such as markets clearing instantly. CGE models are calibrated against the real economy by choosing certain parameters in line with the previously observed or actual state of the economy.

For the purpose of this study, we use a CGE model with the aim to assess the impact in the year 2030 after the transition process. CGE models have been used in several instances in the Ukrainian context in the past, which also allows for comparability with previous studies.

An appropriate starting point to conceptualise a CGE is Figure 13. The Figure demonstrates the circular flow of commodities in an economy. The two main central actors in the CGE are households and firms. Households own the factors of production and consume the products sold by firms. In turn, firms 'rent' the factors of production to offer products and services, which households buy. Many CGE models also represent the government, albeit their function is commonly constrained to collecting taxes and disbursing subsidies.

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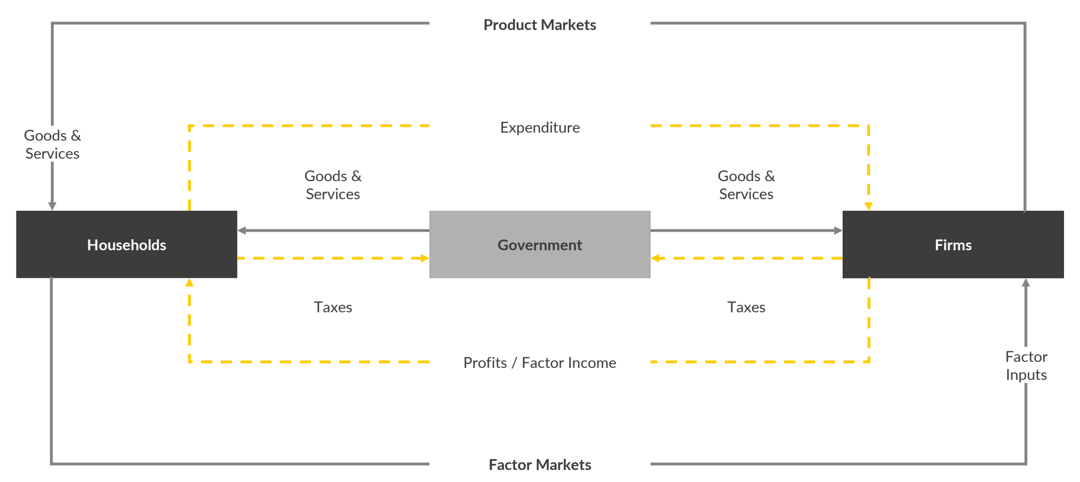
[43] Rounded average of salary levels published in financial statements of public companies.

[44] Ukrhydroenergo, Apr. 2019

A computable general equilibrium model follows a simple rule: there must be a balance (i.e., equilibrium) between, for instance, household's factors of production must be completely absorbed by firms in the economy. Similarly, all products and services firms sell, must be completely bought by households. Hence, no value within the economy can come out of nowhere and cannot simply disappear. These accounting principles are the foundation of the CGEs and are commonly called 'market clearance'. In addition, the CGEs commonly assume perfect competition (resulting in 'zero profits'), constant return to scales in the production function and income balance conditions (i.e., all household income must be used for good purchases, which can also be commodities for the purpose of saving).

These assumptions are taken to simplify and allow the model to simultaneously solve for the set of prices and allocation of goods. The model is normally implemented via a 'barter economy', which is made up of circular flows in commodities and factors, without having to track 'financial transfers'. Hence, CGE models normally do not explicitly represent financials transfers. Yet, the value of commodities and factors are denominated using a common unit of account (called 'numeraire good', whose price is fixed, and the value all of all other goods is expressed as the value relative to it').



Sources: Aurora Energy Research, Wing 2009

Figure 13: Schematic illustration of a Static General Equilibrium Model

Detailed description of the model

We use a standard static single-country multi-sector CGE model. The model follows a canonical general equilibrium representation of economic activities combining assumptions on the optimizing behaviour of economic agents with the analysis of equilibrium conditions. Decisions about the allocation of resources are decentralized, and the representation of behaviour by producers and consumers in the model follows the standard microeconomic paradigm: producers employ primary factors and intermediate inputs at least cost subject to technological constraints; consumers with given preferences maximize their utility subject to budget constraints.

Primary factors

Primary factors of production are labour, capital, and fossil resources. Labour and capital are assumed to be mobile across sectors but not internationally mobile. Fossil resources (gas, crude oil, and coal) are assumed to be sector-specific capital in fossil fuel sectors. Factor markets are perfectly competitive.

Final consumption

Final consumption is represented by a representative agent who receives income from primary factor endowments and maximizes utility subject to a budget constraint. Utility is represented by a nested constant-elasticity-of-substitution (CES) function. Government demand is fixed at real benchmark levels. Investment is paid by savings of the representative agent, whereas taxes pay for the provision of public goods and services.

Production

The production of goods other than fossil resources is represented by a nested CES function, which is structured as follows. At the top level, a composite of value added and energy trades off with material intermediate inputs. The second level describes substitution possibilities between value added and energy, as well as between different material intermediate inputs. At the third level labour and capital form the value added aggregate and the different energy carriers (electricity, gas, oil, and coal) form the energy aggregate. In fossil resource production, the specific capital (resource) trades off with a Leontief composite of all other inputs at a constant elasticity of substitution. Output of each production sector is allocated either to the domestic market or the export market according to a constant-elasticity-of-transformation function.

International trade

International trade is modelled following Armington’s differentiated goods approach, where goods are distinguished by origin. The Armington composite for a traded good is a CES function of domestic production and an imported composite. The Armington representation of international trade is most commonly used in applied CGE analysis, as it accommodates any observed pattern of trade (cross-hauling in particular). A balance of payment constraint incorporates the base-year trade deficit or surplus. We employ a small open economy setting where a single region -- in our case: Ukraine -- is treated as small relative to the world market. We thus assume that changes in the region's import and export volumes have no effect on international prices; in other words, export and import prices in foreign currency are fixed.

Data

For the calibration of model parameters, we use the most recent Ukrainian input-output data with base year 2018 (SSCU, 2018), consisting of an inter-industry matrix for 39 sectors as well as labour renumeration, capital earnings, sector-specific imports and exports, and final consumption activities. The model represents all sectors available in the data, which we then aggregate for the reporting of results.

We calibrate the model to base-year input-output data, that is, we determine the parameters of functional forms such that the economic flows represented in the data are consistent with the optimizing behaviour of the economic agents. The responses of agents to price changes are then determined by the choice of CES functions for economic activities, benchmark data, and a set of exogenous elasticities taken from the econometric literature. In fossil fuel production, elasticities of substitution between the resource and all other inputs are calibrated to match exogenous estimates of fossil-fuel supply elasticities. Find details on the sectoral aggregation in the appendix.

Scenarios and sensitivities

We investigate the BAU and TRA scenarios for the year 2030. The main distinguishing feature is different levels of investment identified as direct effects. In the model this is implemented as an exogenous increase in demand for investment goods in the respective amount.

Impacts of such investments include direct, indirect and induced effects. Direct effects are created directly in the industry being invested in. Indirect effects pertain to the upstream supply-chain effects resulting from the direct effect: If a sector is expanding through a positive demand shock it will require more inputs from its suppliers, resulting in increased productivity needs for the supplying sectors. Induced effects pertain to the increases in wage and salary spending by both directly and indirectly affected industries[45]. Likewise, sectors can suffer if they compete for economic resources like labour, mobile capital, and intermediates with expanding sectors. As such, the CGE analysis is not an assessment of a policy intervention but quantifies second-order (indirect and induced) effects implied by the already identified first-order effects.

In addition to the core scenarios, we perform simulations with more details that allow robustness testing of our overall results along three important dimensions. Firstly, we introduce a small bottom-up representation of the electricity sector where we distinguish between coal power, renewables, and other power generation technologies (primarily nuclear). This accommodates a forced targeting of electricity supply by generation technology according to the direct impacts assessed. Secondly, we introduce a constraint on domestic coal supply where we make sure that the coal price remains constant when coal power generation is reduced. At the same time, total domestic labour supply is reduced in accordance with domestic coal supply to reflect that coal workers cannot easily be employed by other industries. This makes sure that reduced coal consumption in power generation does not lead to increased coal consumption in other sectors. We only activate coal resource scaling in combination with targeting of electricity supply. Thirdly, we introduce targeting of electricity prices through supply scaling according to exogenous calculation of total system costs as shown. This is important to assess spill-over effects to other sectors.

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[45] In input-output modelling, this is usually referred to as multiplier effects. Our CGE Approach is quite similar to a demand driven input-output analysis, but additionally we allow for relative price changes according to elasticities and price-responsive agents.

Essentially, the different more detailed specifications entail additional (positive or negative) endowment shocks of either sector-specific capital in the electricity sector (capacities) or the fossil resource (coal) or the labour force.

We refer the setting without further details along the three dimensions as our core scenarios, and mark scenarios with targeting of electricity supply with ET, with coal resource scaling as CT, and electricity price targeting as EP. For example, we refer to scenarios as BAU core or TRA ET+CT.

3 Power sector impacts

The following section presents the impacts from the BAU and Transition scenario on critical power-sector metrics, such as generation, emissions and investment needs.

Main takeaways & conclusion

1) A coal phase-out by 2030 does not threaten system stability and is technically achievable.
2) The power mix resulting from an accelerated energy transition implies less baseload generation (especially nuclear) and requires additional flexibility to complete RES generation.
3) A combination of available and commercialised technologies, like OCGT, gas peakers and battery storages, as well as smart grid management, is sufficient to phase out coal by 2030.
4) Under the transition scenario, CO2 emissions can be reduced significantly, leading to total emissions of 9 Mt in 2030 (in comparison to 55 Mt under BAU). The cumulative emissions till 2030 amount to 50% or 247 Mt less in TRA in comparison to BAU.
5) Under the transition scenario the total investment for new capacities amount to 14 bnEUR till 2030 (11 bnEUR more than in BAU). Though they constitute additional investment cost in comparison to BAU, the Ukrainian power sector will require new investments in the medium-term future to rehabilitate or replace aging assets.

3.1 Installed capacity

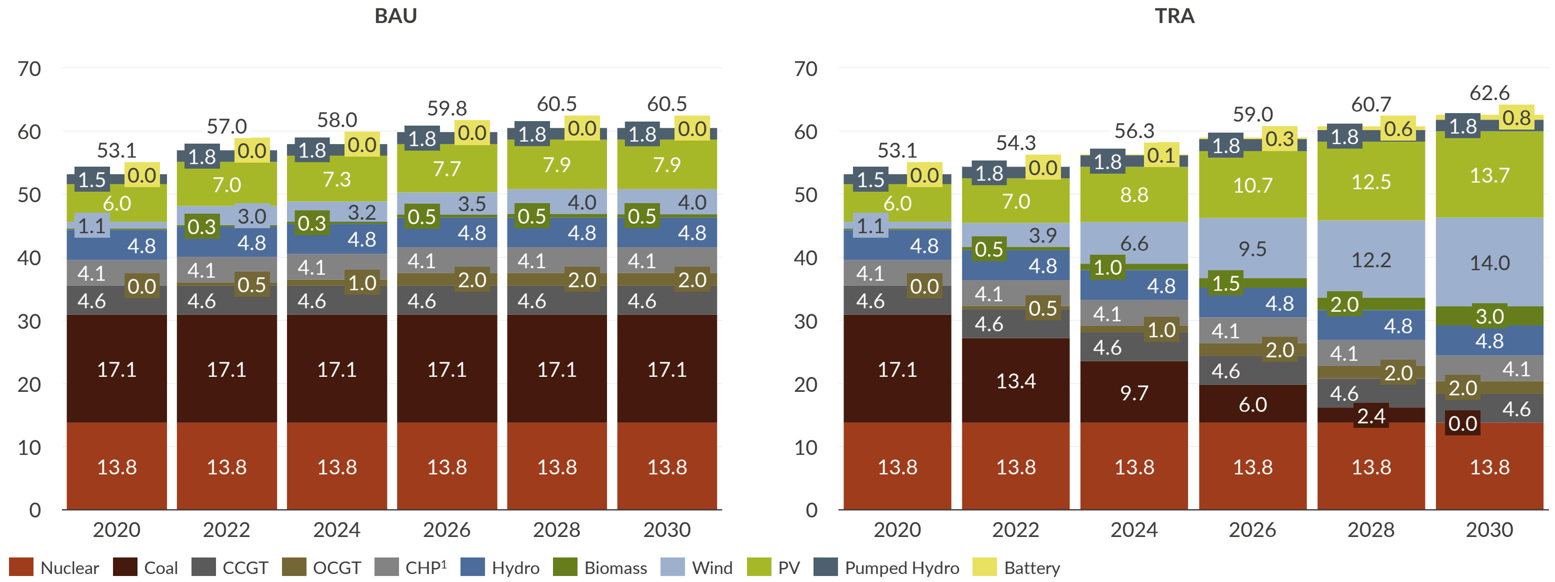
In the BAU scenario the capacities remain largely constant from 2020 to 2030. Despite slight increases in power demand, the existing generation fleet has sufficient capacity to cover the demand, provided it is maintained regularly and operational stability of the old fleet is ensured. As we estimate that project and financing costs for RES in Ukraine will not allow to achieve grid parity with incumbent technologies, new RES capacities will highly depend on existing support policies. A conservative approach to reach Energy Strategy targets is likely to be overshot by 2030 by existing pipeline of the project plus modest auctioning quotas. The result is growth of total PV, Wind and Bioenergy capacity from 7.3 GW in 2020 to 12.3 GW in 2030.

The transition scenario envisages total phase-out of existing coal capacities by 2030 reducing by, on average, 1.7 GW per year. To meet the demand, renewables capacity significantly increases to 30.7 GW of PV, Wind and Bioenergy. The battery storage is introduced to the system for additional flexibility and to avoid ecological risks associated with developing new pumped hydro storage.

In total, BAU scenario envisages 7 GW of new capacities (2 GW of conventional and 5 GW of renewable) by the end of the decade, while TRA requires a net increase of 9.1 GW (26.2 GW of new capacities, of which 2 GW conventional, 23.4 GW renewable and 0.8 battery storage with 17.1 GW of decommissioned coal). The summary of two scenarios in terms of installed capacity in the system is shown in Figure 14 and Figure 15. Considering that the availability of wind and solar is lower than the availability of thermal power generation (so called “dispatchable” generation), this difference is very low. It hints at the large overcapacities that are currently installed in the Ukrainian power system.

Installed generation capacity

GW



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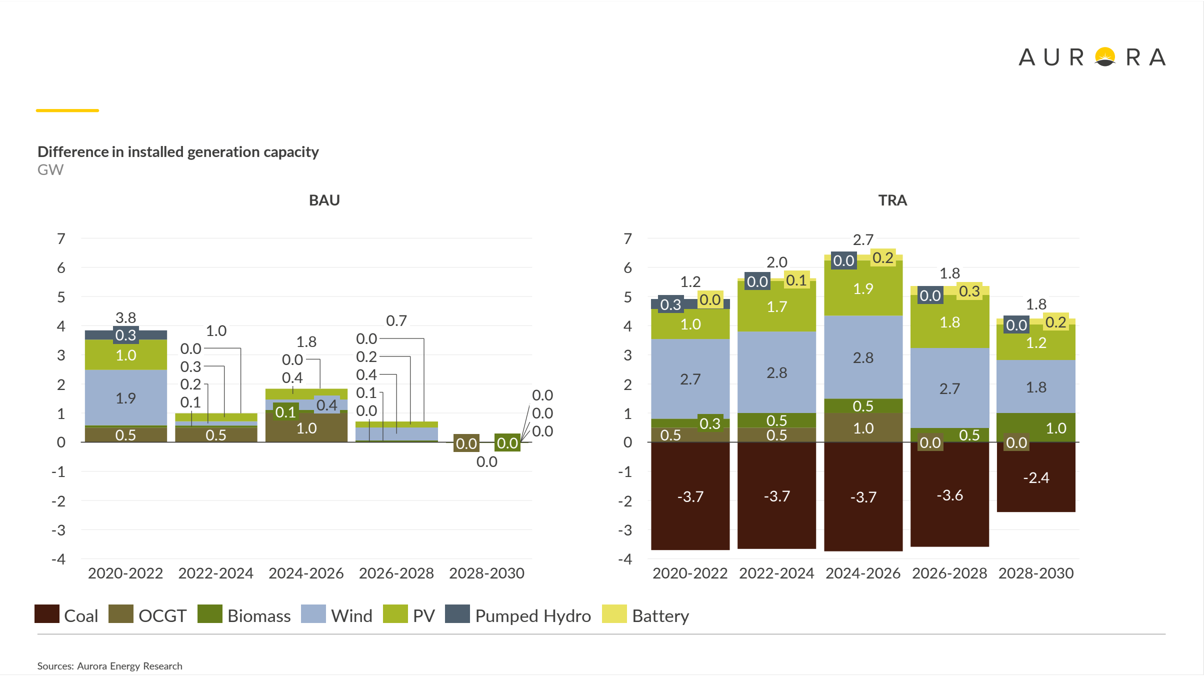
1) Coal CHP in TRA is gradually converted into Biomass CHP.

