Agora Energiewende

STUDY

Modernising Kazakhstan's coal-dependent power sector through renewables

Challenges, solutions and scenarios up to 2030 and beyond

Open Energy Transition
from the creators of PyPSA meets Earth

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Preface

Dear reader,

Kazakhstan, with its vast territory, holds immense potential for the development of cheap solar and wind energy. As of mid-2023, the country had a share of 5% variable renewable generation (vRES) in its power mix. The national objective is to elevate this proportion to 15% by 2030. Our research shows that significantly higher shares are realistic.

The aim of this study is to present pathways for achieving this share of 15% as well as even higher shares of vRES. Critically, the pathways presented in this paper minimize power system costs and ensure security of supply while phasing down carbon intensive coal-fired power generation. Transitioning away from coal is a particularly important contribution towards reaching Kazakhstan's climate targets.

This study also underscores the significant opportunities and advantages for the wider energy sector and the whole economy associated with rapidly increasing the share of vRES. It also proposes solutions to multiple challenges that arise on the way, such as cost-effective grid integration of wind and solar PV, the necessary transformation of combined heat and power (CHP) systems, and the social implications of coal usage.

I hope that this study will support an informed debate on power system modernisation in Kazakhstan and inspire similar discussions in other countries of Central Asia.

Markus Steigenberger
Managing Director, Agora Energiewende

Key findings at a glance

1 **Solar PV and wind will be the cheapest sources of power in Kazakhstan in 2030 for new generating facilities.** The 2030 levelised cost of energy (LCOE) from new build solar PV and wind power plants across all scenarios outlined in this report is estimated to be only about a half (47–62% less) of that from new build coal-fired generation.

2 **Kazakhstan can minimise the overall costs of its power system while reducing the share of coal from the current level of 67% to 45% by 2030.** Such a scenario will enable the country to achieve the energy-related emissions cuts necessary to reach its 2030 emissions reduction target and will mark a major milestone on its path to carbon neutrality by 2060.

3 **The acceleration of renewable energy deployment, grid reinforcement and extension, renewable hydrogen, energy storage and related technologies are key elements of a successful transformation of Kazakhstan's energy sector.** Some of the topics currently discussed in the country, such as a coal-to-gas transition and clean coal technologies, would divert investments from an efficient path to carbon neutrality.

4 **The country urgently needs a long-term coal phase-out plan, as well as a more balanced and holistic approach to planning for the whole energy sector.** Such an approach should put the lowest cost technologies, i.e. wind and solar PV, at the centre of its transformation; and gradually couple the green power sector with heating/cooling and transport sectors.

Content

Introduction: Kazakhstan's energy transition at a crossroads

Kazakhstan's power industry has gone through dramatic changes during the last three decades. Its vertically integrated state monopoly was unbundled into generation, transmission and distribution; many generating and distribution assets were privatised; a multi-market model with bilateral long-term, spot, balancing, system and ancillary services and capacity markets was introduced; and variable renewables – wind and solar PV – started to gain ground in the national power mix, starting from scratch and aiming for 15% of generation by 2030 and for 50% for all renewable and alternative energy sources in generation by 2050. There were some severe setbacks on the way, such as the decline of private ownership in power generation, the re-emergence of excessive government control, and the long delay in setting up a balancing market. This is why in 2017 the World Bank characterised Kazakhstan's power sector as "stuck in transition".[1] In addition, after the dissolution of the USSR, the country has failed to attract investment and modernise its obsolete power plants and grids, which now poses a serious threat to the electricity supply stability. However, Kazakhstan was and still is often called a power market reform leader among the former Soviet Union countries, and especially in Central Asia.

From the climate goals perspective, Kazakhstan has also taken the lead in its region. In December 2020, its President Kassym-Jomart Tokayev pledged that the country will achieve carbon neutrality by 2060.[2] In 2023, this was followed by the adoption of the 'Strategy to achieve carbon neutrality of the Republic of Kazakhstan by 2060' (hereinafter referred to as Carbon neutrality strategy).[3] The document even notes that „phasing out the dependence of Kazakhstan's economy on coal is important for low-carbon development and achieving carbon neutrality". However, neither this strategy nor other official documents contain a clear commitment to abandon coal permanently, and timelines for such a phase-out are also missing. At the same time, some of aged coal power plants might be retrofitted or replaced by new coal- or gas-fired power plants, which will make it difficult to achieve the goal of carbon neutrality by 2060. According to the official numbers from the above-mentioned Carbon neutrality strategy, the energy sector of Kazakhstan accounted in 2020 for almost 78% of greenhouse gas emissions, including land use, land-use change and forestry (LULUCF), and the contribution of coal to national net emissions exceeded 55%.[4]

The official rhetoric regarding the energy transition in Kazakhstan now also suggests that the country is at a crossroads. In contrast to the situation a decade ago, key officials no longer deny the importance of renewable energy for the country and the need for its development. The President of Kazakhstan has stated that the country could become a world centre for renewable energy, and that coal-fired power plants should be completely decommissioned by 2050. At the same time, Prime Minister Alikhan Smailov noted that the structure of electricity generation in the country will see no significant changes in the near future (Table 1).

1 The World Bank (2017). Stuck in Transition: Reform Experiences and Challenges Ahead in the Kazakhstan Power Sector. URL: https://www.worldbank.org/en/country/kazakhstan/publication/kazakhstan-power-sector-note.

2 Climate Ambition Summit (2020). Kassym-Jomart Tokayev President of Kazakhstan. URL: https://www.climateambitionsummit2020.org/ondemand.php.

3 Decree of the President of the Republic of Kazakhstan dated February 2, 2023 No. 121. On approval of the Strategy for achieving carbon neutrality of the Republic of Kazakhstan until 2060. URL: https://adilet.zan.kz/rus/docs/U2300000121.

4 Ibid.

Views of key officials in Kazakhstan on energy transition prospects → Table 1

Date	Event	Speaker	Quotation
8 June 2023, Astana	Astana International Forum	Kassym-Jomart Tokayev, President of the Republic of Kazakhstan	*"Our country could offer huge green economy opportunities and become a renewable energy hub. However, time is not on our side. To decarbonize and build a green economy at the speed we need, we need partners".*[5]
8 November 2022, Sharm el-Sheikh	The World Leaders Summit, COP27	Alikhan Smailov, Prime Minister of the Republic of Kazakhstan	*"Kazakhstan has the potential to become one of the global centres of green energy. Therefore, we are ready to act as a regional centre for the development of renewable energy sources and, in general, stimulate the transition of Central Asia to green technologies".*[6]
18 October 2022, Astana	Meeting of the Government chaired by the Prime Minister of the Republic of Kazakhstan Alikhan Smailov	Alikhan Smailov, the Prime Minister of the Republic of Kazakhstan	There is a trend towards increasing electricity generation from renewable sources, but more than 80% of the energy produced still comes from fossil fuels. *"In the short term, there will be no significant change in this ratio in the [electricity] industry. At the same time, the focus will be on the use of modern technologies for capturing and utilizing carbon dioxide, reducing emissions into the atmosphere".*[7]
13 September 2022, Almaty	1st Central Asia Clean Energy Forum (CACEF)	Zhandos Nurmaganbetov, Vice Minister of Energy of the Republic of Kazakhstan	*"The energy sector of Kazakhstan traditionally operates mainly on coal, and the share of coal consumption is quite large. We will not throw coal out of the equation. Moreover, we want to build new coal power blocks and modernise those coal power plants that we already have".*[8]
13 October 2021, Nur-Sultan (now Astana, the capital of Kazakhstan)	International conference on „Ways to achieve the goals of the Paris Agreement and carbon neutrality of Kazakhstan"	Kassym-Jomart Tokayev, President of the Republic of Kazakhstan	*"According to the draft [Carbon neutrality strategy], by 2050 all coal-fired power plants [in Kazakhstan] will be decommissioned. By 2060, the share of renewable energy sources will exceed 80% of the total energy generation of the country".*[9]
26 May 2021, online	Online meeting on the development of the electric power industry	Kassym-Jomart Tokayev, President of the Republic of Kazakhstan	*"I am a firm supporter of the clean energy, and green technologies as a whole. I support the construction of power plants using renewable energy sources".*[10]

Agora Energiewende (2024).

5 Official website of the President of the Republic of Kazakhstan (2023). President Kassym-Jomart Tokayev's speech at the Plenary Session of Astana International Forum. URL: https://www.akorda.kz/ru/vystuplenie-prezidenta-respubliki-kazahstan-ktokaeva-na-plenarnoy-sessii-mezhdunarodnogo-foruma-astana-851830.

6 Official Information Source of the Prime Minister of the Republic of Kazakhstan (2022). Kazakhstan is ready to become regional centre for renewable energy development – Alikhan Smailov. URL: https://primeminister.kz/ru/news/kazahstan-gotov-stat-regionalnym-centrom-razvitiya-vozobnovlyaemyh-istochnikov-energii-alihan-smailov-8101253.

7 Official Information Source of the Prime Minister of the Republic of Kazakhstan (2022). Kazakhstan plans to introduce "green coal" technology and develop renewable energy. URL: https://primeminister.kz/ru/news/vnedryat-tehnologii-chistogo-uglya-i-razvivat-vozobnovlyaemuyu-energetiku-planiruetsya-v-kazahstane-1893523.

8 Zakon (2022). Kazakhstan is not ready to abandon coal power plants even by 2035. URL: https://www.zakon.kz/politika/6024684-kazakhstan-i-k-2035-godu-ne-gotov-otkazatsia-ot-ugolnykh-elektrostantsii.html.

9 Sputnik (2021). Heads of the EAEU will adopt a statement on the union's climate agenda – Tokayev. URL: https://ru.sputnik.kz/20211013/eaes-zayavlenie-klimat-tokaev-18399002.html.

10 Official website of the President of the Republic of Kazakhstan (2021). The Head of State held a meeting on the development of the electric power industry. URL: https://akorda.kz/en/the-head-of-state-held-a-meeting-on-the-development-of-the-electric-power-industry-2641630.

As the average age of the coal power fleet passes 50 years, the need to modernise the country's energy system is becoming increasingly obvious. And the important question here is whether this modernisation will involve patching over holes in an attempt to maintain the old proven fossil fuel technologies or whether the imperative of modernisation will be used as an opportunity to transition away from outdated and environmentally harmful technologies and lead the way in creating a modern, forward-looking power system that can serve as a positive example for the whole of Central Asia.

It is also obvious that Kazakhstan needs international cooperation in the field of green energy, and this was acknowledged in the official statements above (Table 1), as well as in the recent meeting between Kazakhstan's President Kassym-Jomart Tokayev and the German Federal President Frank-Walter Steinmeier, where President Tokayev invited German companies to invest in green energy.[11]

So there is a discrepancy between the ambitious goals and some of the results already achieved on the one hand, and, on the other hand, the lack of action and political will to strive for much more significant results in the longer term. Accordingly, this study aims to inform the debate through thorough analytical scenario assessments. It presents scenarios of RES development in Kazakhstan up to 2030: a business as usual scenario that assumes the achievement of the current target of 15% of variable RES in the power mix by 2030 and three more ambitious but still realistic scenarios that assume slightly higher shares of variable renewable electricity (given a phase-down of coal generation to 45%) and thus put Kazakhstan on a path to nationally determined contribution (NDC) implementation by 2030 and carbon neutrality by 2060. It also analyses the outcomes (in terms of emissions and costs) which bolder renewables policies might bring up to 2030, how the uncertain plans for a coal phase-out fit in with the global energy transition concept up to 2050–2060 and beyond, and how Kazakhstan could overcome its huge energy transition challenges and achieve carbon neutrality by 2060.

11 Official website of the President of the Republic of Kazakhstan (2023). Kassym-Jomart Tokayev and Frank-Walter Steinmeier hold negotiations in extended format. URL: https://www.akorda.kz/en/kassym-jomart-tokayev-and-frank-walter-steinmeier-hold-negotiations-in-extended-format-205383.

1 Methodology, assumptions, input data and scenarios for the 2030 power mix

This study models Kazakhstan's power system in 2030 using the open-source framework Python for Power System Analysis (PyPSA). The model simulates how the electricity demand can be met by a combination of different conventional and renewable power sources in 2030, under different scenarios. The model covers generation (power plants), electricity transmission infrastructure and load (electricity demand). Simulation is performed at hourly intervals, with 14 nodes representing Kazakhstan's regions (the administrative structure of Kazakhstan changed in 2022 when the number of administrative zones or regions was increased from 14 to 17, but this data has not yet been fully incorporated into the model). The model is openly released, including mathematical model formulation and data, and free to re-use by anyone.

To achieve precise energy modelling for Kazakhstan, the model incorporates both PyPSA default data and custom data. The PyPSA-Earth default data encompasses grid topology details, climate data, and electricity demand. The custom data comprises specifics about individual power plants, electricity import-export statistics, and official consumption figures for Kazakhstan, all of which are used to fine-tune the model. Detailed information about the data used, both default and custom, can be found in Annexes 1 and 2.

The table below (Table 2) shows the annual generation of electricity in Kazakhstan broken down by the technology deployed, using data from various open sources and optimisation results obtained using the PyPSA model. It should be noted that the default data assumptions of the PyPSA-Earth model require thorough review and updates to accurately represent today's system. However, the proposed PyPSA-KZ model, which includes additional data collected for this study (demand rescaling, line modification, and exports/imports), significantly improves the results. Deviations from the 2020 actual National report data are close to 1% of total demand for every technology.

This study addresses four main scenarios. The key factor differentiating them is the share of variable renewables (solar PV + onshore wind) vs coal in generation.

- → **Business as usual (BAU).** In this scenario the share of variable renewables in generation reaches about 15%, which corresponds to current strategic documents and goals up to 2030, in particular to the goal set by the President of the Republic of Kazakhstan Kassym-Jomart Tokayev in 2021,[12] and to the Energy Balance of the Republic of Kazakhstan up to 2035 adopted in 2022 and amended in 2023.[13]
- → **Improved business as usual (iBAU).** This scenario envisages that the share of variable renewables reaches 20% of generation, slightly higher levels than provided for in the current strategic documents and goals up to 2030.
- → **Cost-optimised generation mix (OPT).** This scenario estimates how far coal generation capacity can be economically phased down in Kazakhstan by 2030, subject to cost optimisation of the generation mix, with the same (existing) transmission line capacities. The assumption is that some of the existing coal generation plants may be abandoned and their contribution to total power generation will be replaced by variable renewable energy sources.
- → **Cost-optimised generation mix and cost-optimised transmission line capacities (OPT^2).** This scenario explores how far coal capacity can be economically phased down in Kazakhstan by 2030, subject to cost co-optimisation of both generation mix and transmission capacities.

12 Kazinform (2021). I set the task to increase the share of renewable energy sources in power generation to 15% by 2030 – Head of State. URL: https://www.inform.kz/ru/uvelichit-dolyu-vie-v-elektrogeneracii-do-15-k-2030-godu-poruchenie-glavy-gosudarstva_a3792969.

13 Order of the Minister of Energy of the Republic of Kazakhstan dated March 24, 2022 No. 104 "On approval of the Energy Balance of the Republic of Kazakhstan until 2035" (as amended on January 30, 2023). URL: https://online.zakon.kz/Document/?doc_id=37351758&pos=4;-90#pos=4;-90.

Annual generation (TWh) – dispatch optimisation results → Table 2

	IRENA[14]	Our World in Data[15]	National report[16]	PyPSA-Earth default	PyPSA-KZ
Focus year	2020	2020	2020	2020	2020
Coal	65.44	-	74.47	86.33	74.16
Gas	19.06	-	21.73	7.84	20.44
Hydro	9.66	-	9.51	10.87	11.28
Wind	1.08	-	1.08	1.67	1.61
Solar	1.35	-	1.30	1.05	1.06
Total	**96.59**	**107.80**	**108.09**	**107.75**	**108.56**
Description					Demand profiles are scaled based on the national report[17] for each administrative zone. Imports/exports to Russia, Kyrgyzstan, and Uzbekistan are added. Custom power plants are considered. Reference weather year 2018.

Agora Energiewende (2024).

14 IRENA (2023). Installed electricity capacity (MW) by Country/area, Technology, Grid connection and Year. URL: https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/ELECCAP_2023_cycle2.px/.
15 Our World in Data (2023). Energy. URL: https://ourworldindata.org/energy.
16 Kazenergy (2021). The national energy report Kazenergy 2021. URL: https://www.kazenergy.com/upload/document/energy-report/NationalReport21_en.pdf.
17 Kazenergy (2021). The national energy report Kazenergy 2021. URL: https://www.kazenergy.com/upload/document/energy-report/NationalReport21_en.pdf.

In addition, the complete removal of coal from the power system by 2030 was explored. Theoretically, if Kazakhstan decided to phase out all its coal power plants after 40 years (standard period) of use, there would only be 12 MW of coal capacity remaining by 2030, or 0.1% of today's fleet.[18] However, this scenario is not included in this study because a complete phase-out of coal by 2030 appears unrealistic.

All scenarios assume that by 2030 Kazakhstan will experience a significant increase in electricity production and consumption. The anticipated surge in demand is attributed to the observed demographic growth, driven primarily by high birth rates, as well as to the continued expansion of energy-intensive industries. And this assumption is in line with the projections of the 'Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035', which predicts that power consumption will grow by 18% by 2030 and power generation by 23% compared to 2022.[19]

18 Agora Energiewende (2023). From coal to renewables. A power sector transition in Kazakhstan. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2022/2022_09_INT_Kazakhstan/A-EW_295_Kazakhstan_EN_WEB.pdf.

19 The Ministry of Energy of the Republic of Kazakhstan (2022). Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.

According to the approved Forecast Balance of Energy for 2023–2029, the capacity shortage by 2025 is projected to be 1.4 GW. Currently, energy system operates in deficit mode, requiring to limit the consumption by industrial consumers.[20]

Kazakhstan is a net importer of electricity, with electricity consumption exceeding production by 4%.[21] The electricity shortfall is covered by purchases from Russia, which makes Kazakhstan's energy system dependent and creates risks for its security of energy supply.

There have been signs that Kazakhstan may build significant new coal-fired capacity in the coming years. The state company Samruk-Energo (the largest electricity supplier in Kazakhstan) intends to build a new GRES-3[22] in Ekibastuz by 2029. The new power plant is planned to have improved environmental characteristics (lower emissions) and a capacity of 1.2 GW. In addition, the company plans to complete the construction of two new power units at GRES-2, also in Ekibastuz: block No. 3 by 2026, block No. 4 in 2027. The capacity of each unit is currently planned to comprise 636 MW, and in the future they may be supplemented by two further blocks.[23] In addition, in 2024 a restored power unit No. 1 with a capacity of 500 MW is to be commissioned at the Ekibastuz GRES-1.[24] All of these units are coal-fired. Thus, the total generating capacity of the new coal-fired units planned for construction by 2030 exceeds 4 GW. It should be noted that for all coal-fired power plants, except for the 500 MW power unit No. 1 at the Ekibastuz GRES-1, a final investment decision has not been made yet. Some coal-fired power plants are being converted to natural gas. Taking all these developments together, we assume in our BAU and iBAU scenarios that the total coal generation capacity will not increase up to 2030.

The study does not assume any nuclear generation in 2030, though it might follow later. The proposed construction of the first commercial nuclear power plant is currently a very controversial issue in Kazakhstan. Some experts are in favour of building a standard nuclear power plant, others are in favour of building small modular reactors (SMR). At the same time many citizens and experts are expressing concerns about the safety of nuclear power plants and oppose their construction. In September 2023, President Kassym-Jomart Tokayev even proposed to hold a national referendum to decide whether the country should build a nuclear power plant.[25] However, with or without a referendum, nuclear power will not happen in Kazakhstan before 2030. Construction times for reactors are 5–10 years,[26] with the 10-year timeframe being more common than the shorter 5-year period. The forecast balance of electricity of the Unified Power System of Kazakhstan up until 2035 predicts the emergence of nuclear generation only in 2032.[27]

The study does not assume a significant rise in electric vehicle numbers or in power-to-X (PtX or P2X) technologies[28] in Kazakhstan by 2030 due to the fact that these industries are taking their first steps in the country at the moment. In 2022, the total number of electric vehicles was 451 or 0.01% of the whole

20 Decree of the Government of the Republic of Kazakhstan dated March 28, 2023 No. 263 "On approval of the Concept for the development of the electric power industry of the Republic of Kazakhstan for 2023–2029". URL: https://adilet.zan.kz/rus/docs/P2300000263.
21 Ibid.
22 GRES is a large thermal power plant in post-Soviet countries that is designed only to produce electricity.
23 Kazinform (2023). The construction time frame for GRES-3 in Ekibastuz has become known. URL: https://www.inform.kz/ru/stali-izvestny-sroki-stroitel-stva-gres-3-v-ekibastuze_a4028889.
24 Inbusiness (2023). In Ekibastuz they promise to build GRES-3 by 2029. URL: https://inbusiness.kz/ru/last/v-ekibastuze-obeshayut-postroit-gres-3-do-2029-goda.
25 Official website of the President of the Republic of Kazakhstan (2023). President Kassym-Jomart Tokayev`s State of the Nation Address "Economic course of a Just Kazakhstan". URL: https://www.akorda.kz/en/president-kassym-jomart-tokayevs-state-of-the-nation-address-economic-course-of-a-just-kazakhstan-283243.
26 World Nuclear Association (2020). Median construction times for reactors since 1981. URL: https://www.world-nuclear.org/gallery/world-nuclear-performance-report-gallery/median-construction-times-for-reactors-since-1981.aspx.
27 Order of the Minister of Energy of the Republic of Kazakhstan dated March 24, 2022 No. 104 "On approval of the Energy Balance of the Republic of Kazakhstan until 2035" (as amended on January 30, 2023). URL: https://online.zakon.kz/Document/?doc_id=37351758&pos=4;-90#pos=4;-90.
28 Power-to-X technologies provide for the conversion of electricity into gases (e.g. green hydrogen), liquids (synthetic fuels) or heat. The term encompasses a large number of technologies.

passenger car market. According to the "Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035", by 2030 there will be 6 267. And they will consume just 21.3 GWh or 0.014% of all electricity.[29] In 2021, the government of Kazakhstan and the German-Swedish group Svevind Energy GmbH signed an agreement on the construction of a solar PV and wind farm to generate 40 GW of renewable electricity and to use it for the production of green hydrogen in the Mangistau region. However, the first green hydrogen will only be produced in 2030, while the full capacity will be achieved in 2032.[30] And this hydrogen will be supplied to Europe. The deployment of other P2X technologies in Kazakhstan is not even being discussed yet, with the only exception being heat pumps (power-to-heat or P2H), the penetration of which is also very slow and so far negligible.

