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Kazakhstan: Decarbonisation Pathways towards a Net Zero Future by 2060 – The Opportunities and Challenges ahead

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DIW Berlin
Deutsches Institut für Wirtschaftsforschung
Mohrenstraße 58
10117 Berlin
Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
www.diw.de

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Lars Handrich*
Nadiya Mankovska*
Frank Meißner*
Maria Polugodina*
Oleksandr Diachuk**
Roman Podolets**
Andrii Semeniuk**
Andrea Bassi***
Georg Pallaske***

Kazakhstan: Decarbonisation pathways towards a Net Zero future by 2060 - The opportunities and challenges ahead

Final report

Project commissioned by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and funded by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

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* DIW Econ GmbH
** National Academy of Sciences of Ukraine, Institute for Economic Forecasting
*** KnowlEdge Srl

Preface and Acknowledgements

The Republic of Kazakhstan adopted in 2013 the "Concept for the transition of the Republic of Kazakhstan towards a green economy" and belonged to the group of countries committed to tackle climate change. Since then, Kazakhstan has successfully established itself as a long-time frontrunner in the CIS and Central Asia in particular.

Kazakhstan signed the Paris Agreement on August 2, 2016 and ratified it shortly afterwards on December 6, 2016. With the ratification of the Agreement and in line with Article 4.2 of it, Kazakhstan submitted its first Nationally Determined Contribution (NDC) to the UNFCCC. The first NDC set the economy-wide unconditional target to reduce GHG emissions by 15% below 1990 levels by 2030.

The implementation of the Paris Agreement requires a huge economic and social transformation based on the best available science. It works on a 5-year cycle of continuously increasing ambitious climate action carried out by countries. Complementary to the NDC, the signatories of the Paris Agreement are encouraged to formulate and communicate long-term low greenhouse gas emission development strategies, which account for the different national circumstances, their common but differentiated responsibilities and respective capabilities in reducing greenhouse gas emissions.

The Ministry of Ecology and Natural Resources of the Republic of Kazakhstan (MENR) reached an agreement with the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety about receiving technical assistance for drafting a National Strategy for Low-Carbon Economic Development until 2050 (LEDS). The German Federal Ministry for the Environment assigned the task to provide such technical assistance to the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

In turn, GIZ launched a call for tenders for the development of a comprehensive assessment framework based on an integrated empirical modelling approach. In December 2019 the project was commissioned to the consortium led by DIW Econ. In January 2020 we were introduced by GIZ to our two local project partners, two well-established national think-tanks: JSC Zhasyl Damu, entrusted by the MENR with fostering the transition of the Republic of Kazakhstan to low-carbon development and the JSC Economic Research Institute, which is in charge of providing economic analysis for the Ministry of National Economy of the Republic of Kazakhstan.

Outside a small group of experts most people in Kazakhstan were not aware about the urgent need for climate mitigation action, not to mention about the 30 years long transition pathways

ahead towards a low-carbon future. Hence, our project started with comprehensive stakeholder consultations, only to be interrupted abruptly in March 2020 by the unfolding COVID-19 pandemic. All work had immediately to be reorganised and conducted virtually. The virtual meetings and the collection of the needed empirical data and the exchange of information on government strategies and programmes, already in existence or in preparation, turned out to be quite demanding for all sides involved. During these consultations with the Kazakh partners, we developed and agreed upon the assumptions for the different scenarios and the breadth and scope of the respective modelling work.

When in December 2020 our first results from the integrated modelling were ready for discussion, the President of Kazakhstan announced during the UN climate ambition summit that Kazakhstan would aim at reaching carbon neutrality until the year 2060. This pledge surprised all parties involved in the project and implied that almost all work had to be revised in order to elaborate new economic, technical and social pathways for achieving of the net zero emissions target and to adjust for the extended time horizon.

In August 2021 the project team handed over the new modelling results and accompanying reports to the MENR for their further integration into a draft Strategy of transition of the Republic of Kazakhstan towards carbon neutrality until 2060. Since then, due to competing interests, private and public, several drafts and redrafts of the Strategy have emerged, significant changes were made to the elaborated pathways, numbers altered and indicators omitted, but so far without finally adopting the Strategy. To add some transparency, we publish now our results in this report.

This report is the product of collaboration among many institutions and individuals. We would not have advanced much without the encouragement, patience and support we received from Ministry of Ecology and Natural Resources of the Republic of Kazakhstan, and special thanks go to Zulfia Suleimenova, Olzhas Agabekov, Ainur Kopbaeva, and Aida Aliyeva. MENR has been the most supportive partner and steered our project through some difficult and tense discussions with other ministries and departments and helped with raising the awareness about climate change and the necessary adjustments ahead.

We would like to express our gratitude for the productive exchange with the Government of Kazakhstan and the different line ministries and departments affected by climate change, among them agriculture, buildings, economy, energy, infrastructure and transport for providing us with questions, advice, information and inspiration.

We received plenty of valuable comments from national business associations, NGO's, private and state-owned companies, and representatives of international organisations in the country, like EBRD, OECD, USAID and many others.

Without the flexible and efficient project management of GIZ and especially its project manager Johannes Schuhmann and his local team, in particular Dana Yermolyonok, Rassul Amerguzhin and Zhanat Murzakulova, we would never have arrived where we are today.

The greatest support as regards data, necessary institutional information and support for capacity building related to the integrated modelling approach we received from Gulmira Ismagulova and Aidyn Bakdolotov.

We thank Clarissa Behr and Yasmin Bakr assisted with the 'nuts and bolts' of compiling this report.

Of course, all remaining errors and omissions are our own.

The authors

January 2023

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List of Abbreviations

°C	degrees Celsius
%	percent
ADB	Asian Development Bank
AFOLU	agriculture, forestry, and other land uses
Al_2O_3	aluminium oxide
ASCM	Agreement on Subsidies and Countervailing Measures
ASI	Avoid-Shift-Improve approach
BAU	Business as usual scenario
$CaCO_3$	calcium carbonate
CaO	calcium oxide
CBA	cost-benefit analysis
CBAM	carbon border adjustment mechanism
CCS	carbon capture and storage
CCUS	carbon capture, use, and storage
CGE-KAZ	Computable General Equilibrium model for Kazakhstan
CH_4	methane
CHP	combined heat and power plant
CLD	causal loop diagram
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
CRF	Common Reporting Format to the UNFCCC
DD	deep decarbonisation scenario
DRI	direct reduced iron
EAF	electric arc furnace
EBRD	European Bank for Reconstruction and Development
ECI	Economic Complexity Index
ETS	Emissions Trading System
EU	European Union
EUR	euro
EV	electric vehicle

FEC	final energy consumption
F-gases	fluorinated gases
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GE	green economy scenario
GHG	greenhouse gases
GW	gigawatt
ha	hectare
HFCs	hydrofluorocarbons
ICE	internal combustion engine
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
IRENA	International Renewable Energy Agency
ktoe	thousand tonnes of oil equivalent
kWh	kilowatt per hour
kWh/m^2	kilowatt per hour per square meter
KZT	Kazakhstani tenge
LEDS	low-emission development strategy
LiDAR	light imaging, detection and ranging
LPG	liquified petroleum gas
LULUCF	land use, land use change & forestry
ME RK	Ministry of Energy of the Republic of Kazakhstan
MEGNR RK	Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan
MIID RK	Ministry of Industry and Infrastructural Development of the Republic of Kazakhstan
MJ	megajoule
MSW	municipal solid waste
Mt	million tonnes
Mtoe	million tonnes of oil equivalent
MW	megawatt
N_2O	nitrous dioxide
na	not available

NDC	Nationally Determined Contribution
NEB	National Energy Balance
NF_3	nitrogen trifluoride
NIR	National Inventory Report
NZE	net zero emissions scenario
O&M	operation and maintenance
ODS	ozone depleting substance
OECD	Organisation for Economic Cooperation and Development
PFCs	perfluorocarbons
PV	photovoltaics
RCP	representative concentration pathways
RE	renewable energies
RK	Republic of Kazakhstan
SAM	social accounting matrix
SCC	social cost of carbon
SDG	Sustainable Development Goals
SD-KAZ	System Dynamics models for Kazakhstan
SF_6	sulfur hexafluoride
SMEs	small and medium enterprises
TICS-KAZ	Hybrid TIMES-CGE-SD model for Kazakhstan
TIMES-KAZ	The Integrated MARKAL-EFOM System model for Kazakhstan
toe	tonnes of oil equivalent
TPES	total primary energy supply
TPP	thermal power plant
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US SIF	The Forum for Sustainable and Responsible Investment
USA	United States of America
USD	United States dollar
WACC	weighted average cost of capital
WTO	World Trade Organisation

1 The decarbonisation context

1.1 The goal: Reducing GHG emissions in line with the 2 °C limit or less

This report analyses the optimal pathways and the implications of the necessary decarbonisation of the economy in Kazakhstan. “Decarbonisation” refers to the reduction of greenhouse gas (GHG) emissions over time in order to keep the global average temperature well below 2 °C above pre-industrial levels, preferably below 1.5 °C. This goal is stipulated in the Paris Agreement adopted on December 12th, 2015, by Parties to the United Nations Framework Convention on Climate Change (UNFCCC). It is also based on the scientific consensus that higher levels of temperature increase pose an unacceptably high risk of dangerous anthropogenic interference with the climate system (IPCC, 2014). Climate change will impact Kazakhstan by modifying the biome, changing precipitation patterns, and increasing water scarcity, thus impacting - among other things - agriculture. To limit the temperature increase to the 1.5-2 °C goal, it is necessary to reach the global peak in GHG emissions as quickly as possible and achieve a net neutral greenhouse gas emission world by mid-century. Thus, a fast and comprehensive reduction of GHG emissions to net zero is the most urgent political and societal objective.