Sources: Aurora Energy Research

Figure 14: Installed capacity in BAU and TRA



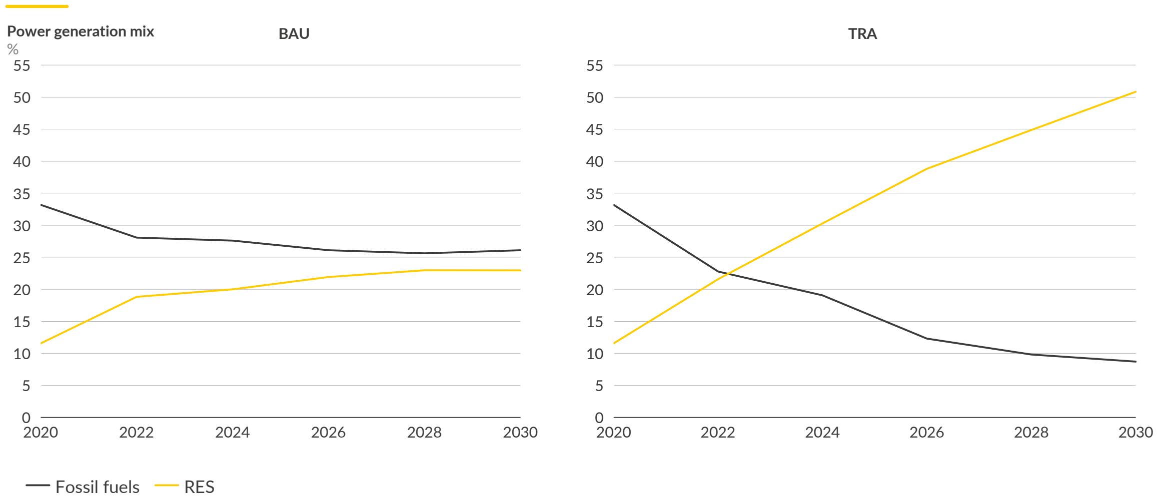
Sources: Aurora Energy Research

Figure 15: New and decommissioned capacities for BAU and TRA

Please also consult Section 2.3.5 for more details on power generation capacities under the two scenarios.

3.2 Generation

With the changed system composition, generation changes as well. The transition scenario allows to achieve the share of fossil generation of mere 5% of total, compared to 23% under BAU (see Figure 16). With the overall power mix and increased shares of intermittent RES, the operational patterns of dispatchable power plants change. A reduction in baseload generation paired with more flexible capacities is required to accommodate increased share of renewables. With this shift, the transition scenario results are technically and economically achievable. In this section of the report, we describe the key differences and highlights of the scenarios.

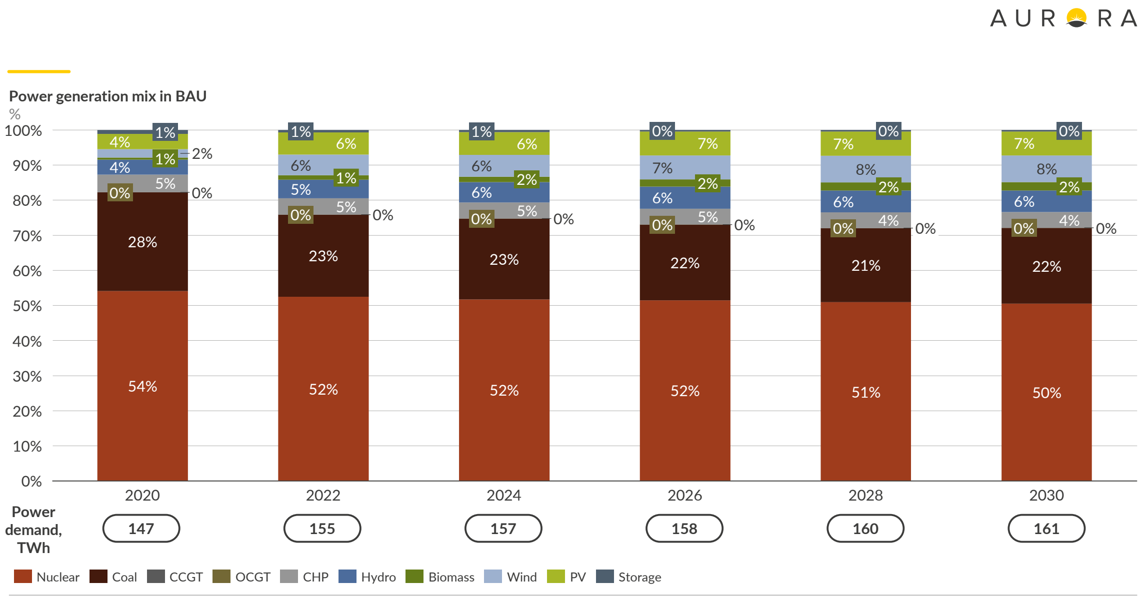


Source: Aurora Energy Research

Figure 16: Fossil and renewable share of power generation in BAU and TRA

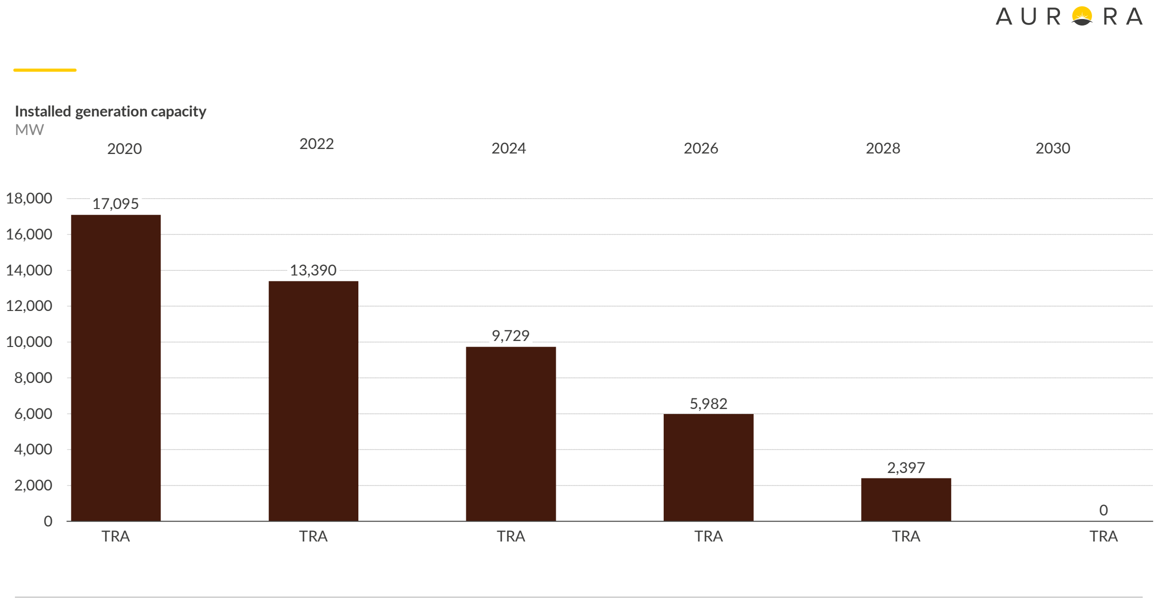
Figure 17 shows the electricity mix in the BAU scenario. Throughout the decade, nuclear power plants continue to provide roughly half of the electricity. Around a quarter is produced by coal-fired power generation. The remainder is generated by hydro, wind, photovoltaic and biomass. In this relative stable mix in the BAU scenario, two developments nearly balance each other out. RES generation increases as new capacities are introduced over the decade, yet their share rises by merely 10 percentage points from 13% to 23%. This can be explained by the demand growth. As discussed in section 2.3.1, Ukrainian power demand is expected to grow by almost 10% to more than 160 TWh per year. In consequence, the build-out of renewables in the BAU scenario leads to modest decarbonisation gains, with increasing power demand continuing the need for carbon-intense generation.

It is noteworthy that even in the BAU scenario, existing coal capacities are not utilised at a high rate. The average load factor of coal plants is a mere 24% in its peak (in 2022). The highest utilisation rate (at peak demand) in that year is 69%, dropping further in the following years. This means that given existing flexible backup capacities, in the form of existing gas plants and newly added OCGTs, roughly a third or over 5 GW of coal plants can be closed without any material impact on the system composition in BAU. Targeting the oldest, least efficient and most polluting plants can yield environmental and economic benefits already in the status quo.



Source: Aurora Energy Research

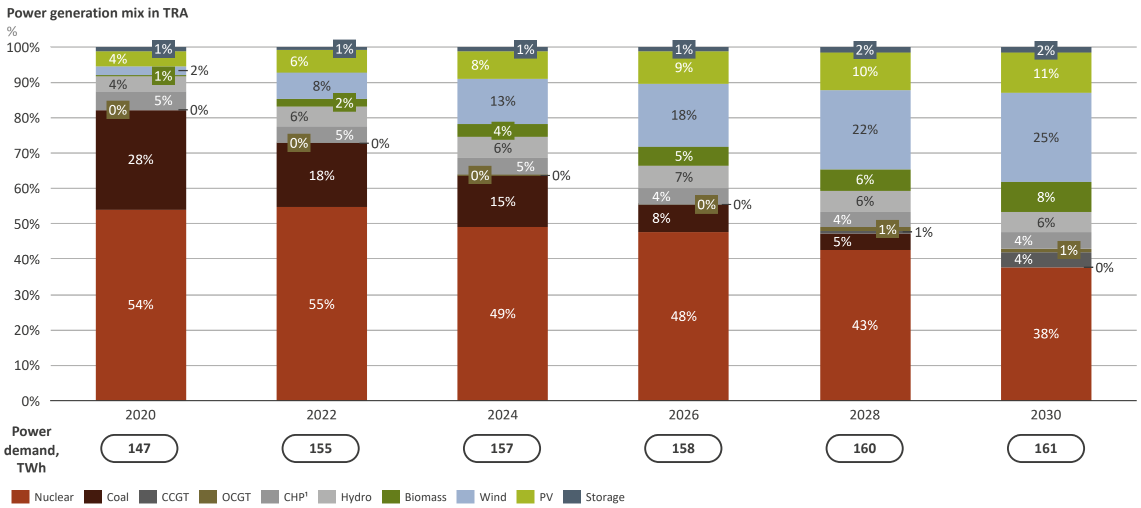
Figure 17: Power generation mix in BAU



Sources: Aurora Energy Research

Figure 18: Installed coal-fired generation capacity, TRA

In contrast, the electricity mix in TRA undergoes profound changes. This is visible in Figure 19. Coal generation decreases from 28% (or 40 TWh) to less than 20 TWh in the mid-twenties until its phase-out in 2030. Renewables take an increasing share in the electricity mix. In 2030, they generate more than 83 TWh, making up more than half of the total electricity mix. Generation from wind contributes the largest of all renewable sources. From 3.3 TWh in 2020, it increases to 29 TWh in 2026 and 42 TWh by 2030, making up 25% of the total generation mix. PV almost triples its share from 4% to 11% in 2030. This corresponds to an increase of over 12 TWh, from 6.2 TWh in 2020 to 18.6 TWh in 2030. By 2030, biomass generates almost 14 TWh of electricity, increasing from 1 TWh in 2020 to around 7 TWh in the middle of the decade. In the transition scenario, we also see that gas capacities are being relied on significantly more to provide the needed flexibility. Almost 9 TWh are generated by gas in 2030 in total. Notably, the old gas-powered steam turbines replace coal in mid-peak load.



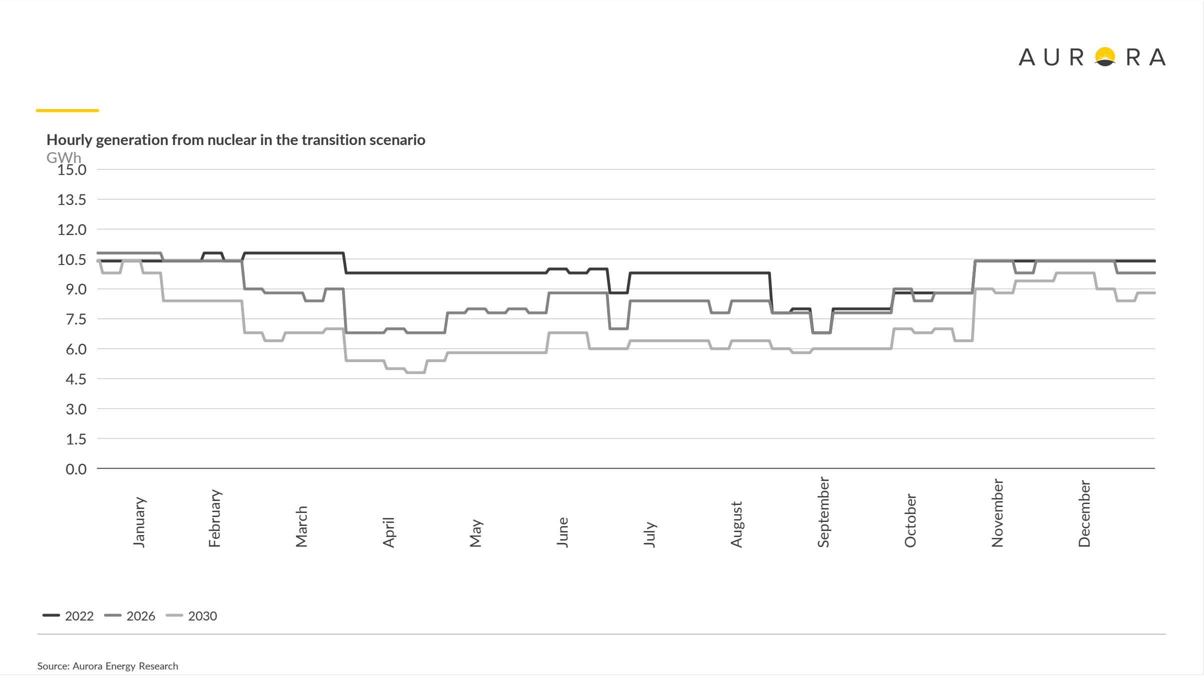
Power generation mix in TRA

1) Coal CHP in TRA is gradually converted into Biomass CHP.

Source: Aurora Energy Research

Figure 19: Power generation mix in TRA

TRA also impacts the operations of nuclear power plants. Thus, nuclear decreases its share from 54% to 38% over the decade. Nuclear power plants in Ukraine generate around 19 TWh less in the transition scenario in 2030 compared to the BAU view. This is due to the fact that renewables do not only replace coal-fired power generation but have the potential to generate even beyond that volume. Here, the high share of renewables pushes out less flexible baseload generation like nuclear. Nuclear power plants are required to adjust their generation pattern to the supply patterns of intermittent renewables, as depicted in Figure 20. Hence, the power mix in the transition scenario requires less maximum output from nuclear plants, but more daily and weekly flexibility. Average load of nuclear decreases from 8.7 GW in 2020 to 7.1 GW in 2030. This, potentially, could allow start decommissioning of the most outdated nuclear units in the next decade already without risks in non-satisfying electricity demand.



Source: Aurora Energy Research

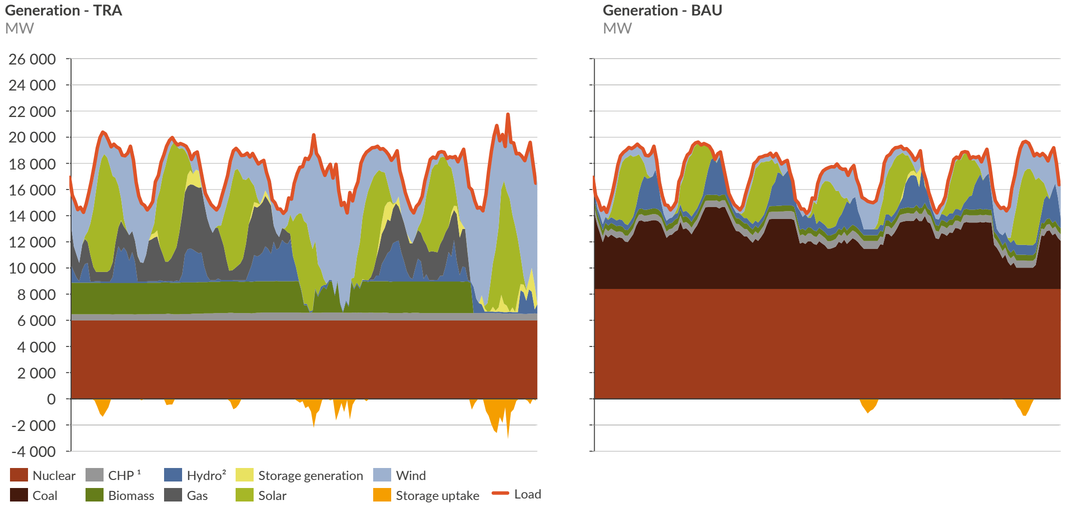
Figure 20: Operation of the nuclear power plants in TRA

Due to the age of nuclear power plants and the nature of the technology, they are restricted in their flexibility to ramp up and down. This also helps to answer questions on future decommissioning of nuclear plants and the addition of new reactors. A system with high renewables shares described in the transition scenario employs less blocks and thus the decommissioning of blocks becomes more feasible. Additionally, this shows that the future Ukrainian power system does not need additional baseload generation. As discussed above, high-RES electricity systems require flexibility to balance the volatility of PV and wind (see also Figure 21 and Figure 22 for an hourly representation of the interaction of the technologies in an exemplary summer and winter week).

In the modelling for the transition scenario, we see this flexibility supplied by a mix of biomass, batteries, and gas power plants (on the generation side) and RES curtailment and the participation of wind in the balancing market (on the regulatory side). OCGTs play a significant role in the transition scenario, being used for almost 1,600 hours per year in 2030, or 18% of the time with a total utilisation factor of 9%. This is higher than in the BAU scenario, where OCGTs are used only at 0.1-0.5% of their availability. While max load of OCGT in TRA reaches maximum of 2 GW installed, in BAU it never reaches even 1 GW. This also raises a question about the necessity of 2 GW OCGT capacities in BAU stated by the Ukrainian TSO. Our analysis shows the power system under BAU can be managed securely with less than 2 GW of new OCGT capacities. However, the buildout stated in the generation adequacy report might be beneficial in case if Ukraine chooses to speed up its power sector's transition to renewable energy.