In this study, calculations were based on weather data from the year 2018. Though we also examined weather data from 2011 and 2013, the impact on the study results was minimal, so we used the 2018 weather data for the final calculations.

The assumed cost of capital (WACC)[31] is 15%. This is lower than the base rate at the time of preparation of this study (16%)[32], but the authors are optimistic that by 2030 the base rate will decrease significantly, and the full cost of capital will be no more than 15% (though this is also very high, especially for capital-intensive new energy technologies). When capital costs are high, renewables may not be able to outcompete fossil-fired generation. Renewables are characterised by very low operating costs, and thus a significant portion of lifetime costs is attributed to the initial capital expenditure.[33]

29 The Ministry of Energy of the Republic of Kazakhstan (2022). Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.

30 Forbes (2023). $50 billion project: how green hydrogen will be produced in Kazakhstan. URL: https://forbes.kz/economy/energy-subsoil/kak_v_kazahstane_realizuyut_proekt_po_proizvodstvu_zelenogo_vodoroda_stoimostyu_50_mlrd/.

31 Weighted average cost of capital (WACC) – the cost of capital proportionally weighted for each category of capital.

32 National Bank of the Republic of Kazakhstan (2023). Base rate decision-making schedule 2015–2023. URL: https://www.nationalbank.kz/ru/news/grafik-prinyatiya-resheniy-po-bazovoy-stavke/rubrics/1843.

33 Agora Energiewende (2019). Unlocking low cost renewables in South East Europe. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2019/De-risking_SEE/161_Unlocking_SEE_EN_WEB.pdf.

2 Modelling results: 2030 scenarios for Kazakhstan's power system

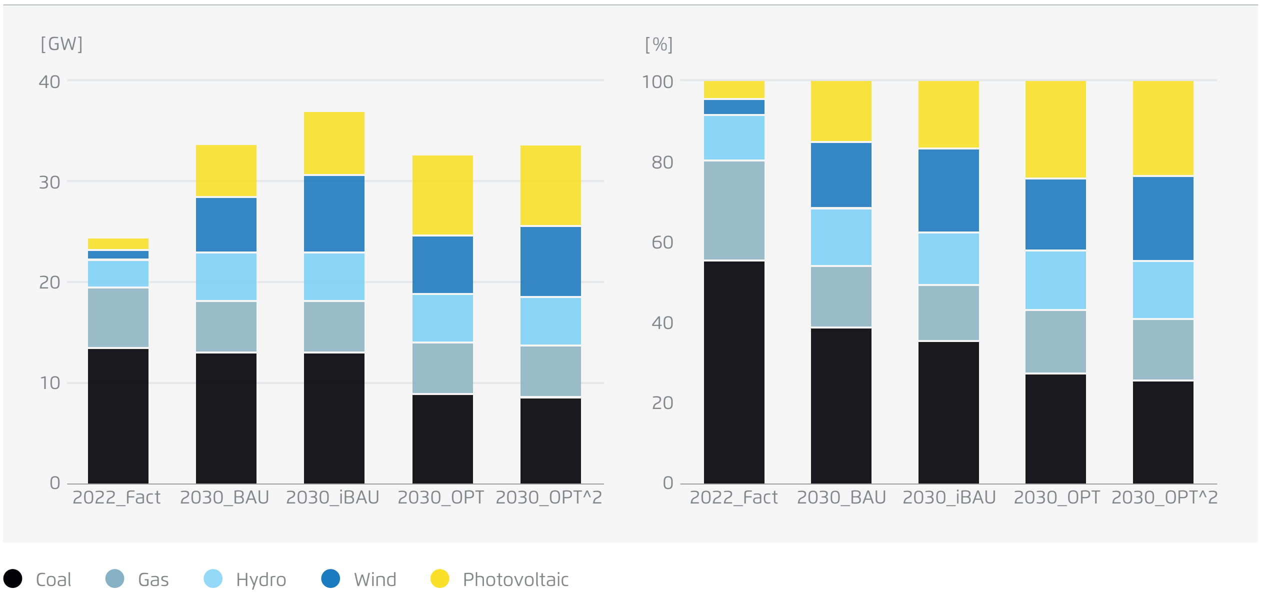
This section presents the main PyPSA-KZ 2030 modelling results, which include capacity and power mixes, system costs, CO_2 emissions, curtailment, storage capacities, power plant dispatch, transmission capacities and other data.

2.1 Capacity and power mixes

Figure 1 shows the scenario-specific optimised power generation capacities by energy source, presented in both gigawatts (GW) and percentages of total capacity (%). All 2030 scenarios indicate a substantial overall increase in installed capacity. Simultaneously, it is anticipated that coal capacity in absolute terms will either remain stable or decline. The proportion of coal in the capacity mix is expected to decrease markedly in all scenarios. In 2022, coal accounted for over 50% of the capacity mix, but in the BAU and iBAU scenarios it is projected to fall below 40%, and in the OPT and OPT^2 scenarios it drops below 30%.

The model assumes that this decline in coal power capacity will be offset by the rise in renewables – specifically solar PV and wind. The share of solar PV and wind in the installed capacity may increase by up to five times from the current 9%. Even under the most conservative scenario (BAU), which assumes just the implementation of the existing renewable energy goals until 2030, there will be a notable diversification of Kazakhstan's capacity mix, although coal's predominance will remain. This underscores the shift towards a cleaner and more sustainable energy landscape in the country. And this trend for diversification is exemplified by the OPT^2 scenario, where 2030 capacity levels are almost equal for coal, solar PV and wind.

Actual 2022 data and 2030 scenarios for Kazakhstan's capacity mix → Fig. 1



Kazenergy (2021). The national energy report Kazenergy 2021: https://www.kazenergy.com/upload/document/energy-report/NationalReport21_en.pdf; Decree of the Government of the Republic of Kazakhstan dated March 28, 2023 No. 263: *On approval of the Concept for the development of the electric power industry of the Republic of Kazakhstan for 2023–2029*: https://adilet.zan.kz/rus/docs/P2300000263 and Agora Energiewende.

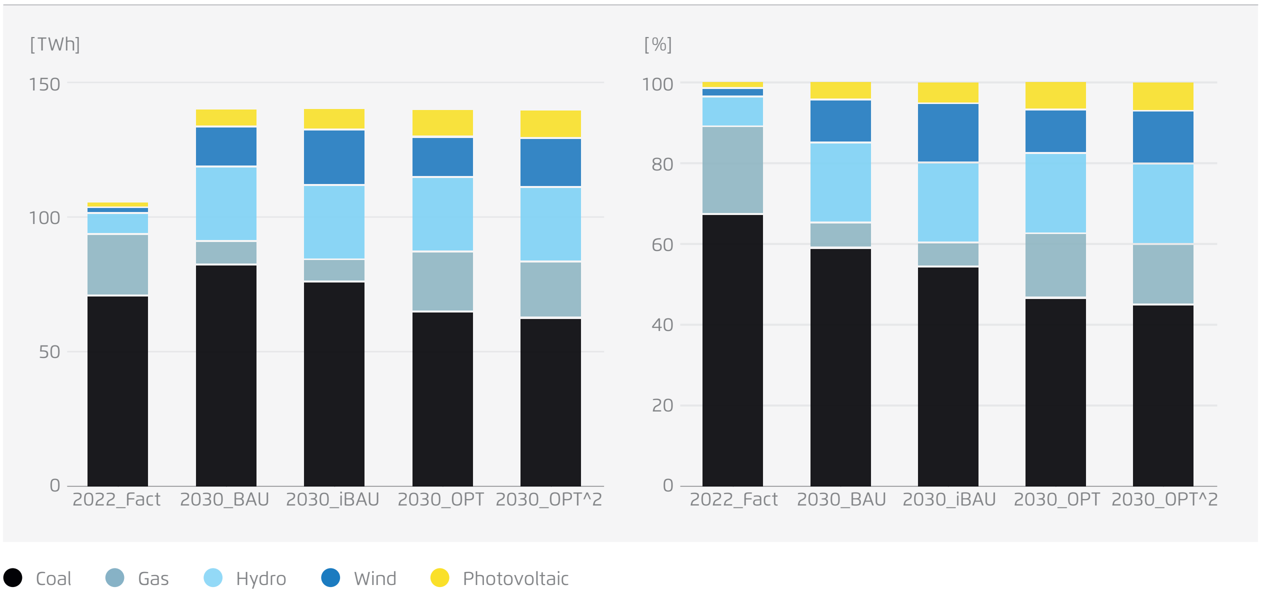
Anticipated shifts in the electricity production mix may in practice display less pronounced alterations due to the comparatively lower capacity factors of solar PV and wind power plants as against thermal power plants (Figure 2). Consequently, absolute volumes of coal generation might even witness a slight increase in the BAU and iBAU scenarios. Nonetheless, a crucial transformation is expected, with the share of coal-fired generation projected to dip below 60% in both the BAU and iBAU scenarios, and dropping below 50% in the OPT and OPT^2 scenarios. In this transition, wind energy is the frontrunner among variable renewable energy sources.

It is noteworthy that in the scenario of cost co-optimisation of generation mix and transmission capacities (OPT^2), the combined share of solar PV and wind generation reaches 20%, as in the iBAU scenario, while the share of coal is about nine percentage points lower (45% of coal in OPT^2 versus 54% coal in BAU). This underscores the importance of cost-efficiency considerations in creating an updated national energy strategy, favouring a blend of solar, wind, and other renewable sources, while gradually reducing reliance on traditional coal-based generation.

The results of the OPT^2 scenario are of particular importance when looking at Kazakhstan's international commitments to lower GHG emissions. Its unconditional nationally determined contribution commits the country to a 15% reduction in GHG emissions by the end of 2030 compared to 1990, including land use, land-use change and forestry (LULUCF). The conditional NDC commits Kazakhstan to a 25% reduction in GHG emissions by the end of 2030 compared to 1990, but is subject to additional international investments and significant grant assistance, access to an international technology transfer mechanism, co-financing and participation in international research projects, the development of promising low-carbon technologies and initiatives to build local expertise.[34] According to the 8th

34 UNFCCC (2023). Kazakhstan first NDC (updated submission). URL: https://unfccc.int/sites/default/files/NDC/2023-06/12updated%20NDC%20KAZ_Gov%20Decree313_19042023_en_cover%20page.pdf.

Actual 2022 data and 2030 scenarios for Kazakhstan's power generation mix → Fig. 2

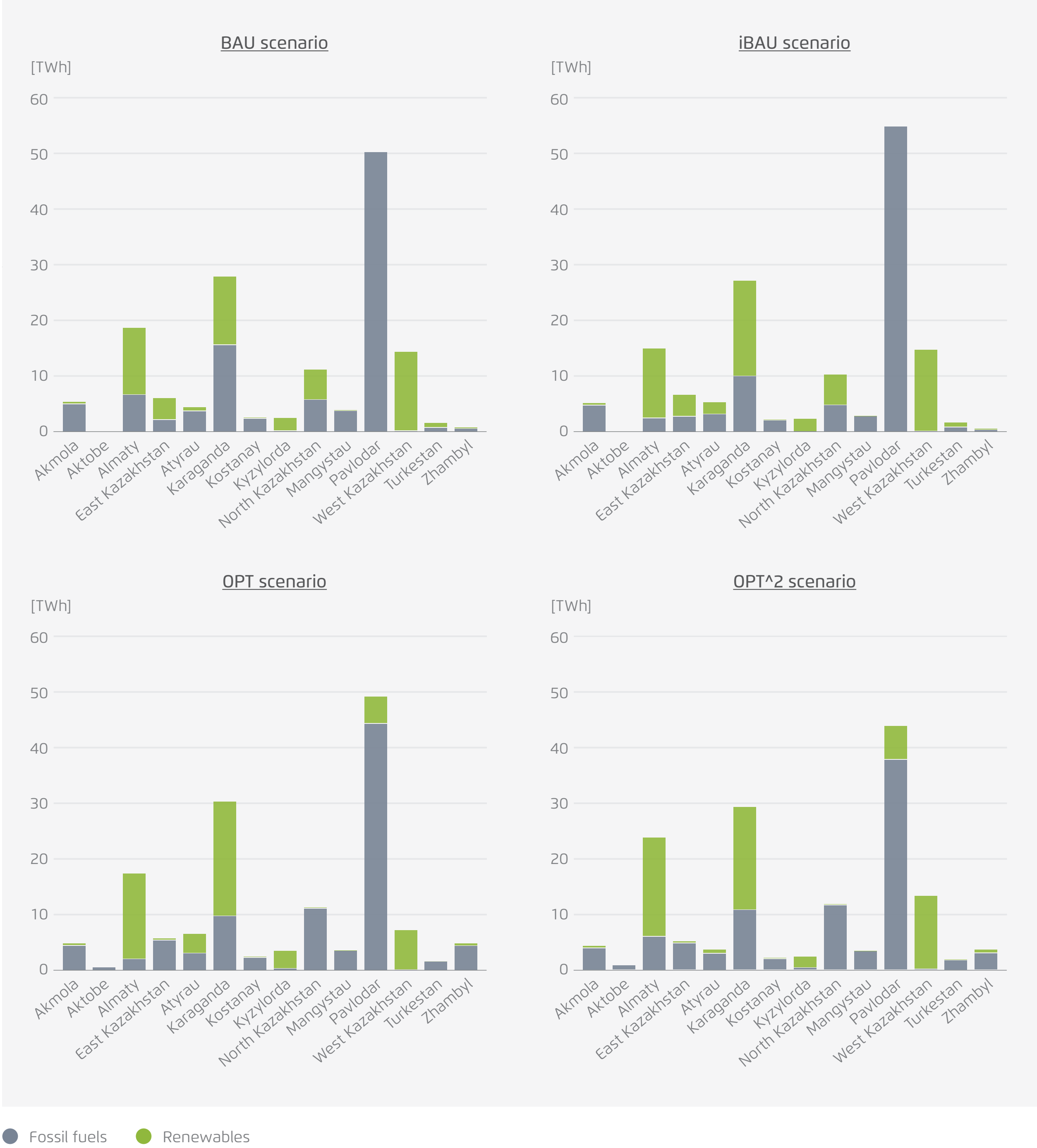


Kazenergy (2021). The national energy report Kazenergy 2021: https://www.kazenergy.com/upload/document/energy-report/NationalReport21_en.pdf; Decree of the Government of the Republic of Kazakhstan dated March 28, 2023 No. 263: *On approval of the Concept for the development of the electric power industry of the Republic of Kazakhstan for 2023–2029*: https://adilet.zan.kz/rus/docs/P2300000263 and Agora Energiewende.

National Communication and the 5th Biennial Report of the Republic of Kazakhstan to the UN Framework Convention on Climate Change, in order to achieve a reduction in greenhouse gas emissions from the energy sector to a level that is 15% lower than in 1990 or less, and therefore meet its unconditional NDC, Kazakhstan must reduce the share of coal in

Renewable generation by bus (region), including hydropower

→ Fig. 3



Agora Energiewende (2024). Note: this shows the former administrative division of Kazakhstan, which changed in 2022 when the number of regions increased from 14 to 17.

electricity generation to 40% by 2030.[35] Thus, the implementation of the OPT^2 scenario will make it possible not only to select the most cost-effective generation sources, but also to fulfill the 2030 commitment under the Paris Agreement.

The regional breakdown of our scenario results shows that for some regions of the country the share of renewables in the 2030 power mix will be 100% (Turkestan region) or close to 100% (Kyzylorda region), while in many others the share of fossil fuels will remain at or close to 100% (Pavlodar, Mangistau, Aktobe, etc. regions) – see Figure 3. It should be noted that in regions where the 2030 share of renewable energy sources may be close to 100%, the generation mix will consist of variable renewable energy sources plus hydropower. No region in Kazakhstan is expected to produce electricity almost entirely from vRES by 2030.

2.2 CO_2 emissions

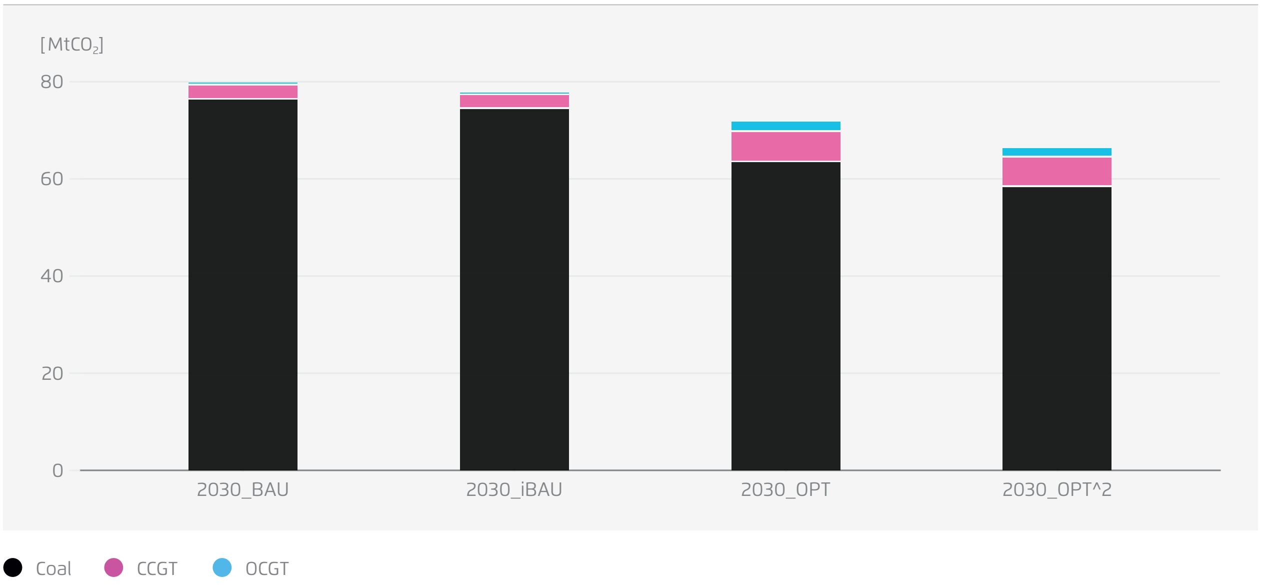
Kazakhstan's total power sector CO_2 emissions in 2030 in the cost optimisation scenarios (OPT and OPT^2) will be lower than in scenarios where existing targets for variable renewable energy sources are met (BAU) or slightly exceeded (iBAU), as shown in Figure 4. This is because in the cost optimisation scenarios, electricity production from coal will decrease not only in relative but also in absolute terms and vRES generation will grow strongly. The majority of emissions in all scenarios come from coal (88–96%), the rest comes from gas: from combined cycle gas turbine power plants (CCGT[36]) and to a lesser extent from open cycle gas turbines (OCGT[37]). Geographically, the majority of power sector CO_2 emissions (59–73%) is expected to occur in the Pavlodar region (Figure 5), which is also the leading coal mining region in the country. The Karaganda region, another

35 The 8th National Communication and the 5th Biennial Report of the Republic of Kazakhstan to the UN Framework Convention on Climate Change. URL: https://unfccc.int/sites/default/files/resource/8NC_Kazakhstan_2022v1.0.pdf.

36 Combined cycle power plants (CCGT) combine the functionalities of both a gas turbine and a steam turbine. CCGT captures the waste heat from its gas turbine exhaust to generate steam that drives its steam turbine.

37 Open cycle gas turbines (OCGT) generate mechanical power by expanding a combination of compressed air and high-pressure, high-temperature flue gas. In an open-cycle system, the exhaust is discharged into the environment.

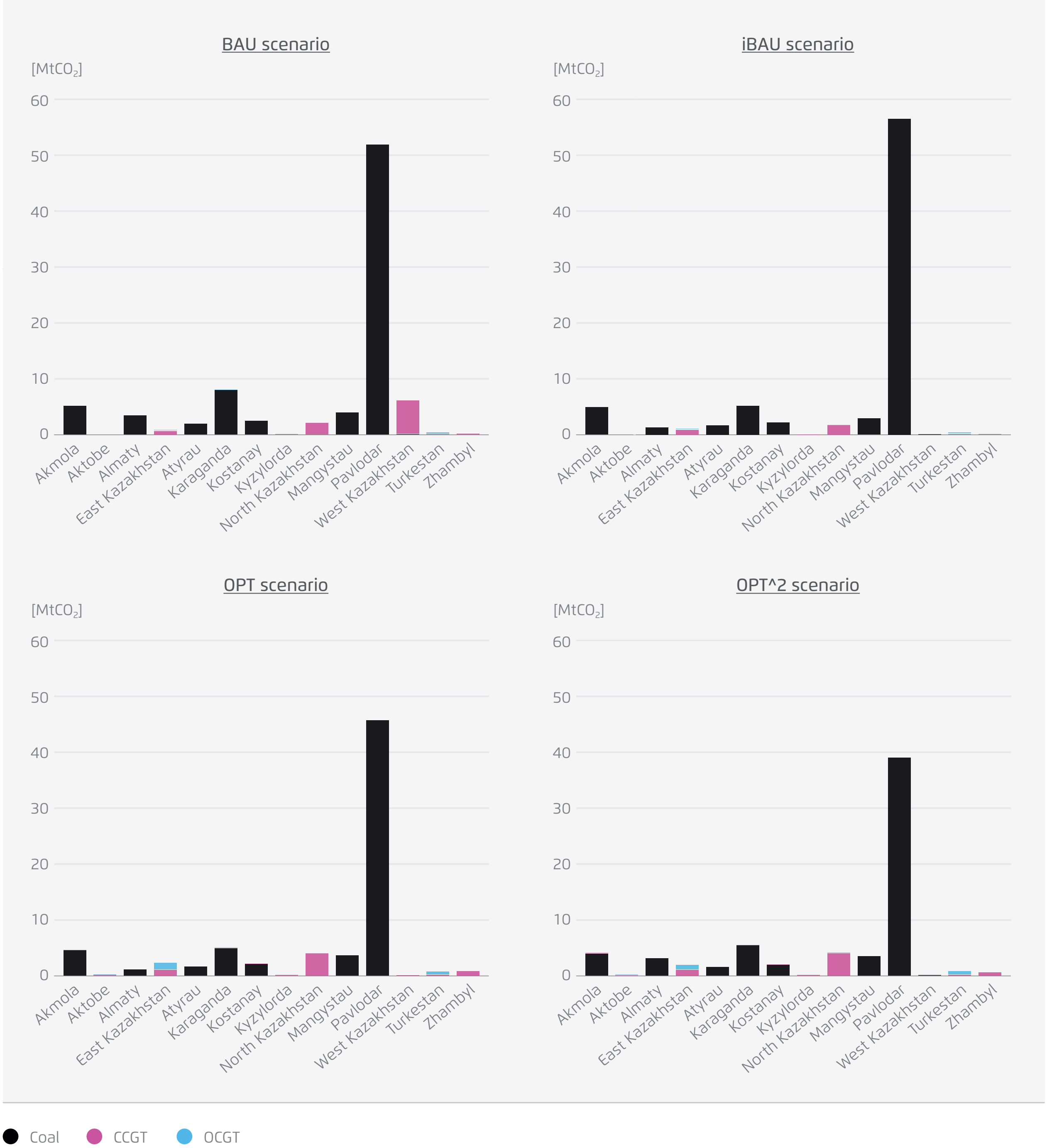
National 2030 power sector CO_2 emissions mix per scenario → Fig. 4



Agora Energiewende (2024)

major coal mining area, takes second place, significantly behind the Pavlodar region, and accounting for just 7–9% of all emissions. The lowest emissions are expected in Aktobe, Kyzylorda, West Kazakhstan and Zhambyl regions, and their values vary depending on the scenario.