As a signatory of the Paris Agreement – the legally binding international treaty on climate change – the Republic of Kazakhstan has taken the obligation to contribute to the global response to the threat of climate change: Kazakhstan has made the pledge to achieve carbon neutrality by 2060.

The transformation towards a decarbonised economy is not only beneficial for the climate, but, as shown in this report, also for Kazakhstan’s economy. The assessment of the development pathways is based on technical and economic feasibility and the cost of different technology options for reducing GHG emissions (expressed in CO_2-eq) until the year 2060.[1] The analysis rests on a comprehensive integrated modelling framework and proceeds along two alternative scenarios for the future development of Kazakhstan.

The elaboration and communication of national low-carbon economic development strategies (LEDS) is stipulated in the Paris Agreement’s Article 4.19, and, as end of December 2022, 56 countries and the European Union have already submitted their LEDS to UNFCCC. (UNFCCC, n.d.). However, most of the submitted LEDS still have a declarative character without outlaying the countries’ decarbonisation pathways in detail. To this date, this report presents the first comprehensive quantitative assessment of decarbonisation pathways, both based on explicit and

[1] The assessment includes the technologies either already in operation or at a stage of research and development, when estimations of their technological feasibility and costs exist.

integrated modelling of *all* GHG-emitting sectors and including a scenario of economy-wide net zero GHG emissions by the year 2060.

1.2 Scoping the LEDS

The goal of limiting the temperature increase to 1.5-2 °C requires both urgent action and deep transformations in the economy and society in the decades ahead. Current decisions will significantly affect the nature and scale of these transformations; lack or delay of action in the coming years can lead to lock-in effects[2] and increases the risk of stranded assets[3]. In addition, delayed action and postponed capital investments into renewable energies deprive future generations of a clean and safe environment as well as subjecting them to consumption-restricting budget constraints due to the potentially high demand on saving and investment expenditure. This would contradict the principle of fair transition to low-carbon future emphasised during several recent COP meetings.

Because GHG emissions occur across all – complex and interlinked – sectors and activities, policies towards decarbonisation should consistently cover the whole economy and society. Therefore, it is necessary to elaborate a vision for the most feasible, fair and least costly transformation into a low-carbon economy by mid-century while also pursuing sustainable economic development.

Against this backdrop, the LEDS is a crucial policy tool that helps place short-term actions in the context of the long-term structural changes required for a decarbonised and resilient economy. Furthermore, it provides a framework for exploring the cross-sectoral interactions in light of the multiple policy objectives of mitigation, socio-economic development, and adaptation, specific to each national context (Colombier, Spencer, & Waisman, 2016, p. 2). Unlike, e.g., the nationally determined contributions to climate change mitigation (NDCs), which are regularly submitted to the UNFCCC in the framework of the Paris Agreement, the LEDS is not a precise implementation roadmap or forecast. Due to its longer time horizon, it faces higher levels of uncertainty in terms of future technological developments and costs. Instead, the LEDS outlines the potential pathways over the next decades towards a future with

[2] In the context of emissions, the (carbon) lock-in effect refers to a situation when a system (industry, economy) becomes dependent on emission-intensive (in the case of energy, fossil-based) technologies and practices and cannot move towards low-emission alternatives without substantial costs.

[3] According to IEA, stranded assets are "those investments which have already been made, though at a point in time prior to the end of their economic life (as assumed at the investment decision point), are seen to no longer earn economic returns as a result of changes in the market and regulatory environment brought about by climate policy" (IRENA, 2017, p. 13).

a decarbonised economy and thus will require regular monitoring and updating to reflect new technological advancements and changing global conditions.

In line with its objectives, the present LEDS of Kazakhstan is based on comprehensive quantitative modelling of Kazakhstan's economy and energy system following the *backcasting* approach. It takes into account the intersectoral linkages, energy-system peculiarities and dependencies as well as relevant socioeconomic benchmarks. Unlike forecasting, which utilises recent developments in an attempt to predict the future, in backcasting the starting point of analysis is the future target, e.g., the goal of carbon neutrality in 2060 as pledged by Kazakhstan in December 2020. Going backwards in time from the desired future state, the modelling determines the direction of structural and technological development that aligns the present setting to the stated goal. To assess the socioeconomic impacts of such developments, backcasting is done in combination with a counterfactual analysis, where scenarios reaching the desired outcomes are compared to a benchmark of no-action ("business as usual") scenario (for a description of scenarios used in this LEDS, see Section 3.5).

1.3 Greenhouse gases specified by UNFCCC

The Paris Agreement takes the greenhouse gases as specified by UNFCCC into account. Greenhouse gases contribute to global warming and rising temperatures, therefore their release into the atmosphere needs to be reduced and eventually stopped.

The most important greenhouse gas in terms of released volumes is carbon dioxide (CO_2), of which the largest part originates from combusting fossil fuels (coal, oil, gas), solid waste and other organic materials. Some industrial processes and product uses (IPPU) and their related chemical reactions also cause significant CO_2 emissions. Carbon dioxide is removed from the atmosphere (or "sequestered") and stored in carbon sinks when it is absorbed by vegetation as part of the biological carbon cycle and in the oceans.

Methane (CH_4) ranks second in terms of the released volumes of GHG emissions, but it has a 25 times higher global warming potential (i.e., methane causes much stronger trapping of heat in the atmosphere). Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock farming and other agricultural practices as well as through the decay of organic waste in municipal solid waste landfills and from handling wastewater under anaerobic conditions (in absence of oxygen).

Nitrous oxide (N_2O) is emitted during agricultural and industrial activities, combustion of fossil fuels and solid waste, as well as during the treatment of wastewater.

Finally, the F-gases[4] are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes (e.g., production of aluminium). While the released volumes of F-gases are relatively low, they are extremely dangerous for the climate due to both their enormous global warming potential and the very long time they remain in the atmosphere.

In Table 1-1, the GHG emissions in Kazakhstan are presented as reported by the UNFCCC. Between 1990 and 2017, emissions of CO_2 increased and accounted for almost 85% of all GHG emissions in 2017.[5] Over the same period, methane emissions declined, mostly because of a decline in agricultural production as well as improvements in the oil and gas sector with increased attention to fugitive emissions from the exploration, extraction, processing, transportation, and distribution of fossil fuels[6] (see Sections 2.2 and 2.4, respectively, for more detail).

Table 1-1
Gross GHG emissions by gas, as reported by the UNFCCC, Mt CO_2-eq and % of total

	1990		**2017**	
	Mt CO_2-eq	**%**	**Mt CO_2-eq**	**%**
CO_2	274.9	72.0%	327.0	84.8%
Non-CO_2	106.8	28.0%	58.8	15.2%
CH_4	*87.7*	*23.0%*	*39.4*	*10.2%*
N_2O	*19.1*	*5.0%*	*17.9*	*4.6%*
Aggregate F-gases	*na*		*1.5*	*0.4%*
HFCs	*na*		*1.1*	*0.3%*
PFCs	*na*		*0.4*	*0.1%*
Unspecified mix of HFCs and PFCs	*na*		*na*	
SF_6	*na*		*0.002*	*0.001%*
NF_3	*na*		*na*	
Total GHG	**381.7**	**100%**	**385.8**	**100%**

Data: (UNFCCC)

[4] Fluorinated gases (F-gases) are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). They have global warming effect up to 23 000 times greater than carbon dioxide (CO2). While HFCs are relatively short-lived, PFCs and SF_6 can remain in the atmosphere for thousands of years.

[5] The reference year with most available information and data is 2017. When available, more recent data was incorporated and the models respectively calibrated.

[6] The improvements reported for methane emissions are not the result of actual measurements and a rigorous bottom-up assessment at facility level, identifying equipment-specific emission sources, numbers of equipment units and measurement of rates per type. Instead, Kazakhstan reports methane emissions under Tier 1, the simplest method using relatively aggregate and readily available activity variables, with default emission factors for activity variables. The default emission factors are listed in the IPCC Guidelines.