The two figures below show the hourly breakdown for two representative weeks in winter and summer comparing the BAU and transition scenario[46]. Two things are noticeable: in the BAU scenario both coal and nuclear generation continue to play a crucial role in 2030. In contrast, in the transition scenario, particularly solar and wind contribute a significant share of power generation over the weeks. In summer the solar peaks are more pronounced than in winter, due to longer sun hours. Wind generation generally also is higher in winter (compared to summer), which can also be seen from the figures. In hours of low wind and solar generation, particularly biomass/gas step in to fill the reduction in RES generation.

Hourly generation profile for 20-27 June 2030



1) Coal CHP in TRA is gradually converted into Biomass CHP. 2) Note that hydro includes small hydro.

Source: Aurora Energy Research

Figure 21: Hourly generation pattern in a summer week in 2030 between BAU and TRA scenario

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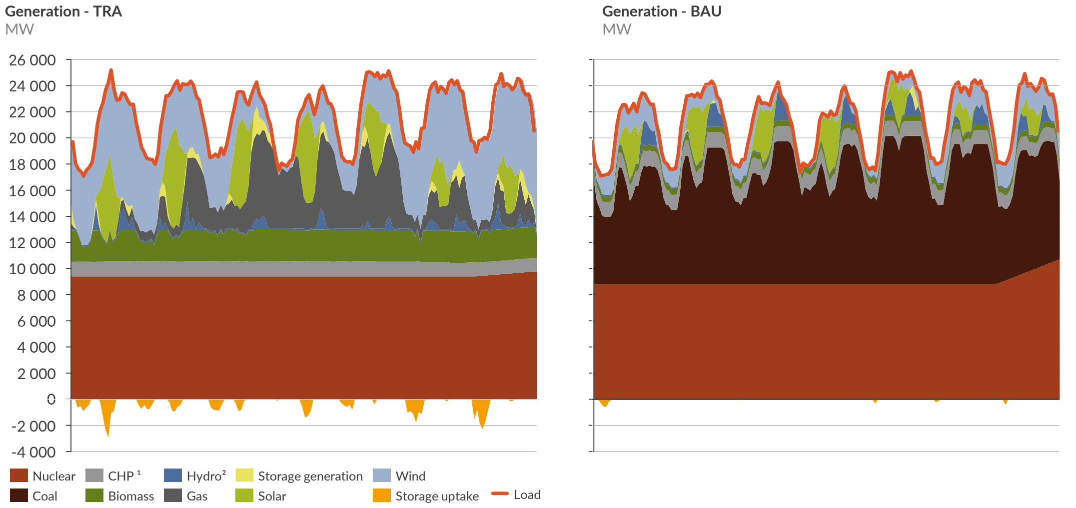
[46] The red line represents total load, which includes power consumption of storage technologies. Thus, the load profiles are different on the Figure 21 and Figure 22 but represent the same demand in the system.

Hourly generation profile for 21-28 November 2030



1) Coal CHP in TRA is gradually converted into Biomass CHP. 2) Note that hydro includes small hydro.

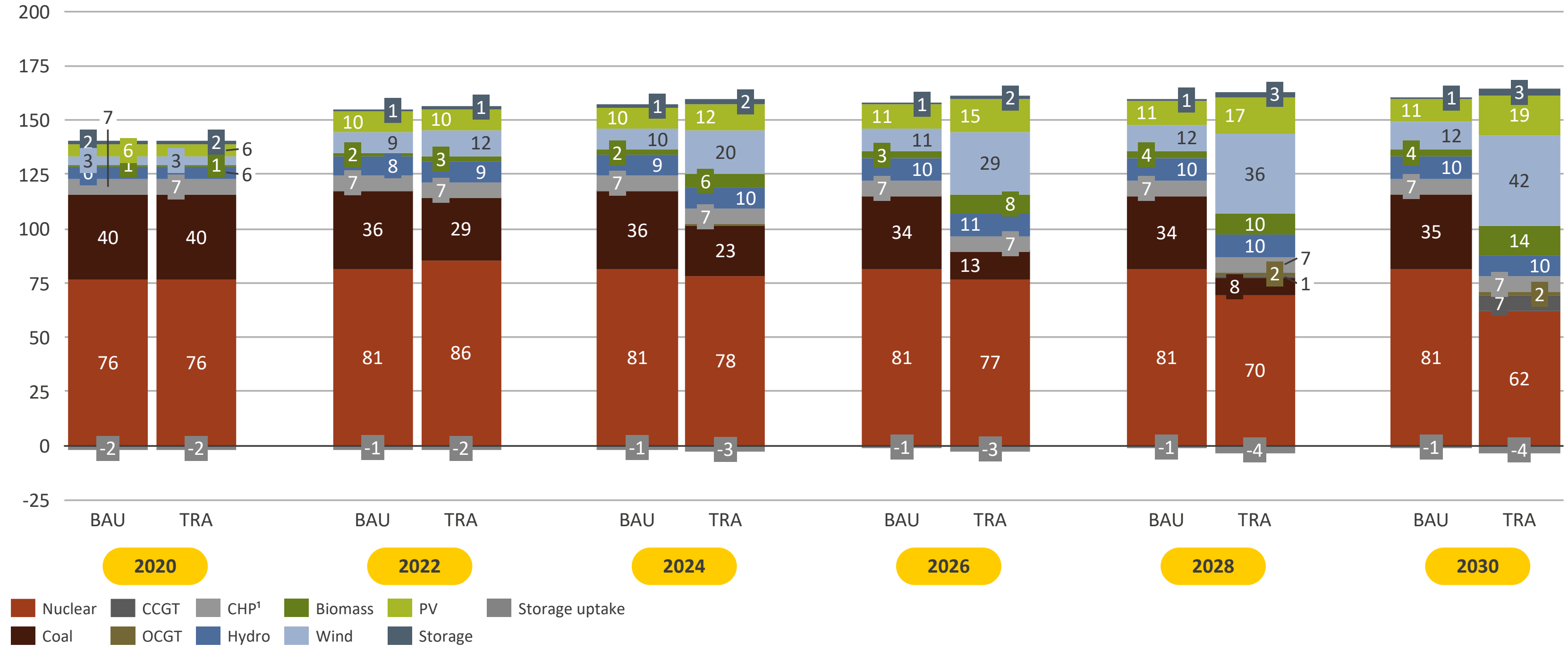
Source: Aurora Energy Research

Figure 22: Hourly generation pattern in a winter week in 2030 between BAU and TRA scenario

Lastly, the Ukrainian energy system is characterised by a relatively high usage of CHPs for heating. In both scenarios, we see CHPs generating the same amount of electricity across all years. This is due to the fact that the primary function of these plants is to generate heat for district heating and other applications. This heat demand follows temperature and thus, varies over time of the year and day. Electricity is only a by-product and therefore does not react to the changes we introduced with the scenarios. (To complete the phase-out of coal from the system, the remaining coal CHPs are replaced by biomass-fired CHP in the transitions scenario). Figure 23 compares the generation between the scenarios.

Power generation

TWh



1) Coal CHP in TRA is gradually converted into Biomass CHP.

Source: Aurora Energy Research

Figure 23: Total power generation in comparison between BAU and TRA

Firstly, a certain amount of coal capacity can be retired without any ramifications for power generation. This becomes visible in the hourly generation patterns. Even in hours with no or little RES generation and high demand, hence, the hour in which coal is most called upon, only 11.7 GW (BAU 2022) or 9.8 GW (TRA 2022) of coal generate. This means that only around 70% of the whole coal fleet are utilised, with the share reducing further in later years. This shows the current overcapacity in the Ukrainian electricity system, suggesting the retirement of especially old and inefficient plants is possible without any material effects on the power sector.

Secondly, security of supply can be ensured with the build-out of renewable and flexible capacities. However, this should not be viewed purely as cost stemming from a phase-out of coal. As the generation fleet is old, replacement of the generation fleet will have to happen eventually, requiring new investments. Since the costs for electricity on a per MWh-basis (or LCOE) are already lower than thermal alternatives and continue to decrease for RES technologies, introducing more renewables can represent an economically competitive solution for the power system. As discussed earlier, such a system operates differently and requires more flexibility. In the transition scenario, this is provided by new biomass and battery capacities in addition to existing hydro and planned gas turbine plants.

To complement bigger shares of RES, increasing the system's flexibility is a required next step in the modernisation of the electricity sector. For this study, we assumed that all flexibility is provided by domestic generation capacities. Other sources of flexibility could also be demand-side-response, (i.e. flexible demand by industrial consumers) as well as imports and exports via interconnections to the power system of other countries. Interconnections can provide a significant source of flexibility, as seen in the energy transition in EU countries. The upcoming integration into the ENTSO-E synchronous area could both provide additional flexibility and reduce costs for the transition scenario. Expanding the cross-border capacities and decreasing barriers for cross-border trade should be one of the priorities that could help integrate more renewable energy.

3.3 Emissions

The generation mix under the two scenarios leads to a vastly different development of CO_2 emissions. Whereas emissions stay nearly constant between 2020 and 2030 in the BAU scenario at around 55 Mt/year, emissions in the transition scenario fall to below 10 Mt/year in 2030. This is 84% lower in comparison to BAU.

In the transition scenario emissions decrease from 59[47] Mt in 2020 to 9 Mt in 2030. These emissions stem from the remaining gas capacities within the system that are utilised to meet demand in hours with low RES generation. In the scope of this report, we only account for direct emissions, which leads to a simplified assumption that biomass, nuclear, and hydropower are emission-free (in practice the technologies are not emission-free due to emissions in the lifecycle and from reservoirs). The cumulative savings from 2020 – 2030 between the BAU and the

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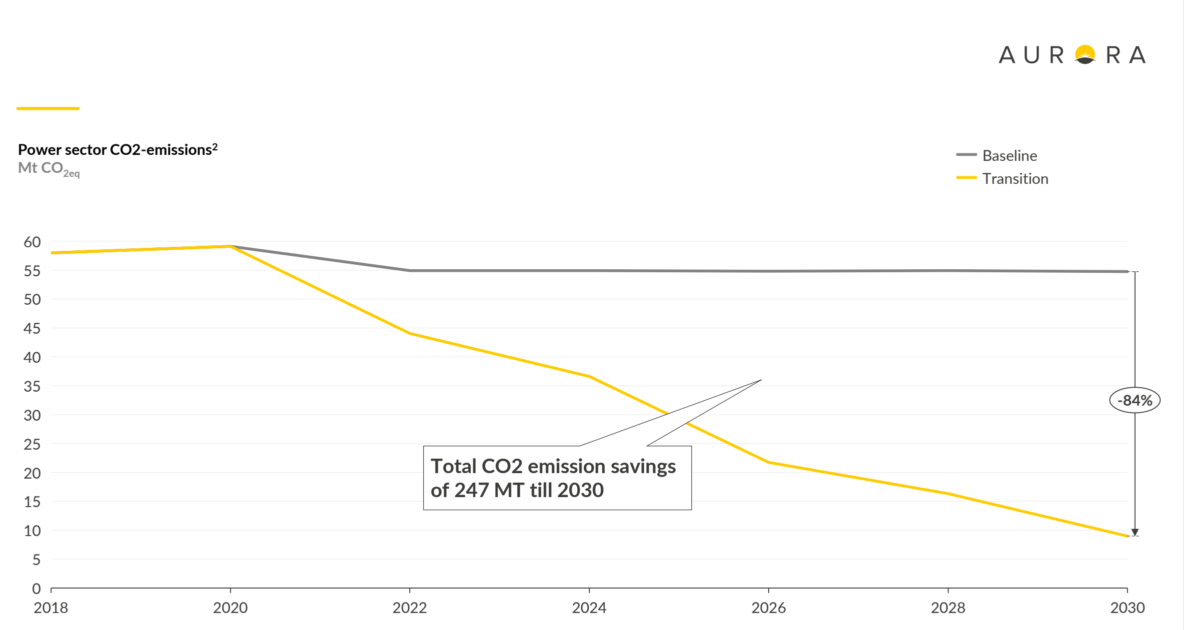
[47] The figure is based on the emission from all power and co-generation units connected to the transmission grid. The national emissions reporting to the UNFCCC for 2018 shows higher totals of 73 MT. These figures include a higher power and heat generation and include on-site and industrial plants

Transition scenario are around 247 Mt. This means that Ukraine's power sector can already emit 50% less CO_2 over the next 9 years, if coal generation is phased out.

Assuming a carbon price of close to 38 EUR/t (in line with the EU ETS) as externality cost, this would constitute savings of 10 bn EUR in that time span. The number of avoided environmental and health cost would be even higher if other pollutants from coal power plants like SO_x, NO_x and particulate matter were considered.



1) Numbers for 2020 are estimates based on historical emissions, 2) Emissions include CHP plants, which provide both heat and power, 3) No official 2020 data has been published; we interpolate actual 2018 emissions data with 2022 modelling results

Sources: Aurora Energy Research

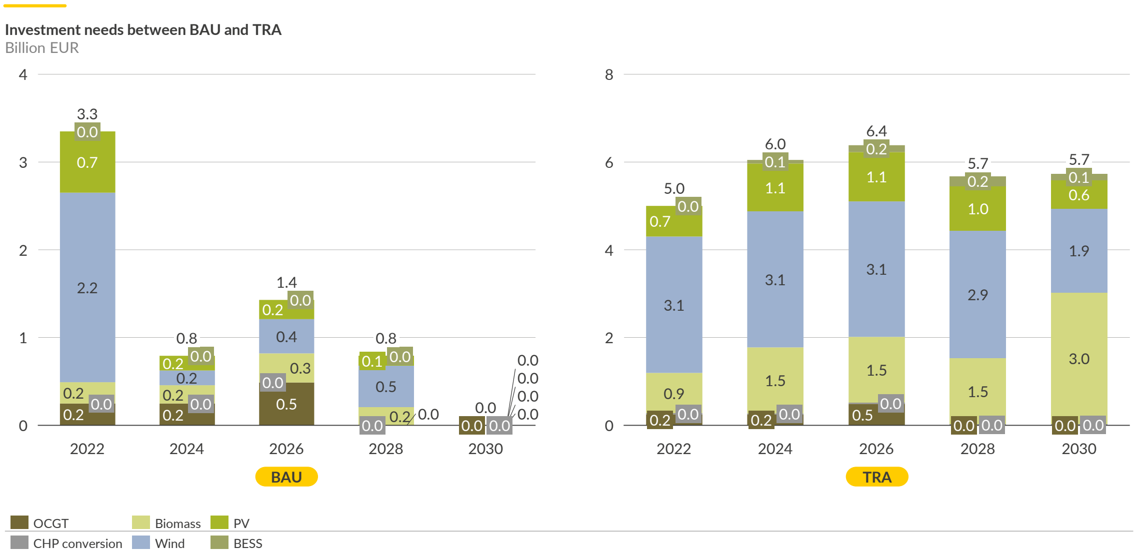
Figure 24: Power sector emissions 2020-2030

3.4 Investment needs

Transitioning the power system requires investments into new renewable generation assets. Figure 25 shows the investment needs in generation till 2030 in both scenarios. In the transition scenario, the cumulative investments add up to 14.3 bnEUR in comparison to 3.2 bnEUR in the BAU scenario. This is mostly driven by investments into renewable capacities. Investments into wind and solar total 9.2 bnEUR in comparison to 2.2 bnEUR under BAU. An additional 4.2 bnEUR are mobilised for more biomass capacities (under BAU this totals 0.5 bnEUR). The addition of batteries to stabilise the system in the transition scenario add up to 0.3 bnEUR and are almost negligible in the totals.

Though the energy transition requires the mobilisation of large investments in the near future, it is important to consider the following points:

- Especially wind and solar PV require up-front investments but have no fuel and little operational cost. Hence, the picture for power generation cost looks different.
- With aging coal and nuclear plants, the Ukrainian power sector will require large investment into generation assets in the medium term. The transition scenario anticipates a big share of these cost that will occur over the next 20 years.

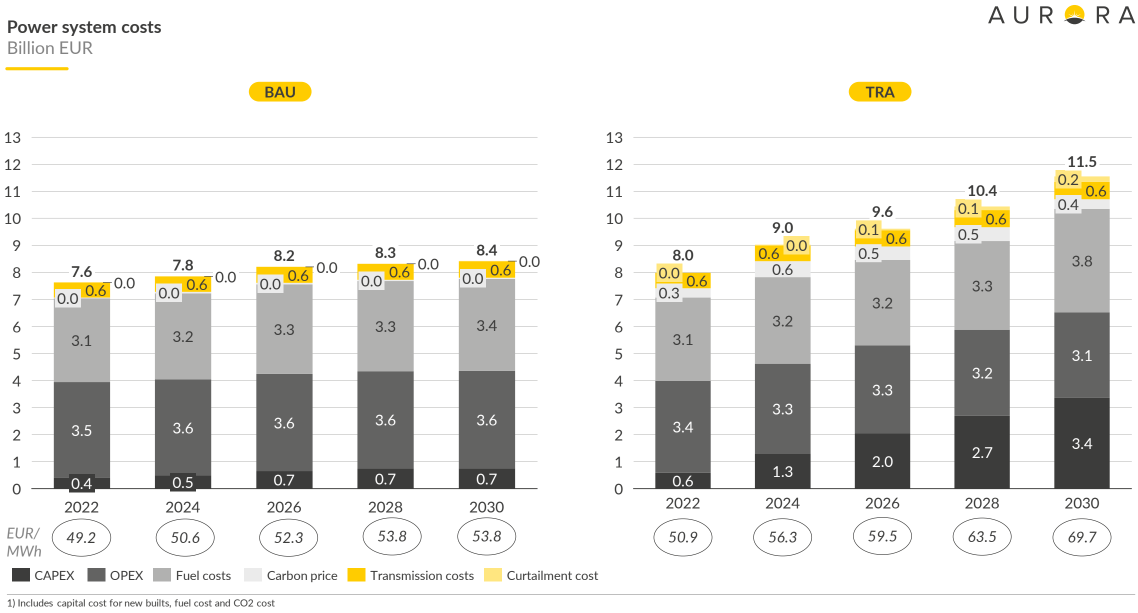


Source: Aurora Energy Research

Figure 25: Investment needs in generation capacities in both scenarios

3.5 Total system cost

When comparing the total cost for the power system, the picture slightly changes. While investment needs under the transition scenario are more than four times higher, the total cost until 2030 are only about 25% more than under BAU. The totals over the time period are 56.2 bnEUR (in TRA) versus 44.4 bnEUR (in BAU). It is important to note that this view is limited to the cost within the power sector and hence does not include required subsidies for coal mining companies. These are assessed in more detail in Section 4.3. Beside higher investment needs in TRA the rise of system costs is driven by the costs for biomass, which substitutes coal as a fuel in CHP facilities and the progressively rising carbon tax.