CO_2 emissions by bus (region) and by technology → Fig. 5



Agora Energiewende (2024). Note: this shows the former administrative division of Kazakhstan, which changed in 2022 when the number of regions increased from 14 to 17.

2.3 Economic system costs

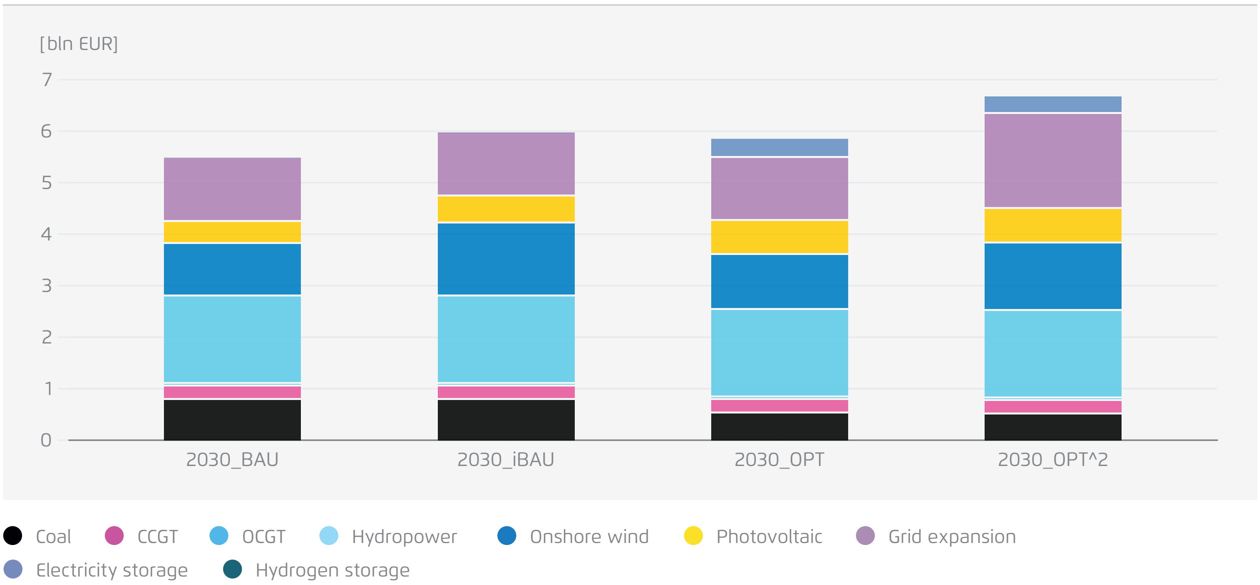
The total annualised capital expenditure (CAPEX) for the OPT^2 scenario will be higher than for all other scenarios, mostly due to significantly higher grid expansion expenditure (Figure 6). Compared to the BAU scenario, OPT^2 will be 22% more capital-intensive. CAPEX in this case is calculated as annualised capital expenditure plus fixed operating expenditure. Since all coal-fired power plants in the system are already amortised, and we assume no new capacity, coal CAPEX values are comprised of fixed operating expenditure only and are thus relatively low. Also worth noting is that the OPT and OPT^2 scenarios introduce some electricity storage capacity which shows up in the CAPEX values.

When looking at operating expenditure (OPEX), including maintenance and fuel costs, it can be seen that in all scenarios, the primary contributors to total OPEX are coal- and gas-fired power plants (Figure 7). While other technologies also entail operating expenditure, it is negligible in comparison to conventional fossil fuel-based technologies, due to the high fuel costs of fossil technologies (in contrast, renewables do not use any fuels, except for biomass/biogas technologies, which are barely used in Kazakhstan) as well as higher maintenance costs compared to renewables.

Knowing CAPEX and OPEX allows us to calculate TOTEX – total economic system costs, which include both categories of expenditure and span both plant-level generating costs and grid-level system costs. Measured by TOTEX, the OPT^2 scenario is still the most expensive, but not as clearly as when measured by CAPEX alone – the difference is 14% (Figure 8). Coal is the most expensive technology by total economic system costs in all four scenarios, with its overall share varying from 39% in the BAU scenario down to 25% in the OPT^2 scenario.

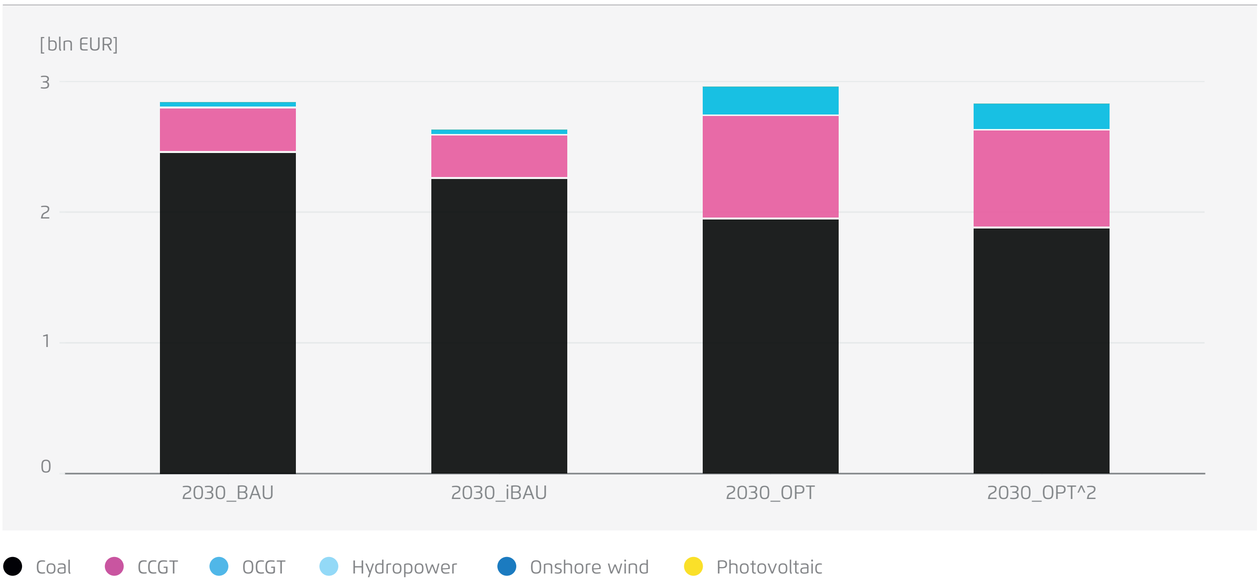
The levelised cost of energy (LCOE) for new solar PV and wind power plants in 2030 in all scenarios is significantly lower than the LCOE for new thermal power plants. Solar PV and wind LCOE comprises just 47–62% of coal-fired LCOE. In scenarios with cost optimisation, LCOE values for all conventional technologies are lower than in the BAU and iBAU scenarios, due to cost optimisation. This holds particularly

Total 2030 annualised capital expenditure by generation technology for each scenario → Fig. 6



Agora Energiewende (2024)

Total 2030 operating expenditure by generation technology for each scenario → Fig. 7



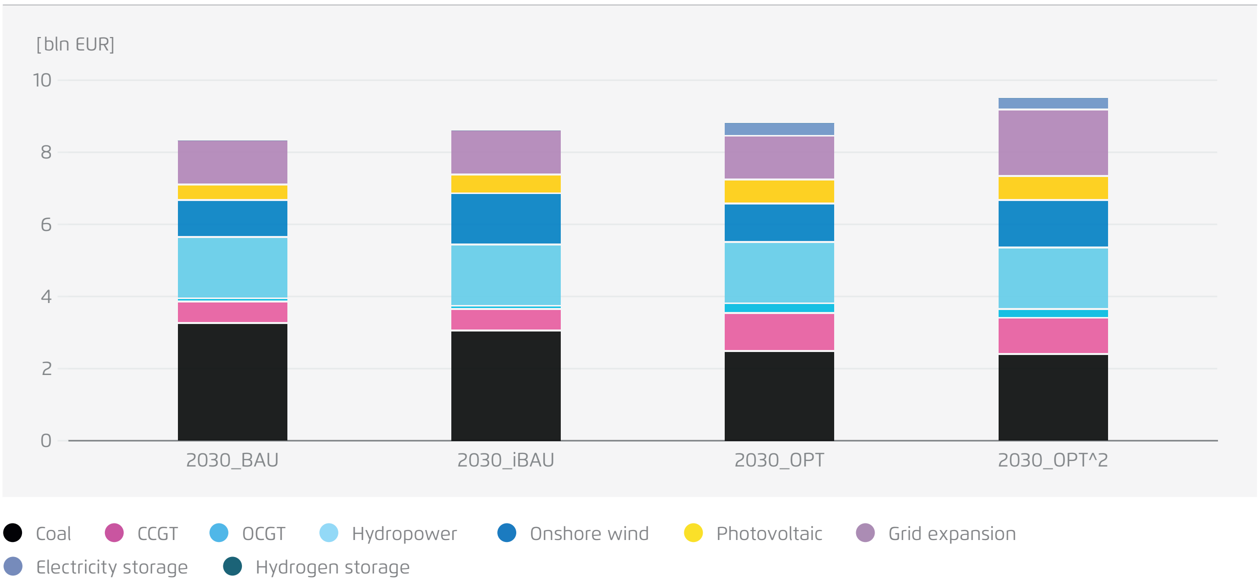
Agora Energiewende (2024)

true for open-cycle gas turbines (OCGT), which are extremely expensive in the BAU and iBAU scenarios because of lower hours of operation (in some cases less than 10% of total time, compared to over 80% for coal-fired power plants).

2.4 Curtailment, storage, dispatch and transmission

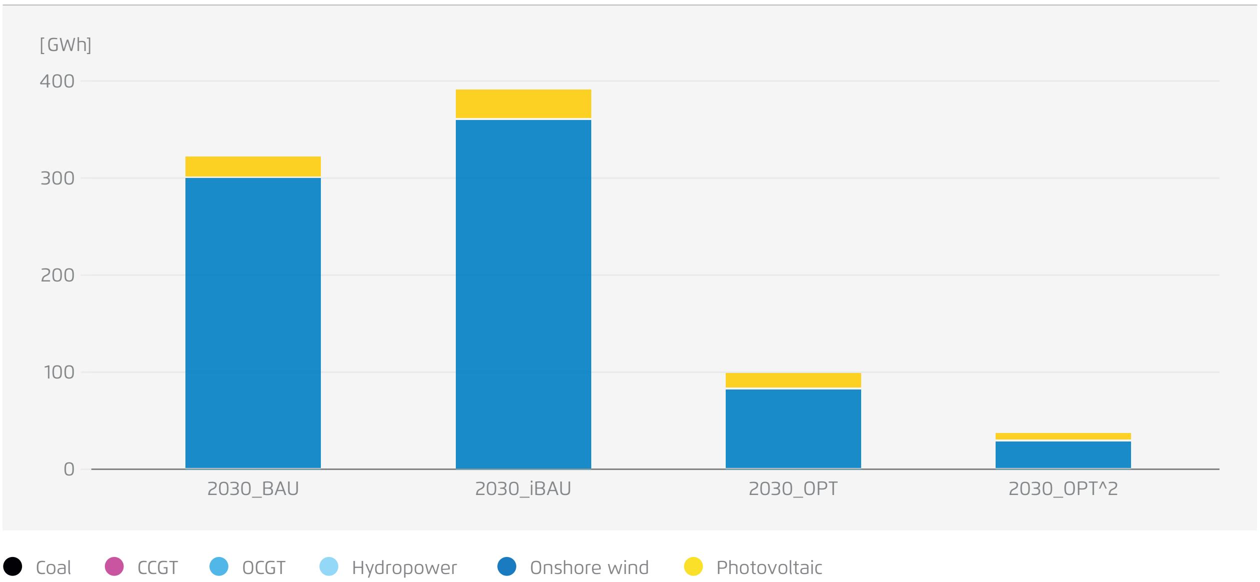
Scenarios of cost optimisation are also characterised by much lower curtailment of variable renewables, which is especially high for wind energy in the BAU

2030 total economic system costs (TOTEX) by technology per RE scenario → Fig. 8



Agora Energiewende (2024)

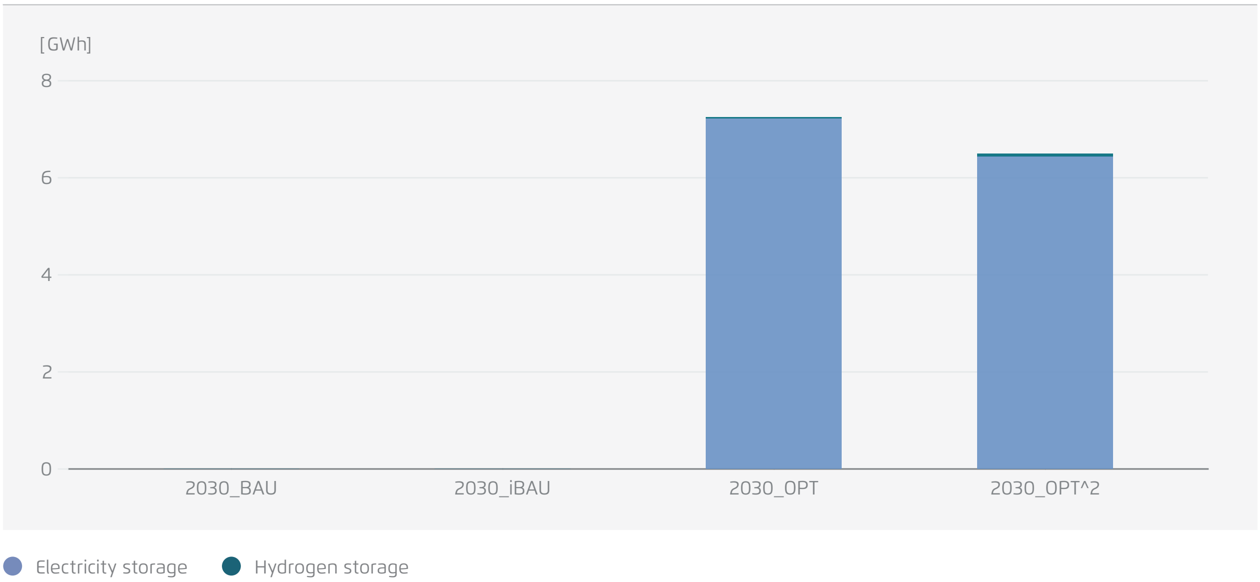
National 2030 curtailment by technology → Fig. 9



Agora Energiewende (2024)

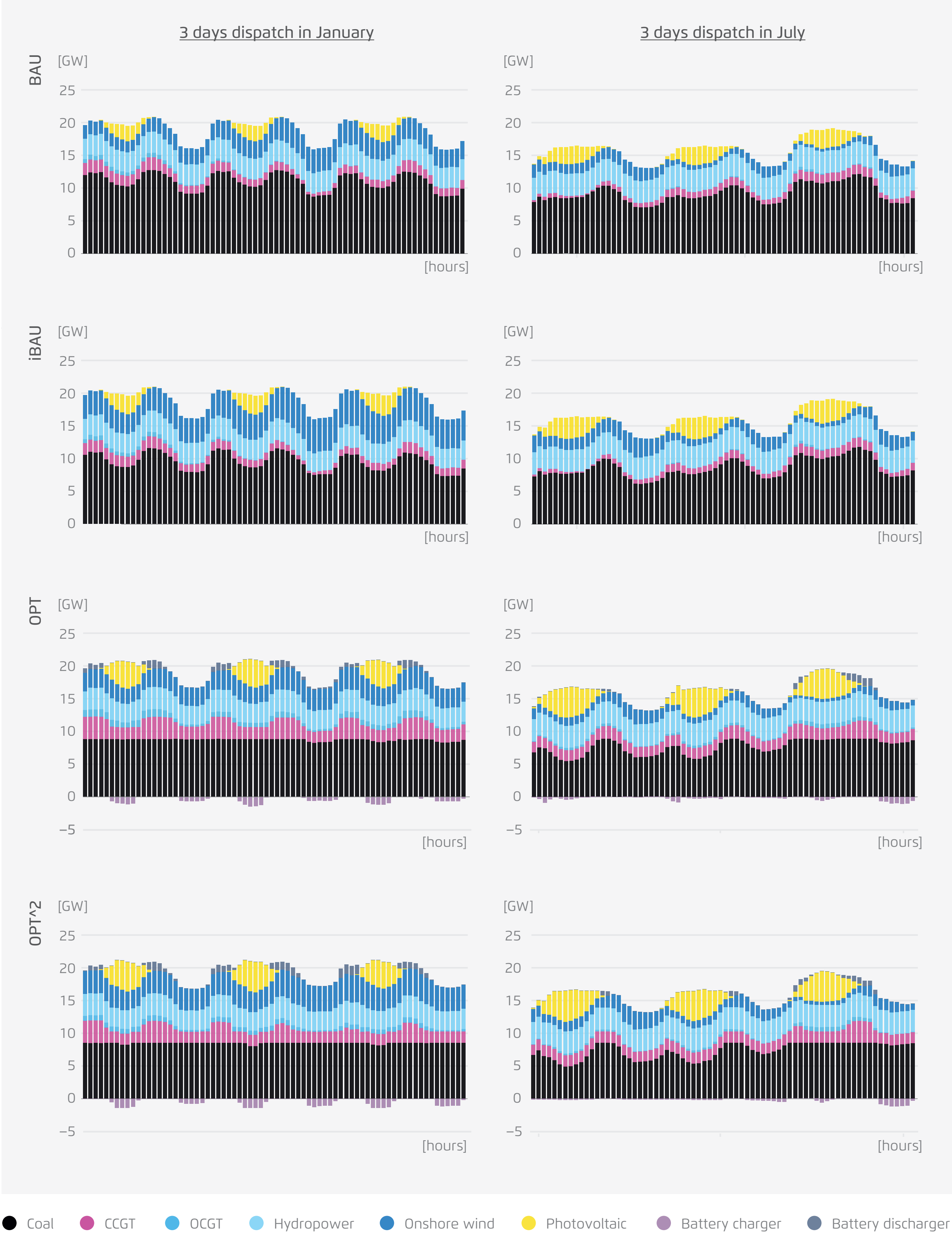
and iBAU scenarios (Figure 9). Curtailment of renewables is considered undesirable because it wastes available green energy resources with very low operating expenses and may result in financial losses for renewable power providers, and because it detracts from the overall efficiency of the power system, especially affecting its efforts to pursue the energy transition route. As of today, the Ministry of Energy is debating to introduce curtailment measures for new renewable energy projects in order to relax the grid that lacks flexible capacities for balancing.