1.4 The IPCC common reporting format sector classification

The Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change, sets the guidelines for reporting National Greenhouse Gas Inventories to the UNFCCC. The IPCC common reporting format (CRF) differentiates between emissions and removals by source and type[7] and contains the following sectors:

The **energy sector** covers *all* emissions related to the production and combustion of fossil fuels, independent of where they are combusted. Therefore, it covers not only the production of electricity and heat but also emissions from fuel combustion in industry, transport, as well as in commercial and residential buildings. The energy sector also includes fugitive emissions resulting from extraction and transportation of fossil fuels (e.g., gas flaring, pipeline leakages).

The category of **industrial processes and product use** (IPPU) covers all emissions from industry *not related* to fuel combustion. Such emissions mostly result from the chemical reactions in industrial processes (e.g., CO_2 emissions in production of cement and aluminium) or the use of solvents, F-gases, etc.

The **agriculture, forestry, and other land uses (AFOLU)** sector includes emissions resulting directly from agricultural production, such as emissions from enteric fermentation, the application of mineral nitrogen fertilisers, manure management, and from soil cultivation and agricultural waste. But AFOLU is also capable of absorbing GHG emissions, i.e., storing carbon in a sink. This is because it includes emissions and absorption from all types of land, such as forest land, cropland, grassland, wetlands, or settlement land. Whether the sector is a net carbon emitter or net carbon sink depends on the relative amounts of carbon sequestration by the vegetation (biomass), carbon release from, e.g., soil degradation or forest fires, and changes in both resulting from land conversion, wood harvesting, etc.

The **waste** sector covers methane (CH_4) emitted by the anaerobic decomposition of organic waste disposed of in solid waste disposal sites and by the handling of wastewater under anaerobic conditions. In addition, the incineration of waste produces emissions of CO_2, CH_4 and N_2O.

Table 1-2 provides an overview of the IPCC categories in relation to the sectoral classification of economic activities in Kazakhstan. It particularly illustrates how all economic activities contribute to emissions from the energy sector.

[7] The IPCC sector classification by source and type of emissions differs from the more common approach developed by the UN Statistical Division to differentiate sectors by economic activity.

Table 1-2
IPCC categories and economic sectors in Kazakhstan

IPCC category	Emission source	Gases	Economic activity (classification code)
Energy: Electricity & heat	- Electricity & heat plants - Other energy industries	CO_2	Electricity & heat consumption by - Agriculture & forestry (A) - Mining, manufacturing & construction (B, C, F) - Trade & services (G, H52-H53, I-U) Fuel combustion by - Electricity & heat generation & distribution (D)
Energy: Manufacturing & construction	Direct fuel combustion in industry	CO_2	Direct fuel combustion by - Mining (B) - Manufacturing (C) - Construction (F)
Energy: Transport	Direct fuel combustion in transport	CO_2	Direct fuel combustion by - Rail and road transport, pipeline transport (H49) - Water transport (H50) - Air transport (H51)
Energy: Other fuel combustion	Direct fuel combustion by other sectors; biomass combustion	CO_2, CH_4, N_2O	Direct fuel combustion by - Agriculture & forestry (A) - Commercial & residential buildings (G, H52-H53, I-U)
Energy: Fugitive emissions	Emissions from extraction & transportation of fossil fuels	CO_2, CH_4, N_2O	- Coal mining: CH_4, N_2O (B05) - Gas flaring: CO_2 (B06) - Oil & gas natural system: CH_4 (H49)
Industrial processes & product use (IPPU)	Emissions from industrial production unrelated to fuel combustion or energy use	CO_2, CH_4, N_2O, F-gases	- Mineral production (C23) - Chemical products (C20) - Metallurgy (C24-C25) - Cooling, air conditioning, use of solvents
Agriculture	- Fertiliser application - Livestock & manure - Other agricultural processes	CH_4, N_2O	Agriculture (A01)
Land use, land use change & forestry (LULUCF)	Emissions and sequestration from all types of land and biomass	CO_2	Forestry (A02)
Waste	Emissions from waste decomposition and waste treatment	CO_2, CH_4, N_2O	Water and waste management (E)

Source: Own presentation

2 The decarbonisation challenge in Kazakhstan

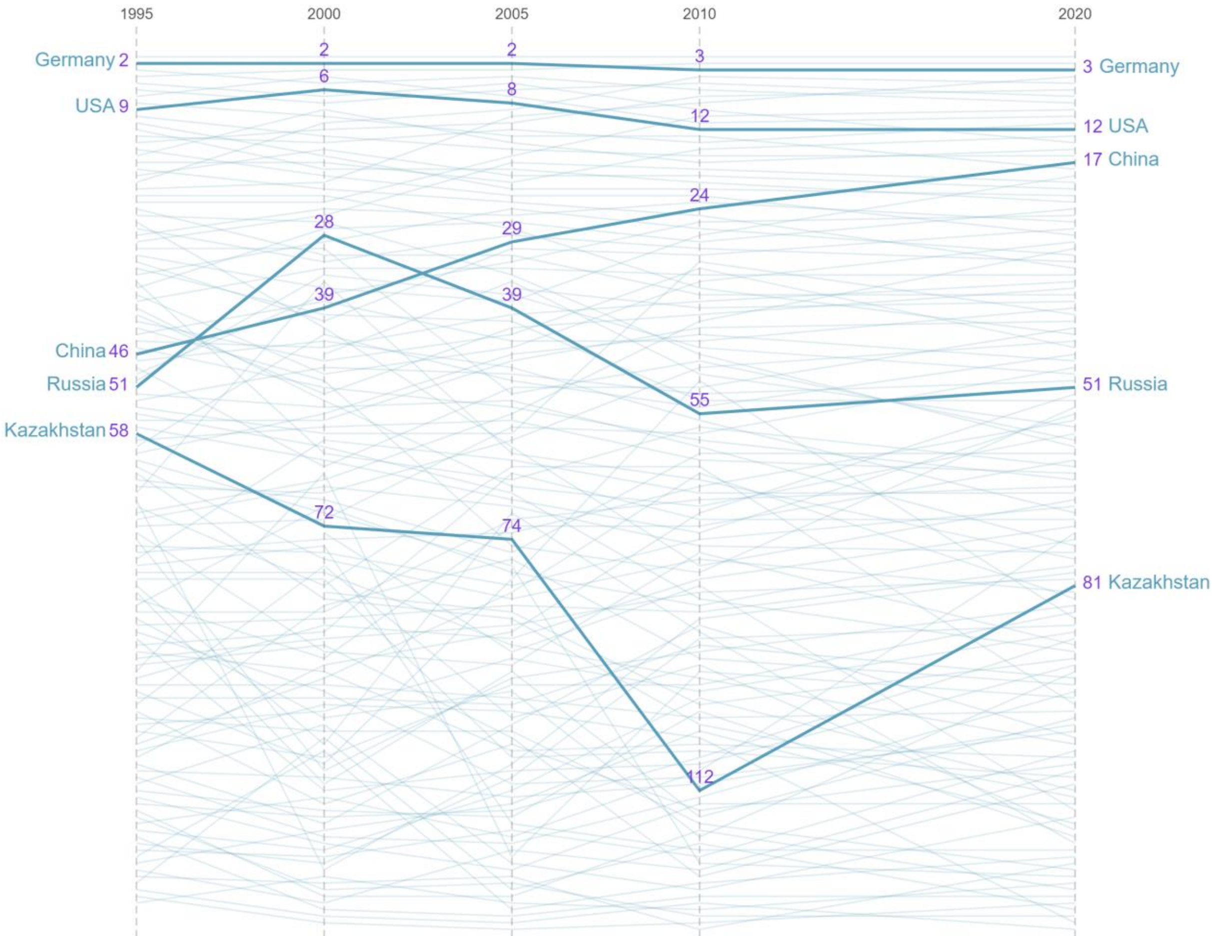
2.1 Economic challenges

Over the last decades, the government of Kazakhstan has pursued with top priority the fast scaling up of the fossil fuel and mining sectors, building an economic model deeply founded on the rich natural endowments of the country and dependent on the export of fossil fuels and minerals. This strategy created the impressive economic growth in the aftermath of the Russian financial crisis, and the Kazakh economy grew by about 300% since 1998. The downside of this growth strategy is that, while overall exports and export revenues increased, the so-called 'complexity' of the economy and exports continuously declined, especially in comparison to Kazakhstan's main trading partners (see Figure 2-1).[8] An economic complexity expresses the diversity and sophistication of the productive capabilities embedded in the exports of each country. The higher the economic complexity the more accumulated productive knowledge and its use in more and more complex industries are required. In fact, economic complexity is a fair predictor of future economic growth. With exports currently dominated by fossil fuels, Kazakhstan is less complex than its income level suggests. Thus, if the current policies continue, the economic growth is likely to slow down in the coming decades.