1) Includes capital cost for new builts, fuel cost and CO2 cost

Source: Aurora Energy Research

Figure 26: Power system costs in BAU and TRA[48]

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[48] Transmission costs here represent the sum of dispatch and transmission tariffs set out for 2021, excluding RES support costs.

4 Macro-economic impacts

4.1 Overview of the first-order macroeconomic effects

The energy transition causes a complex set of changes with far reaching effects on the wider economy. Hence, in the first step the report looks at the direct impacts on the economy. In the second step, changes to the macroeconomic and sectoral balance are assessed. The chapter aims to estimate and compare implications of the transition on the very tangible social issue of employment and direct economic implications for the public budget. The impacts on each of the aspects will be discussed in the following sub-chapters.

4.1.1 How can energy transition facilitate post-COVID recovery?

To address the ageing energy infrastructure of Ukraine's power generation and transmission system, a planned increase in post-COVID construction offers an opportunity to fundamentally renew the system. In wake of low interest rates, investments made now can be paid off quicker, while stimulating the domestic economy[49]. Some of this investment will also come from abroad. Firstly, the EU has already pledged 105 mEUR for the reduction of COVID-19's socio-economic impacts[50]. Secondly, stand-by-agreements with the IMF also aim to resolve the economic consequences of the COVID-19[51]. While the International Energy Agency (IEA) feared in May 2020 that the drastic investment curb will hamper the global energy transition and threaten energy security, recent announcements and the current investment climate both point towards further continued and increased investment[52] in the sector. A rise in investment and construction activity can also help to address the increase in unemployment figures caused by COVID-19.

4.1.2 Business-as-usual scenario

The BAU scenario is an ultimate one for the Ukrainian case. Minor investment into ageing energy infrastructure will only postpone modernization that is necessary. Economic outlook of the business-as-usual is merely unsustainable one. Growing debt embedded in the unprofitable coal mining will rise further until the sector, which already lacks long-term future perspective, shuts down due to low global demand. Our analysis works with the assumption that the margin profit

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[49] Reuters, Oct. 2020

[50] Service of the Deputy Prime Minister of Ukraine, Jul. 2020

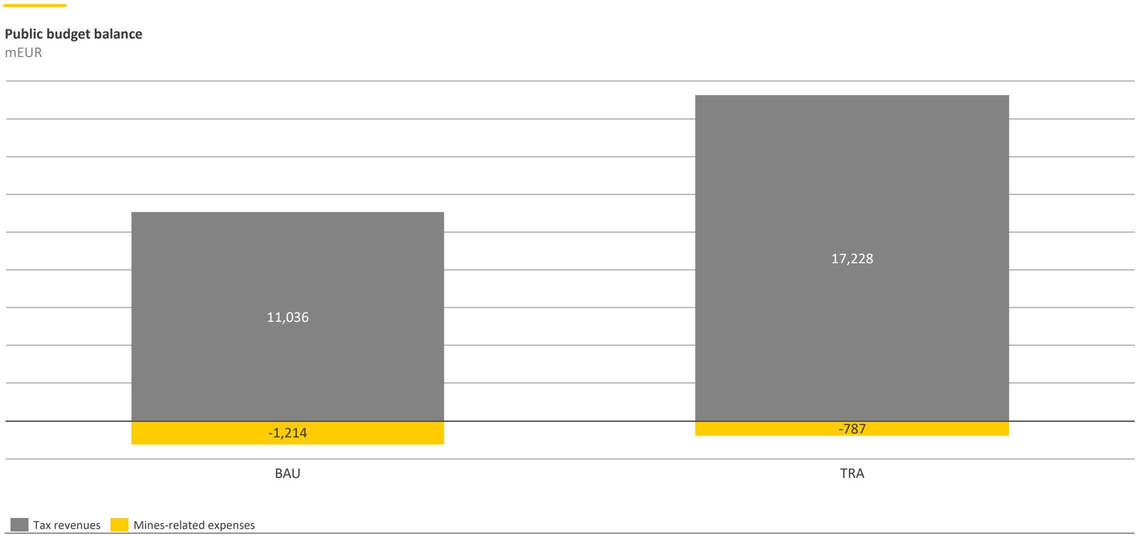
[51] WKO.AT, Apr. 2021

[52] Reuters, Apr. 2020

per produced ton will not decrease, which is overly optimistic taking into account lifetimes of the mines and low level of modernisation.

4.1.3 Transition scenario

In contrast to the expectations, economic outlook of TRA is cheaper for the state budget and pre-emptively solves the ever more present needs for transmission system modernization and transition into cleaner power generation. Present value of the 10-year transition is higher than the value brought by BAU. In addition, transition scenario has a high potential to improve local environment.



Note: Net present value with the 10% ROR

Source: Aurora Energy Research

Figure 27: Public budget balance in BAU and TRA

4.1.4 Final net effects on employment and public finance

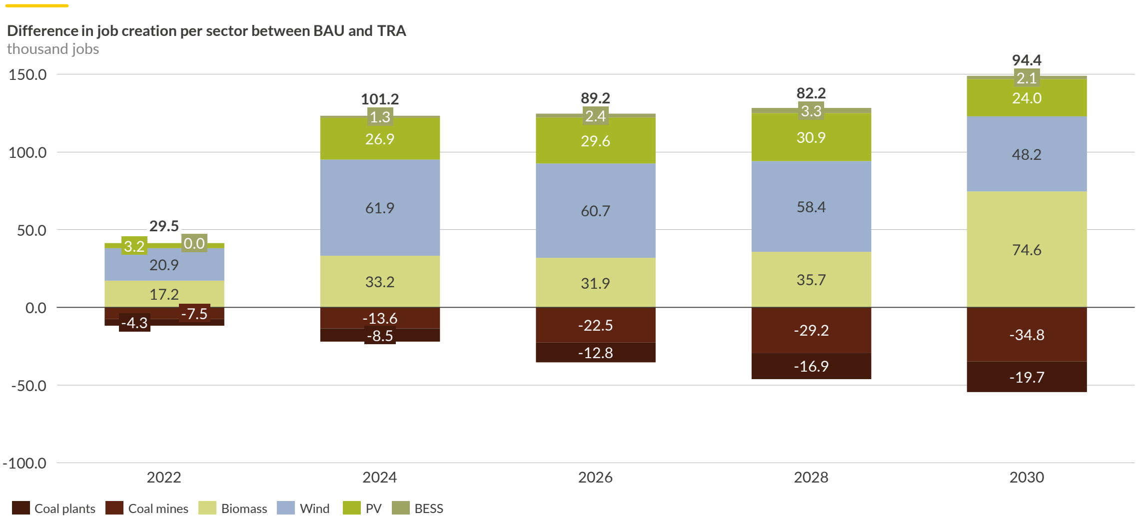
Main takeaways & conclusion

Direct effects of the Transition scenario are generally positive. Economic relief caused by closure of public mines and their replacement by other sources of domestic power production will outperform BAU by as much as **6.6 bnEUR** in net present value of public budget revenue. Employment figures will grow significantly in the transition scenario within the coming period. Later, they are projected to drop unless the sector establishes itself to continue production for further demand domestically or for export.

Affected area		BAU	TRA
Employment in reference to 2020	Lost	2,076	56,569
	Created	12,358	44,456
	Temporary jobs (min)	0	98,382
	Temporary jobs (max)	60,238	123,792
	Total in 2030	10,282	104,692
Public spending related to public coal mines - NPV (mEUR)	Operational costs	-1,195	-484
	Decommissioning	-17	-146
	Welfare spending	-3	-157
Taxes NPV (mEUR)	Carbon tax	272	2838
	VAT	9,930	11,770
	Personal income + Military tax	392	1,231
	Social security tax	442	1,389
Public budget balance NPV (bnEUR)		**9.8**	**16.4**

4.2 Direct employment effects

The energy transition is accompanied by a transition of the labour market. Employment opportunities will be lost on the side of conventional energy sources and new ones will emerge in the renewable energy industry. As discussed in section 2.4.2.1 we assume between 5 and 10 new full-time jobs per MW of new-built RES adding up to 160,000 new jobs in the transition scenario. At the same time, we see a loss of more than 56,000 jobs from decommissioning coal plants and closing down mines. Six drivers and aspects shown in Figure 28 will be discussed in the following sections: plant and mine closures, as well as job creation in biomass, wind, PV and battery.


Difference in job creation per sector between BAU and TRA
thousand jobs

Source: Aurora Energy Research

Figure 28: Difference in job creation per sector between BAU and TRA

4.2.1 Coal plant closures

In the transition scenario, we assume coal power plants to shut down by 2030. As it stands, they employ almost 20,000 people. Due to the wider geographical distribution of thermal power plants, laid-off workers will find new employment easier than their counterparts working in coal mining. The proposed order of plant closures is in line with the age of respective power plant blocks. The eldest is closed first etc. Factors other than age are not considered and the order is to be understood as an approximation of a closure pathway rather than a policy recommendation (as the focus of the study lies on the overall effects of a transition rather than on a precise closure plan).

Figure 29 shows the distribution of 20,000 jobs lost in proportion to the plant closures.

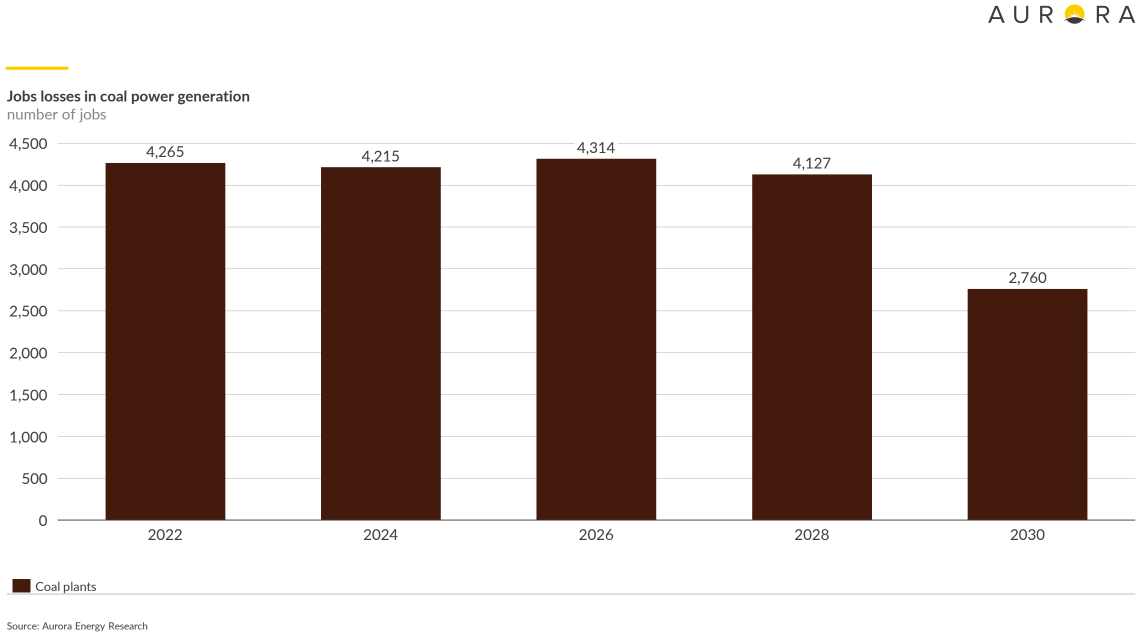


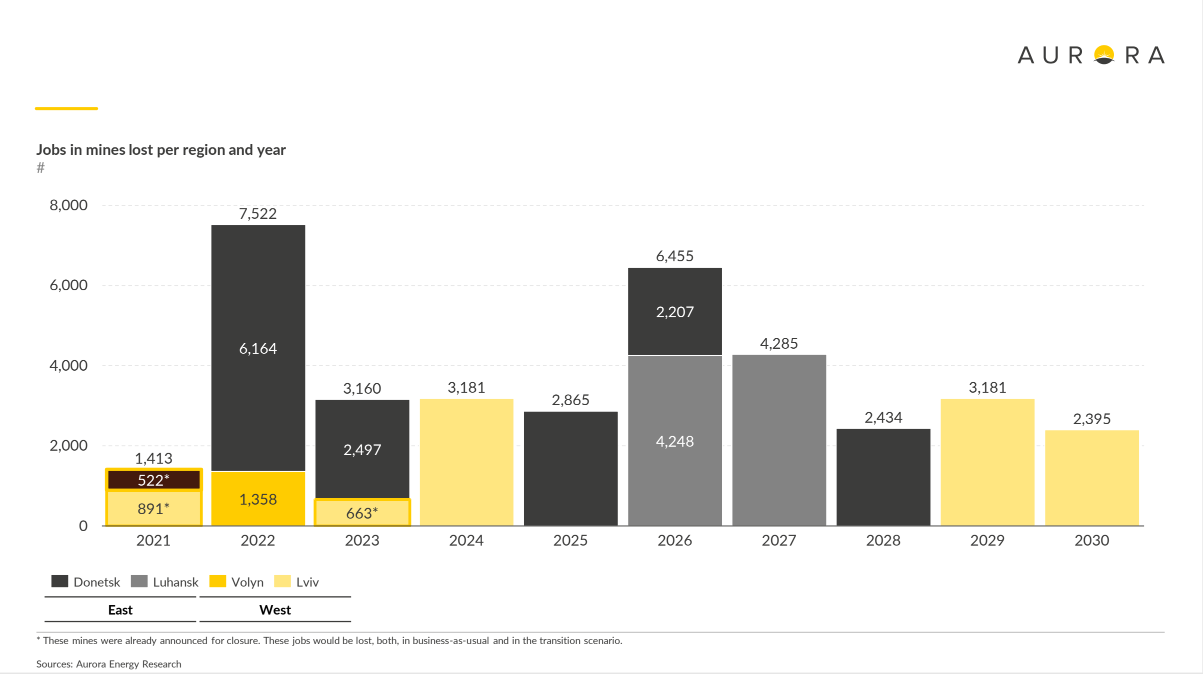
Figure 29: Job losses in coal plants

4.2.2 Mine closures

As discussed in section 2.4.2.2, we assume a coal phase-out in Ukraine also implies the closure of the state-owned mines by 2030. As it stands, more than 36,000 people are employed in state-owned mines. Figure 30 shows the effect of the closures by the number of laid-off workers per region. The figures for 2021 are already decided closures that occur irrespective of a stronger policy planning assumed for the transition scenario.

Coal mines provide essential work opportunities in many towns or regions. The loss of these jobs (>36,000) will not only affect the national labour market, but especially the individual economies of respective regions. In order to consider both aspects, jobs losses and costs for public budget, the closure order follows the metric “profitability per worker” (see section 2.4.2.2) while maintaining a regional balance.

As no public mine was making profit in 2018 (reference year), profitability in the approach is in fact financial loss per ton of produced coal, which multiplied by production accumulates into total loss of a company. The total loss is then divided by number of workers. Finally, public coal companies are listed in accordance with the amount of public financial support necessary to sustain a job in the company. To avoid excessively strong regional impacts, an additional constraint of closing no more than one company in a region per year is followed. Selydivvugillia is the first entire company shutting down operation. It is the most unprofitable in terms of earned profit per extracted ton, accumulated annual loss as well as our profitability metric. Lvivvugillia, which employs the largest number of people, is suggested to shut operation in two phases, namely in 2024 and 2029 to keep lay-offs distribution regionally balanced.



* These mines were already announced for closure. These jobs would be lost, both, in business-as-usual and in the transition scenario.