National 2030 storage capacities → Fig. 10



Agora Energiewende (2024)

Dispatch in winter and in summer for each of the scenarios → Fig. 11



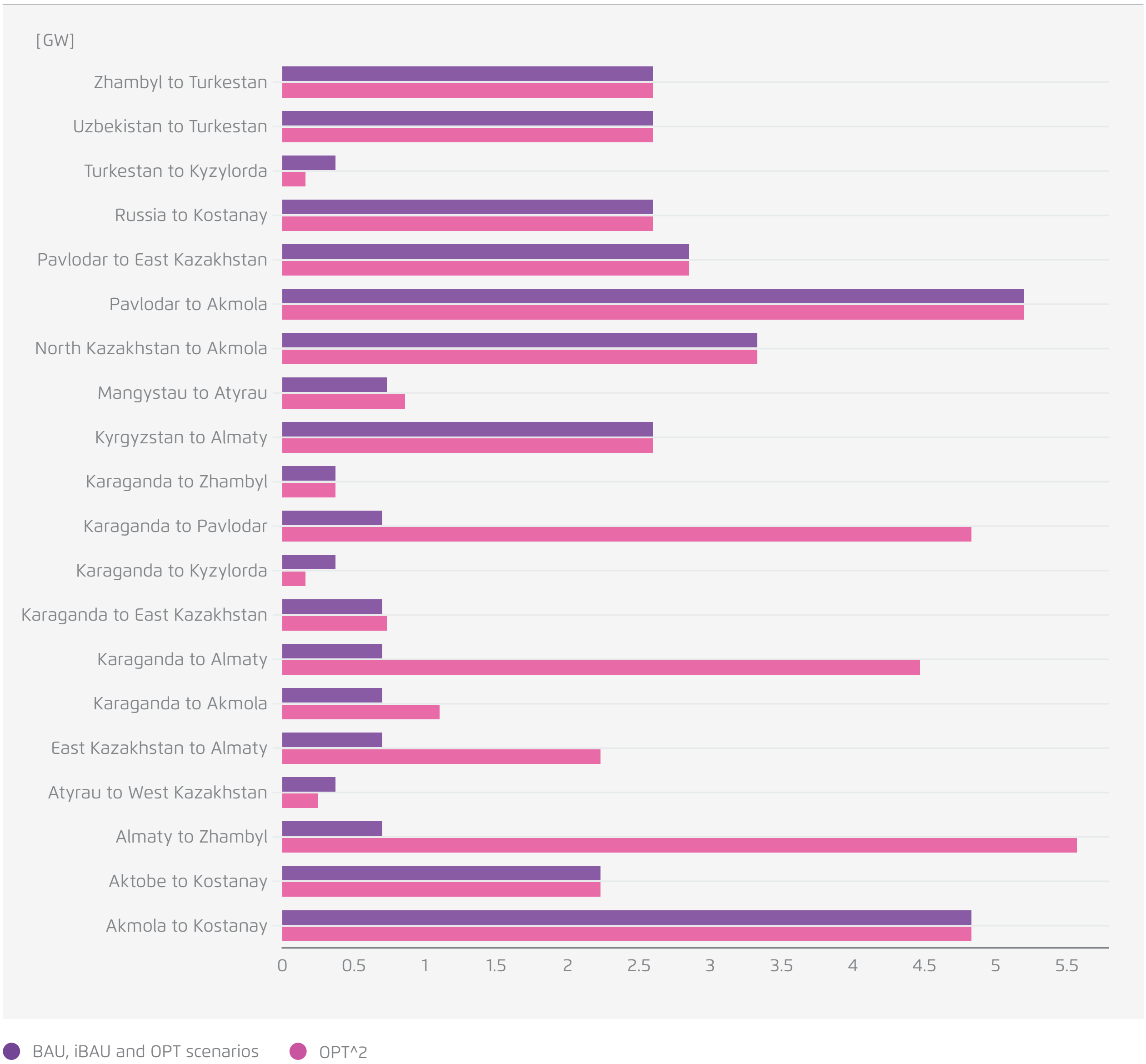
Agora Energiewende (2024)

As already mentioned, cost optimisation scenarios include significant electricity storage and a small amount of hydrogen storage as well (Figure 10). The OPT scenario involves 7.22 GWh electricity storage, and the OPT^2 scenario 6.44 GWh. For comparison, at the end of 2021, global online energy storage installations amounted to 56 GWh.[38] The BAU and iBAU scenario results include very small (negligible) volumes of both electricity and hydrogen storage capacity. For the last 2 years, the system operator

38 BNEF (2022). Global energy storage market to grow 15-fold by 2030. URL: https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/.

Net transfer capacity between the regions of Kazakhstan and neighbouring countries

→ Fig. 12



Agora Energiewende (2024). Note: this shows the former administrative division of Kazakhstan, which changed in 2022 when the number of regions increased from 14 to 17.

KEGOC has been actively proposing to oblige the renewable energy power plants to install storage systems that would cover 50% of their installed capacity.

To assess the operational implications of the 2030 scenarios, we look into the hourly dispatch of different types of power plants. Specifically, Figure 11 illustrates the dispatch for cold January and hot July days for all the scenarios. At some times, the model predicts that solar PV and wind will be able to produce over one-third of all electricity, while at other times coal- and gas-fired power plants will have to cover almost the entire load. As this figure shows, the whole electricity system will need to respond in a more flexible manner to variable solar PV and wind generation which is dependent on weather conditions and solar irradiance. At some times, even the conventional coal-fired power plants will have to ramp up and down frequently and react flexibly. All this means that Kazakhstan's power system will need less baseload capacity and more flexible capacity.

Since in one of the scenarios – OPT^2 – transmission capacities are cost-optimised, net transfer capacities for the scenarios without such an optimisation (BAU, iBAU and OPT) and with it (OPT^2) will be different. Net transfer capacity is the expected maximum volume of electricity that can be transferred between the two systems without any constraints. As the figure below shows (Figure 12), the scenario with transmission capacities optimisation has significantly higher net transfer capacity values for some regions, e.g. for the connection between Karaganda and Pavlodar regions, Karaganda and Almaty regions and Almaty and Zhambyl regions.

3 Horizon 2030 and beyond: charting the trajectory of the energy transition in Kazakhstan

The global energy sector is undergoing dramatic changes. The adoption of energy-efficient appliances and industrial processes is one change that is fundamental to sustainable energy practice. Simultaneously, a significant shift towards increased reliance on renewable electricity is under way, aiming to raise its use to remarkably high levels. This transition encompasses the electrification of heat, industrial applications and transport, thereby gradually reducing reliance on coal, oil and natural gas. Such transformations may be extremely challenging for countries dependent on fossil fuels, such as Kazakhstan. This section investigates how developments in Kazakhstan relate to all these trends.

3.1 Global energy trends: deep renewables deployment and electrification

International organisations such as IEA and IRENA, transnational corporations such as BP, and other important global stakeholders such as REN21 all share a vision of the global energy transition such as that shown in Figure 13. This vision focuses on several key strategies.

First and foremost is energy efficiency, recognised as a very important "energy source" but one that is as yet underutilised in some countries (including Kazakhstan). Energy efficiency, or optimising energy use and curbing waste, is a cornerstone of sustainable energy practice. Smarter energy consumption patterns, coupled with energy-efficient appliances and industrial processes, reduce the need for additional energy generation.

Another crucial element of the transition is a substantial increase in the use of renewable electricity. This includes ambitious goals for elevating renewable electricity use to exceptionally high levels. In addition, a pivotal shift is envisaged in the electrification of heat, industrial applications and transport. These transformative drivers are anticipated to gradually diminish the consumption of coal, oil, and natural gas, thereby ushering in a cleaner and greener energy era. Electricity, and especially renewable electricity, is therefore regarded as a key to the global energy transition.

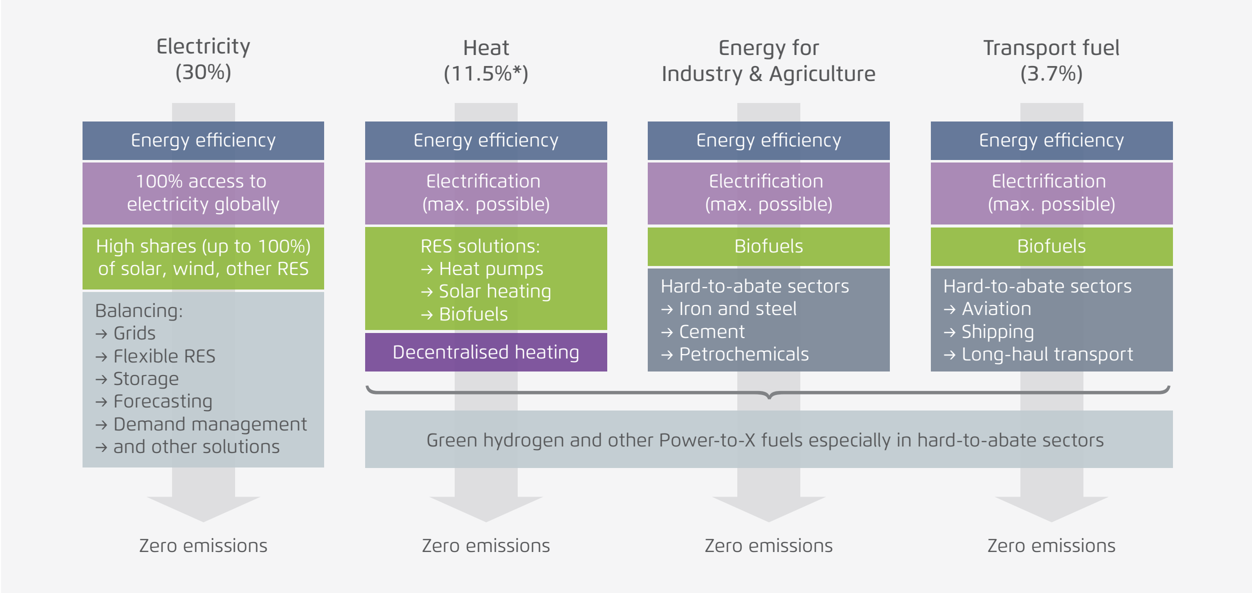
In particularly challenging transport sectors such as aviation, shipping and long-haul transportation, and in certain industrial applications like iron and steel production, cement and petrochemicals, conventional transition pathways might not be adequate. A transition towards green hydrogen and other power-to-X fuels, along with biofuels, is therefore gaining prominence. Although fully commercial technologies for these sectors are not yet readily available, rapid technological advances suggest a promising future.

As shown in Figure 13, the power sector has witnessed more rapid progress along the energy transition path than the heat and transport sectors. With nearly one-third of global electricity sourced from renewables, the power sector is leading the charge in driving the transformation towards a more sustainable energy landscape. According to estimates made by the International Renewable Energy Agency (IRENA), transitioning to renewables, coupled with a greater focus on energy efficiency, could potentially deliver 80% of the global CO_2 emissions reductions required to align with the 1.5 °C scenario.[39] Renewable electricity is thus poised to emerge as a cornerstone industry within the energy sector of the future, potentially relegating coal power plants to the status of stranded assets.

39 IRENA (2021). Reaching Zero with Renewables. Capturing Carbon. URL: https://www.irena.org/-/media/Irena/Files/Technical-papers/IRENA_Capturing_Carbon_2021.pdf?rev=bf05359177504164aab7fad527b35e0d.

Pathways to zero emissions from fossil fuels and global current shares of renewables in relevant energy supply sectors

→ Fig. 13



Agora Energiewende (2024). Note: (shares of renewables: for electricity the data is provided for 2022, for other energy supply sectors for 2020); shares of RES: REN21 (2023). Renewables 2023 Global Status Report collection, Renewables in Energy Supply: https://www.ren21.net/gsr-2023/modules/energy_supply/01_energy_supply. Note: *Including industrial heat

International organisations and transnational corporations expect electricity to be dominated by wind (both onshore and offshore) and solar PV generation. These technologies cause the least harm to the climate and the environment, they are safe, reliable, scalable, applicable in almost any country and economically viable, and in many regions of the world they are the cheapest sources of electricity. However, they are variable, and this raises concerns that if their share becomes significant, they will jeopardise the stability of the entire energy system. And this might be one of the reasons why Kazakhstan avoids setting more ambitious goals for solar PV and wind up to 2050, though there are already examples of very high variable renewables shares in national power mixes, such as Australia (25%), Chile (28%), United Kingdom (29%), Germany (32%), Spain (33%), Uruguay (36%) and Denmark (61%).[40]

As already mentioned, renewables have been developing faster in the power sector than in other sectors globally. Thus, according to REN21, in 2022, targets for the share of renewable power were adopted in 174 countries across the world, including 100% renewable power targets in 37 countries. For comparison, only 46 countries had targets for renewable heat and 49 for biofuels.[41] However, the need to accelerate the energy transition in heating/cooling and transport is now increasingly recognised, and some countries, especially European ones, are focusing more on this. For Kazakhstan, the energy transition in the heating sector is especially challenging, since many of its thermal power plants co-generate electricity and heat (in 2022, 57% of its heat was produced at CHP power plants[42]), and heating has special social importance because of its cold winters.

40 Ember (2023). Yearly electricity data. URL: https://ember-climate.org/data-catalogue/yearly-electricity-data/.

41 REN21 (2023). Renewables 2023 Global Status Report collection, Renewables in Energy Supply. URL: https://www.ren21.net/gsr-2023/modules/energy_supply/01_energy_supply.

42 Office of National Statistics (2023). Fuel and energy balance of the Republic of Kazakhstan (2022). URL: https://stat.gov.kz/ru/industries/business-statistics/stat-energy/publications/5186/.

As the world increasingly recognises the need to switch to renewable energy sources across all sectors, it is becoming evident that a comprehensive approach encompassing power, heating, cooling and transportation is vital for achieving sustainability goals. Renewable power is a linchpin in this broader strategy. But concerted efforts are still essential to bolster the adoption of renewables in heating/cooling and transport, ensuring a holistic transformation towards a sustainable energy future and carbon neutrality.

3.2 Addressing Kazakhstan's fragmented energy policies

The Kazakh economy is one of the least energy-efficient in the world. National energy efficiency goals were set in the 'Concept for the transition of the Republic of Kazakhstan to a "green economy" of 2013'.[43] In accordance with this document, the energy intensity of GDP should have decreased by 10% compared to the 2008 level by 2015, 25% by 2020, 30% by 2030 and 50% by 2050. According to Enerdata, the 2015 and 2020 targets were met. However, in 2022, Enerdata ranked Kazakhstan 12th by energy intensity, at 0.145 koe/$15p.[44] Since the first half of the 1990s, the country has significantly improved its energy efficiency; however, the energy intensity of its GDP is still about 50% higher than the global average (Figure 14). It means that the preeminent renewable energy source – energy efficiency – remains largely underutilised in Kazakhstan.

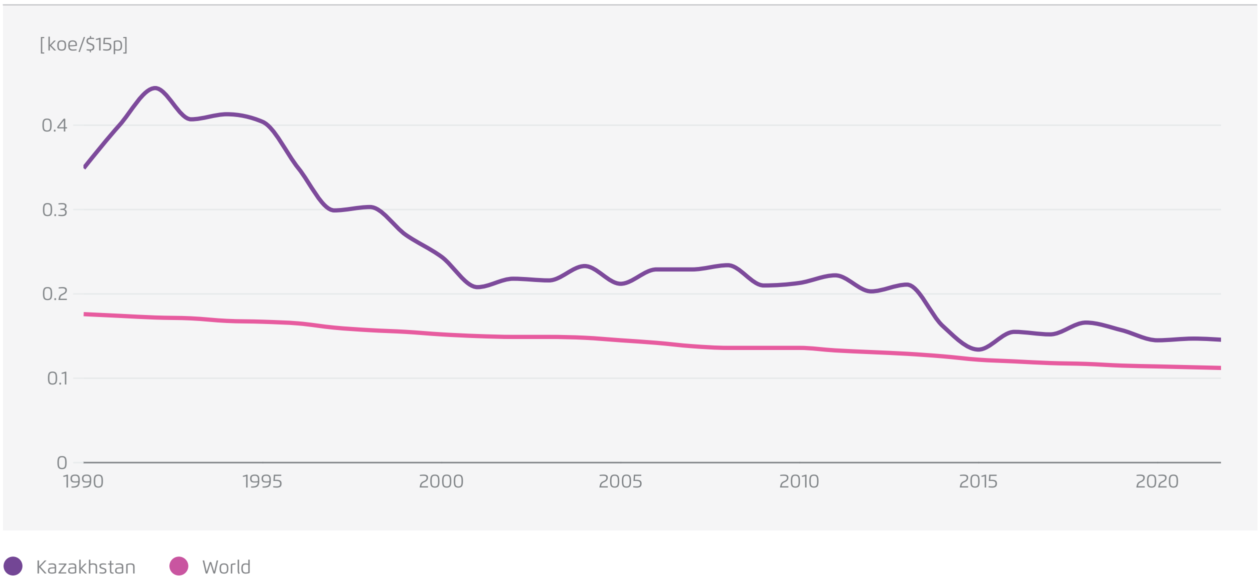
Road vehicles in Kazakhstan run almost exclusively on fossil fuels, and the electrification of the heat and transport sectors in the country is further ahead (Figure 15). Solar PV and wind are two emerging sources of power in Kazakhstan and reached a combined share of 3.7% of electricity generation in 2022[45]

43 Decree of the President of the Republic of Kazakhstan of May 30, 2013, #557. Concept for transition of the Republic of Kazakhstan to Green Economy. URL: https://adilet.zan.kz/rus/docs/U1300000577.

44 Enerdata (2023). Energy intensity. URL: https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html.

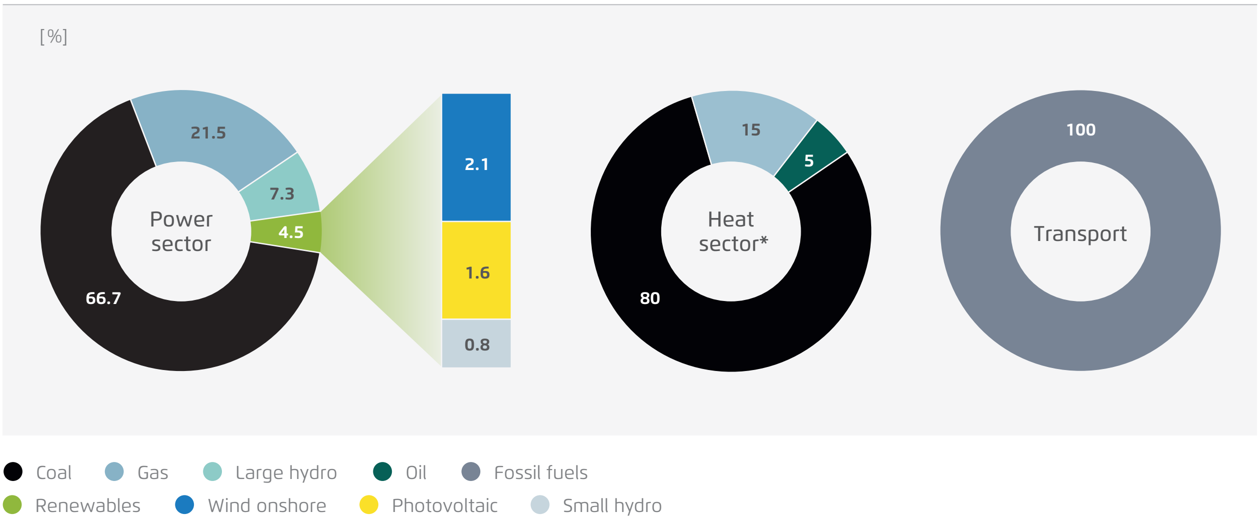
45 The Ministry of Energy of the Republic of Kazakhstan (2022). Information on the production of electrical energy by renewable energy facilities based on the results of 2022. URL: https://www.gov.kz/memleket/entities/energo/documents/details/403997?lang=ru.

Energy intensity in Kazakhstan and the world → Fig. 14



Enerdata (2023). Energy intensity: https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html

Structure of generation in Kazakhstan's power, heat and transport sectors, by energy source, 2022 → Fig. 15



Agora Energiewende (2024). Note: (shares of renewables: for electricity the data is provided for 2022, for other energy supply sectors for 2020); shares of RES: REN21 (2023). Renewables 2023 Global Status Report collection, Renewables in Energy Supply: https://www.ren21.net/gsr-2023/modules/energy_supply/01_energy_supply. On approval of the Concept for the development of the power industry of the Republic of Kazakhstan for 2023-2029: https://adilet.zan.kz/rus/docs/P2300000263. Note: * Excluding individual heating

and 5% by the middle of 2023.[46] According to the current national goals, by 2030 their share is expected to rise to 15%,[47] and by 2050 the share of alternative (i.e. including projected nuclear generation) and renewable energy (including all hydropower) in the electricity mix should reach 50%.[48] However, the 'Energy Balance of the Republic of Kazakhstan until 2035' envisages that the share of variable RES will reach almost 15% by 2030, remaining unchanged afterwards until 2035, while the share of alternative energy will exceed 40% by 2035, due to the commissioning of nuclear power (which is not used currently).[49] The optimistic plan for variable RES for Kazakhstan might therefore be limited to 25% by 2050.

For comparison, Germany plans to generate 80% of its electricity from renewables by 2030, and some other European countries, such as Portugal, Denmark and Austria, 100%; the implementation of national renewable electricity goals in the EU-27 countries by 2030 will increase the share of renewables in the power mix of the EU-27 to 63%.[50] Neighbouring Uzbekistan plans to achieve carbon neutrality in the energy sector by 2050, and to that purpose in 2021 its Ministry of Energy signed a Memorandum of Understanding with the European Bank for Reconstruction and Development (EBRD).[51]

46 The Ministry of Energy (2022). Information on the production of electricity by renewable energy facilities in the first half of 2023. URL: https://www.gov.kz/memleket/entities/energo/documents/details/496972?lang=ru.
47 Kazinform (2021). I set the task to increase the share of renewable energy sources in power generation to 15% by 2030 - Head of State. URL: https://www.inform.kz/ru/uvelichit-dolyu-vie-v-elektrogeneracii-do-15-k-2030-godu-poruchenie-glavy-gosudarstva_a3792969.
48 Decree of the President of the Republic of Kazakhstan of May 30, 2013, #557. Concept for transition of the Republic of Kazakhstan to Green Economy. URL: https://adilet.zan.kz/rus/docs/U1300000577.
49 Order of the Minister of Energy of the Republic of Kazakhstan dated March 24, 2022 No. 104 "On approval of the Energy Balance of the Republic of Kazakhstan until 2035" (as amended on January 30, 2023). URL: https://online.zakon.kz/Document/?doc_id=37351758&pos=4;-90#pos=4;-90.
50 Ember (2023). EU power sector 2030 target tracker. URL: https://ember-climate.org/data/data-tools/european-renewables-target-tracker/.
51 UZ Daily (2021). EBRD to support Uzbekistan in achieving carbon neutrality. URL: https://www.uzdaily.uz/en/post/65118.

The country plans to focus on nuclear, solar PV, wind and hydropower, as well as on the modernisation of its grid.

Kazakhstan has been working on improving its energy policies to align with its sustainable development goals and global environmental commitments. In addition to the targets for renewables in the power sector, there is also a target of carbon neutrality for the whole economy by 2060.

The prospect of a complete phase-out of coal-fired power generation by 2050 against the backdrop of the adoption of the national 2060 carbon neutrality goal was voiced at the highest state level (by President Tokayev) back in 2021. Kazakhstan also endorsed clause 4 of the 'Global coal to clean power transition statement' at COP26 in Glasgow, with the support of coal workers and sectors and communities affected by the energy transition (although ignoring clauses 2 and 3, which contained the commitment to a coal phase-out in the power sector itself).[52] Despite this, work on the planning of a coal power phase-out has not started in Kazakhstan yet. Moreover, the discussion about abandoning coal has not been taken any further.