The destinations of Kazakh exports also play a role, since fossil fuels and especially oil from Kazakhstan are mostly exported to OECD countries, and the largest share is absorbed by the European Union, followed by South Korea, China, and Japan (Figure 2-2). With few exceptions, the current importers of fossil fuels from Kazakhstan announced comprehensive policies to fight climate change and some already actively pursue ambitious decarbonisation strategies. The European Union is targeting carbon neutrality by the year 2050, while China made a pledge to zero carbon emissions by 2060. The USA re-joined the Paris Agreement in 2021 and announced that it would reach net zero emissions economy-wide by no later than 2050.

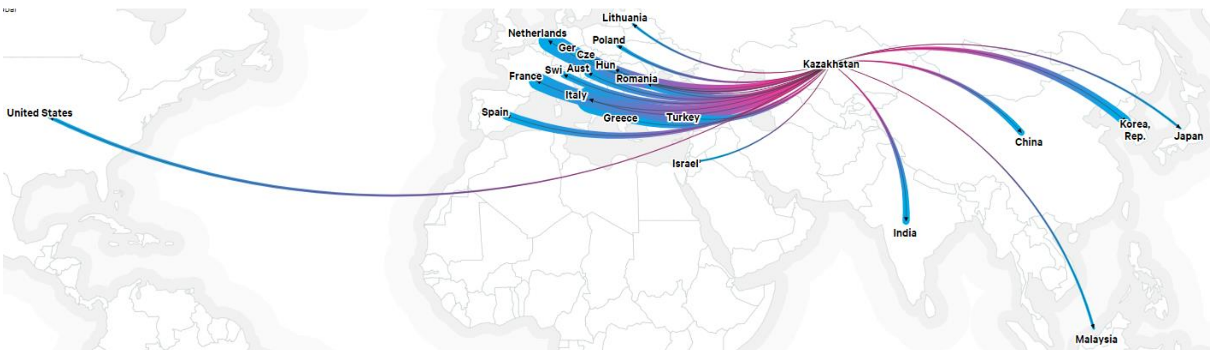
[8] Harvard Growth Lab's Country Rankings assess the current state of a country's productive knowledge through the Economic Complexity Index (ECI). The Economic Complexity Index is a ranking of countries based on the diversity and complexity of their export basket. High-complexity countries are home to a range of sophisticated, specialised capabilities and are, therefore, able to produce a highly diversified set of complex products. Economic complexity of a country depends not only on the productive knowledge of a country and the absolute number of products that it makes. It also depends on the ubiquity of those products (the number of countries that export the product) and the sophistication and diversity of products those other countries make. https://atlas.cid.harvard.edu/what-is-the-atlas, retrieved May 11, 2021.

Figure 2-1
Complexity of exports from Kazakhstan and its main trading partners (2018)



Source: https://atlas.cid.harvard.edu/

Figure 2-2
Destinations of oil exports from Kazakhstan (2019)



Source: https://resourcetrade.earth/

The most resolute policies so far are implemented by the European Union. The EU adopted ambitious targets and put a set of policies into action with the goal of transitioning to a net-zero carbon economy by 2050. First, the "European Green Deal" will both broaden the sectoral coverage of the EU-ETS and introduce a carbon tax on most other greenhouse gas emissions. Second, as part of the "Action Plan on Financing Sustainable Growth", the EU Commission is establishing a clear and detailed "EU taxonomy", a classification system for sustainable activities aiming to direct financial investments towards GHG emitting projects and activities while drying out investments in carbon assets. Third, a new "Green" foreign trade strategy of the EU is prepared to integrate the bloc's economic and climate-related priorities as reflected in the Green Deal. Fourth, the upcoming EU carbon border adjustment mechanism (CBAM) is set to start its operation and will be phased in gradually over the next few years. With the CBAM, the carbon content of imported goods exceeding specific benchmarks and originating from countries with less ambitious climate policies and lower carbon prices will be priced at the EU border. The EU-CBAM will cover initially a selected number of goods with a high risk of carbon leakage: e.g., iron and steel, cement, fertiliser, aluminium, and electricity generation. A reporting system will initially be applied for those products with the objective of facilitating a smooth rollout and stimulating dialogue with third countries. It is expected that from 2026 onwards, importers will start paying a financial compensation.

Talks between the USA and the EU have commenced about creating a "carbon club" and aligning climate policies. While the outcome of these talks is still uncertain, they may result in the integrated carbon markets or sectoral carbon clubs across the Atlantic, while other countries like Japan and South Korea may join the clubs as well.

Decarbonisation in major export markets will reduce future global demand for fossil fuels, which in turn increases the risk of stranded upstream fossil fuel assets in Kazakhstan. Moreover, sustainability considerations (both, environmental and social) and various climate change mitigation efforts are increasingly included in investment decisions and will have profound effects on international financial markets. The EU investment taxonomy is just one example of explicitly including such considerations into the regulatory framework. Another example is the increasing inclusion of climate and environmental risks into the policy and supervision activities of central banks (NGFS, 2022). These changes in regulations and decision-making approaches also increase the risk of stranded downstream fossil fuel assets in Kazakhstan, specifically in power generation, buildings, and industry. For the latter, a decline in demand for carbon-intensive products will lead to even higher risks of stranded assets. The fossil-fuel-based economic model of Kazakhstan will turn increasingly unsustainable and pressure for change will mount.

2.2 Energy sector

The energy sector is the largest source of GHG emissions in Kazakhstan. At present, about 80% of all annual GHG emissions in Kazakhstan are generated in the energy sector, and 32% of these are attributed to heat and power generation (MEGNR RK, 2020). Although the sector emissions were 6% below the 1990 level in 2017, the emission levels have steadily increased since 2001, on average by 5% annually.

The high emission level of the energy sector results from the extensive use of fossil fuels accounting for 98.9% of total primary energy supply in 2017, whereas the share of alternative energy sources was just 1.7% (Table 2-1). On the final demand side, the direct combustion of fossil fuels covered 69% of energy end use, the remainder is accounted for by the electricity and heat generated from fossil fuels (mostly coal).

Table 2-1
Structure of primary energy supply and final energy demand in 1990 and 2017

	Primary energy supply		Final energy demand	
	1990	**2017**	**1990**	**2017**
Coal	55%	54%	26%	23%
Oil and oil products	29%	24%	26%	31%
Natural gas	15%	22%	13%	14%
Renewables	0.8%	1.7%	0.2%	0.2%
Electricity	-	-0.6%[9]	14%	16%
Heat	-	-	21%	15%

Data: ADB (2009), Bureau of National statistics

Coal is currently the main energy source in Kazakhstan, and it carries the largest carbon footprint. In 1990, coal accounted for 65% of GHG emissions in the energy sector, and for 59% in 2017, despite its smaller share in energy supply or demand (MEGNR RK, 2020). A fuel switch from thermal coal to natural gas would significantly reduce GHG emissions from the energy sector. Because natural gas is a considerably cleaner fuel with a higher energy content, the combustion of natural gas causes fewer emissions of nearly all types of air pollutants and produces half as much carbon dioxide than burning coal for the same amount of energy. While the current gasification projects are pursued to replace thermal coal with more environmentally friendly natural gas, their implementation is progressing rather slowly.

The persistent high energy intensity of the other economic sectors is adding to the challenges of decarbonisation in the energy sector. While efforts are being made to increase the energy

[9] Electricity exports.

efficiency of the economy of Kazakhstan, as stipulated by the Concept for transition of the Republic of Kazakhstan to Green Economy (Green Economy Concept, 2013), the use of fossil energies across economic sectors is still extensive and excessive and accounts for almost a third of all emissions in the energy sector. Improving energy efficiency and shifting away from fossil fuels remains an important challenge for the economy of Kazakhstan.

Finally, although fugitive emissions in the energy sector were successfully reduced in the 1990s and the 2000s, they have stabilised since 2010 and still account for around 10% of energy sector GHG emissions as of 2020[10]. Fugitive emissions occur both in primary energy extraction (e.g., associated gas in oil extraction and coalbed methane released during mining) and in distribution (e.g., pipeline leakages)[11]. This implies, that further efforts for reducing fugitive emissions are necessary. Overall, the decarbonisation of the energy sector will require large investments and will trigger major shifts in consumer behaviour on the final energy demand side.

2.2.1 Primary energy supply

At present, primary energy in Kazakhstan is supplied mainly through the extraction of coal, crude oil, and natural gas. These three economic activities together account for 12.5% of value added and 2.4% of employment (see Table 2-2)[12]. However, 79% of crude oil and 89% of natural gas extracted in Kazakhstan are exported. As a result, coal, crude oil, and natural gas account for 11% of total demand in the economy (including exports) but only 1.8% of the domestic demand (the intermediate use for production in other sectors and the final consumption within Kazakhstan).