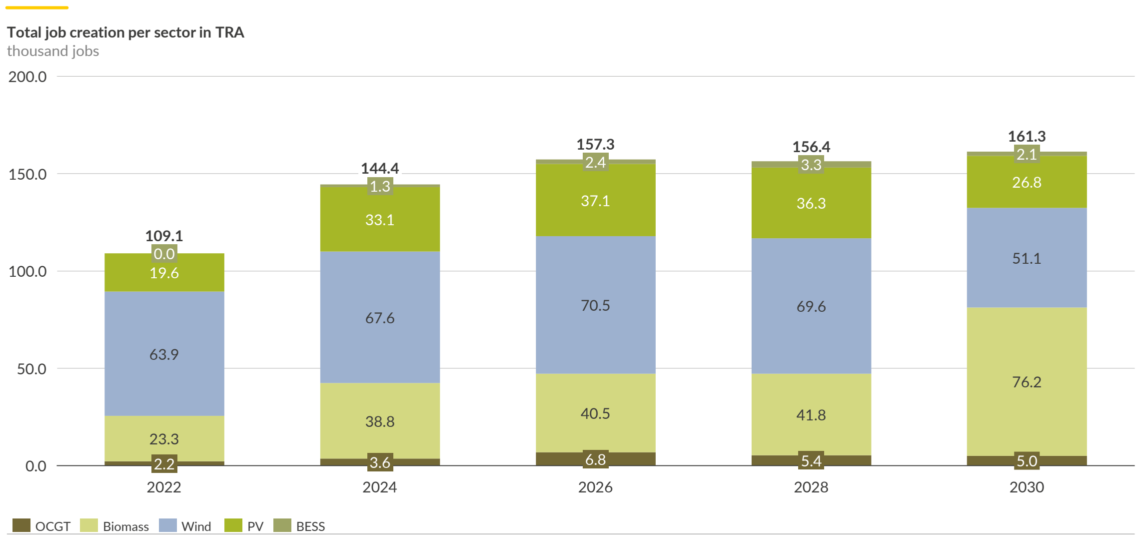
Sources: Aurora Energy Research

Figure 30: Lost jobs in mines

The closure of coal mines has tangible social consequences due to the often strong mutual interdependence of regional economies and mining. It is concentrated in a limited number of regions and their economy is often centred around mining. Hence, mine closures tend to create an economic vacuum in mining-dependent regions. Large numbers of workers with similar skill sets face a regional labour market with limited opportunities. Thus, worker compensation in the form of welfare benefits and job trainings as well as broader support for the transformation of regional economies need to be considered. These issues are generally discussed in the debate around “just transition”. Section 4.4 of the report looks in more detail into workers’ compensation and upskilling needs.

4.2.3 Job creation in RES industry

Parallel to the closure of coal facilities, we see a build-out of renewable assets, fostering job creation in this sector. With the addition of large capacities of especially wind and solar PV under the transition scenario, the report assumes an increase in local value creation (see Section 2.4.2.1). The assessment of job opportunities differentiates between temporary and permanent jobs.



Source: Aurora Energy Research

Figure 31: Total job creation per sector in TRA

The RES industry will temporarily boost labour demand in fields directly related to construction and, gradually, manufacturing of parts of equipment. The transformation of the energy system and, consequently, the economy will create new job opportunities needed during the construction boom for new capacities. Although these jobs are primarily needed during the transition phase, the global convergence towards green energy could make the temporary employment opportunities sustainable in the long run.

In BAU, the assessment shows the potential for the creation of 8,300 permanent jobs created in wind, solar and biomass operation. Under the much more ambitious plans of the TRA scenario, these sources have the potential to create almost 45,000 jobs.

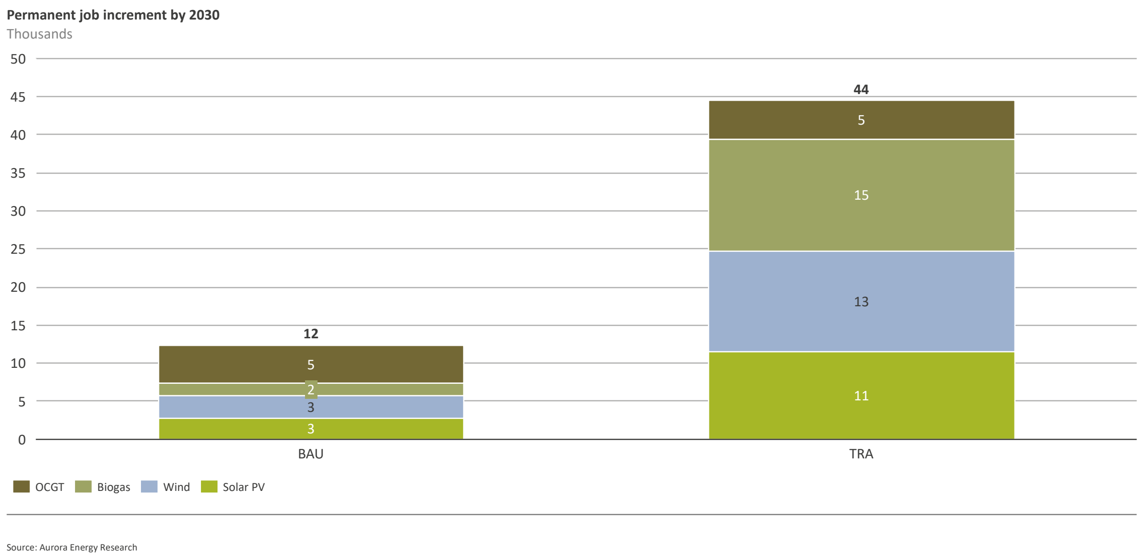


Figure 32: Permanent job creation

The total number of jobs in operation and maintenance of power-generating facilities will decrease due to lower requirements compared to conventional sources in Ukraine. On average, each MW of RES capacity is projected to be operated by 0.37 workers by 2030 in comparison to 1.3 workers in coal power plants. The average number of jobs that a sector creates in manufacturing differs between scenarios. With the growing domestic demand for renewable equipment, domestic production becomes more attractive and the share of value and job creation in Ukraine increases. This is especially the case for wind and solar PV (see Section 2.4.2.1).

In total, 56,000 jobs get lost whereas 45,000 permanent and, on average, 116,000 temporary jobs are created over the course of the decade in TRA. In the BAU scenario, we also see the loss of 2,000 jobs and the creation of around 21,000 temporary employment opportunities as shown in the Figure 33.

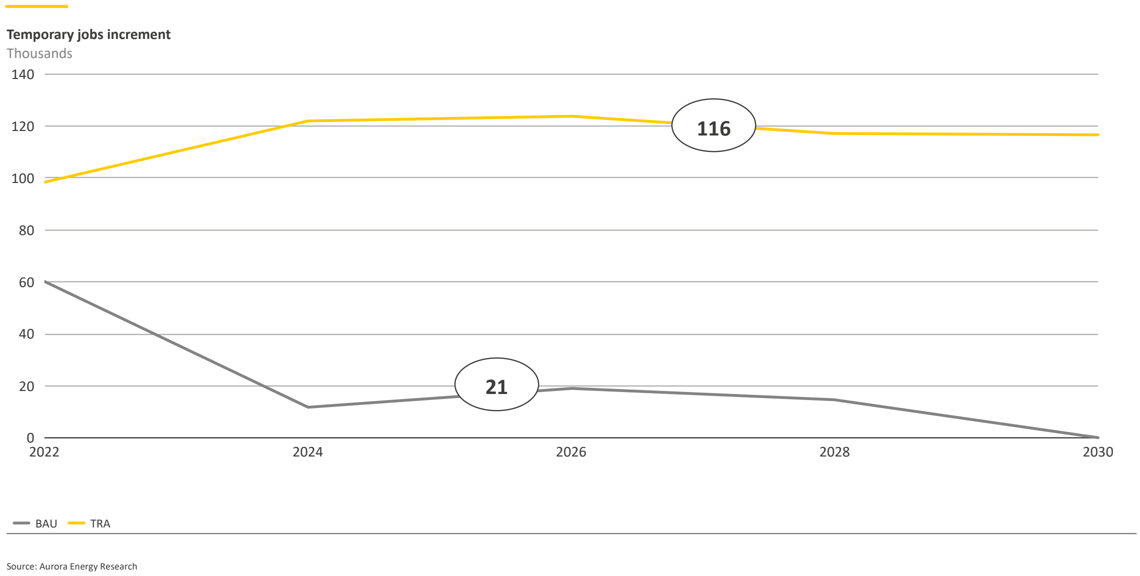
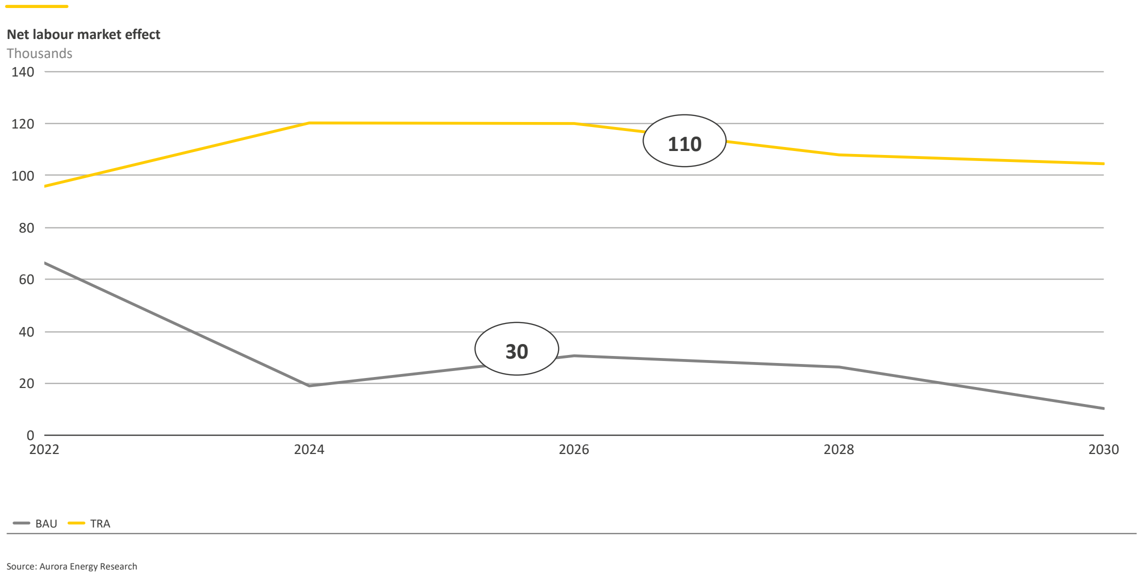


Figure 33: Temporary employment effects in BAU and TRA

4.2.4 Comparison between BAU and TRA

According to the macroeconomic modelling TRA will induce up to 100,000 jobs more than BAU by 2024 (see Figure 28). The difference in temporarily induced employment flattens as the decade nears its end. On average, TRA offers 80,000 job opportunities more than BAU (see Figure 34).



Source: Aurora Energy Research

Figure 34: Net labour market effect in BAU and TRA

Therefore, it can be concluded that the energy transition has a big potential to benefit Ukraine's labour market. Furthermore, a large part of the financially unsustainable jobs in public mining companies would likely be lost in the medium term under the BAU scenario. This means that the transition will accelerate this process that needs to be carefully managed but offers the potential to boost the labour market directly.

The re-employment of laid-off workers can be possible without major transformation of the labour market itself as a US study by Louie and Pierce suggests. The skill sets of miners can be transferred to support the needs in the solar industry[53]. Ukraine's existing, small, domestic RES industry could be built on to facilitate the transfer of skills.

4.3 Economic effects of mine closures

A potential early coal phase-out is frequently portrayed as an expensive policy option, posing an unnecessary burden on state budgets. However, such assessment does not consider the full cost of a continuation of the status quo. Especially the closure of coal mines can be beneficial from an economic point of view as the following chapter will show. In the assessment, we consider two types of costs associated with mines: the cost for the (continued) operation (BAU) and the cost associated with their decommissioning (TRA).

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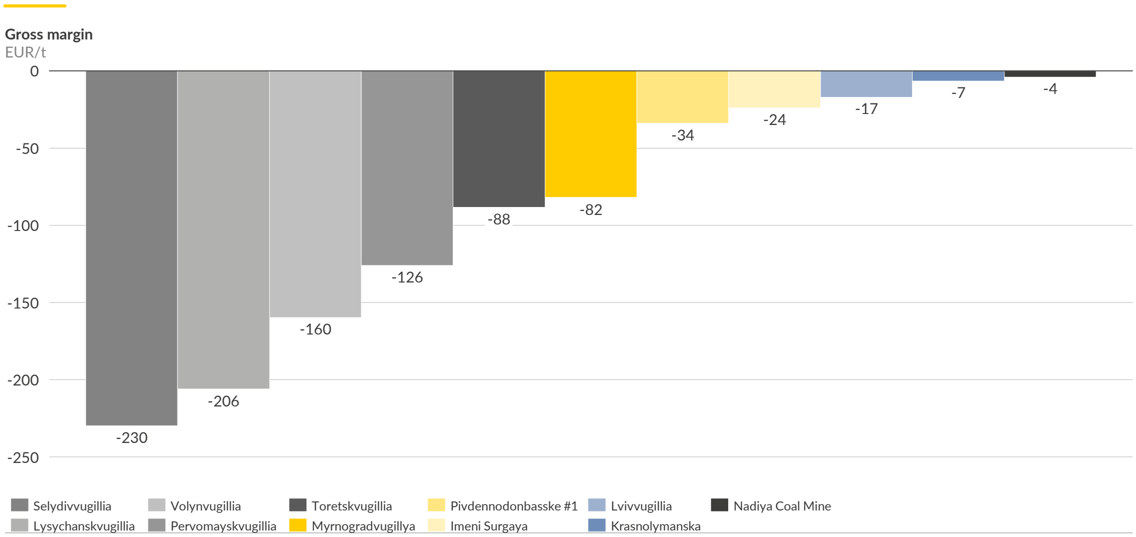
[53] Retraining Investment for U.S. Transition from Coal to Solar Photovoltaic Employment, Edward P. Louie1 and Joshua M. Pearce2,3*

Michigan Technological University; 2016

4.3.1 Operation costs

Figure 35 shows the public coal mining companies considered in this study and their average gross margin (per ton of coal) in past 5 years. The graph shows that all public companies report losses per ton of coal produced. Costs for wages, extraction work and technical maintenance exceed the sales revenue from hard coal, as further shown in Table 10 in the Section 2.4.2.2.



Note: Figures represent 5-year average

Source: Aurora Energy Research

Figure 35: Gross margins per ton for public mining companies[54]

This trend has further deteriorated over the past years, as depicted in Figure 36. As the companies are state-owned, their losses are currently covered by subsidies or accrued in public liabilities as long-term debt.

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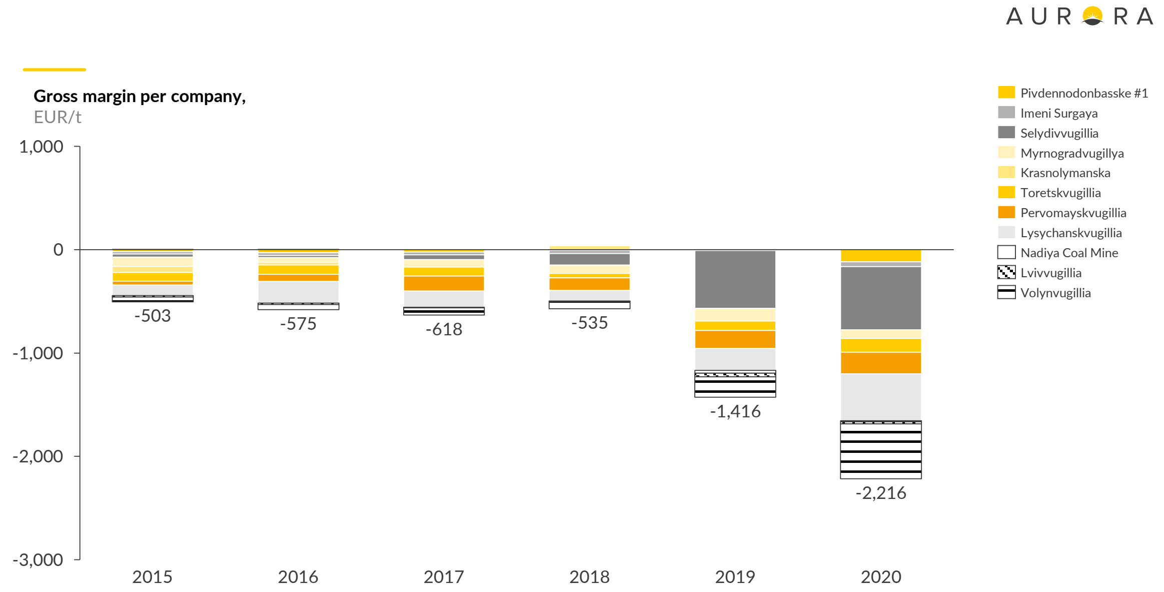
[54] Financial statements of the respective companies



Note: Data for Krasnolymanska only available until 2018.

Sources: Respective companies' balance sheets, Aurora Energy Research

Figure 36: Historic gross margins per company

Annual paid subsidies and generated debts are summed for each operating company. Considering the trend of the past years, an increase in losses would be a justifiable assumption. However, as a conservative estimate, we assume the 2019 value as gross margin for the following years until closure. This results in a present value of 710 mEUR saved on subsidies, if their level remained unchanged over time. As the trend of profitability is decreasing, even higher potential saving may arise from timely transition away from unprofitable coal mining.