The hope that a discussion on the phasing out of other types of fossil fuels in Kazakhstan might begin is also proving illusory. Back at COP26, Kazakhstan refrained from joining the Beyond Oil and Gas Alliance (BOGA) to end oil and gas exploration and production.[53] And this is easily explained – oil is one of the main sectors of Kazakhstan's economy . In 2019, tax revenues from the oil and gas sector formed 44% of the state budget.[54] In 2021, oil rents in Kazakhstan were estimated by the World Bank at 14.8% of GDP.[55] For comparison, its natural gas and coal rents were estimated at 2.0%[56] and 0.8% of GDP respectively.[57]

Kazakhstan has not yet set out a clear official position regarding the prospects for the development of the electric vehicle market, and official forecasts for the number of electric vehicles expected by 2035 are extremely conservative, at 40 thousand units for a population of almost 20 million people.[58] A large-scale transformation of heat production in the country is also not yet envisaged, nor the electrification of this sector. However, the 'Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035' notes that the creation of an effective heat supply system would be made possible by increasing the share of thermal energy sources based on the use of renewables and alternative energy sources.[59] Kazakhstan therefore requires a more balanced and at the same time ambitious policy aimed at the development of renewable energy sources in the electricity sector, taking into account the future electrification of other sectors.

52 UN Climate Change Conference UK 2021 (2021). Global coal to clean power transition statement. URL: https://webarchive.nationalarchives.gov.uk/ukgwa/20230313120149/https://ukcop26.org/global-coal-to-clean-power-transition-statement/.
53 BOGA (2021). Who we are. URL: https://beyondoilandgasalliance.org/who-we-are/.
54 Forbes (2019). 44% of the state budget of Kazakhstan is formed by the oil and gas sector. URL: https://forbes.kz/process/energetics/44_gosudarstvennogo_byudjeta_kazahstana_formiruet_neftegazovyiy_sektor/.
55 The World Bank (2023). Oil rents (% of GDP). URL: https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS?locations=XO.
56 The World Bank (2023). Natural gas rents (% of GDP). URL: https://data.worldbank.org/indicator/NY.GDP.NGAS.RT.ZS?locations=XO.
57 The World Bank (2023). Coal rents (% of GDP). URL: https://data.worldbank.org/indicator/NY.GDP.COAL.RT.ZS?locations=XO.
58 Ministry of Energy of the Republic of Kazakhstan (2022). Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.
59 Ibid.

4 Embarking on the energy transition journey

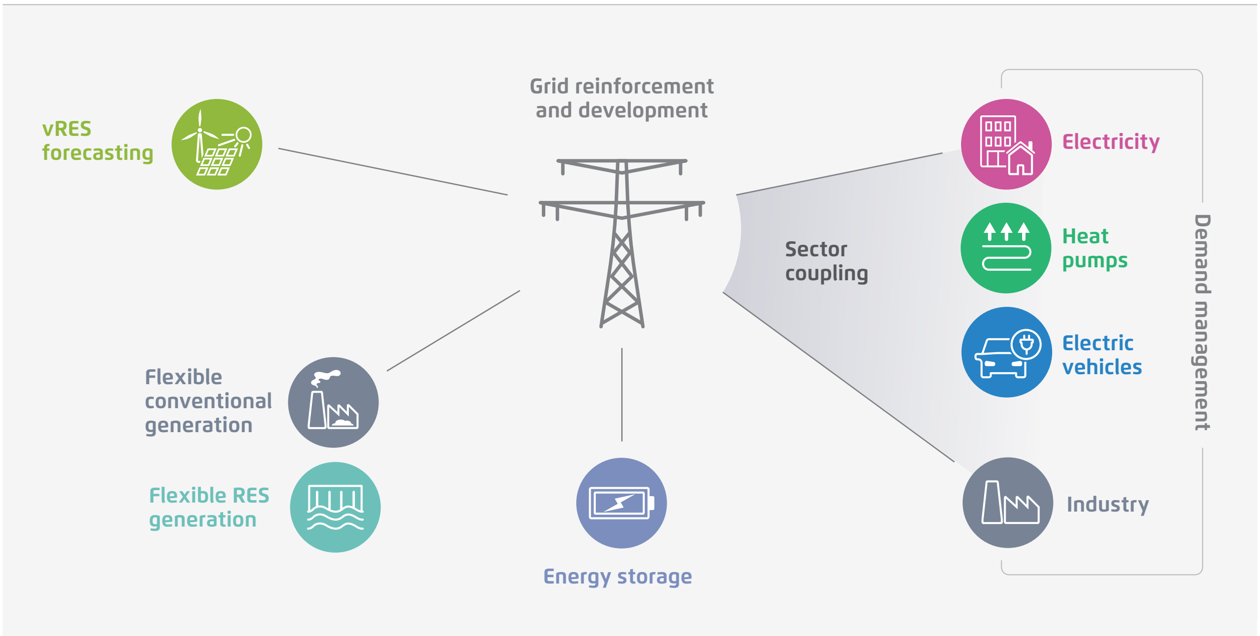
As the share of variable renewables surpasses minimal thresholds and the imperative of a comprehensive transformation and modernisation of the entire power system becomes increasingly evident, a multitude of formidable questions emerges. These relate to effectively balancing the rising shares of variable solar and wind generation; incentivising investors via appropriate price signals to drive investments into cost-efficient energy technologies; managing the phased retirement of antiquated coal-fired infrastructure without detrimental impacts on coal mining regions and workforce; and curbing electricity price hikes to mitigate potential social unrest. This chapter explores strategies for navigating these challenges and avoiding unnecessary costs and adverse repercussions associated with the energy transition.

It is essential to tread carefully in this transformative journey, leveraging the right mix of policy interventions, technological advances and socio-economic measures. Misguided strategies, such as an overreliance on back-up fossil fuel power plants or an excessive investment in energy storage devices, could prove counterproductive and burden the economy. A prudent and informed approach is crucial to ensuring a successful transition to a sustainable and efficient energy landscape.

4.1 Balancing variable renewables

High shares of variable electricity sources, such as solar PV and wind, raise the problem of balancing supply and demand in the power system, which comes loaded with myths and misconceptions that need to be addressed. The most popular misconceptions are: balancing renewables is impossible or too costly, or possible only if their share is negligible; all variable renewable power plants must be backed-up "1:1" by reserve conventional generating facilities; and energy storage is the only solution while renewables continue to compromise grid reliability.

Options for balancing variable renewables in Kazakhstan (and elsewhere) → Fig. 16



Agora Energiewende (2024)

However, there are a number of standard solutions (Figure 16), the holistic introduction of which allows the variability problem to be solved without building huge storage capacities or reserve conventional power plants and without negative consequences for grid reliability.

Grid reinforcement and development is perhaps the solution that is needed most urgently in Kazakhstan, and this issue has been on the agenda of the Ministry of Energy for years. The grid has not been significantly modernised since the Soviet era; the number of unscheduled outages, following a drop in 2019, has again been on the rise in recent years;[60] and the western energy zone is still not integrated with the rest of the country, while the connection between the northern and southern zones is also weak. Measures to increase the overall stability of the grid and to enable the transportation of variable power over greater distances are therefore urgently necessary. And the correct sequence is not grid expansion following new generation, as often happens, but grid planning and VRES deployment in parallel, in order to avoid unnecessary investments and delays.[61]

According to the 'Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035', published in September 2022, the Western energy zone is to be connected with the Unified Energy System of Kazakhstan through a 220–500 kV overhead line by 2025.[62] The importance of this plan was again confirmed in 2023.[63] KEGOC has started to develop the project "Connection of the power system of Western Kazakhstan with the UES of Kazakhstan. Construction of power grid facilities". However, KEGOC is only planning to complete this project by 2028. Regional interconnection is a crucial prerequisite for power supply security, especially for the systems with high shares of variable renewable generation. One of the expected results of the integration of the Western zone with the UES is the use of flexible generation in the Western zone to compensate for imbalances in electricity and power in the Northern and Southern zones. The new overhead line is planned to connect the Atyrau and Aktobe regions.[64]

Flexible generation, often with gas-fired power plants, can be dispatched on command to compensate for the intermittency of solar PV and wind technologies. However, Kazakhstan faces a scarcity of natural gas for domestic consumption (for more details see section 5.1), and even now, at a relatively low level of development of variable RES, there is a shortage of flexible capacity and growing dependence on Russia for balancing the energy system. Starting from July 1, 2023, a balancing market has been in operation in Kazakhstan, which may give price signals to investors and stimulate them to invest in flexible capacity. However, natural gas is a fossil fuel that can be considered as a transitional bridge, but only for a limited time. Given that investments in new flexible natural gas capacity are long-term (for the next 30–40 years, but in practice often for longer periods), it is essential, given Kazakhstan's 2060 climate-neutrality target, to plan for their conversion to clean fuels in the future, for example, to biogas or green hydrogen.

There is also the option of **flexible (dispatchable) renewable generation**, for example with hydropower or biofuel/biomass power plants. Kazakhstan has a significant hydropower industry that generates about 8% of all electricity in the country and is the third most important source of electricity, after coal (67%) and natural gas (20%).[65] Biofuel power plants are rare in Kazakhstan. Compared to variable wind and solar PV power plants, which together generated

60 KEGOC (2017–2021). Annual Reports 2017–2021. URL: https://www.kegoc.kz/ru/for-investors-and-shareholders/raskrytie-informatsii/annual-reports/.
61 Agora Energiewende (2019). A word on grids. How electricity grids can help integrate variable renewable energy. URL: https://agora-energiewende.de/en/publications/a-word-on-grids/.
62 Ministry of Energy of the Republic of Kazakhstan (2022). Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.
63 Sputnik (2023). To prevent blackouts in the west of Kazakhstan: what does the Cabinet of Ministers plan besides repairs at MAEK. URL: https://ru.sputnik.kz/20230817/ne-dopustit-bleekautov-na-zapade-kazakhstana-chto-planiruet-kabmin-krome-remonta-na-maek-37746323.html.
64 KEGOC (2023). Project Integration of the energy system of Western Kazakhstan with the UES of Kazakhstan. URL: https://www.kegoc.kz/ru/about/investicionnye-proekty/155662/.
65 IEA (2020). Kazakhstan. URL: https://www.iea.org/countries/kazakhstan.

almost 2.9 TWh, biofuel power plants produced just 1.8 GWh of electricity in the first half of 2023.[66] Agriculture is also important for Kazakhstan, and crop and livestock waste, too, could be used to generate electricity.

Furthermore, embracing a diversified energy mix, where various renewable sources complement each other, can substantially enhance system stability. Such an integrated approach mitigates the risk of over-reliance on a single energy source and enables a more reliable and consistent power supply. Additionally, it provides a conducive environment for the phased retirement of coal-fired power plants without causing abrupt disruptions.

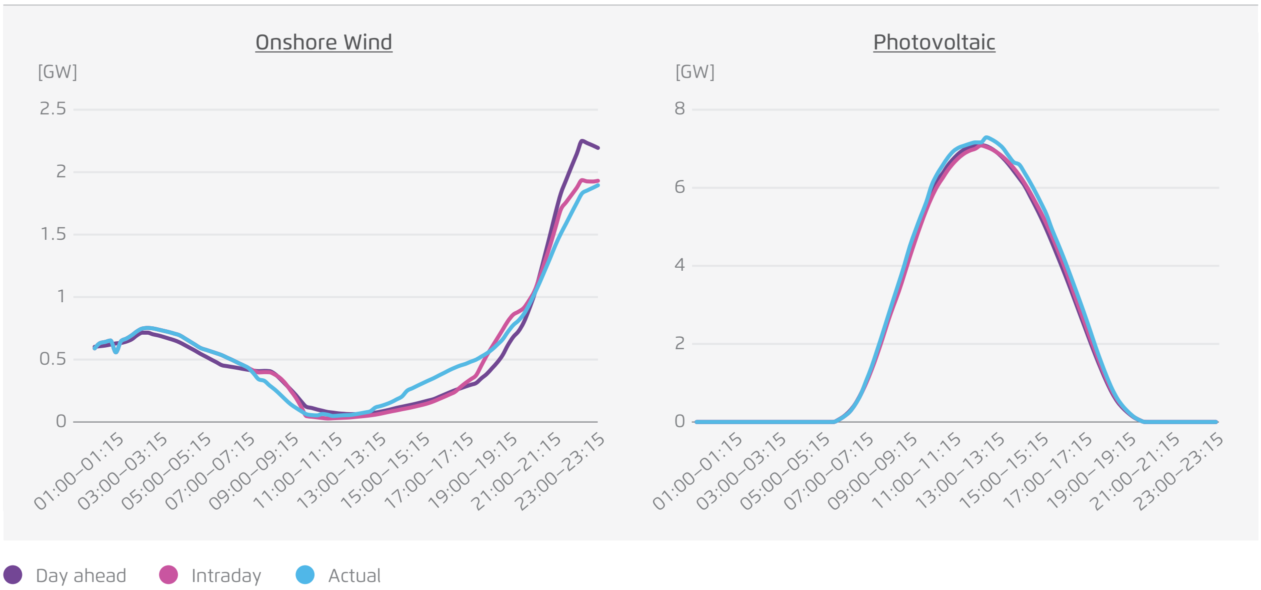
Increasing the flexibility of (modernising) existing coal power plants in order to integrate more variable renewable electricity into the grid could also be an option. This is of course not an optimal solution, but if it allows more solar and wind power to penetrate the grid in the medium term, it is in any event a better option than building new coal (or even natural gas) power plants that will remain in the system for another 30–40 years or longer or turn into stranded assets.

Energy storage is another solution. In 2026–2027, the French company Total Eren, together with the Kazakh companies Samruk-Kazyna and NC KazMunayGas, intends to build a 1 GW wind farm with a power storage system of 300 MW–600 MWh in the Zhambyl region in Kazakhstan. Another 500 MW wind power plant with an energy storage system is planned by the state investment development fund KIDF and the UAE-government owned company Masdar. Energy storage systems are just beginning to develop in the country, and this process should be accelerated.

Qualitative forecasting of variable RES generation is crucial for integrating it into the grid. Forecasting Variable Renewable Energy (VRE) generation through precise weather predictions offers notable benefits to system operators, especially in cases of extreme

66 The Ministry of Energy (2022). Information on the production of electricity by renewable energy facilities in the first half of 2023. URL: https://www.gov.kz/memleket/entities/energo/documents/details/496972?lang=ru.

Day-ahead and intraday forecasts and actual generation for onshore wind (left) and solar PV (right) for German grid operator Amprion, 24 August 2023 → Fig. 17



Entsoe (2023). Generation forecasts for wind and solar: https://transparency.entsoe.eu/

weather events.[67] KEGOC is currently planning pilot projects to predict generation from renewable energy facilities,[68] while many other countries already have abundant positive experience in this area. The accuracy of modern forecasts is quite high. In 2016, German grid operator 50Hertz reported an average deviation of 2–4% for wind power and 5–7% for solar PV power for day-ahead forecasts.[69] Figure 17 shows a comparison of day-ahead and intraday forecasts with actual wind and solar PV generation on August 24, 2023 in the control area of another German grid operator, Amprion. Amprion uses different models and different types of data to predict wind and solar PV energy feed-in for approximately 1 400 wind turbines and 15 000 solar PV power plants within its designated zone. Prediction time frames are between 15 minutes and 4 days.[70]

Electricity demand management is a set of tools for influencing the patterns and volumes of electricity consumption to minimise peak demand and reduce stress on the electrical grid. It involves encouraging consumers to shift their power demand to periods when power is not scarce. Demand response relies on two primary mechanisms: price-based initiatives (implicit demand response) employ price signals to motivate consumers to adjust their consumption, while incentive-based initiatives (explicit demand response) involve direct payments to consumers to modify their demand as part of a demand-side response programme.[71] Demand management is becoming increasingly popular globally but is not used in Kazakhstan yet, although Kazakhstan experimented with time-of-use tariffs several years ago but abandoned them because night energy consumption remained almost the same.[72] According to different estimates, the potential for reducing peak load in Kazakhstan's energy system through electricity demand management is as high as 10%.[73]

Closely related to the need for a holistic approach as discussed above (see section 3.2) is the idea of **sector coupling**, which means the integration of the power sector with two other energy-consuming sectors: heating/cooling and transport. When variable renewables generate excess electricity, the surpluses can be used for heating or cooling (e.g. to power heat pumps) or to charge electric vehicles. Otherwise, these surpluses would be curtailed and thus wasted. Sector coupling can also help extend the energy transition to other energy sectors beyond the power sector.

Generating power at small or micro scale RES facilities (e.g. rooftop solar for small and medium enterprises and households) and feeding it into the grid at medium or low voltage might also be helpful. This is especially important given the fact that carbon neutrality implies the electrification of transport and heating/cooling, in which case the more electricity is produced locally, the better, due to lower transmission and distribution losses. Also, appliances such as electric vehicles can be charged when there is an abundance or excess of cheap locally produced electricity – e.g. solar electricity during the day.

In the longer term, flexibility may also be provided by electrolysers, which can be used during periods of high variable generation, again to avoid the curtailment of excess solar PV and wind generation. Moreover, electrolysers can be installed at locations close to grid bottlenecks, given the availability of water.

67 IRENA (2020). Advanced forecasting of variable renewable power generation. Innovation landscape brief. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Advanced_weather_forecasting_2020.pdf?la=en&hash=8384431B56569C0D8786C9A4FD-D56864443D10AF.

68 KEGOC (2022). JSC KEGOC: the advanced development of the National Electric Grid of Kazakhstan is what we need now. URL: https://www.kegoc.kz/ru/press-center/mass-media-about-the-company/158042/.

69 CLEW (2016). Volatile but predictable: Forecasting renewable power generation. URL: https://www.cleanenergywire.org/factsheets/volatile-predictable-forecasting-renewable-power-generation.

70 Amprion (2023). The energy transition demands innovators. URL: https://www.amprion.net/documents/Amprion/Innovation/Amprion-Innovation-Report.pdf.

71 IEA (2023). Demand response. URL: https://www.iea.org/energy-system/energy-efficiency-and-demand/demand-response.

72 Kazpravda (2022). What's wrong with the night rate? URL: https://kazpravda.kz/n/chto-ne-tak-s-nochnym-tarifom/.

73 Kim I. (2023). Prospects for implementing a demand response program in Kazakhstan // Qazaq Green. URL: https://qazaqgreen.com/journal-qazaqgreen/analitycs/1424/.

Electricity and heat are interconnected in Kazakhstan through CHP to a much higher extent than in most other countries of the world – over one-third of heat in the country is generated at CHP power plants,[74] and CHP is highly reliant on coal. This means that planning for the electricity sector cannot be entirely separated from the heat sector. Indeed, Kazakhstan needs to plan all its energy infrastructure holistically, taking into account at the same time the latest tendencies in the developed energy markets, such as the penetration of heat pumps and pellet boilers, the electrification of heat and transport, emerging green hydrogen and other P2X technologies, the gradual phase-out of coal, etc.

By combining the strategies outlined above and tailoring them to the specific renewable energy mix and local conditions, a reliable and well-balanced renewable energy system can be achieved in Kazakhstan, contributing to a sustainable and resilient energy future.

The growing complexity of the energy sector calls for a comprehensive transformation of the overall energy system. Electric vehicles, heat pumps, green hydrogen production – none of these are yet visible in Kazakhstan, nor will they be in the coming few years. But for an efficient energy transition, even if far from 100%, a holistic management that takes into account all the latest trends across the whole energy sector and plans for a phase-out of coal is vital. The lack of such an approach is typical not only of Kazakhstan but of the global energy transition leaders as well. However, the sooner Kazakhstan starts, the faster it will catch up with other countries and the lower its losses from stranded assets will be.

4.2 The role of electricity market design

The structure of the electricity market in Kazakhstan has evolved over the past decades from a vertically integrated monopoly to a partially liberalised, multi-market system comprising bilateral, spot, balancing (in a simulation mode), system and ancillary services and capacity markets, with unbundled generation, transmission and distribution. Electricity generation has long been carried out by a large number of companies including private generators, though the state-owned Samruk-Energo has been dominant. Until mid-2023, the wholesale electricity market in Kazakhstan was largely characterised by bilateral contracts between generators and large consumers as well as regional distributors.[75]

From 1 July 2023, a single electricity buyer model and a balancing electricity market in real time were introduced in Kazakhstan.[76] The Financial Settlement Center of Renewable Energy (originally created by the system operator KEGOC, but transferred in 2022 to the Ministry of Energy[77]), which originally purchased and resold only renewable electricity supplied to the UES of Kazakhstan, was then appointed as the sole buyer of all electricity.[78] Now the single buyer purchases the planned volumes of electricity to be generated the following day from domestic power plants. These transactions are carried out through centralised tenders on the electronic trading system of the state-owned KOREM (operator of centralised electricity trading). When there is a shortage of electricity from domestic power plants, the single buyer will purchase electricity from the energy systems of neighbouring countries. The costs of imported electricity will be distributed evenly between all wholesale consumers.

One of the main reasons for introducing a single buyer was to cushion the impact of high tariffs from newly commissioned power plants or expensive imported electricity on individual consumers. Kazakhstan has been holding back tariff increases

74 Carbon Tracker (2023). Kazakhstan Energy Transition. URL: https://carbontracker.org/reports/kazakhstan-energy-transition/.

75 Agora Energiewende (2023). From coal to renewables: a power sector transition in Kazakhstan. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2022/2022_09_INT_Kazakhstan/A-EW_295_Kazakhstan_EN_WEB.pdf.

76 Central Communication Service under the President of the Republic of Kazakhstan (2023). URL: https://ortcom.kz/ru/deyatelnost-pravitelstva/1688116720.

77 Financial Settlement Center of RE (2023). About us. URL: https://www.rfc.kz/about.

78 Ibid.

for many years in order to avoid consumer dissatisfaction, which has resulted in underinvestment and equipment becoming obsolete.