Furthermore, because emissions occur in sectors where the fuels are combusted, and exported fossil fuels are combusted outside of Kazakhstan, their use is not part of the national GHG inventory. At the same time, fuels combusted for the secondary energy conversion and final demand are attributed to the respective sectors, e.g., building, transport, industry and agriculture. Consequently, while GHG emissions from the production of primary energy account for 16.9% of the GHG emissions, 7.7% of those are fugitive emissions, while 6.5% are covered alone by the fugitive emissions from coal extraction (22.4 Mt CO_2-eq in 2017).

[10] Based on the 2022 CRF submission of Kazakhstan. The measurements of fugitive emissions are generally characterised by high levels of uncertainty.

[11] After building and burying a pipeline geologic hazards, corrosion, and third-party damages all pose cumulative internal and environmental risks to the pipeline's integrity. The detection of pipeline leaks requires permanent pipeline mapping and modern leak detection and repair programmes (e.g., with LiDAR).

[12] For employment, data are only available for the mining sector, i.e., including mining of ores and minerals. In terms of value added, the share of coal, oil, and gas accounts for 75% of the sector.

Table 2-2
Characteristics of economic activities related to primary energy supply

	2017
Total production, billion USD	32.62
Value added in extraction of coal, crude oil, and natural gas, billion USD	18.53
Share in total value added, %	12.5%
Share in employment (with other mining), %	3.3%
Share in total domestic use, %	1.8%
Share in fuel combustion emissions (energy use only), %	11.3%
Share in total emissions (including fugitive), %	16.9%
Fugitive emissions	*7.7%*
- of those, fugitive emissions from coal extraction, %	*6.5%*

Data: Bureau of National Statistics, MEGNR RK (2020)

In short, coal accounts for the largest share of GHG emissions in the primary energy supply, because of both the coalbed methane released during coal extraction and coal combustion. Therefore, stopping coal extraction and coal combustion (coal exit) is the most important step for any GHG decarbonisation effort in Kazakhstan.

2.2.2 Secondary energy conversion: Power and heat sector

The sector of heat and power generation is relatively small in economic terms, accounting for just under 2% of the total value added and employment in Kazakhstan. It is, however, vital for the proper functioning of the Kazakh economy and society. Moreover, its impact on GHG emissions is massive: power and heat generation alone accounts for about a third of all energy-related GHG emissions and over a quarter of total GHG emissions in the country (Table 2-3).

The power and heat sector currently depends on thermal coal. In 2017, almost 70% of electricity and 99% of heat were generated by burning coal. 20% of electricity was generated on gas-fired power plants, while the remainder was supplied by hydro, wind, and solar power (KAZENERGY, 2019).

In addition to the extensive use of fossil fuels, the depleted capital stock in the energy sector accelerates GHG emissions further. The aged distribution systems in both power and heat generation lead to high losses in energy distribution (up to 35% total electricity losses in some regions).

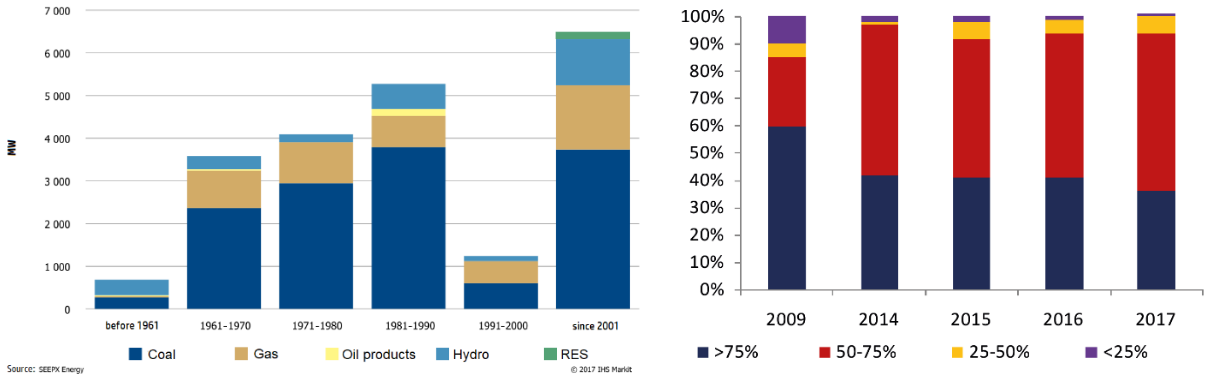
Table 2-3
Characteristics of the power & heat sector

	2017
Total production, billion USD	5.51
Value added, billion USD	2.67
Share in total value added, %	1.8%
Share in employment, %	1.8%
Share in energy emissions, %	33%
Share in total emissions, %	27%

Data: Bureau of National Statistics, MEGNR RK (2020)

Most power plants still operate with rather outdated technologies. In 2015, Kazakhstan counted 74 power plants with 267 generating units (Assembayeva, Egerer, Mendelevitch, & Zhakiyev, 2019). The average coal-fired unit was 55 years in operation, while gas-fired units are on average 40 years old, and hydro-powered units 56 years old. About 39% of installed power generation capacity older than 40 years and 64% older than 30 years (Figure 2-3)[13]. This implies that most power plants operate beyond their designed lifetimes and will need to be replaced until 2060.

Figure 2-3
Power plant capacities by age, MW (left) and capital stock depletion, % (right)



Source: KAZENERGY (2017; 2019)

The picture is similar for combined heat and power plants (CHPs). In 2016, 42% of CHP's operated beyond their intended lifetime, while 15% of installed capacity was not available for production due to maintenance and repair (KAZENERGY, 2017). In 2018, about one third (36%) of CHPs operated on a 75% worn-out capital stock, while for 58% of CHPs capital stock depletion was over 50% (KAZENERGY, 2019).

[13] Data on individual power plants and generating units compiled by Assembayeva, Egerer, Mendelevitch, & Zhakiyev (2019) paint a much gloomier picture: 78% of generating units are older than 40 years, and very few generating capacities have been added since 1991.

This implies that almost the entire capital stock in power and heat generation needs to be replaced anyway over the next four decades leading up to 2060. This provides an opportunity to replace existing outdated carbon-intensive equipment and infrastructure with modern low- and zero-carbon technologies, initially with gas-fired CHPs in combination with the enhanced and comprehensive roll-out of renewable energies. **In other words, decarbonisation will be achieved by replacing existing worn-out equipment and infrastructure at the end of its economic lifetime. But the failure to replace it with zero-carbon and low-carbon equipment risks either missing the net zero GHG emission goal or additional investment costs of modernising high-carbon equipment and its early retirement, turning it into a stranded asset.**

Besides the climate aspects, the key advantage of renewable energies is their very low operating cost, given that wind and sunshine are provided free of charge. Because of technological advances and a steep market expansion worldwide, the capital cost of electricity generated from new utility-scale on-shore wind and photovoltaic facilities has fallen dramatically over the last decade. Since 2019, costs for on-shore wind and solar PV have become lower than the marginal operating costs of many existing coal-fired power plants. This is both because of higher maintenance costs of coal-fired power plants and the necessity to pay for acquiring the fuel, the latter cost being absent for the renewables. It is expected that the total cost of renewables will decline further and remain below the cost range of power generation based on fossil fuel combustion. Even the costs of solar thermal power – the most expensive of the renewable sources – are already in the middle range of fossil fuel cost (IRENA, 2022). In other words, fossil-based power generation is becoming uncompetitive.

But in Kazakhstan investments in electricity networks and alternative power and heat generation remain so far economically not feasible, because regulations ensuring low consumer tariffs for electricity, heat and fossil fuels prevent the upgrading of networks and switching to more sustainable generation sources. Therefore, in order to decarbonise the power and heat sector, the introduction of market prices for energy services will be necessary for stimulating the uptake of energy saving technologies and changes in consumer behaviour.

2.2.3 Final energy demand

Final demand for energy comprises the use of electricity and heat and direct fuel combustion in industry, transport, agriculture as well as commercial and residential buildings. Taking into account the high share of direct fuel combustion, current final energy demand in Kazakhstan is also characterised by the heavy use of fossil fuels. Oil products account for 31% of final consumption, followed by coal (24%, mostly in buildings and industry) and electricity (16%), heat (15%), and natural gas (14%). However, the present share of coal in final energy demand is much higher when coal combustion for power and heat generation is considered. Moreover, coal is actively used by households in rural areas for heating and other purposes.

Since agriculture makes up only a marginal share of final energy consumption, this section will focus on the three major sectors of energy end-use: transport, buildings, and industry.