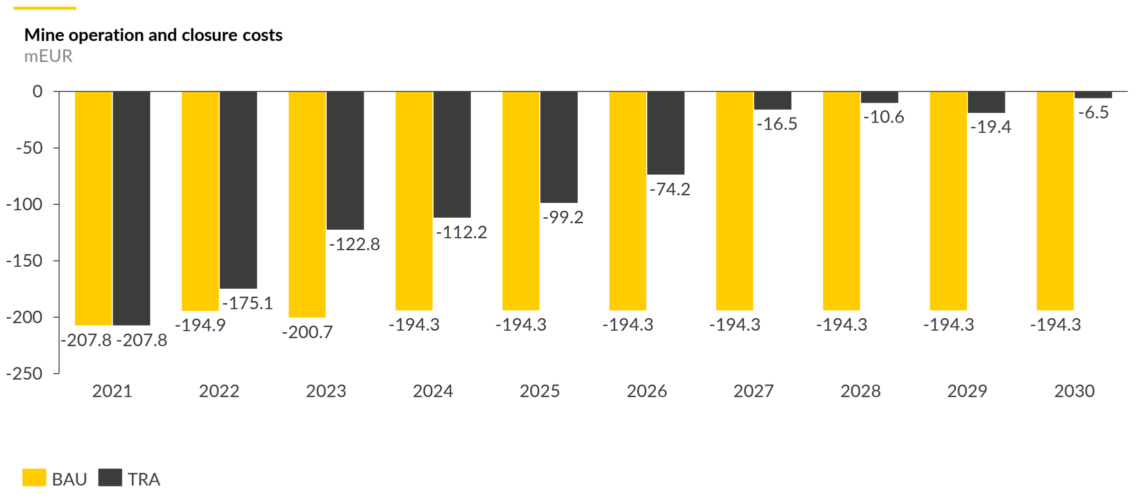
4.3.2 Decommissioning costs

With the closure of mines, additional, so-called "decommissioning" costs occur. They consist of process planning and execution providing stability of the underground workings and avoiding of the formation of sinkholes or potential pollution causing health and safety risk. Mine decommissioning costs are another argument in the debate about mine closures claiming high costs of transition. Although not negligible due to its significance in the final costs of mine closures, the argument is misleading. If subsidies are directly linked to the operation of mines, decommissioning is a process linked to the existence of the mining facility itself. The decommissioning cost is foreseen for each mine introduced into operation. Therefore, the argument is correct to the extent of immediate cost arising through sped-up transition process, but the present cost of decommissioning does not lose importance by postponing of the very process.

The total costs of the decommissioning process (if exercised in the order and amplitude suggested by transition scenario) is 146 mEUR compared to 17 mEUR spent on announced mine closures.

4.3.3 Conclusion on mines

The operation of public coal mines is and, unless radically modernised, will remain largely unprofitable. Coal extraction cost of these mines exceeds the actual market value of the produced coal or the salary payments of the workers it employs. Early closure of all public coal mines will save 427 mEUR in the observed time span. Furthermore, it would also avoid additional debts generated by concerned companies beyond 2030. Short-term cost comparison of public expenses on coal mines clearly shows large economic benefits of closures over a continued operation of public coal mine. A critical consequence of the mine closures are the effect on employment and the economies of traditional coal regions. This is considered in Section 2.4.2.2.



Source: Aurora Energy Research

Figure 37: Cost of mine operation and closures

4.4 Welfare benefit and compensation

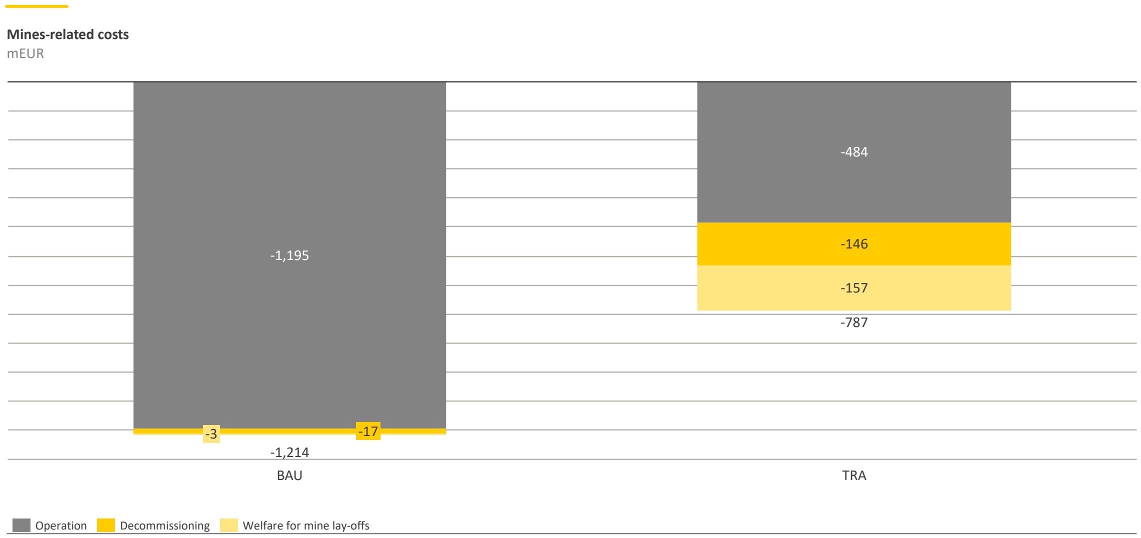
As discussed above, 56,000 workers will lose their work in TRA. For the workers of coal mining companies, we calculate welfare benefits based on the methodology presented in Section 2.4.2.3. The cost is calculated for a conservative and a progressive policy option. The latter offers a more generous compensation along with a higher focus on training opportunities.

Hereby, the following costs occur:

Table 13: Welfare costs per worker per policy option

Group of people		Conservative	Progressive
Eligible for pension (50 – 55 years old)	Sum of 3-year retirement payments	11,945 EUR	11,945 EUR
	One-off payments upon employment termination	--	1,244 EUR
Below pension age (18 – 49 years old)	Sum of unemployment benefits payments	1,244 EUR	2,488 EUR
	One-off payment upon lay-off	--	415 EUR
	Upskilling	--	4,354 EUR

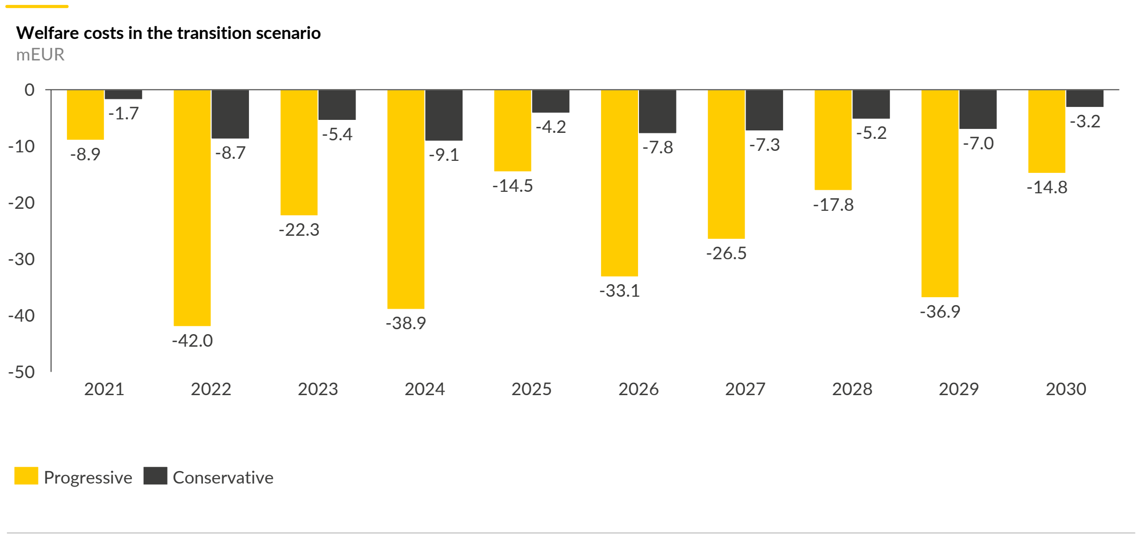
With these assumptions, we observe around four times higher costs in the progressive scenario than when only the legal minimum is guaranteed. This estimate opens a range of possible pathways. The direct economic costs can be held low following the conservative policy option. The progressive policy option results in higher direct costs. However, it mitigates social hardship by allowing affected workers to transition into other forms of employment. In Germany, for instance, the law to phase out coal from the electricity sector was negotiated in parallel with an agreement on generous investment programmes for affected regions. Additionally, coal power plants who apply for compensation payments have to present own social plans. It has been argued that these benefits have made the coal phase-out politically feasibility in this country. Therefore, we will base our calculations on the progressive option. Its costs total at around 157 m EUR in net present value (see Figure 38).



Note: Net present value with the 10% ROR

Source: Aurora Energy Research

Figure 38: NPV of mine operation expenses in BAU and TRA



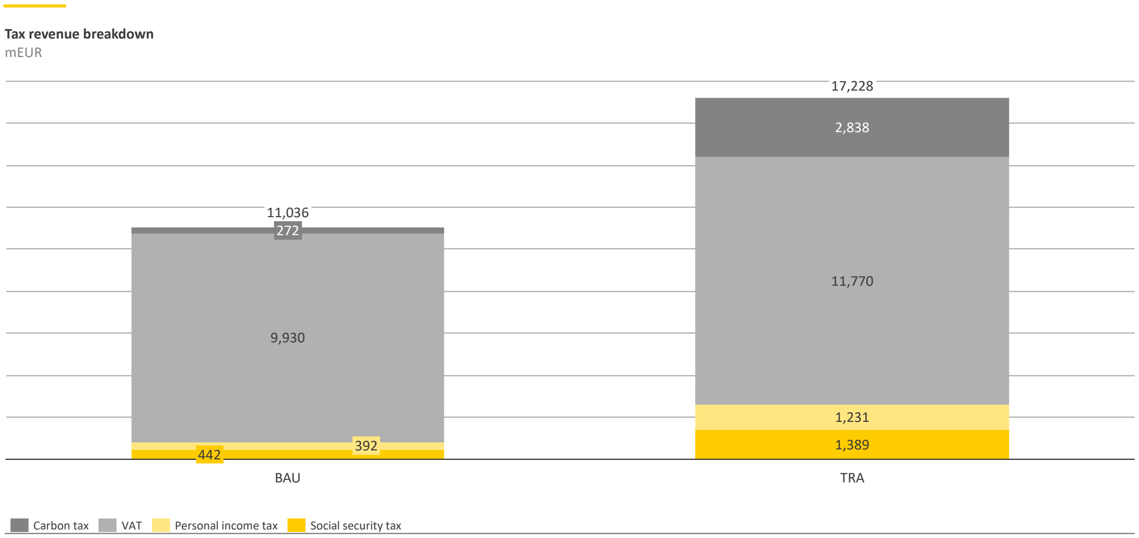
Source: Aurora Energy Research

Figure 39: Welfare costs of transition per policy option

4.5 Taxes

Another aspect of the economy that is impacted by a clean energy transition is taxes. For the purpose of this study, we have considered 4 types of taxes: carbon tax, personal income tax+military tax, social security tax and VAT. Overall, we see an increase in tax revenue, mostly driven by the growth in carbon tax and VAT collection.

With changing employment structures, we expect an increase in revenues from income taxes. This increase is explained by around 30% higher salaries paid in the RES sector[55] than in mining and more jobs being created in the course of the transition than jobs being lost.



Note: Net present value with the 10% ROR

Source: Aurora Energy Research

Figure 40: NPV of tax revenues in BAU and TRA

4.5.1 Carbon tax

As TRA is accompanied by higher carbon price, proportional as well as nominal contribution to the public budget is 10 times higher in TRA than in BAU. In the case of TRA it would contribute present value of 2.8 bn EUR which is equal to 16% of the tax revenue collected in 10 years.

4.5.2 VAT on power

The most significant differences between the scenarios are in tax revenue deducted from CAPEX. Other elements adding to the final VAT value, such as OPEX, fuel and transmission costs fluctuate in a similar fashion over time. All in all, TRA creates additional 1.8 bnEUR in revenues

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[55] Ukrhydroenergo, Apr. 2019

in the form of VAT annually by 2030. The hike in state revenues is largely caused by investment inflow as well as elevated CO_2 price.

4.5.3 Personal income tax and military tax

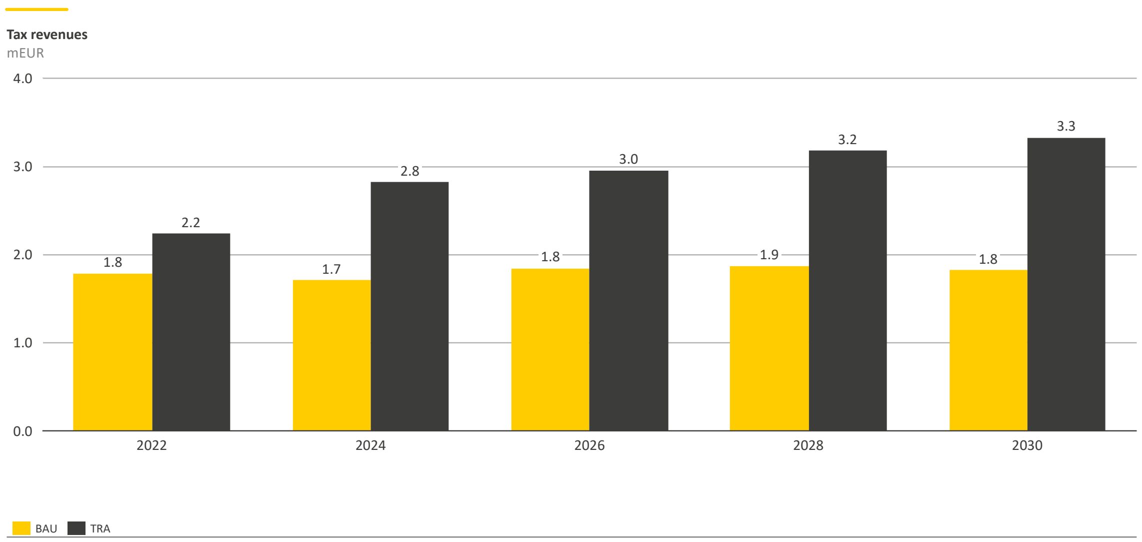
About 280 mEUR will flow into the state budget in 2030 compared to 32 mEUR in the same in BAU scenario. The contribution has a constantly growing tendency in the TRA scenario, while it fluctuates between 30 and 100 mEUR received in the form of tax annually. An increase in income tax revenues is largely caused by a higher number of employed people and real wage growth. Higher salary level in RES industry is responsible for less than 1% of the increase.

4.5.4 Social security tax

Following the pattern of the personal income tax, social security tax is calculated from accumulated annual salaries paid and tax rate. The amount collected in the form of social security tax is correlated to the personal income tax, as they are calculated on the basis of salaries. Consequently, the level of collected tax grows constantly from 2020 to 2030 reaching 319 mEUR, while the pinnacle of collected tax sums in BAU is in the first period between 2020 and 2022. It is merely a result of a hike in new RES installations.

4.5.5 Net impact

According to the analysis, the energy transition can have a strongly positive impact on tax revenues and public budgets. Significant tax inflows emerge due to greater employment and economic activity, which is subject to taxation. These are direct effects. Further indirect impacts of the energy transition on other sectors and the overall economic equilibrium were assessed in the Section 4.6.



Source: Aurora Energy Research

Figure 41: Annual tax revenues in BAU and TRA

4.6 Second-order macroeconomic effects

Main takeaways & conclusion

Based on the assessment of the direct economic effects of the TRA scenario, CGE modelling was performed to capture second-order macroeconomic effects on GDP and sectoral balances.

The analysis shows that the TRA scenario through the mobilised investments has a positive effect on GDP. In comparison to the 2018 equilibrium, the analysis shows for TRA in 2030 that direct investment amounts to +12 % GDP and induces a total GDP growth of 15% (second-order effects of 3%). In comparison, direct investments under BAU amount to 2% of GDP, inducing a 3% growth (second-order effect of 1%). This result is robust across sensitivities that take into account the impact on electricity prices and supply, and domestic coal supply. These findings suggest that the positive direct impacts cause further positive spill-over effects in the wider economy.

The assessment of the impacts on individual sectors shows that certain sectors benefit, while others are negatively affected. The assumed investment benefits construction directly, while other service-oriented, low energy-intense sectors profit from second-order effects of the investment inflow. More energy-intense sectors (like industry) are being negatively affected by higher electricity prices and import competition. This points to the need of interlinking energy sector policies with industrial policy and sectoral strategies (potential measures can include targeted exemptions for energy-intense sectors, support for energy efficiency measures). Although, the overall economic impact is positive, negative impacts on

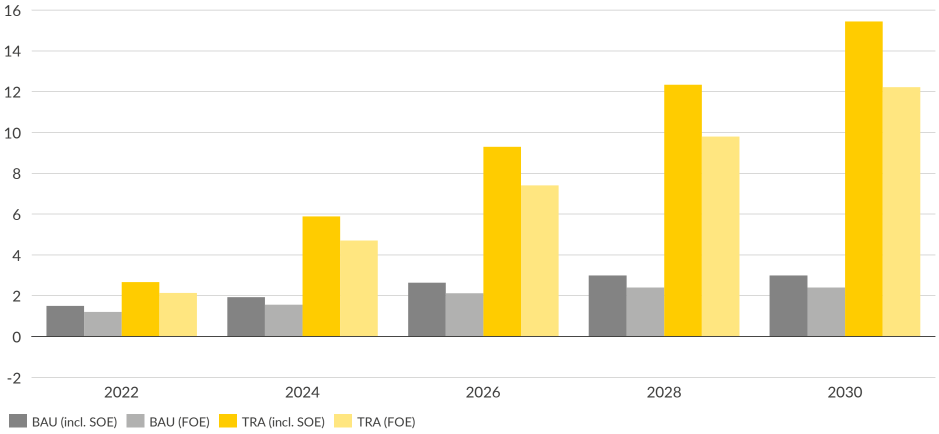
4.6.1 Gross Domestic Product

We first present results for the core scenarios and subsequently discuss implications in the additional sensitivities. If not stated otherwise, results are reported as percentage changes against the 2018 benchmark equilibrium as provided by the input-output data (for 2018 the benchmark economy's GDP stood at 3,560,596 million UAH).