Previously, enterprises or regional distribution grids bought electricity from nearby power plants with available capacity at prices dictated by suppliers.[79] Now the high tariffs applied by new power plants will be distributed between all consumers and thus will have less impact on individual ones. It is expected that, consumer electricity prices will in future be equalised between regions. Other goals of the reform were, firstly, to minimise electricity flows between Kazakhstan and neighbouring countries by replacing daily schedules based on the technical capacities of power plants with actual consumer demand schedules, and in addition to eliminate speculative transactions in the buying and selling of electricity.[80]

Before 1 July 2023, the balancing electricity market had been operating in a simulation mode for years. However, KEGOC, the system operator, failed to put into operation the automated software mechanism of the real-time balancing electricity market within the scheduled timeframe.[81]

Worldwide, there is a variety of electricity market models. At one end of the range are centralised investment decisions made within a vertically integrated utility; at the other, fully liberalised wholesale and retail markets where investments are made by companies which conduct market research and decide which power plants will maximise their future returns . The single buyer model is between these two extremes but is very close to vertically integrated utilities (Figure 18). Between the single buyer model and liberalised wholesale markets there are many different models based on private initiative to make investment decisions, which can include investment support mechanisms, such as renewable energy auctions, capacity payments, etc.

The single buyer model first appeared in the 1990s in developing countries and has been popular in Asia as well as in many transition economies (e.g. in Eastern Europe); however, it has been heavily criticised in recent decades. For example, in 2000, the World

79 Tengri News (2023). KEGOC JSC sums up the first results of reforms in the energy supply market. URL: https://tengrinews.kz/kazakhstan_news/ao-kegoc-podvodit-pervyie-itogi-reform-ryinke-506577/.
80 Zakon (2023). A single electricity purchaser will appear in Kazakhstan from July 1. URL: https://www.zakon.kz/sobytiia/6398580-v-kazakhstane-s-1-iyulya-poyavitsya-edinyy-zakupshchik-elektroenergii.html.
81 Ministry of Energy of the Republic of Kazakhstan (2023). On the balancing electricity market. URL: https://www.gov.kz/memleket/entities/energo/press/news/details/589399?lang=ru.

Electricity market design models

→ Fig. 18

Agora Energiewende (2024)

Bank called it "a dangerous path toward competitive electricity markets", citing such drawbacks as low payment discipline, inefficiency of investment decisions made by government officials, opportunities for governments to intervene in dispatch from generators and to distribute cash between, them, and many others.[82] Other negative aspects of this model are diminished incentives for innovation and efficiency, limited negotiation power for generators, and inflexibility. In most European countries, there are no single buyers nowadays, even though many of them used this model in the past, and new capacity is self-dispatched. Decisions to invest in new power plants are made by for-profit companies based on their assessment of the future profitability of investments.[83]

Market design is crucial for appropriate price signalling and thus for the integration of high shares of VRES at low cost. It is especially important not only to generate more renewable kilowatt-hours but also to provide the flexibility to integrate those renewable kilowatt-hours within the system. And for that, a market that fairly prices both new renewable kilowatt-hours and balancing services is necessary.[84] Currently, thermal power plants in Kazakhstan have very limited technical capability and no economic incentive to adjust their schedules to the availability of wind and solar PV electricity. And this creates a huge barrier to the further development of VRES in the country.

If implemented well, fully liberalised electricity markets can be extremely efficient, because competition is a better driver of wholesale prices than price regulation, and because liquid short-term markets create the price signals needed for flexible generation to be added into the system and for thermal power plants to accommodate the variable generation. The marginal pricing model, under which the price for all traded electricity is cleared at the level of the most expensive generators (often open-cycle gas turbines, OCGT), is regarded as the most efficient model for liberalised electricity markets.[85] The single buyer model could be considered an intermediate step on the way to fully liberalised and competitive electricity markets in Kazakhstan.

4.3 The difficult decision to phase out coal

Coal phase-out is a difficult decision to make, because of its complex social, economic and energy security implications as well as the conservatism and rigidity traditional in the energy sector. At the same time, some of the common arguments in favour of coal power and heat hardly apply to Kazakhstan in the first place. For example, the argument that Kazakhstan is a country with a harsh, cold climate, and because coal is used not only for electricity production but also for heating, it would therefore be impossible to supply the country with heat without coal. Due to the obsolescence of coal power equipment and of the energy infrastructure and the rising number of accidents at coal power plants, apartments in the coal regions are sometimes left without heating. On the night of November 27, 2022, as a result of an emergency shutdown of several boiler units at the Ekibastuz CHP (put into operation in 1956), part of Ekibastuz city (with a population of over 145 thousand people[86]) was left without heat and hot water for several days at a temperature of -30 degrees Celsius. A state of emergency was declared in the city, educational facilities switched to distance learning, and kindergartens were closed. In some residential

82 The World Bank (2000). The Single-Buyer Model. A Dangerous Path toward Competitive Electricity Markets. URL: https://documents1.worldbank.org/curated/en/779321468780281965/pdf/22403-Replacement-file-225LOVEI.pdf

83 Guidehouse, Agora Energiewende (2023). Electricity Market Design for Climate Neutrality: Fundamentals. URL: https://static.agora-energiewende.de/fileadmin/Partnerpublikationen/2023/Agora_Power_market_design_fundamentals_Guidehouse.pdf.

84 IRENA (2019). Solutions to integrate high shares of variable renewable energy. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_grid_integration_2019.pdf.

85 European Commission (2023). Electricity market design. URL: https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/electricity-market-design_en.

86 AZ Nations (2023). Population of countries of the world. URL: https://ru.aznations.com/population/kz/cities/ekibastuz.

buildings, batteries burst due to defrosting.[87, 88] At the beginning of 2023, the temperature in apartment blocks in some residential areas in Ekibastuz was still below 11–13 degrees Celsius.[89] Accidents resulting in heating shutdowns in the winter of 2022–2023 also occurred in Astana, Petropavlovsk, Ust-Kamenogorsk, Zhezkazgan and Ridder.

It is clear that both generating equipment and energy infrastructure in Kazakhstan are in acute need of modernisation whatever happens. There is a great temptation for the authorities to invest in the repair and construction of the same energy facilities that have been operating for decades and that are familiar to local engineers, in particular in coal-fired power units and boilers and in centralised heat networks. Like the energy transition, this will require huge investments, since most of the facilities must be replaced. Meanwhile, however, renewable energy technologies continue to become cheaper. The use of fossil fuels is becoming increasingly expensive in many countries due to stricter environmental regulations, rising carbon prices, etc. This still applies mainly to Europe and the USA, but it also applies to countries that supply products to these countries. By investing in the modernisation and renaissance of coal, Kazakhstan therefore risks spending huge amounts of money on assets which will be more expensive to operate than renewable energy facilities. Moreover, their use will create obstacles to the export of products to Europe and over time to other regions (e.g. China).

At the same time, heat-power decoupling, or the separation of heat production from power generation, and the replacement of fossil fuels by renewables in both the heat and power sectors can offer higher energy security and better opportunities for international economic cooperation than a status quo strategy, both for traditional and new industries in Kazakhstan. One of the most reliable and affordable options for heat supply is heat pumps. They can provide both heating and cooling, making them suitable for year-round use. This is important for Kazakhstan, since it is characterised not only by cold winters but also by hot summers. In some countries with cold winters, heat pumps are already the most important source of heating. For example, in Norway they provide over 60% of buildings with heating, in Sweden and Finland over 40%.[90]

Kazakhstan is a district heating country – it serves about 70% of the population.[91] Heat pumps can be easily integrated into district heating systems and significantly increase their overall efficiency. Large-scale heat pumps can meet the heating or cooling demands of large buildings, industrial facilities, or entire districts. Another increasingly popular option for district heating is bioenergy. Biomass boilers or combined heat and power (CHP) plants can coexist with traditional fossil fuel-based heating systems or even replace them. However, both these options have a very limited scope for deployment in Kazakhstan.

All these new options for heat production, as well as renewable electricity generation, can contribute to the diversification of regional economies and to local job creation. Social and economic considerations – the fear of job losses and economic downturn– can be another obstacle to a coal phase-out. But even without any plans for a coal phase-out they will happen anyway, due to the changing economic landscape. The only difference is that without planning, jobs will disappear anyway over time and former coal regions will turn into depressed zones. This can also cause social unrest. A strategic coal phase-out plan will allow coal regions and towns to gain time and

87 Kazinform (2022). Eleven houses in Ekibastuz are still without heat connection – Akimat. URL: https://www.inform.kz/ru/odin-nadcat-domov-v-ekibastuze-vse-esche-ostayutsya-bez-pod-klyucheniya-k-teplu-akimat_a4009481.
88 Tengri News (2023). Accident at Ekibastuz Thermal Power Plant: the case was sent to court. URL: https://tengrinews.kz/kazakhstan_news/avariya-na-ekibastuzskoy-tets-delo-napravili-v-sud-502399/.
89 Tengri News (2023). Residents of Ekibastuz are freezing in their apartments again: the thermal power plant commented on the situation. URL: https://tengrinews.kz/kazakhstan_news/jiteli-ekibastuza-snova-zamerzayut-kvartirah-tets-491567/.
90 IEA (2022). The Future of Heat Pumps. URL: https://www.iea.org/reports/the-future-of-heat-pumps.
91 World Bank (2023). Europe and Central Asia: Toward a Framework for the Sustainable Heating Transition. URL: https://documents1.worldbank.org/curated/en/099092023140527206/pdf/P1777440fed3230ce089060ff8ce59c9f5e.pdf.

to prepare the transformation by diversifying their economies, retraining the workforce, funding early retirement, etc.

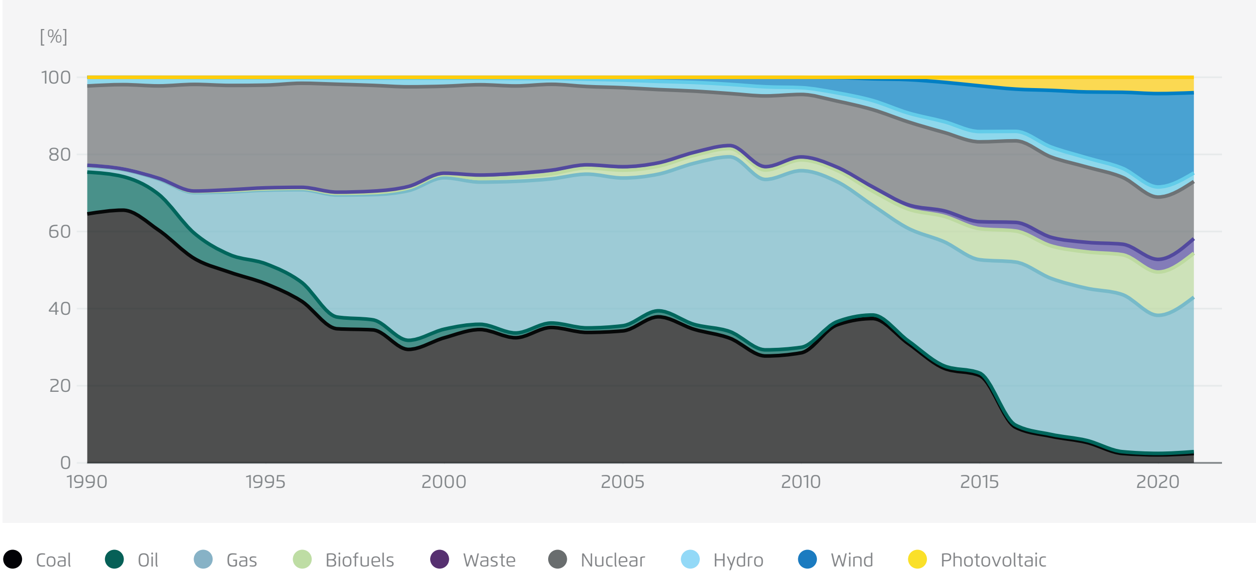
Some coal-dependent single-industry towns in Kazakhstan are already making efforts to diversify their economies. For example, Ekibastuz has been planning the creation of a railway cluster for several years. By the end of 2024, the city plans to build a plant for the production of locomotive tyres, creating 160 jobs.[92] By the end of 2023, a non-ferrous metallurgy plant with 800 jobs is expected to open.[93] In 2020, a pilot project was launched in the city – a small industrial zone. Its occupants are 18 small and medium-sized enterprises, which for 5 years will pay only utility bills and will be able to use production facilities equipped with the necessary infrastructure for free. Before the creation of the zone, the entrepreneurs involved worked from home.[94] These signals are very timely and positive, but coal-dependent cities still need comprehensive and well-developed plans to transition away from coal. The comprehensive plan for the socio-economic development of Ekibastuz for 2021–2025 contains both measures aimed at developing non-coal industries and measures supporting the development of various types of coal facilities. Examples of measures aimed at developing non-coal industries include the expansion of a small industrial zone and the formation of a larger industrial zone, small business support, production of railway cluster products, production of technical silicon, construction of a plant producing screws and terminals, and the expansion of the greenhouse complex. In the coal sector, a research centre for coal chemistry and the coal industry in the city of Ekibastuz is planned, together with a switch to auto-conveyor technology for mining and transporting coal, a new coal power unit No. 3 at Ekibastuz GRES-2 Power Plant and the restoration of coal power unit No. 1 at Ekibastuz GRES-1 Power Plant.[95] The modernisation of coal mining and the construction of new coal-fired power plant units mean that a phase-out of coal is not planned for at least the next 40 years, neither in Ekibastuz nor in Kazakhstan.

For many countries that rely heavily on coal, its phase-out may seem impossible. However, the world has already seen examples of phase-outs in such countries. One of the most striking examples is the United Kingdom, where coal was a significant element of its industrial revolution and an essential industry for centuries. This example is especially interesting because the abandonment of coal began in the UK as a response to a confluence of economic and environmental factors, and well before the phase-out decisions were made at the state level.[96] The decline of coal mining in the UK started long ago, in the mid-20th century, due to increased costs and intensified market competition. The number of coal miners fell from 607 000 in 1960 to 1 000 in 2016,[97] and the last deep coal mine, Kellingley Colliery in North Yorkshire, closed in December 2015.[98] Coal-fired power plants still supplied over 20% of all electricity in 2015, though this was much lower than the 65% supplied in 1990. By 2021, the share of coal had dropped below 3%; it was largely replaced by natural gas and renewables, especially wind (Figure 19). Now, coal-fired power plants only help to meet peak demand. Thus, in three decades, the UK has almost phased out coal from its power sector entirely, even though in 1990 it provided almost the same share of electricity as it does in Kazakhstan now – two-thirds.

92 Inbusiness (2023). Ekibastuz plans to build a plant for the production of locomotive tires. URL: https://inbusiness.kz/ru/last/v-ekibastuze-planiruyut-postroit-zavod-po-proizvodstvu-lokomotivnyh-bandazhej.
93 Inbusiness (2023). A non-ferrous metallurgy plant is expected to be launched in Ekibastuz by the end of the year. URL: https://inbusiness.kz/ru/last/do-konca-goda-v-ekibastuze-ozhidaetsya-zapusk-zavoda-cvetnoj-metallurgii.
94 Inbusiness (2020). A small industrial zone opened in Ekibastuz. URL: https://inbusiness.kz/ru/last/v-ekibastuze-otkrylas-malaya-industrialnaya-zona.
95 On approval of the Comprehensive plan for the socio-economic development of the city of Ekibastuz, Pavlodar region for 2021 – 2025. URL: https://adilet.zan.kz/rus/docs/P2100000819.
96 Fothergill S. (2017). Coal Transition in the United Kingdom // IDDRI and Climate Strategies. URL: https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Rapport/201706-iddri-climatestrategies-coal_uk.pdf.
97 Ibid.
98 Reuters (2015). Britain's last deep coal mine Kellingley Colliery closes. URL: https://www.reuters.com/article/uk-britain-coal-idUKKBN0U11BU20151218.

Power mix of the United Kingdom, 1990–2021

→ Fig. 19



IEA (2023); United Kingdom: https://www.iea.org/countries/united-kingdom

One of the key milestones in the UK's coal phase-out was the introduction of the Carbon Price Support (CPS) in 2013, which imposed a tax on carbon emissions from power generation at the level of £16 (€18.05) per tonne of carbon dioxide-equivalent (t CO_2e), and was set to increase gradually.[99] This made coal less economically attractive. In 2017, the UK and Canada launched the Powering Past Coal Alliance,[100] which signalled the UK's commitment to phasing out unabated coal power. In 2015, the UK Government set a groundbreaking milestone by becoming the world's first country to declare the objective of entirely eliminating unabated coal power generation from its power mix, with a target date of 2025.[101] This deadline was later brought forward to 1 October 2024.[102]

As the experience of the United Kingdom shows, as do the results of the modelling presented earlier in this study, even if Kazakhstan decides to abandon coal in the near future, this path will take at least three decades. However, that leaves enough time to achieve carbon neutrality by 2060.

99 LSE (2019). What is a carbon price and why do we need one? URL: https://www.lse.ac.uk/granthaminstitute/explainers/what-is-a-carbon-price-and-why-do-we-need-one/.
100 The Guardian (2021). Cancel all planned coal projects globally to end 'deadly addiction', says UN chief. URL: https://www.theguardian.com/environment/2021/mar/02/cancel-all-planned-coal-projects-globally-to-end-deadly-addiction-says-un-chief.
101 PPCA (2023). United Kingdom. URL: https://poweringpastcoal.org/members/united-kingdom/.
102 UK Government (2021). End to coal power brought forward to October 2024. URL: https://www.gov.uk/government/news/end-to-coal-power-brought-forward-to-october-2024.

5 Thin ice on the path to power sector decarbonisation

Navigating the complexities of energy transition requires a comprehensive approach that recognises the ongoing need for power sector reforms and substantial investments to modernise ageing infrastructure. While the allure of simpler paths, like reverting to familiar technologies such as coal (including CHP) or gas power plants, or swiftly transitioning from coal to natural gas, may seem tempting, such paths pose significant risks. They could in reality result in stranded assets, wasted time, compromised energy security, and ultimately higher costs compared to a carefully planned and gradual shift towards sustainable energy options. This section delves into the substantial risks associated with pursuing these seemingly easy alternative options.

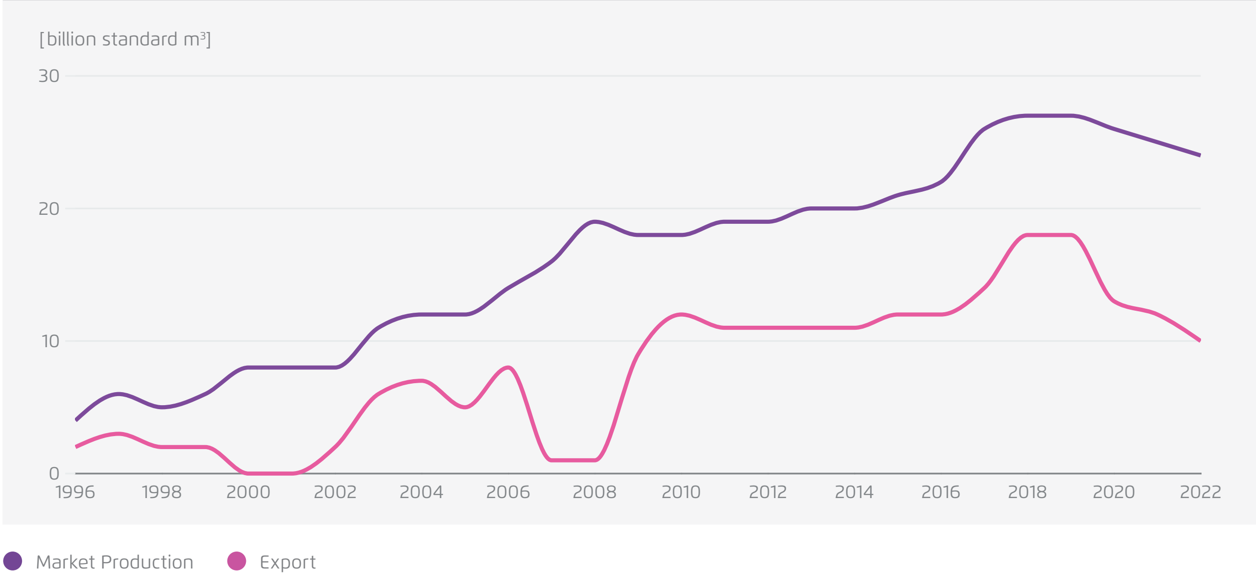
5.1 Coal-to-gas transition

For many years, natural gas has been seen as a transitional energy source in the shift towards a decarbonised power system. However, the Russian war in Ukraine has called this pathway into question for many countries, and especially for the EU, where a quick phase-out of Russian gas became essential. And even before this, doubts were raised that natural gas could really function as a bridge fuel, since it potentially impedes rather than enables the energy transition and crowds out investment in renewables.[103,104]

According to OPEC data, in 2022, Kazakhstan took 21st place globally for proven natural gas reserves, 30th place for marketed production and 25th place for exports.[105] However, its domestic gas consumption is growing, which jeopardises the continued

103 IISD (2021). Gas Is Not a Bridge Fuel, It's a Wall. So Why Are Governments Still Financing It? URL: https://www.iisd.org/articles/gas-bridge-fuel.
104 Gürsan C., de Gooyert V. (2021). The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition? // Renewable and Sustainable Energy Reviews. – Vol. 138, 110552. URL: https://doi.org/10.1016/j.rser.2020.110552.
105 OPEC (2023). Data download. URL: https://asb.opec.org/data/ASB_Data.php.

Natural gas production and export in Kazakhstan → Fig. 20



OPEC (2023). Data download: https://asb.opec.org/data/ASB_Data.php export of this fuel and even threatens to create a shortage within the country (Figure 20). The threat of a shortage was noted, in particular, by the Vice Minister of Energy Zhandos Nurmaganbetov,[106] as well as by President Kassym-Jomart Tokayev.[107]

At the same time, as the President rightly noted,[108] restricting the sale of natural gas on foreign markets in order to provide supplies to the domestic market will entail economic losses. Kazakhstan sells its gas abroad at a higher price than within the country. Gas exports are already carried out on a residual basis, after the full satisfaction of domestic needs. There have been discussions over stopping gas exports completely in the winter of 2023–2024.[109] Kazakhstan (together with Turkmenistan and Uzbekistan) mainly supplies gas to China via the Central Asia-China gas pipeline. Uzbekistan also faces a shortage of energy and, in particular, a shortage of its own gas for domestic supplies. For that reason it may stop gas deliveries to the south of Kazakhstan in the very near future.[110]

Saving natural gas through a direct transition to renewable energy sources, bypassing the stage of using it as a transition fuel, will allow Kazakhstan to sell gas in foreign markets at higher prices. In some areas, switching from coal to gas will be practically unavoidable, particularly in large cities suffering from harmful emissions from coal-fired power plants, such as Almaty, Astana and Karaganda. Many power plants in these cities produce not only electricity but also heat for district heating systems. Combined heat and power (CHP) plants will be difficult to replace quickly with RES, since this will require investment not only in new cleaner electric power facilities, but also in cleaner heat, as well as in the entire local energy infrastructure. However, it would be sensible to limit the coal-to-gas transition only to such cases of urgent necessity, where a reduction of harmful emissions has been badly needed for many years already. In less acute circumstances, it makes more sense to switch directly from coal to RES without transitional stages.