2.2.3.1 Transport

The favourable economic development of recent years stimulated economic activity in the transport sector, which in turn increased transport related GHG emissions. Currently, the transport sector accounts for 7.5% of value added and around 6.6% of employment (Table 2-4). It is relatively evenly spread across the regions of Kazakhstan, with the lowest employment share of 5.9% found in the Kostanay region and the largest share of 9.4% in the Kyzylorda region. Railroad transport is actively used for long-distance freight transportation, with 0.39 billion tonnes (10% of total volume) transported over an average shipment distance of 688 kilometres in 2017. Road transport dominates the shorter-distance cargo shipments, with 3.3 billion tonnes (84% of total volume) transported over an average distance of 50 kilometres. The rest is covered by pipeline transportation of fossil fuels and, to a small extent, by water and air freight transport.

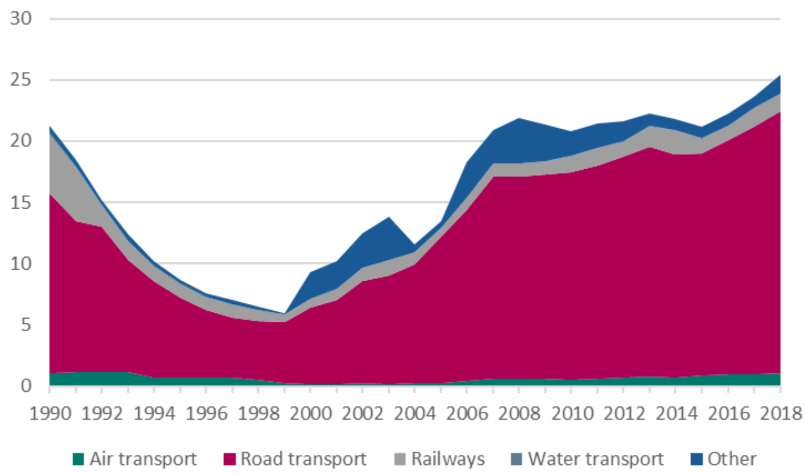
Table 2-4
Characteristics of the transport sector in Kazakhstan

	2017
Total production, billion USD	19.55
Value added, billion USD	11.13
Share in total value added, %	7.5%
Share in employment (transport & warehouses), %	6.6%
Share in energy emissions, %	7.7%
Share in total emissions, %	6.3%

Data: Bureau of National Statistics, MEGNR RK (2020)

Comparatively, public passenger transportation is almost completely covered by road transport, with buses and taxis together supplying 88% of public passenger traffic (182 billion passenger-kilometres); the rest is covered by railways (7%) and air transport (5%). Private cars contribute to the significant share of road transport in Kazakhstan. It is estimated that, in 2017, around 50 billion vehicle-kilometres driven with privately-owned cars could be added to the passenger traffic[14]. This is mirrored in the structure of GHG emissions from the sector (Figure 2-4).

Figure 2-4
CO_2 emissions from the transport sector, Mt



Data: MEGNR RK (2020)

The large share of road transport in GHG emissions from fuel combustion mirrors the relatively high level of individual motorisation in the country, while at the same time the stock of old and obsolete vehicles is rather high. On the other hand, public transport systems are underdeveloped even in large cities. Several factors pose a significant challenge for the decarbonisation of the transport sector:

- Firstly, considering the low population density in the Republic of Kazakhstan, the relatively low urbanisation rate and the large distances, the level of motorisation is likely to remain high. The largest reduction could be achieved within cities through improvements of public transport and other individual modes of mobility;
- Secondly, renewal of the transport fleet (and switching to cleaner technologies such as LPG-fuelled or electric vehicles) requires additional expenditure by private households and needs to be encouraged through respective policies;
- Thirdly, switching to cleaner technologies also requires the roll-out of appropriate infrastructure such as CNG, LPG and hydrogen fuelling stations and power charging points and, thus, investments.

[14] The estimate is based on the number of privately owned cars as per Bureau of National Statistics and the average annual mileage of a private car.

Overall, the gasification and electrification of road transport necessary for reducing its emission intensity have to be accompanied by a paradigm shift in demand for mobility, which means reducing the private use of cars and avoiding high-emission transportation modes like aviation. This would require investments in enabling infrastructure and at the same time changes in consumer behaviour. Transport is one of the largest sectors, where switching to green technologies and demand shifts create immediate co-benefits such as decreased air pollution, reduced number of accidents and lower levels of noise.

2.2.3.2 Buildings

Commercial and public services, related to energy use in non-residential buildings, account for a large share in the national economy in terms of both production and employment (Table 2-5). Even though emission intensity in trade and services is lower than in industry, the commercial and public sectors still account for a sixth of all energy emissions because of the high energy use in the buildings they utilise. In addition, fuel combustion for space and water heating and for cooking in residential buildings account for a further 8% of energy emissions.

Table 2-5
Characteristics of trade and commercial and public services in Kazakhstan

	2017
Total production, billion USD	120.42
Value added, billion USD	79.38
Share in total value added, %	53.4%
Share in employment, %	57.7%
Share in energy emissions, %	17%
Share in total emissions, %	14%

Data: Bureau of National Statistics, MEGNR RK (2020)

The climatic conditions in Kazakhstan with very cold winters and hot summers induce high energy demand for the heating and cooling of buildings. The average energy consumption level in the buildings sector is at about 270 kWh/m², which is more than double of that in the European Union (100-120 kWh/m²) and significantly exceeds the energy consumption in the neighbouring Russia (210 kWh/m²).

The main reason for this high energy demand of buildings, besides the harsh climatic conditions, are the very high energy losses due to the insufficient thermal insulation of the buildings stock. Heat losses in buildings are caused by drafts and ventilation (56% of all losses), losses through (not sufficiently insulated) walls (22%), through windows (14%), and through floors (the remaining 8%).[15] Together, residential and non-residential buildings accounted for 28% of total final energy consumption in Kazakhstan in 2017 (16% and 12%, respectively).

The share of buildings that do not meet modern energy efficiency standards is rather high. Overall, of 2.4 million buildings in Kazakhstan, 31.5% are older than 50 years and another 32.9% are older than 25 years. In 2021, 34% of multi-apartment buildings were in need of major repairs.[16]

With a 95% share of private home ownership, Kazakhstan is among the countries with the highest rates of private homeowners in the world (World Bank, 2018). This is largely the result of the privatisation of residential buildings in Kazakhstan in the early 1990s when tenants received the legal title to their apartments. At the same time, the buildings' envelope, roofing, cladding, but also stairs, elevators, floors, and utility lines constitute common property of the condominium. Apartment owners are collectively responsible for the maintenance of common property and pay respective fees for condominium management and the maintenance of common property of the condominium. The law defines a minimum list of services included in these fees, but the decision on major repairs in each specific case is made by the meeting of owners.[17] Moreover, the minimum list of services does not include measures to improve the energy efficiency of buildings.[18] Given the large number of owners in one building with very different social statuses and interests, the current layout of apartment buildings and lack of individual control of households over energy saving do not encourage meaningful investments in the thermal retrofit of such apartment buildings. Investments are discouraged further by the rather low energy tariffs, implying very long time periods necessary for refinancing energy efficiency investments through energy savings.

At the same time, due to the growing population and the necessity to increase the available per capita housing, the residential buildings stock is planned to expand by 27.6% over the next five years.[19] Therefore, while reduction of energy consumption and GHG emissions would require a large-scale modernisation of buildings, the current conditions in the housing sector provide a window of opportunity for such modernisation.

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[15] Information by Scientific and Technical Centre for Housing and Communal Services Development in Kazakhstan.

[16] Based on data from Government of Kazakhstan (2019) and consultations with the MIID RK.

[17] See the Rules of maintenance of the common property of the condominium in the edition of the Order No. 202 of the Minister of Industry and Infrastructure Development of the Republic of Kazakhstan from April 14, 2020.

[18] See the Methodology for calculating the cost estimate for condominium facility management and maintenance of the common property of the condominium facility in the edition of the Order No. 166 of the Minister of Industry and Infrastructure Development of the Republic of Kazakhstan from March 30, 2020.

[19] Based on consultations with MIID RK.

Considering the climatic conditions and the current poor thermal insulation, heat production is the most important source of emissions from buildings. Most heat is produced from direct combustion of fossil fuels or in small boiler houses. In rural areas, most heat is generated by combusting coal and oil products. Significant investments in the gasification and electrification of heating as well as the use of renewable energies (e.g., solar thermal, solar PV) are required to reduce GHG emissions of buildings.

In large cities, central heating covers about 50% of consumption. But lacking investment in the aging distribution networks causes energy losses from distribution of up to 30% of energy supply. In recent years more attention has been paid to network renovation and maintenance. This needs to continue to further improve energy efficiency in the buildings sector. Moreover, the reduction of emissions in buildings is tightly connected to the decarbonisation of the heat and electricity generation.