Figure 42 shows the effects on GDP of the assumed changes in investment assessed in the preceding chapter. The first-order effect (FOE) simply states the amount of additional investment as a percentage share of 2018 GDP, ranging from 1.2% in 2022 to 2.4% in 2030 under BAU, and from 2.1% in 2022 up to 12.2% in 2030 under TRA.

The results show that the second-order effects increase the GDP figures implied by the different levels of investment. The reason is that additional demand for investment goods induces the described spill-over effects along the value chain.

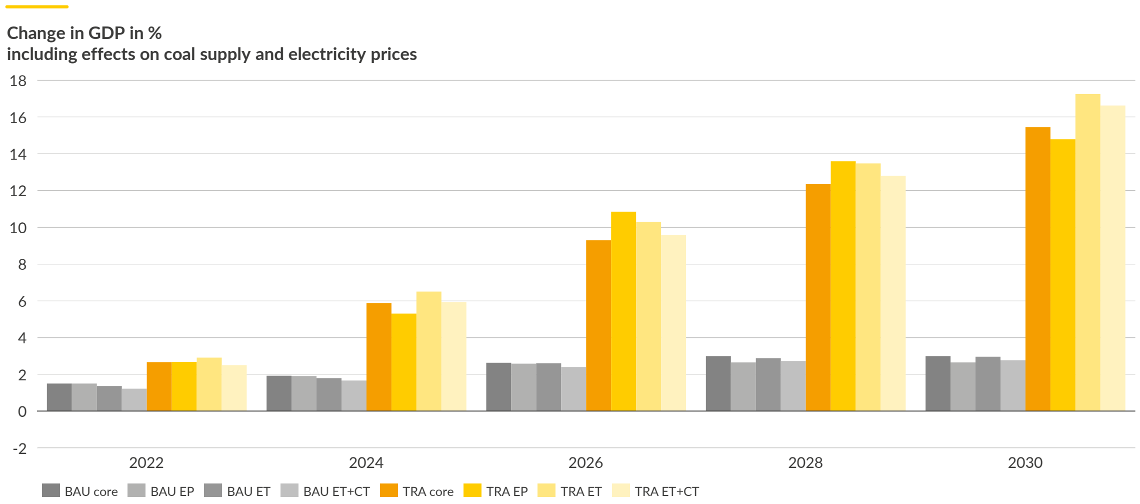
Change in GDP in %
for first-order and second-order effects



Source: Aurora Energy Research

Figure 42: First-order effects (FOE) and second-order effects (SOE) on GDP of increased investment demand in BAU and TRA (core scenarios)

Figure 42 shows that overall effects on GDP are quite robust across the core scenarios and the additional more detailed specifications, indicating that our core scenarios provide a robust impact assessment of second-order effects.

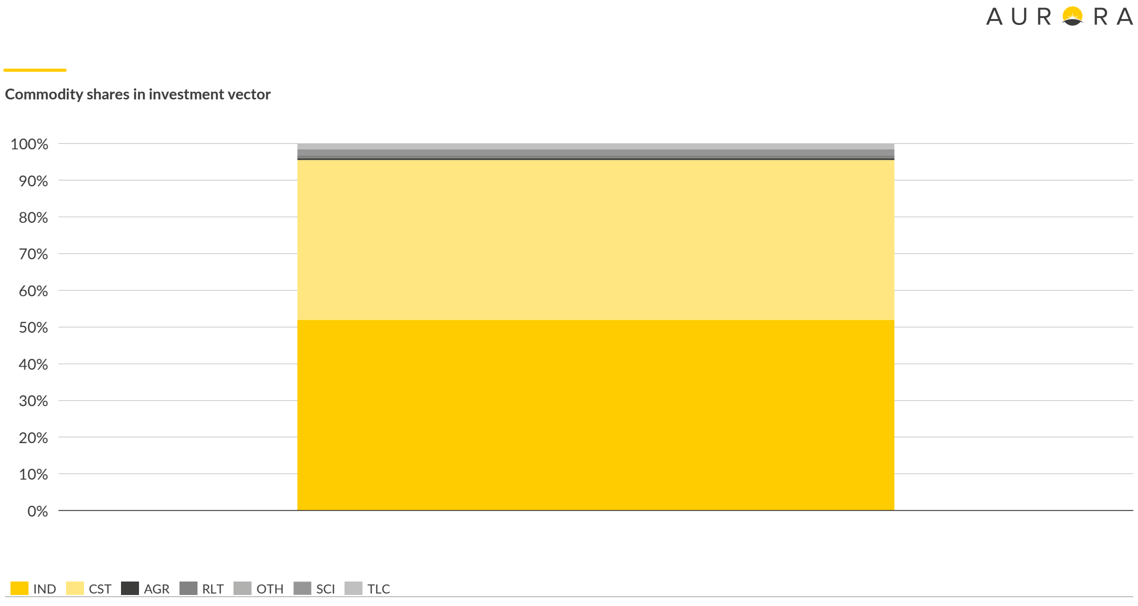


Source: Aurora Energy Research

Figure 43: GDP impacts (incl. SOE) in core scenarios and additional scenarios EP (electricity price targeting), ET (electricity supply targeting), and ET+CT (ET + coal supply constraint)

4.6.2 Sectoral output

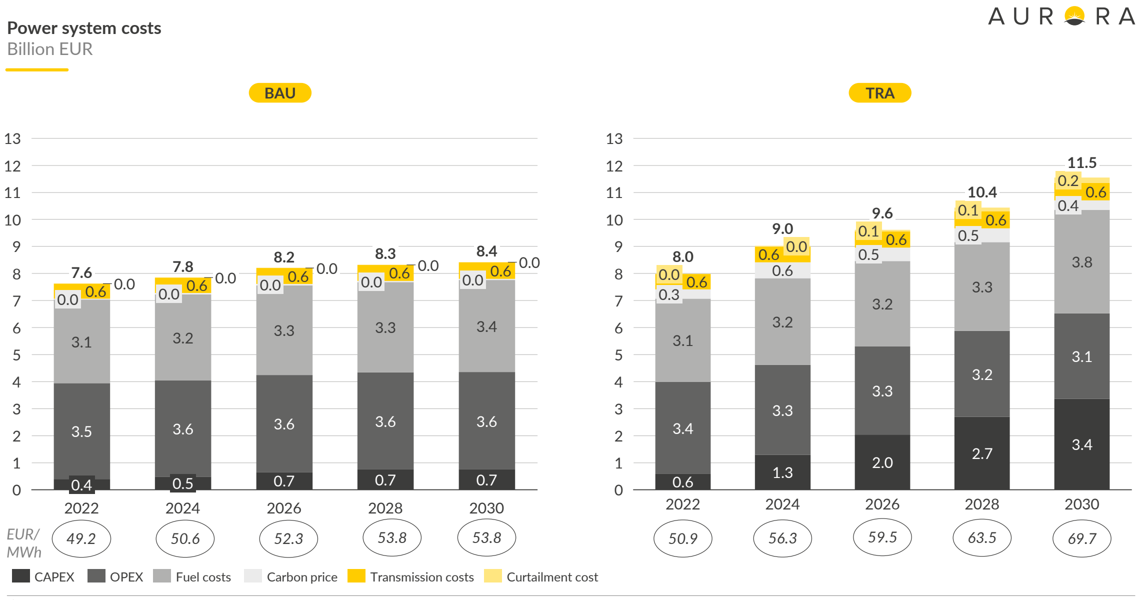
A major determinant of sectoral outcomes is the composition of investment demand. Figure 44 shows the composition of sectoral shares in investment demand as observed in the benchmark. Investment is almost completely composed of manufactured products (sector IND) and construction (CST). This plays an important role for direct and spill-over effects under increased investment demand.



Source: Aurora Energy Research

Figure 44: Sectoral shares in investment demand

For the presentation of sectoral outcomes we focus on 2030 and the scenarios BAU EP and TRA EP, where electricity prices adjust through supply scaling to the values presented in Figure 26 in the power sector chapter.



1) Includes capital cost for new builts, fuel cost and CO2 cost

Source: Aurora Energy Research

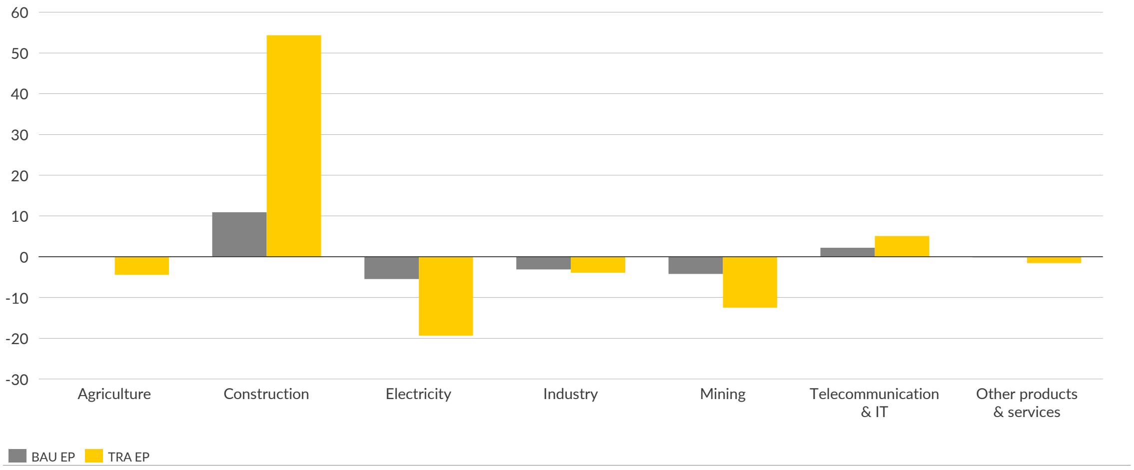
Figure 45 shows output effects under BAU EP and TRA EP in 2030. We find that – as expected – the construction sector (CST) expands drastically, by more than 50% under TRA EP. The industry sector (IND), on the other hand, even declines in output. The main reason is that the industry sector is energy- (electricity) intensive and at the same time exposed on international markets through a high trade intensity: 30% of manufactured products are exported, and imports amount to about 60% of domestic production in the benchmark. The price increase of electricity leads to rising input costs. As international market prices for exports and imports are fixed in the small open economy assumption, exports decline by more than 10% in BAU EP and more than 20% in TRA EP. At the same time imports increase by 2.3% (BAU EP) and over 15% (TRA EP), respectively.

The telecommunications and IT sector (TLC) is an example showcasing benefits of indirect and induced effects. While there is almost no additional direct demand through the exogenous investment shock, TLC gains in comparative advantage because of its relatively low electricity intensity and high labour intensity compared to other sectors and thus increases output by up to 5% under TRA EP.

The sectoral analysis shows that second-order effects can play out strongly favourable for individual sectors but can also have negative consequences for the international competitiveness of sectors and might even lead to job losses. Such dynamics need to be carefully assessed. Policy intervention can help ease the transition for such sectors and protect their competitiveness, where further sectoral analysis is warranted that reflects more technological detail and labour market rigidities.

AURORA

Change of sectoral output under BAU EP and TRA EP in 2030.



Source: Aurora Energy Research

Figure 45: Sectoral output under BAU EP and TRA EP in 2030

5 Recommendations for further policy considerations

The analyses in the study show that a rapid transition away from coal power generation to increased shares of renewable energy in Ukraine is not only technically feasible but can offer wider economic benefits. Such a transition can address the existing economic inefficiencies in the public mining sector and overcapacity in power generation. The mobilisation of new investments into power generation assets offers a big opportunity to create a stimulus for the country's economy, while tackling the issue of Ukraine's aging power plant fleet and providing replacements with more efficient and cleaner alternatives. This offers direct environmental and climate mitigation benefits. Furthermore, in such a transition there is potential for modern industries to be established, which create new jobs and economic growth.

To steer the transition of a sector as central to the economy as the power sector, there are however important policy questions to be considered:

Power sector and investment

Important policy considerations for the power sector include clear long-term planning, mechanisms to insure sufficient system flexibility and the question on attracting new investments into the sector.

Transparent long-term planning can ensure system adequacy and efficiency, while creating security for market participants and investors in the liberalised power market. Here, the study shines a spotlight on the required system flexibility: what processes are used to plan required capacities? And in what way are they renumerated? Here a range of options can be considered, including capacity payments for new entries or targeted TSO-driven investments.

Another important issue to be considered are policies to mobilise the large volumes of investment required into the Ukrainian power sector. After the restructuring of feed-in-tariffs in 2020, these are a highly important consideration. Here it is especially key to be able to provide investors and financiers of renewable projects security and transparency. This can in turn lower the cost of renewables and the overall system cost.

Stakeholders and political process

In shaping the phase-out of coal and a transition to renewables, the inclusion of key societal stakeholder and appropriate decision mechanisms should be considered. Examples from Germany or Canada have shown that a commission including major stakeholders can improve the political acceptance of such a process. The inclusion of experts in the decision on adequate policy tools can help ensure the economic efficiency of the transition process further.

Wider impacts: just transition and industrial policy

As shown in the study, the transition of the power sector has far-reaching impacts. This includes – what is often referred to as questions of *just transition* – that these changes affect some regions and people disproportionally, but also the energy transitions impact on other sectors of the economy and how this can be managed.

The analyses in the report focus on the impact on the labour force. Here, adequate policies to reskill and compensate workers need to be considered. The changing power sector can create new opportunities and accommodate workers laid-off at coal plants and mines.

Another element that needs to be considered goes beyond the individual worker. As coal mining activities are concentrated in regions and often represent a major part of a region's or town's economic activity, regional policies need to be considered to enable a structural change of a region's economy and avoid its economic collapse. Examples in the US or Germany show that this is a politically highly sensitive consideration that requires close attention.

Other impacts of the transformation of the power sector can include a rise in end-consumer prices. They reflect the investment needs in the Ukrainian power sector and would likely require modest increases. As this can affect vulnerable households disproportionally and attention needs to be paid to avoid social hardship.

Lastly, the changes in the power sector have an impact on other sectors of the economy. Though there is potential for overall economic gains, an increase in power prices can impact more energy-intense sectors negatively. Here a strategic alignment of industrial and power sector policies needs to be considered: what sectors are negatively impacted; do they continue to be economically relevant in the future and how can their competitiveness internationally be preserved? Several other countries grant exemptions on energy-related fees and levies for energy-intense industries. Another option is increased public support for energy efficiency and modernisations. This can help energy-intense companies to compete globally and is especially effective for sectors in Ukraine that operated outdated technologies and have seen little investment.

We suggest further study of these important policy considerations to ensure a politically feasible, socially equitable and economic efficient transition of a greener power sector.

Annexes

6 Additional Tables

Installed capacities

Business as usual

	2020	2022	2024	2026	2028	2030
Nuclear	13,800	13,800	13,800	13,800	13,800	13,800
TPP coal	17,095	17,095	17,095	17,095	17,095	17,095
TPP gas	4,600	4,600	4,600	4,600	4,600	4,600
OCGT	0	500	1,000	2,000	2,000	2,000
CHP	4,059	4,059	4,059	4,059	4,059	4,059
Hydro	4,761	4,761	4,761	4,761	4,761	4,761
Biomass	194	275	345	455	525	500
Wind	1,114	3,014	3,164	3,524	3,963	3,963
PV	5,979	7,017	7,287	7,657	7,857	7,857
Hydro storage	1,515	1,839	1,839	1,839	1,839	1,839
BESS	0	0	0	0	0	0
Total capacity, MW	**53,117**	**56,960**	**57,950**	**59,790**	**60,499**	**60,474**
Generation, MW	**51,602**	**55,121**	**56,111**	**57,951**	**58,660**	**58,635**
Storage, MW	**1,515**	**1,839**	**1,839**	**1,839**	**1,839**	**1,839**
Hydro storage	7,012	7,012	7,012	7,012	7,012	7,012
BESS	0	0	0	0	0	0
Total storage volume, MWh	**7,012**	**7,012**	**7,012**	**7,012**	**7,012**	**7,012**

Transition

	2020	2022	2024	2026	2028	2030
Nuclear	13,800	13,800	13,800	13,800	13,800	13,800
TPP coal	17,095	13,390	9,729	5,982	2,397	0
TPP gas	4,600	4,600	4,600	4,600	4,600	4,600
OCGT	0	500	1,000	2,000	2,000	2,000
CHP	4,059	4,059	4,059	4,059	4,059	4,059
Hydro	4,761	4,761	4,761	4,761	4,761	4,761
Biomass	194	500	1,000	1,500	2,000	3,000
Wind	1,114	3,850	6,646	9,487	12,216	14,039
PV	5,979	7,016	8,750	10,651	12,469	13,685
Hydro storage	1,515	1,839	1,839	1,839	1,839	1,839
BESS	0	0	100	300	600	800
Total capacity, MW	**53,117**	**54,316**	**56,284**	**58,978**	**60,741**	**62,583**
Generation, MW	**51,602**	**52,477**	**54,345**	**56,839**	**58,302**	**59,944**
Storage, MW	**1,515**	**1,839**	**1,939**	**2,139**	**2,439**	**2,639**
Hydro storage	7,012	7,012	7,012	7,012	7,012	7,012
BESS	0	0	400	1,200	2,400	3,200

Total storage volume, MWh	**7,012**	**7,012**	**7,412**	**8,212**	**9,412**	**10,212**

Carbon price EUR/t

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BAU	0.3	0.4	0.6	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9
TRA	0	4	8	12	16	19	23	27	31	35	38