But even in situations where a coal-to-gas transition is urgently needed, it should be borne in mind that in a longer term perspective, green hydrogen may replace natural gas. In fact, any new gas-fired capacities should be H2-ready, while policies on natural gas at the national level should be reviewed more thoroughly. Such an approach will definitely help Kazakhstan to avoid investing in a great number of potential stranded assets.

5.2 Coal-to-"green" coal transition

Kazakhstan is one of the few countries in the world where building new coal power plants is still being discussed. In order to make this debate less self-contradictory and to maintain the country's ambitious climate goals, many officials and company representatives sometimes speak of a mysterious "green" or "clean" coal. For example, in 2022, plans to develop "clean" coal technologies, along with both renewable energy technologies and modern gas and nuclear generation, were announced by Prime Minister Alikhan Smailov.[111] As Energy Minister Bolat Akchulakov explained, such technologies assume the maximum possible waste-free use of coal. According to the minister himself, such technologies are still experimental throughout the world. However,

106 Sputnik (2023). Gas shortage is brewing in Kazakhstan – Ministry of Energy. URL: https://ru.sputnik.kz/20230622/v-kazakhs2tane-nazrevaet-defitsit-gaza---minenergo-36243718.html.
107 Official website of the President of the Republic of Kazakhstan (2022). Speech by Head of State Kassym-Jomart Tokayev at an expanded meeting of the Government. URL: https://akorda.kz/ru/vystuplenie-glavy-gosudarstva-kasym-zhomarta-tokaeva-na-rasshirennom-zasedanii-pravitelstva-1463854.
108 Ibid.
109 Zakon (2023). They turned the valve: why Kazakhstan may refuse gas exports. URL: https://www.zakon.kz/stati/6388799-zakrutili-ventil-pochemu-kazakhstan-mozhet-otkazatsya-ot-eksporta-gaza.html.
110 Ibid.

111 Official Information Source of the Prime Minister of the Republic of Kazakhstan (2022). Kazakhstan plans to introduce "green coal" technology and develop renewable energy. URL: https://primeminister.kz/ru/news/vnedryat-tehnologii-chistogo-uglya-i-razvivat-vozobnovlyaemuyu-energetiku-planiruetsya-v-kazahstane-1893523.

Kazakhstan intends to launch a „clean coal" project for the efficient use of coal reserves in the country's energy sector.[112]

One much-debated idea for making coal "clean" is carbon capture and storage (CCS). In 2021, KazMunayGas (the national oil and gas company of the Republic of Kazakhstan) and Shell Kazakhstan B.V. signed a Memorandum of Cooperation in the development of carbon capture, utilisation and storage (CCUS) technology.[113] A similar memorandum was signed between KazMunayGas and Chevron in 2022.[114] Since 2022, KazMunayGas has been developing a CCUS pilot project and determining the potential of CO_2 injection for increasing oil recovery from depleted oil reservoirs.[115] In its low-carbon development concept document, Samruk Kazyna (an investment holding company, the sole shareholder being the Government of the Republic of Kazakhstan) predicts that in one of its scenarios (the decarbonisation scenario) the share of thermal power plants with CCUS may comprise 13% by 2032; and in another scenario (the deep decarbonisation scenario), 7% by 2040. The organisation is also investigating the scope for implementing CCUS technologies in Kazakhstan.[116]

As an IRENA study notes, carbon capture and utilisation (CCU), carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies are often confused with CCUS, which is not correct since these technologies have fundamental differences.[117] CCU and CCS technologies are at a very initial stage of discussion in Kazakhstan. Globally, they are not laboratory technologies any more, but they are still far from full commercial availability (e.g. very few thermal power plants with CCS have been built in the world) and still too expensive. According to current estimates, CCS adds 70%-100% to generation costs, which makes power produced at coal power plants with CCS more expensive than solar or wind power.[118],[119] Moreover, CCS capital costs are mostly made up of balance-of-system components, and for that reason they may not decrease significantly, even if innovations occur.

It should also be noted that implementing CCS in a power plant reduces its overall energy efficiency. The process of capturing, transporting, and storing carbon dioxide requires a considerable amount of energy, which reduces the net energy output of the power plant. Also, there are potential environmental risks associated with the storage of CO_2 underground, including leaks and groundwater contamination. Ultimately, it makes little sense to mine coal, then combust it, then capture CO_2 emissions, and then store them, especially when less environmentally damaging and more affordable options are available, such as renewable energy.

112 Kazinform (2022). The Ministry of Energy is considering more environmentally friendly methods of using coal. URL: https://www.inform.kz/ru/bolee-ekologichnye-metody-ispol-zovaniya-uglya-rassmatrivaet-minenergo_a3991682.

113 Shell (2021). Press release on the signing of a memorandum of cooperation between NC Kazmunaygas JSC and Shell Kazakhstan B.V. URL: https://www.kmg.kz/ru/press-center/press-releases/876/.

114 Chevron (2022). Chevron and Kazmunaygas announce collaboration on lower carbon opportunities. URL: https://www.kmg.kz/ru/press-center/press-releases/956/.

115 Kazmunaygas (2022). Sustainable development report. URL: https://www.kmg.kz/upload/iblock/637/7xc3c1l11d0zzuzrmpmlzd0byw6esnmf/KMG_RU_29.08.23_Spread.pdf.

116 Samruk Kazyna (2022). Concept of low-carbon development of Samruk-Kazyna. URL: https://sk.kz/investors/financial-performance/reports/low-carbon_development_concept_ru.pdf.

117 IRENA (2021). Reaching Zero with Renewables. Capturing Carbon. URL: https://www.irena.org/-/media/Irena/Files/Technical-papers/IRENA_Capturing_Carbon_2021.pdf?rev=bf05359177504164aab7fad527b35e0d.

118 Wood Mackenzie (2022). Renewable power in Asia Pacific gains competitiveness amidst cost inflation. URL: https://www.woodmac.com/press-releases/renewable-power-in-asia-pacific-gains-competitiveness-amidst-cost-inflation/.

119 Lazard (2023). Lazard's Levelized Cost of Energy Analysis—Version 16.0. URL: https://www.lazard.com/media/typdgxmm/lazards-lcoeplus-april-2023.pdf.

Another very important aspect of CCS, CCU and CDR technologies is that their role in decarbonisation is often misunderstood. The idea is not that they should decrease the emissions that result from business-as-usual fossil fuel use, but that they should be used where emissions are unavoidable.[120] They will therefore be necessary above all in the cement, steel and chemical industries, but not in coal-fired power plants, where fossil fuel can be replaced by renewables. CCS, CCU and CDR technologies may therefore play a very important role in the achievement of carbon neutrality, but not in the coal sector and not in the next few years.

As already mentioned in the previous chapter, some existing coal-fired power plants could be used in Kazakhstan to increase flexibility so as to integrate more variable renewable power in the medium term. No new coal power plants should be built in Kazakhstan, and a plan must be developed for a gradual and just phase-out of existing coal power plants.

120 IRENA (2021). Reaching Zero with Renewables. Capturing Carbon. URL: https://www.irena.org/-/media/Irena/Files/Technical-papers/IRENA_Capturing_Carbon_2021.pdf?rev=bf05359177504164aab7fad527b35e0d.

6 Concluding remarks

In the next few years, Kazakhstan will have to make a choice between trying to maintain the existing structure of its electricity sector (and thus the status quo of its whole economy) at any cost, as one option, and pursuing a transition of its power sector from coal directly to renewables, as the other option. This choice will determine the signals that Kazakhstan will send to domestic and foreign investors far beyond the electricity sector alone.

If the country chooses new huge conventional power plants, it will most likely have to finance them from public funds or foreign credits in view of the shrinking number of financial institutions still willing to finance, for example, coal. And it will miss the opportunity to create a foundation for the development of a modern environmentally-friendly and socially-inclusive economy together with the associated emerging high-added-value industries such as electric transport and power-to-X, as well as for the production of carbon-neutral products. The electricity sector is the load-bearing pillar for the transition to a green economy. The under-reformed and patched-up electric power industry simply will not withstand the pressure of such a large-scale transition.

And very different prospects open up for Kazakhstan if it decides to begin the energy transition now, creating a flexible and competitive electricity industry and integrating as much variable RES as possible. Such a modernised power industry will later help open the doors to foreign private investment into many other industries and thus strengthen Kazakhstan's leadership within Central Asia and perhaps beyond.

This study employs a robust modelling approach using the Python for Power System Analysis (PyPSA) framework to simulate Kazakhstan's power system in the year 2030. The model integrates an array of conventional and renewable power sources to determine how electricity demand can be met under diverse scenarios, incorporating varying shares of renewable energy. The scenarios shed light on potential shifts in Kazakhstan's energy landscape , taking into account the country's ambitious goals and strategic energy plans.

The scenarios analysed in this study are: **Business as usual (BAU)**, which envisages a share of 15% for variable renewables in 2030, corresponding to current strategic documents and goals up to 2030; **Improved business as usual (iBAU)**, which provides for a slightly higher share of 20% for variable renewables; **Cost-optimised generation mix (OPT)**, which estimates how far coal capacity can be economically phased down in Kazakhstan by 2030, subject to cost optimisation of the generation mix and the same (existing) line capacities; and **Cost-optimised generation mix with cost-optimised transmission capacities (OPT^2)**, where both the generation mix and transmission capacities are cost-optimised. These scenarios vary in the proportion of variable renewables (solar PV and wind) versus coal in their generation mix, providing valuable insights into the country's energy transformation trajectory.

The results reveal a substantial increase in overall installed capacity by 2030, with a notable decline in the proportion of coal both in capacity (from the current 55% to below 30%) and generation (from the current 67% to below 50%) mixes, reflecting a transition towards a cleaner, more diversified energy portfolio. This shift is driven by the remarkable rise in solar PV and wind capacity, approaching a five-fold increase from current levels. It is crucial to align these scenarios with environmental commitments, particularly Kazakhstan's nationally determined contribution (NDC) under the Paris Agreement up to 2030. Achieving the 2030 NDC commitment, in particular an unconditional 15% reduction in GHG emissions compared to 1990 levels, requires a substantial reduction in the share of coal in electricity generation, down to 40%. The OPT^2 scenario, which provides for the lowest (45%) share of coal in the power mix and 11% lower annualised CAPEX than the BAU scenario, emerges as a strategically optimal pathway, aligning with cost-efficiency requirements and at the same time meeting the 2030 NDC. Solar PV and wind are projected to be the most cost-effective power sources in Kazakhstan in 2030. The levelised cost of energy (LCOE) for these renewables in 2030 across all scenarios is estimated to be almost two times (47–62%) cheaper than for new build coal-fired power plants.

Embarking on the journey of energy transition unveils a multitude of challenges, particularly as variable renewables rise to significant proportions in the power system. Striking the delicate balance required in handling the increasing shares of solar and wind generation, judiciously incentivising investors, phasing out outdated coal-fired infrastructure, and at the same time mitigating electricity price spikes demands strategic and careful planning. Tempting shortcuts, such as a swift transition from coal to gas, or building new coal capacities and decarbonising them with CCS technologies, pose a significant risk of creating stranded assets, compromising energy security, and higher costs. A prudent approach is imperative to ensure a successful transition to a sustainable and efficient energy landscape, avoiding unnecessary expenditure and adverse consequences.

Up until 2030, addressing the variability of high shares of solar PV and wind power involves dispelling myths and misconceptions, highlighting feasible solutions, and building up a diversified energy mix. Grid reinforcement and development, including the connection of the Western energy zone with the rest of the system, are urgent priorities in Kazakhstan to enhance stability and enable the efficient transportation of variable power over larger distances. Flexible generation (including dispatchable renewables), energy storage and accurate forecasting of variable renewable energy generation will all play pivotal roles in enabling a smooth transition. Sector coupling, demand management and embracing small-scale renewable facilities will also contribute to a reliable and balanced renewable energy system, aligning with the nation's sustainable energy objectives.

In the longer term, up until 2050, strategies like integrating electrolysers and electric vehicles for enhanced flexibility can further optimise the renewable energy system. A holistic approach, combining multiple strategies in all energy sectors, all tailored to the renewable energy mix and local conditions, is crucial to achieving a resilient and sustainable energy future for Kazakhstan. The evolving energy landscape demands comprehensive transformation and careful planning, incorporating current trends and a gradual coal phase-out to minimise losses from stranded assets and position Kazakhstan as a leader in the global energy transition.

Market design is crucial to integrating high shares of variable renewable energy sources at a low cost. The evolution of Kazakhstan's electricity market structure over the years demonstrates a shift from a vertically integrated monopoly to a more diversified and partially liberalised multi-market system. The most recent significant transformation occurred on July 1 2023, when Kazakhstan adopted the single electricity buyer model and a real-time balancing electricity market. The introduction of the single buyer model is intended to mitigate the impact of high tariffs from new power plants or costly imported electricity on individual consumers. By distributing the tariffs among all consumers in order to reduce the burden on individual consumers, the model is meant to help maintain a balance between affordable prices and affordable investments. Additionally, it seeks to equalise consumer electricity prices across regions. Globally, there is a consensus that well-designed liberalised electricity markets can maximise efficiency, especially for the integration of variable renewables. The single buyer model should serve as an intermediate step towards achieving fully liberalised and competitive electricity markets in Kazakhstan.

The decision to phase out coal presents Kazakhstan with an especially formidable challenge due to its complex social, economic, and energy security implications coupled with the traditional conservatism within the energy sector. However, the usual arguments in favour of coal power in Kazakhstan are gradually losing their relevance. For example, the country's energy security, and especially its heat supply during harsh winters, is compromised by the obsolescence of coal-fired power plants and their associated infrastructure and by frequent accidents causing disruptions in heat supply to communities.

Decoupling heat from power generation, and transitioning to renewable alternatives in both sectors, offers enhanced energy security and fosters international economic collaboration. Heat pumps can efficiently cater for both heating and cooling needs, which is crucial for Kazakhstan's diverse climate. The country's existing widespread district heating systems can be compatibly enhanced by heat pumps, significantly boosting overall efficiency.

Social and economic considerations, particularly concerns about job losses, often obstruct coal phase-out plans. But a well-structured coal phase-out plan can facilitate a smooth transition, enabling regions to prepare for economic diversification, workforce retraining, early retirement and other necessary adjustments. Some coal-dependent towns in Kazakhstan are already making efforts to diversify their economies and thereby demonstrating the potential benefits of a well-prepared transition.

Countries like the United Kingdom have successfully phased out coal from their power mix, demonstrating the feasibility of such transitions. In Kazakhstan's case, a phased approach spanning at least three decades seems a plausible plan. International examples and modelling outcomes show that transitioning away from coal is a realistic endeavour that provides ample time to achieve carbon neutrality by 2060 — a vital goal for a sustainable future.

Annex 1. PyPSA default data

1. Grid topology data
The power grid topology is constructed using OpenStreetMap (OSM) data. OSM is the largest collectively contributed repository containing geographic information and geolocations updated on a daily basis. OSM data are retrieved and stored by executing the *download_osm_data* rule. The data is stored in *data/osm/<region>/pbf/*, where "region" represents the country or continent of interest (e.g. Kazakhstan). As an output of *download_osm_data* rule, generators, substations, lines, and cables are individually saved as geojson files in the folder *resources/<project name>/osm/raw/*. The rule *clean_osm_data* refines OSM network data by transforming the initial raw OSM data into polished datasets containing all network assets—namely, generators, substations, lines and cables. These datasets are stored within the *resources/<project name>/osm/clean/* folder.

2. Climate data
In PyPSA-Earth, the atlite package manages the handling of climate data. It retrieves all necessary weather and climate information to produce renewable potential time series through the *build_renewable_profiles* rule. The primary source of climate-related data is the ERA5 reanalysis dataset.

3. General data
Several datasets are utilised within PyPSA-Earth to construct a realistic model. The initial datasets are stored in the designated *data/* directory. These datasets can be grouped into environmental, economic and technological data. At present, the following resources are in use:

3.1. Environmental data
The **copernicus** repository comprises raw land coverage data sourced from the Copernicus database. In the *build_renewable_profiles* rule, this information is employed to assess the viable land areas for implementing renewable resources. For instance, renewable installations might be restricted from being set up on cultivatable land.

The **eez** dataset encompasses Exclusive Economic Zones (EEZ) data sourced from Marine Regions. Within the *build_shapes* rule, this file is used to determine the maritime regions linked to each country and provide the corresponding shapes of these oceanic areas. These shapes can be potentially employed for estimating offshore renewable potential, among other applications.

The **gebco** is a gridded bathymetric dataset that can be converted into measurements of underwater depths and configurations of submerged landscapes. This dataset find application within the *build_renewable_profiles* rule. The acronym GEBCO stands for the General Bathymetric Chart of the Oceans.

hydrobasins datasets pertain to delineations of watershed boundaries and basins, sourced from HydroBASINS. These datasets play a role in approximating hydropower generation within the *build_renewable_profiles* rule.

The landcover dataset defines the outlines of globally protected areas, essential for pinpointing regions where no (renewable) assets can be placed. This landcover dataset was employed to create a natura.tiff raster image.

3.2. Economic data
The **costs.csv** file contains information about the typical costs of various technologies, their lifetimes and efficiency metrics. This dataset is designed to provide an initial reference for initiating the model, although there might be a requirement for regional modifications. For individual information, see https://github.com/PyPSA/technology-data.
The **gadm** directory holds information regarding the outlines of administrative regions within each country (such as regions, districts, provinces, etc.), tailored to the resolution specified in the configuration file. The data in this directory are automatically generated by the *build_shapes* process, which retrieves this information from the gadm website.

The **GDP** raster dataset, sourced from DRYAD, provides information about Gross Domestic Product (GDP) across global regions.

The **WorldPop** raster dataset, used in the *build_shapes* rule, provides population data based on geographical divisions.

3.3. Technological data

The **eia_hydro_annual_generation.csv** file holds information about the collective energy output from existing power plants, reported on a country basis by the open platforms of the US Energy Information Administration (EIA). This data is employed for aligning the runoff time series, which is derived from global reanalysis data.

Annex 2. PyPSA custom data

1. Custom power plants data
The **custom_powerplant.csv** file located in *pypsa-kz-data/data/* folder contains information about Kazakhstan's power plants obtained from open sources[121],[122],[123]. The data contains the name, fuel type, technology, type (PP or CHP), capacity (in MW), installed date and exact geographic location (i.e. latitude and longitude) of the power plants. In total, 144 power plants are reported, comprising 30 coal, 33 gas, 42 small and large hydro, 16 onshore wind and 23 solar power plants.

2. Demand data
The **official_demand.csv** file contains the total annual consumption in 2020 in each administrative zone. The data is taken from the official national report of KAZENERGY[124]. The file is located in the *pypsa-kz-data/data/* folder. The data consists of the names of the administrative zones, their corresponding buses, and their annual consumption in GWh.

3. Imports/exports data
The **electricity_exp-imp.csv** file contains monthly electricity imports and exports of Kazakhstan to neighbouring Russia, Kyrgyzstan, and Uzbekistan. The volume of the imports and exports is provided in GWh.

121 Open Infrastructure Map (2023). Kazakhstan Power Plants. URL: https://openinframap.org/stats/area/Kazakhstan/plants.
122 Wikipedia (2023). List of Kazakhstan's power plants. URL: https://ru.wikipedia.org/wiki/%D0%A1%D0%BF%D0%B8%D1%81%D0%BE%D0%BA_%D1%8D%D0%BB%D0%B5%D0%BA%D1%82%D1%80%D0%BE%D1%81%D1%82%D0%B0%D0%BD%D1%86%D0%B8%D0%B9_%D0%9A%D0%B0%D0%B7%D0%B0%D1%85%D1%81%D1%82%D0%B0%D0%BD%D0%B0.
123 Energybase (2023). Energy of Kazakhstan: oil and gas sector, electric power industry. URL: https://energybase.ru/country/kazakhstan.
124 Kazenergy (2021). The national energy report Kazenergy 2021. URL: https://www.kazenergy.com/upload/document/energy-report/NationalReport21_en.pdf.