2.2.3.3 Industry

Manufacturing in Kazakhstan constitutes about 14.5% of total domestic production and 6.8% of employment. Non-energy mining (mining of ores and minerals as well as mining services) accounts for another 4.6% of production and around 1.4% of employment. The largest sectors in manufacturing are non-ferrous metallurgy (25%), food industry (22%) and ferrous metallurgy (18%).

Table 2-6
Characteristics of manufacturing and non-energy mining in Kazakhstan

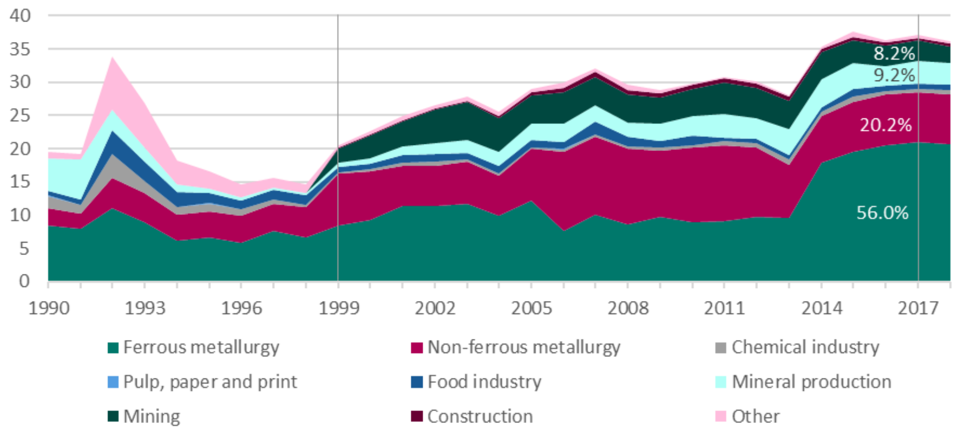
	2017
Total production in manufacturing, billion USD	37.19
Value added in manufacturing, billion USD	16.59
Share in total value added, %	11.2%
Share in employment, %	6.8%
Total production in non-energy mining, billion USD	11.71
Value added in non-energy mining, billion USD	5.97
Share in total value added, %	4.0%
Share in employment, %	1.4%[20]
Share in energy emissions (fuel combustion only) - manufacturing, %	10%
Share in energy emissions (fuel combustion only) - mining, %	0.9%
Joint share in total emissions (fuel combustion only), %	9%

Data: Bureau of National Statistics, (MEGNR RK, 2020)

[20] Does not include small enterprises.

Over the last 20 years, industrial production in Kazakhstan increased and so did the corresponding GHG emissions. By 2017, the emissions from fuel combustion in industry reached 190% relative to the 1990 level (Figure 2-5). Industry is also the largest consumer of final energy (41% at 16.8 Mtoe in 2017) and is expected to remain so in the future.

Figure 2-5
Structure of CO2 emissions from energy use in industry, Mt



Notes: Until 1999, mining and construction are included in the category "other". 2017 shares not shown: food industry (1.9%), chemical industry (1.4%), construction (1.1%), pulp, paper and print (0.1%), other (1.2%).

Data: MEGNR RK (2020)

Over the last decades the government of Kazakhstan pursued with top priority the fast scaling up of the fossil fuel and mining sectors, building an economic model deeply founded on the rich natural endowments and dependent on the export of fossil fuels and minerals. This is well reflected both in the production and export structures and in the structure of the GHG emissions from industry related energy use.

Disaggregating mining and manufacturing into subsectors reveals that 7 out of 10 top sectors (measured by output value) are also among the top 10 most GHG emission-intensive sectors (measured by emissions per output value, see also Table A- 15 in Appendix). Taking into account fugitive and process-related emissions (see also Section 5.2), industry generates over a fifth of all emissions in the economy. Emissions only from fuel combustion, ferrous and non-ferrous metallurgy – two of the top five sectors in Kazakhstan – constituted over three quarters of industrial emissions in 2017 (Figure 2-5).

Decreasing GHG emissions in energy-intensive industries is challenging:

- Firstly, production in the largest sectors relies on high-temperature processes, and heat generation can constitute a large portion of total energy use in these sectors. Green technologies to generate high-temperature heat are not yet commercially available;

- Secondly, many production units include sets of highly integrated processes. A change in one process would often require a redesign of the whole installation;
- Thirdly, given the long life cycle of installed industrial capital stock, this could lead to locking in the more emission-intensive equipment over long periods of time and the increased risk of turning into stranded assets;
- Fourthly, retrofitting existing equipment and replacing physical capital with more advanced technological solutions will require high investments;
- Finally, investment into new GHG-efficient and environmentally friendly technological solutions is constrained by regional competition with producers in and imports from neighbouring countries with lower environmental standards.

Furthermore, the economy of Kazakhstan depends heavily on commodity exports and is profoundly exposed to fluctuations in international prices. Climate policies, especially in the EU, will have a significant negative effect on carbon-intensive exports from Kazakhstan. The EU's and other countries' transition to net carbon neutrality by 2050 will reduce the overall demand for fossil fuels, while at the same time, in order to avoid carbon leakage, so-called carbon border adjustment mechanisms (CBAM) will be introduced to tax the carbon content of emission-intensive imports.

The largest industrial GHG emitters – oil extraction and metallurgy – also produce most of Kazakhstan's exports (62% and 16% respectively). At present, the EU is the largest importer of the Kazakh crude oil with a share of 77% and, after China, the second-largest importer of metals from Kazakhstan (with 34% and 16% respectively). Keeping these market shares will require prompt significant investments in the upgrade of production processes and reduction of energy- and process-related emissions. Otherwise, there will be a risk of losing export revenues and hence income in both, the private and the public sectors. This implies that international GHG mitigation efforts increase the external risk for the economy of Kazakhstan and provide incentives for Kazakh industries to invest in decarbonisation in order to maintain their position in international markets.

2.3 Industrial processes and product use

Most of GHG emissions from industrial processes are released during the production of the basic materials cement, iron and steel, and aluminium[21]. For cement production, limestone ($CaCO_3$ –

[21] Iron and steel metallurgy accounts for 9% of global GHG emissions, cement production – for 7%, and aluminium production – for 2%. Source: Neuhoff et al. (2018, p. 7).

calcium carbonate) is burned to remove its carbon, producing lime (CaO – calcium oxide) and releasing CO_2. This single chemical reaction is a major emitter of global carbon dioxide.[22]
The smelting of aluminium currently takes the form of a reduction-oxidation reaction between the raw material, alumina (Al_2O_3), and carbon anodes, during which aluminium is reduced to its metal form, while the carbon of the anodes is oxidised to carbon dioxide. The chemical reaction is similar in traditional iron ore smelting using coke. In short, in metallurgy a variety of process-related greenhouse gases are emitted, including also fluorinated gases (F-gases).
In Kazakhstan, the two industrial sectors generate over 91% of all industrial process emissions (58% in metallurgy and 33% in mineral industry, see also Figure 2-6).[23] To put this into perspective, in economic terms, the two sectors together account for about 7% of total production and 3% of employment (see Table 2-7).

Table 2-7
Characteristics of the metallurgy and mineral industry in Kazakhstan

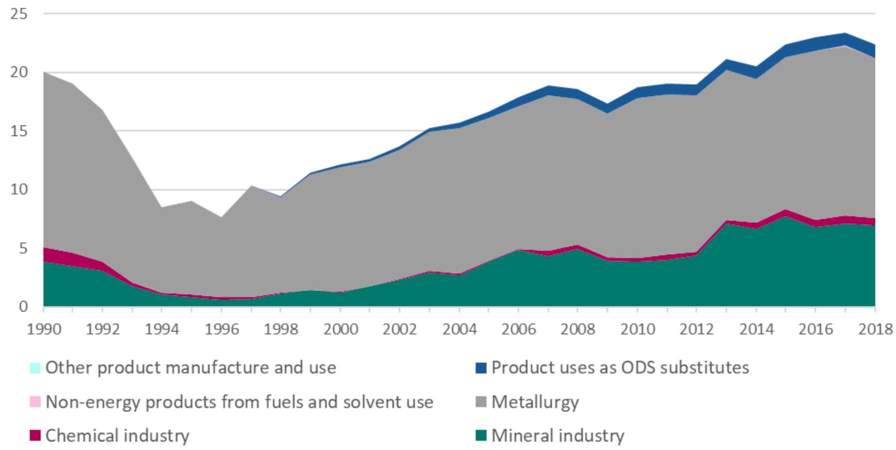
	2017
Total production in metallurgy, billion USD	17.02
Value added in metallurgy, billion USD	7.50
Share in total value added, %	5.0%
Share in employment (medium & large enterprises only), %	0.9%
Total production in mineral industry, billion USD	1.82
Value added in mineral industry, billion USD	0.82
Share in total value added, %	0.6%
Share in employment (medium & large enterprises only), %	0.3%
Share in IPPU emissions - metallurgy, %	58%
Share in IPPU emissions - mineral industry, %	33%
Joint share in total emissions, %	6%

Data: Bureau of National Statistics, MEGNR RK (2020)

[22] About half of the emissions from cement production are related to process emissions, while the other half are emissions from fuel combustion to reach the high temperatures necessary for the production process.