Technology cost of Biomass EUR/kW

Technology	*CAPEX*	*OPEX*
Biomass	*3000*	*52.5*

Technology costs of Batteries EUR/kW

Technology	*CAPEX*					*OPEX*
	2022	*2024*	*2026*	*2028*	*2030*	
Batteries	*902*	*828*	*773*	*731*	*702*	*52.5*

Assumptions on technical features of conventional sources

Technology	*Efficiency*	*Fuel CO2 intensity*	*Emissions factor*
TPP coal	*31%*	*406*	*1.31*
TPP gas	*33%*	*200*	*0.61*
OCGT	*33%*	*200*	*0.61*
CHP coal	*26%*	*406*	*1.56*
CHP gas	*26%*	*200*	*0.77*
CHP biomass	*30%*		

Thermal coal power plants list of closures

Generating unit	*Commissioning (retrofit)*	*Capacity (MW_{el})*	*Phase out*
Myronivska 3	1954 (1998)	60*	2021
Slovyanska 3	1957	80	2021
Zmiyivska 1	1960	175	2021
Dobrotvorska 6	1961 (2015)	100	2021
Zmiyivska 2	1961	175	2021

Prydniprovksa 11	1962 (2016)	310*	2021
Luganska 9	1962 (2017)	200*	2021
Luganska 10	1962 (2012)	210	2021
Zmiyivska 3	1962	180	2021
Kryvorizka 1	1963 (2017)	315	2021
Luganska 11	1963 (2004)	200*	2022
Zmiyivska 4	1963	180	2022
Kryvorizka 2	1964 (1988)	300	2022
Kryvorizka 3	1965 (2013)	300	2022
Kryvorizka 4	1966 (2005)	300	2022
Luganska 13	1967 (2014)	210	2022
Burshtynska 5	1967 (2013)	215	2022
Burshtynska 6	1967 (2015)	195	2022
Dobrotvorska 5	1960 (2018)	100	2023
Dobrotvorska 7	1963 (2011)	150	2023
Dobrotvorska 8	1964 (2014)	160	2023
Burshtynska 1	1965 (2017)	195	2023
Burshtynska 2	1965 (2014)	185	2023
Burshtynska 3	1966 (2013)	185	2023
Burshtynska 4	1966 (2014)	195	2023
Zmiyivska 7	1967	290*	2023
Luganska 14	1968 (2006)	200	2023
Burshtynska 7	1968 (2012)	206	2023
Burshtynska 8	1968 (2009)	195	2024
Burshtynska 9	1968 (2016)	195	2024
Zmiyivska 8	1968 (2005)	325	2024
Luganska 15	1969 (2005)	200	2024
Burshtynska 10	1969 (2018)	210	2024
Burshtynska 11	1969 (2011)	195	2024
Burshtynska 12	1969 (2012)	195	2024
Zmiyivska 9	1969	280	2024
Zmiyivska 10	1969	290	2025
Trypilska 1	1969	300	2025
Ladyzhynska 1	1970 (2017)	300	2025
Trypilska 2	1970	325	2025
Trypilska 3	1970	300	2025
Trypilska 4	1970	300	2025
Prydniprovksa 7	1958 (2013)	150	2026
Prydniprovksa 8	1958 (2014)	150	2026
Prydniprovksa 10	1960 (2006)	150	2026
Kryvorizka 8	1969 (1996)	282	2026
Ladyzhynska 2	1971 (2009)	300	2026

Ladyzhynska 3	1971 (2011)	300	2026
Ladyzhynska 4	1971 (2001)	300	2026
Ladyzhynska 5	1971 (2003)	300*	2026
Prydniprovksa 9	1959 (2012)	150	2027
Ladyzhynska 6	1971 (2004)	300*	2027
Zaporizka 1	1972 (2012)	325	2027
Zaporizka 2	1972 (2017)	300	2027
Zaporizka 3	1972 (2014)	325	2027
Kryvorizka 10	1972 (2007)	300	2027
Kurakhivska 3	1972 (2007)	155	2027
Vuhlehirska 1	1972	300	2028
Zaporizka 4	1973 (2016)	300	2028
Kurakhivska 4	1973 (2017)	160	2028
Kurakhivska 5	1973 (2015)	160	2028
Kurakhivska 6	1973 (2013)	210	2028
Vuhlehirska 2	1973	300	2028
Vuhlehirska 3	1973	300	2028
Zmiyivska 5	1964	190	2029
Zmiyivska 6	1965	185	2029
Kryvorizka 5	1967 (1994)	282	2029
Slovyanska 7	1971	720	2029
Vuhlehirska 4	1973	300	2029
Kurakhivska 7	1974 (2016)	185	2029
Kurakhivska 8	1974 (2017)	210	2029
Kurakhivska 9	1975 (2015)	210	2029
Myronivska 5	2004 (2013)	115	2029

Notes: * Already in preservation.

Sectoral aggregation for reporting of results in the CGE analysis

	SSCU correspondence	
Reporting sector	ISIC classification	Description

AGR (Agriculture)	A01-A03	Agriculture, forestry and fishing
MIN (Mining)	B05	Coal mining
	B06	Crude oil and gas extraction
	B07-B09	Extraction of metal ores and other minerals, quarring; support services for mining and quarring
IND (Industry)	C13-C15	Manufacture of textiles, clothes, leather, leather products and other materials
	C16-C18	Manufacture of products from wood, paper and printing
	C19.1	Manufacture of coke coal related products
	C19.2	Manufacture of products from crude oil
	C20	Manufacture of chemical substances and chemical products
	C21	Manufacture of basic pharmaceutical products and drugs
	C22	Manufacture of rubber, plastic and products
	C23	Manufacture of other non-metallic mineral materials
	C24	Metallurgy

	C25	Manufacture of metals and metal products except for machines and equipment
	C26	Manufacture of components, electric and optic products
	C27	Manufacture of electric equipment
	C28	Manufacture of machines and equipments excluded from other groups
	C29	Manufacture of vehicles, trailers and semi-trailers
	C30	Manufacture of other vehicles
	C31-C33	Manufacture of furniture, other production, repair and installation of machines and equipment
ELE (Electricity)	D35	Supply of electricity, gas, steam and air conditioning
CST (Construction)	F41-F43	Construction
TLC (Telecommunications and IT)	J58-J60	Publishing, production of cinematic and video movies, TV programs, audio recordings, radio and television broadcasting
	J61	Telecommunications
	J62-J63	Computer programming and IT services

OPS (Other products and services)	C10-C12	Manufacture of food products, beverages and tobacco
	E36-E39	Water supply; sewage and waste management
	G45-G47	Repair, wholesale and retail trade of motor vehicles and motorcycles
	H49-H52	Transport, warehousing
	H53	Postal and delivery services
	I55-I56	Temporary accommodation and catering
	K64-K66	Finances and insurance
	L68	Real estate transactions
	M69-M71	Judicial and accounting services, head offices services, management consulting, architecture and engineering services, technical testing and research
	M72	Academic research and development
	M73-M75	Advertisement and market research, other professional, scientific and technical activity, veterinary practice
	N77-N82	Administrative and auxiliary services

	O84	Public administration and defense; compulsory social insurance
	P85	Education
	Q86-Q88	Health care and social assistance
	R90-R93	Arts, sports, entertainment and recreation
	S94-S96, T97	Provision of other types of services

7 List of References

DixiGroup, 2020: *ОЦІНКА ЕФЕКТИВНОСТІ ДЕРЖАВНИХ ВИДАТКІВ НА РЕСТРУКТУРИЗАЦІЮ ВУГІЛЬНОЇ ГАЛУЗІ*
Online available at: https://dixigroup.org/wp-content/uploads/2021/02/dixi-coal-industry-web-2.pdf

Dtek, Online available at: https://dtek.com/media-center/press/transformatsiya-ugolnykh-regionov-dolzhna-proiskhodit-s-privlecheniem-mezhdunarodnogo-opyta-i-ekspertizy-/

E3Modelling – E3MLabh, Mar. 2020: *Main Assumptions For A Baseline Energy Scenario For The Energy Community Countries*
Online available at: https://www.energy-community.org/dam/jcr:aef25aae-2e52-4d8f-a066-0e586529eac0/CarbonWS_E3Modelling_032020.pdf

Energy Ministry of Ukraine, 2020: *Інформація про роботу електроенергетичного комплексу за грудень та 12 місяців 2020 року - фактичні дані*
Online available at:
http://mpe.kmu.gov.ua/minugol/control/uk/publish/article?art_id=245509526&cat_id=245183225

Energy Ministry of Ukraine, Jul. 2020: *Шахти мають вийти із простою, а гірники повернутися до роботи, - Ольга Буславець*

Energy Ministry of Ukraine, Jun. 2020: *Кризова ситуація на шахті "Краснолиманська" буде вирішена у найкоротші терміни, - Ольга Буславець*

Energy Ministry of Ukraine, Nov. 2020: *Ministry of Energy: На зарплати шахтарям виділили 1,4 млрд грн до кінця року*

European Commission, Nov. 2020: *Just Transition Platform Meeting – Coal Regions in Transition Virtual Week 16-19 November 2020*
Online available at: https://ec.europa.eu/info/events/just-transition-platform-meeting-16-19-november-2020_en

European Investment Bank, July 2020: *EIB Project Carbon Footprint Methodologies*
Online available at:
https://www.eib.org/attachments/strategies/eib_project_carbon_footprint_methodologies_en.pdf

Heinrich Boell Foundation Ukraine, 2017: *transition of ukraine to the renewable energy by 2050*
Online available at:
https://ua.boell.org/sites/default/files/transition_of_ukraine_to_the_renewable_energy_by_2050_1.pdf

Institute for Sustainable Futures, UTS, 2015: *Calculating global energy sector jobs: 2015 methodology*
Online available at: https://opus.lib.uts.edu.au/handle/10453/43718

International Monetary Fund: *Ukraine*
Online available at: https://www.imf.org/en/Countries/UKR

IPCC, Mar. 2020: *Special Report - Global Warming of 1.5 °C*
Online available at: https://www.ipcc.ch/sr15/

Irena, Dec. 2013: *Renewable Energy and Jobs*
Online available at:
http://www.irena.org/documentdownloads/publications/renewableenergyjobs.pdf

KT-Energy LLC, Mykola Shlapak, 2017a: *Carbon Emission Factor for Ukrainian Electricity Grid*
Online available at: https://www.slideshare.net/MykolaShlapak/carbon-emission-factor-for-ukrainian-electricity-grid-80745723

Llera, E., Scarpellini, S., Aranda, A., & Zabalza, I., 2013. Forecasting job creation from renewable energy deployment through a value-chain approach. Renewable and Sustainable Energy Reviews, 21, 262-271.

Louie, E. and Joshua M. Pearce, 2016. Retraining Investment for U.S. Transition from Coal to Solar Photovoltaic Employment; Energy Economics.

ManishRam, ArmanAghahosseini, ChristianBreyer (LUT University), Feb. 2020: *Job creation during the global energy transition towards 100% renewable power system by 2050*
Online available at:
https://www.sciencedirect.com/science/article/pii/S0040162518314112

Ministry of Energy of Ukraine, Dec. 2020: *Міненерго представило річні квоти підтримки відновлюваної енергетики та графік проведення "зелених" аукціонів у наступному році*
Online available at:
http://mpe.kmu.gov.ua/minugol/control/publish/article?art_id=245495260

Ministry of Energy of Ukraine: *Інформація про роботу електроенергетичного комплексу*
Online available at:
http://mpe.kmu.gov.ua/minugol/control/uk/publish/officialcategory?cat_id=245183225

Ministry of Energy of Ukraine: *Інформація про роботу електроенергетичного комплексу*
Online available at:
http://mpe.kmu.gov.ua/minugol/control/uk/publish/officialcategory?cat_id=245183225

OECD, 2020: *Monitoring the Energy Strategy of Ukraine 2035*
Online available at: https://www.oecd.org/eurasia/competitiveness-programme/eastern-partners/Monitoring-the-energy-strategy-Ukraine-2035-EN-.pdf

Our World in Data: *Electricity Mix*
Online available at: https://ourworldindata.org/electricity-mix

RAP, May 2020: *Why Not ETS? Comparative assessment of border carbon adjustment and the extension of ETS in the power sector in Europe*
Online available at: https://www.raponline.org/knowledge-center/why-not-ets-comparative-assessment-of-border-carbon-adjustment-and-the-extension-of-ets-in-the-power-sector-in-europe/

Reuters, Apr. 2020: *Renewable energy wins over oil and gas in post-coronavirus world: Russell, Clyde Russell*
Online available at: https://www.reuters.com/article/us-column-russell-health-coronavirus-cli-idUSKBN21P0L5

Reuters, Oct. 2020: *IMF urges infrastructure investment to boost post-COVID growth*
Online available at: https://uk.reuters.com/article/uk-imf-worldbank-infrastructure/imf-urges-infrastructure-investment-to-boost-post-covid-growth-idUKKBN26Q30J

Rutovitz, J., Dominish, E., & Downes, J., 2015. Calculating global energy sector jobs: 2015 methodology.

Service of the Deputy Prime Minister of Ukraine, Jul. 2020: *EU disburses a EUR 105 mn assistance to Ukraine to support SMEs and reforms*
Online available at: https://www.kmu.gov.ua/en/news/yevrosoyuz-vidiliv-ukrayini-105-mln-yevro-na-pidtrimku-malogo-biznesu-ta-reform

The World Bank Group, Oct. 2020: *Coal Regions in Ukraine to Benefit from Poland's Lessons on 'Just Transition'*
Online available at: https://www.worldbank.org/en/news/press-release/2020/10/07/coal-regions-in-ukraine-to-benefit-from-poland-lessons-on-just-transition

The World Bank Group, Oct. 2020: *Notice of Cooperation - Platform in Support of Coal Regions in Transition: Western Balkans and Ukraine*
Online available at:
https://www.worldbank.org/en/topic/extractiveindustries/brief/platform-in-support-of-coal-regions-in-transition-western-balkans-and-ukraine

Ukrainska Energetika, Jul. 2020: *Як карантин вплинув на споживання електроенергії весною 2020 року?*
Online available at: https://ua-energy.org/uk/posts/yak-karantyn-vplynuv-na-spozhyvannia-elektroenerhii-vesnoiu-2020-roku

Ukrenergy, 2020: *Звіту з оцінки відповідності (достатності) генеруючих потужностей — 2020*
Online available at: https://ua.energy/wp-content/uploads/2020/12/Proyekt-zvitu-z-otsinky-vidpovidnosti-dostatnosti-generuyuchyh-potuzhnostej-2020.pdf

Ukrhydroenergo, Apr. 2019: *Based on information published in the annual financial statement by Ukrhidroenergo*
Online available at: https://uhe.gov.ua/sites/default/files/2019-04/richna-informatciia-emitenta-za-2018-rik.pdf

Ukrhydroenergo, Mar. 2021: *НА ДНІСТРОВСЬКІЙ ГАЕС ПОДАНО НАПРУГУ НА КОМІРКИ № 8-№ 9 КРПЕ-330 КВ*
Online available at: https://uhe.gov.ua/media_tsentr/novyny/na-dnistrovskiy-gaes-podano-naprugu-na-komirki-no-8-no-9-krpe-330-kv

UNFCCC, May 2020: *Ukraine. 2020 Common Reporting Format (CRF) Table*
Online available at:
https://unfccc.int/documents/227985?fbclid=IwAR3ISusVIJurEMblY70DWs88LQQadtOq6lXk2IPQegcjKeGs1-OmZnnpV2s

WKO.AT, Apr. 2021: *Coronavirus: Situation in der Ukraine*
Online available at: https://www.wko.at/service/aussenwirtschaft/coronavirus-info-ukraine.html

World Bank Data: *CO2 emissions (kg per 2017 PPP$ of GDP) – Ukraine, European Union, OECD members, Germany, Russian Federation*

World Nuclear Association, Feb. 2021: *Covid-19 Coronavirus and Nuclear Energy*
Online available at: https://world-nuclear.org/information-library/current-and-future-generation/covid-19-coronavirus-and-nuclear-energy.aspx

Worldbank, 2011: Measuring the employment impact of the energy sector.
Online available at:

http://siteresources.worldbank.org/INTOGMC/Resources/Measuring_the_employment_impact_of_energy_sector1.pdf

8 List of Abbreviations

BAU	Business-as-usual scenario
bnEUR	Billion Euro
CAPEX	Capital expenditures
CCGT	Combined-cycle gas turbine plant
CES	Constant-elasticity-of-substitution
CGE	Computable General Equilibrium
CHP	Combined-heat-and-power plants
CO_2	Carbon dioxide
DSGE	Dynamic Stochastic General Equilibrium
EF	Employment factor
ENTSO-E	European Network of Transmission System Operators
ETS	Emissions Trading System
EU	European Union
EUR	Euro
FIT	Feed-in tariff
FOE	First-order effects
GDP	Gross domestic product
GHG	Greenhouse gases
GW	Gigawatt
GWh	Gigawatt hour
IEA	International Energy Agency
IMF	**International Monetary Fund**
IPCC	**International Panel on Climate Change**
LCOE	Levelized cost of electricity
mEUR	Million Euro
Mt	Megaton
MW	Megawatt
MWh	Megawatt hour
NDC	Nationally Determined Contributions
NO_2	Nitrogen dioxide

NPV	Net present value
OCGT	Open-cycle gas turbine plant
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational expenditures
P/E	Power-to-energy ratio
PV	Photovoltaic
RES	Renewable energy sources
SO_2	Sulfur dioxide
SOE	Second-order effects
SSCU	State Statistics Service of Ukraine
t	Ton
tCO_2	Ton of carbon dioxide
TPP	Thermal power plant
TRA	Transition scenario
TSO	Transmission system operator
TWh	Terawatt hour
UAH	Ukrainian Hryvnia
VAT	Value-added tax