Glossary

Term	Explanation
Baseload generation	Power generation that provides a constant, reliable level of electricity to meet the minimum demand on the grid at any given time
Carbon capture and storage (CCS)	A process that captures carbon dioxide emissions from different sources like power plants or industrial facilities (e.g. steel or cement production) and stores them underground to prevent them from entering the atmosphere
Carbon capture and utilisation (CCU)	A process that captures carbon dioxide emissions from different sources like power plants or industrial facilities (e.g. steel or cement production) or from the air and converts or utilises this captured CO_2 to produce valuable products or materials (e.g. synthetic fuels)
Carbon dioxide removal (CDR)	Technologies and approaches aimed at removing carbon dioxide from the atmosphere, contributing to carbon neutrality or negative emissions
Carbon neutrality	Achieving a balance between emitted carbon dioxide and removed carbon dioxide from the atmosphere, resulting in a net zero carbon footprint
Combined cycle power turbine (CCGT)	CCGT combines the functionalities of both a gas turbine and a steam turbine. CCGT captures the waste heat of its gas turbine exhaust to generate steam that drives its steam turbine
Curtailment of renewables	The reduction or limiting of renewable energy output due to various reasons, such as oversupply or grid limitations
Demand response	Adjusting electricity consumption in response to pricing or incentive signals, often to balance supply and demand
Electricity demand management	Strategies and tools to regulate and influence patterns and levels of electricity consumption in order to optimise energy usage
Electrolyser	A device that uses electricity to split water into hydrogen and oxygen, a key technology in producing green hydrogen
Green hydrogen	Hydrogen produced using 100% renewable electricity through electrolysis, typically considered as a clean and sustainable energy carrier
Grid reinforcement	Retrofitting, upgrading, or strengthening of existing power lines and associated components within the transmission and distribution grids to enhance their capacity, reliability, and efficiency, as well as to integrate new sources of energy

Term	Explanation
Levelised cost of energy (LCOE)	The average net present cost of generating a unit of electricity (usually 1 MWh) over the lifetime of a generating asset
Nationally determined contribution (NDC)	Commitments made by countries under the Paris Agreement to reduce their greenhouse gas emissions and achieve specific individual targets
Open cycle gas turbine (OCGT)	An OCGT generates mechanical power by expanding a combination of compressed air and high-pressure, high-temperature flue gas. In an open-cycle setup, the exhaust is discharged into the environment
Power-to-X (PtX or P2X)	Technologies that convert electricity into gases (e.g. green hydrogen), liquids (synthetic fuels) or heat; the term encompasses a large number of technologies
PyPSA (Python for Power System Analysis)	A Python-based framework used for analysing and simulating power systems to study and model energy scenarios
Sector coupling	Integrating different energy-consuming sectors (power, heating, transport) to optimise energy usage and reduce waste
Stranded assets	Assets that have become obsolete or non-viable before the end of their expected economic life
Variable renewables	Renewable energy sources like wind and solar PV that are intermittent and not constantly available for generation, as opposed to continuous sources like hydropower or geothermal
Weighted average cost of capital (WACC)	The cost of capital proportionally weighted for each category of capital

References

Agora Energiewende (2019). *A word on grids*. How electricity grids can help integrate variable renewable energy. URL: https://agora-energiewende.de/en/publications/a-word-on-grids/.

Agora Energiewende (2019). *Unlocking low cost renewables in South East Europe*. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2019/De-risking_SEE/161_Unlocking_SEE_EN_WEB.pdf.

Agora Energiewende (2023). *From coal to renewables: a power sector transition in Kazakhstan*. URL: https://static.agora-energiewende.de/fileadmin/Projekte/2022/2022_09_INT_Kazakhstan/A-EW_295_Kazakhstan_EN_WEB.pdf.

Amprion (2023). *The energy transition demands innovators*. URL: https://www.amprion.net/documents/Amprion/Innovation/Amprion-Innovation-Report.pdf.

AZ Nations (2023). *Population of countries of the world*. URL: https://ru.aznations.com/population/kz/cities/ekibastuz.

BNEF (2022). *Global energy storage market to grow 15-fold by 2030*. URL: https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/.

BOGA (2021). *Who we are*. URL: https://beyondoilandgasalliance.org/who-we-are/.

Carbon Tracker (2023). *Kazakhstan Energy Transition*. URL: https://carbontracker.org/reports/kazakhstan-energy-transition/.

Central Communication Service under the President of the Republic of Kazakhstan (2023). URL: https://ortcom.kz/ru/deyatelnost-pravitelstva/1688116720.

Chevron (2022). *Chevron and Kazmunaygas announce collaboration on lower carbon opportunities*. URL: https://www.kmg.kz/ru/press-center/press-releases/956/.

CLEW (2016). *Volatile but predictable: Forecasting renewable power generation*. URL: https://www.cleanenergywire.org/factsheets/volatile-predictable-forecasting-renewable-power-generation.

Climate Ambition Summit (2020). *Kassym-Jomart Tokayev President of Kazakhstan*. URL: https://www.climateambitionsummit2020.org/ondemand.php.

Decree of the Government of the Republic of Kazakhstan dated March 28, 2023 No. 263. On approval of the Concept for the development of the electric power industry of the Republic of Kazakhstan for 2023–2029. URL: https://adilet.zan.kz/rus/docs/P2300000263.

Decree of the President of the Republic of Kazakhstan dated February 2, 2023 No. 121. *On approval of the Strategy for achieving carbon neutrality of the Republic of Kazakhstan until 2060*. URL: https://adilet.zan.kz/rus/docs/U2300000121.

Decree of the President of the Republic of Kazakhstan of May 30, 2013, #557. *Concept for transition of the Republic of Kazakhstan to Green Economy*. URL: https://adilet.zan.kz/rus/docs/U1300000577.

Ember (2023). *EU power sector 2030 target tracker*. URL: https://ember-climate.org/data/data-tools/european-renewables-target-tracker/.

Ember (2023). *Yearly electricity data*. URL: https://ember-climate.org/data-catalogue/yearly-electricity-data/.

Enerdata (2023). *Energy intensity*. URL: https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html.

Entsoe (2023). *Generation forecasts for wind and solar*. URL: https://transparency.entsoe.eu/.

European Commission (2023). *Electricity market design*. URL: https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/electricity-market-design_en.

Financial Settlement Center of RE (2023). *About us*. URL: https://www.rfc.kz/about.

Financial settlement center of RE (2023). *Auction results*. URL: https://rfc.kz/en/auctions/results.

Forbes (2019). *44% of the state budget of Kazakhstan is formed by the oil and gas sector*. URL: https://forbes.kz/process/energetics/44_gosudarstvennogo_byudjeta_kazahstana_formiruet_neftegazovyiy_sektor/.

Forbes (2023). *$50 billion project: how green hydrogen will be produced in Kazakhstan*. URL: https://forbes.kz/economy/energy-subsoil/kak_v_kazahstane_realizuyut_proekt_po_proizvodstvu_zelenogo_vodoroda_stoimostyu_50_mlrd/.

Fothergill S. (2017). *Coal Transition in the United Kingdom* // IDDRI and Climate Strategies. URL: https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Rapport/201706-iddri-climatestrategies-coal_uk.pdf.

Guidehouse, Agora Energiewende (2023). *Electricity Market Design for Climate Neutrality: Fundamentals*. URL: https://static.agora-energiewende.de/fileadmin/Partnerpublikationen/2023/Agora_Power_market_design_fundamentals_Guidehouse.pdf.

Gürsan C., de Gooyert V. (2021). *The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition?* // Renewable and Sustainable Energy Reviews. – Vol. 138, 110552. URL: https://doi.org/10.1016/j.rser.2020.110552.

IAEA (2008). *Financing of New Nuclear Power Plants // Nuclear Energy Series*. URL: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1345_web.pdf.

IEA (2020). *Kazakhstan*. URL: https://www.iea.org/countries/kazakhstan.

IEA (2022). *The Future of Heat Pumps*. URL: https://www.iea.org/reports/the-future-of-heat-pumps.

IEA (2023). *Demand response*. URL: https://www.iea.org/energy-system/energy-efficiency-and-demand/demand-response.

IEA (2023). *United Kingdom*. URL: https://www.iea.org/countries/united-kingdom.

IISD (2021). *Gas Is Not a Bridge Fuel, It's a Wall*. So Why Are Governments Still Financing It? URL: https://www.iisd.org/articles/gas-bridge-fuel.

Inbusiness (2020). *A small industrial zone opened in Ekibastuz*. URL: https://inbusiness.kz/ru/last/v-ekibastuze-otkrylas-malaya-industrialnaya-zona.

Inbusiness (2023). *A non-ferrous metallurgy plant is expected to be launched in Ekibastuz by the end of the year*. URL: https://inbusiness.kz/ru/last/do-konca-goda-v-ekibastuze-ozhidaetsya-zapusk-zavoda-cvetnoj-metallurgii.

Inbusiness (2023). *Ekibastuz plans to build a plant for the production of locomotive tires*. URL: https://inbusiness.kz/ru/last/v-ekibastuze-planiruyut-postroit-zavod-po-proizvodstvu-lokomotivnyh-bandazhej.

Inbusiness (2023). *In Ekibastuz they promise to build GRES-3 by 2029*. URL: https://inbusiness.kz/ru/last/v-ekibastuze-obeshayut-postroit-gres-3-do-2029-goda.

IRENA (2019). *Solutions to integrate high shares of variable renewable energy*. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_grid_integration_2019.pdf.

IRENA (2020). *Advanced forecasting of variable renewable power generation. Innovation landscape brief.* URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Advanced_weather_forecasting_2020.pdf?la=en&hash=8384431B56569C0D8786C9A4FDD56864443D10AF.

IRENA (2021). *Reaching Zero with Renewables*. Capturing Carbon. URL: https://www.irena.org/-/media/Irena/Files/Technical-papers/IRENA_Capturing_Carbon_2021.pdf?rev=bf05359177504164aab7fad527b35e0d.

IRENA (2023). *Installed electricity capacity (MW) by Country/area, Technology, Grid connection and Year*. URL: https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/ELECCAP_2023_cycle2.px/.

Kazenergy (2021). *The national energy report Kazenergy 2021*. URL: https://www.kazenergy.com/upload/document/energy-report/NationalReport21_en.pdf.

Kazinform (2021). *I set the task to increase the share of renewable energy sources in power generation to 15% by 2030 - Head of State*. URL: https://www.inform.kz/ru/uvelichit-dolyu-vie-v-elektrogeneracii-do-15-k-2030-godu-poruchenie-glavy-gosudarstva_a3792969.

Kazinform (2022). *Eleven houses in Ekibastuz are still without heat connection – Akimat*. URL: https://www.inform.kz/ru/odinnadcat-domov-v-ekibastuze-vse-esche-ostayutsya-bez-podklyucheniya-k-teplu-akimat_a4009481.

Kazinform (2022). *The Ministry of Energy is considering more environmentally friendly methods of using coal*. URL: https://www.inform.kz/ru/bolee-ekologichnye-metody-ispol-zovaniya-uglya-rassmatrivaet-minenergo_a3991682.

Kazinform (2023). *The construction time frame for GRES-3 in Ekibastuz has become known*. URL: https://www.inform.kz/ru/stali-izvestny-sroki-stroitel-stva-gres-3-v-ekibastuze_a4028889.

Kazmunaygas (2022). *Sustainable development report*. URL: https://www.kmg.kz/upload/iblock/637/7xc3c1l11d0zzuzrmpmlzd0byw6esnmf/KMG_RU_29.08.23_Spread.pdf.

Kazpravda (2022). *What's wrong with the night rate?* URL: https://kazpravda.kz/n/chto-ne-tak-s-nochnym-tarifom/.

KEGOC (2017–2021). *Annual Reports 2017–2021*. URL: https://www.kegoc.kz/ru/for-investors-and-shareholders/raskrytie-informatsii/annual-reports/.

KEGOC (2022). *JSC KEGOC: the advanced development of the National Electric Grid of Kazakhstan is what we need now*. URL: https://www.kegoc.kz/ru/press-center/mass-media-about-the-company/158042/.

KEGOC (2023). *Project Integration of the energy system of Western Kazakhstan with the UES of Kazakhstan*. URL: https://www.kegoc.kz/ru/about/investicionnye-proekty/155662/.

Kim I (2023). *Prospects for implementing a demand response program in Kazakhstan* // Qazaq Green. URL: https://qazaqgreen.com/journal-qazaqgreen/analitycs/1424/.

Kursiv (2023). *How much will nuclear energy cost in Kazakhstan?* URL: https://kz.kursiv.media/2023-03-03/zhnb-aesnuclear/.

Lazard (2023). *Lazard's Levelized Cost of Energy Analysis—Version 16*.0. URL: https://www.lazard.com/media/typdgxmm/lazards-lcoeplus-april-2023.pdf.

LSE (2019). *What is a carbon price and why do we need one?* URL: https://www.lse.ac.uk/granthaminstitute/explainers/what-is-a-carbon-price-and-why-do-we-need-one/.

Ministry of Energy of the Republic of Kazakhstan (2022). *Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035*. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.

Ministry of Energy of the Republic of Kazakhstan (2022). *Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035*. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.

Ministry of Energy of the Republic of Kazakhstan (2023). *On the balancing electricity market*. URL: https://www.gov.kz/memleket/entities/energo/press/news/details/589399?lang=ru.

National Bank of the Republic of Kazakhstan (2023). *Base rate decision-making schedule 2015–2023*. URL: https://www.nationalbank.kz/ru/news/grafik-prinyatiya-resheniy-po-bazovoy-stavke/rubrics/1843.

Office of National Statistics (2023). *Fuel and energy balance of the Republic of Kazakhstan (2022)*. URL: https://stat.gov.kz/ru/industries/business-statistics/stat-energy/publications/5186/.

Official Information Source of the Prime Minister of the Republic of Kazakhstan (2022). *Kazakhstan is ready to become regional centre for renewable energy development – Alikhan Smailov*. URL: https://primeminister.kz/ru/news/kazahstan-gotov-stat-regionalnym-centrom-razvitiya-vozobnovlyaemyh-istochnikov-energii-alihan-smailov-8101253.

Official Information Source of the Prime Minister of the Republic of Kazakhstan (2022). *Kazakhstan plans to introduce „green coal" technology and develop renewable energy*. URL: https://primeminister.kz/ru/news/vnedryat-tehnologii-chistogo-uglya-i-razvivat-vozobnovlyaemuyu-energetiku-planiruetsya-v-kazahstane-1893523.

Official website of the President of the Republic of Kazakhstan (2023). *President Kassym-Jomart Tokayev's speech at the Plenary Session of Astana International Forum*. URL: https://www.akorda.kz/ru/vystuplenie-prezidenta-respubliki-kazahstan-ktokaeva-na-plenarnoy-sessii-mezhdunarodnogo-foruma-astana-851830.

Official website of the President of the Republic of Kazakhstan (2021). *The Head of State held a meeting on the development of the electric power industry*. URL: https://akorda.kz/en/the-head-of-state-held-a-meeting-on-the-development-of-the-electric-power-industry-2641630.

Official website of the President of the Republic of Kazakhstan (2023). *Kassym-Jomart Tokayev and Frank-Walter Steinmeier hold negotiations in extended format*. URL: https://www.akorda.kz/en/kassym-jomart-tokayev-and-frank-walter-steinmeier-hold-negotiations-in-extended-format-205383.

Official website of the President of the Republic of Kazakhstan (2023). *President Kassym-Jomart Tokayev `s State of the Nation Address „Economic course of a Just Kazakhstan"*. URL: https://www.akorda.kz/en/president-kassym-jomart-tokayevs-state-of-the-nation-address-economic-course-of-a-just-kazakhstan-283243.

Official website of the President of the Republic of Kazakhstan (2022). *Speech by Head of State Kassym-Jomart Tokayev at an expanded meeting of the Government*. URL: https://akorda.kz/ru/vystuplenie-glavy-gosudarstva-kasym-zhomarta-tokaeva-na-rasshirennom-zasedanii-pravitelstva-1463854.

On approval of the Comprehensive plan for the socio-economic development of the city of Ekibastuz, Pavlodar region for 2021–2025. URL: https://adilet.zan.kz/rus/docs/P2100000819.

OPEC (2023). *Data download*. URL: https://asb.opec.org/data/ASB_Data.php.

Order of the Minister of Energy of the Republic of Kazakhstan dated March 24, 2022 No. 104 *„On approval of the Energy Balance of the Republic of Kazakhstan until 2035"* (as amended on January 30, 2023). URL: https://online.zakon.kz/Document/?doc_id=37351758&pos=4;-90#pos=4;-90.

Our World in Data (2023). *Energy*. URL: https://ourworldindata.org/energy.

PPCA (2023). *United Kingdom*. URL: https://poweringpastcoal.org/members/united-kingdom/.

REN21 (2023). *Renewables 2023 Global Status Report collection, Renewables in Energy Supply*. URL: https://www.ren21.net/gsr-2023/modules/energy_supply/01_energy_supply.

Reuters (2015). *Britain's last deep coal mine Kellingley Colliery closes*. URL: https://www.reuters.com/article/uk-britain-coal-idUKKBN0U11BU20151218.

Samruk Kazyna (2022). *Concept of low-carbon development of Samruk-Kazyna*. URL: https://sk.kz/investors/financial-performance/reports/low-carbon_development_concept_ru.pdf.

Shell (2021). *Press release on the signing of a memorandum of cooperation between NC Kazmunaygas JSC and Shell Kazakhstan B.V.* URL: https://www.kmg.kz/ru/press-center/press-releases/876/.

SMARD (2023). *Electricity generation and consumption in Germany*. URL: https://www.smard.de/en.

Sovacool B.K., Gilbert A., Nugent D. (2014). *An international comparative assessment of construction cost overruns for electricity infrastructure* // Energy Research & Social Science. – Vol. 3, pp. 152–160. URL: https://doi.org/10.1016/j.erss.2014.07.016.

Sputnik (2021). *Heads of the EAEU will adopt a statement on the union's climate agenda – Tokayev*. URL: https://ru.sputnik.kz/20211013/eaes-zayavlenie-klimat-tokaev-18399002.html.

Sputnik (2023). *Gas shortage is brewing in Kazakhstan – Ministry of Energy*. URL: https://ru.sputnik.kz/20230622/v-kazakhstane-nazrevaet-defitsit-gaza---minenergo-36243718.html.

Sputnik (2023). *To prevent blackouts in the west of Kazakhstan: what does the Cabinet of Ministers plan besides repairs at MAEK*. URL: https://ru.sputnik.kz/20230817/ne-dopustit-blekautov-na-zapade-kazakhstana-chto-planiruet-kabmin-krome-remonta-na-maek-37746323.html.

Tengri News (2023). *Accident at Ekibastuz Thermal Power Plant: the case was sent to court*. URL: https://tengrinews.kz/kazakhstan_news/avariya-na-ekibastuzskoy-tets-delo-napravili-v-sud-502399/.

Tengri News (2023). *KEGOC JSC sums up the first results of reforms in the energy supply market*. URL: https://tengrinews.kz/kazakhstan_news/ao-kegoc-podvodit-pervyie-itogi-reform-ryinke-506577/.

Tengri News (2023). *Residents of Ekibastuz are freezing in their apartments again: the thermal power plant commented on the situation*. URL: https://tengrinews.kz/kazakhstan_news/jiteli-ekibastuza-snova-zamerzayut-kvartirah-tets-491567/.

The Guardian (2015). *Wind power generates 140% of Denmark's electricity demand*. URL: https://www.theguardian.com/environment/2015/jul/10/denmark-wind-windfarm-power-exceed-electricity-demand.

The Guardian (2021). *Cancel all planned coal projects globally to end 'deadly addiction', says UN chief*. URL: https://www.theguardian.com/environment/2021/mar/02/cancel-all-planned-coal-projects-globally-to-end-deadly-addiction-says-un-chief.

The Ministry of Energy (2022). *Information on the production of electricity by renewable energy facilities in the first half of 2023*. URL: https://www.gov.kz/memleket/entities/energo/documents/details/496972?lang=ru.

The Ministry of Energy of the Republic of Kazakhstan (2022). *Concept for the development of the electric power industry of the Republic of Kazakhstan until 2035*. URL: https://www.gov.kz/memleket/entities/energo/documents/details/349883?lang=ru.

The Ministry of Energy of the Republic of Kazakhstan (2022). *Information on the production of electrical energy by renewable energy facilities based on the results of 2022*. URL: https://www.gov.kz/memleket/entities/energo/documents/details/403997?lang=ru.

The World Bank (2000). *The Single-Buyer Model*. A Dangerous Path toward Competitive Electricity Markets. URL: https://documents1.worldbank.org/curated/en/779321468780281965/pdf/22403-Replacement-file-225LOVEI.pdf.

The World Bank (2017). *Stuck in Transition: Reform Experiences and Challenges Ahead in the Kazakhstan Power Sector*. URL: https://www.worldbank.org/en/country/kazakhstan/publication/kazakhstan-power-sector-note.

The World Bank (2023). *Coal rents (% of GDP)*. URL: https://data.worldbank.org/indicator/NY.GDP.COAL.RT.ZS?locations=XO.

The World Bank (2023). *Natural gas rents (% of GDP)*. URL: https://data.worldbank.org/indicator/NY.GDP.NGAS.RT.ZS?locations=XO.

The World Bank (2023). *Oil rents (% of GDP)*. URL: https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS?locations=XO.

UK Government (2021). *End to coal power brought forward to October 2024*. URL: https://www.gov.uk/government/news/end-to-coal-power-brought-forward-to-october-2024.

UN Climate Change Conference UK 2021 (2021). *Global coal to clean power transition statement*. URL: https://webarchive.nationalarchives.gov.uk/ukgwa/20230313120149/https://ukcop26.org/global-coal-to-clean-power-transition-statement/.

UZ Daily (2021). *EBRD to support Uzbekistan in achieving carbon neutrality*. URL: https://www.uzdaily.uz/en/post/65118.

Wood Mackenzie (2022). *Renewable power in Asia Pacific gains competitiveness amidst cost inflation*. URL: https://www.woodmac.com/press-releases/renewable-power-in-asia-pacific-gains-competitiveness-amidst-cost-inflation/.

World Bank (2023). *Europe and Central Asia: Toward a Framework for the Sustainable Heating Transition*. URL: https://documents1.worldbank.org/curated/en/099092023140527206/pdf/P1777440fed3230ce089060ff8ce59c9f5e.pdf.

World Nuclear Association (2020). *Median construction times for reactors since 1981*. URL: https://www.world-nuclear.org/gallery/world-nuclear-performance-report-gallery/median-construction-times-for-reactors-since-1981.aspx.

World Nuclear Association (2023). *Small Nuclear Power Reactors*. URL: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx.

Zakon (2022). *Kazakhstan is not ready to abandon coal power plants even by 2035*. URL: https://www.zakon.kz/politika/6024684-kazakhstan-i-k-2035-godu-ne-gotov-otkazatsia-ot-ugolnykh-elektrostantsii.html.

Zakon (2023). *A single electricity purchaser will appear in Kazakhstan from July 1*. URL: https://www.zakon.kz/sobytiia/6398580-v-kazakhstane-s-1-iyulya-poyavitsya-edinyy-zakupshchik-elektroenergii.html.

Zakon (2023). *They turned the valve: why Kazakhstan may refuse gas exports*. URL: https://www.zakon.kz/stati/6388799-zakrutili-ventil-pochemu-kazakhstan-mozhet-otkazatsya-ot-eksporta-gaza.html.

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