[23] In the mineral industry, cement production accounted for 56% of the sector's IPPU emissions in 2018.

Figure 2-6
Emissions from industrial processes and product use, Mt CO_2-eq



Data: MEGNR RK (2020)

The category "industrial processes and product use" (IPPU) also includes emissions from the use of solvents and other components, such as ozone depleting substance (ODS) substitutes. The latter include F-gases used for refrigeration and air cooling, fire extinguishing, aerosols, solvents and foam production.

Although the share of IPPU emissions in total net emissions remained steady at around 6% since 2005, in absolute terms the IPPU emissions were increasing since 1996, largely driven by the mineral industry, whose emissions almost doubled since 1990. Overall, by 2017, the IPPU emissions were 11% above the 1990 level. Although modernisation projects are carried out to reduce process emissions, currently the overall growth in industrial production quickly cancels out the achieved reductions.

Sustainably reducing GHG emissions from industrial processes would require a deep transformation of industry by changing the technological processes in use. This is closely intertwined with the challenges discussed in Section 2.2.3.3, including high investment costs required for the modernisation or replacement of equipment and the close integration of industrial processes, which often requires the restructuring of the whole production process.

2.4 Agriculture, forestry, and other land use – AFOLU[24]

In agriculture, forestry and other land use (AFOLU), land is the critical resource, and this distinguishes the sector among all IPCC sectors, since its emission mitigation potential is two-

[24] We thank Dana Yermolyonok (GIZ GmbH) for her contribution to this section.

fold: the reduction of production-related emissions through changes in management of soil, nutrients and livestock on the one hand, and, on the other hand, the removal of greenhouse gases by sequestration as terrestrial carbon in soils and biomass.[25] Bioenergy produced from biomass and agricultural waste provides another option to mitigate GHG emissions of AFOLU.

Agriculture and forestry account for about 5% of GDP of Kazakhstan and for over 15% of total employment (Table 2-8). Over 40% of Kazakhstan's population lives in rural areas. The arable land area covered 21.8 million hectares in 2017, a decline from 35 million hectares in 1990. About 70% of agricultural land is used for growing cereals (including rice) and legumes, while 15% is used for growing fodder crops for animals. The developments in animal breeding also underwent drastic changes. In 2017, the total number of cattle only amounted to 70% of the 1990 level, the respective figures declined for poultry to 66%, for sheep and goats to 53%, and for pigs to 27%. The amount increased only for horses (144%) and camels (133%).

Table 2-8
Characteristics of agriculture and forestry in Kazakhstan

	2017
Total production, billion USD	12.93
Value added, billion USD	7.30
Share in total value added, %	5.1%
Share in employment, %	15.4%
Share in total emissions – agriculture, %	9.3%
- of which livestock	*5.6%*
Share in total emissions – LULUCF, %	1.7%

Data: Bureau of National Statistics, MEGNR RK (2020)

Agricultural production is simultaneously causing environmental changes and being impacted by these changes, because agriculture has an enormous environmental footprint on climate change, water scarcity, land degradation, deforestation, and other processes.

Agriculture accounts, with 9.3 %, for a large share of Kazakhstan's GHG emissions, of which emissions by livestock reach about 60% of total agricultural GHG emissions, translating into 5.6% of GHG emissions economy-wide. Since reaching a low in 1998, GHG emissions from enteric fermentation are on the rise again on average by 3.5% per year. This growth in GHG emissions reflects both increases in animal stock and increases in the productivity of dairy and other cattle over time (MEGNR RK, 2020).

[25] Until 2006, IPCC classified emissions and removal of anthropogenic GHG from AFOLU in two separate sectors: Land Use, Land Use Change and Forestry (LULUCF) and Agriculture.

The AFOLU mitigation effect of removing greenhouse gases by carbon sequestration in soils and biomass takes place in forests, croplands, grassland, wetlands, settlements, and other land across the country. In terms of land use, land use change, and forestry (LULUCF), forestry and grassland are the largest carbon sinks in Kazakhstan, having absorbed 3.4 Mt CO_2 and 17.8 Mt CO_2 in 2017, respectively. However, in the 1990s the overall LULUCF balance tipped, and in 2017 LULUCF was a net GHG emitter of 1.7% of total GHG emissions. In order to reverse this development, Kazakhstan is increasingly planting trees. The forest fund of the Republic of Kazakhstan manages 30.1 million hectares, and afforestation (public and private) and sustainable forest rehabilitation are necessary mechanisms for extending forest cover (Forest Sector Master Plan, 2020). In late 2020, an ambitious plan of planting more than 2 billion trees until 2025 was announced (MEGNR RK, 2020).

At the same time, the AFOLU sector is itself vulnerable to climate change, as it will modify the precipitation patterns and the biome in Kazakhstan. This will directly impact agriculture with increasing frequency and intensity of extreme weather events, increasing average temperatures and a reduction in water availability for irrigation. Currently, agriculture accounts for almost two thirds of national water consumption (Bureau of National Statistics, 2021). Climate change will reduce yield growth for most crops and in almost all regions (Ruane, et al., 2018).

In addition to serious climate risks, the agricultural sector is losing around USD 1.5 to 4 billion per year due to low and declining land productivity. This loss is expected to increase by 2030, and will have a tremendous social impact. Almost one third of the agricultural lands are either degraded or under serious threat of degradation, with more than 10 million hectares of potentially arable land abandoned so far. 76% of the land in Kazakhstan is considered desertification sensitive and around 80% of land has been in a state of productivity decline since 2000 (Hu, Han, & Zhang, 2020). At the same time, pasture lands close to human settlements suffer from overgrazing (about 20 million hectares), while those in remote areas are undergrazed (Green Economy Concept, 2013).

The government regards the development of agriculture as a main priority, mainly due to its large share in employment, particularly in rural areas, but also for social and food security reasons. The importance for climate change mitigation is also being increasingly acknowledged (Green Economy Concept, 2013). However, limited access to finance hampers many farmers from developing a more productive and sustainable agricultural sector. More than 80% of agricultural infrastructure is outdated. Currently, only 1% of agricultural land in Kazakhstan is devoted to organic agriculture (UNDP Kazakhstan, 2020).

The agricultural sector in Kazakhstan is dominated by small-scale producers, who are responsible for about 80% of meat and milk production. The products of small enterprises are mostly sold in formal or informal markets close to the place of production (IFC & World Bank, 2017). Large agricultural enterprises constituted just 5.5% of specialised agricultural producers and contributed a quarter of total production value in the sector in 2019. Large enterprises are more important in crop agriculture and account for 32% of total crop production and 16% of total animal breeding. In turn, rural households, many as subsistence farmers, produced 27% of crop output value and 66% of livestock output value in 2019. The remaining output is covered by (small) farming cooperatives who account for 41% of crop production and 18% of animal breeding.[26] Medium-sized agricultural producers are almost completely missing in the sector. These structural deficiencies suppress the demand for professional input suppliers and service providers that would help improve productivity and quality of the sector as a whole. Thus, access to technologies and services such as feed, genetics, nutrients, extension services, marketing and packaging, storage, cooling and refrigeration, mechanisation, veterinary services is largely missing for small-scale producers and done in-house by the larger producers (IFC & World Bank, 2017). This producer structure also implies that only the larger agricultural producers have access to financial markets and financial products. Improved access, especially to microfinance, could improve the situation of the small holders and the rural areas in general.[27]

2.5 Waste[28]

The waste sector is responsible for the methane (CH_4) and carbon dioxide (CO_2) emissions caused by the anaerobic decomposition of organic waste and the disposal of sludge in solid waste disposal sites or by the handling of wastewater under anaerobic conditions.[29] In addition, the incineration of waste produces emissions of CO_2, CH_4 and N_2O. The current waste management system of Kazakhstan is largely dominated by landfilling and the combustion of waste. While the waste management sector contributes 0.3% to total value added and 0.9% to total employment, the GHG emissions attributed to waste account for 2% of total emissions (Table 2-9).

[26] Based on the data from the Bureau of national statistics.

[27] At the end of 2020, about 94% of total issued microcredit volume in Kazakhstan was concentrated in the 3 largest cities: Almaty with 83%, Nur-Sultan with 3% and Shymkent with 1% (Association of Microfinance Organizations of Kazakhstan, 2021).

[28] We thank Assel Nurbekova (UNDP) for contribution to this section.

[29] Landfill gas which consists of methane and carbon dioxide at roughly equal shares and typically also contains a small amount of other components like nitrogen, oxygen, ammonia or non-methane organic compounds, though their combined share usually does not exceed 5%.

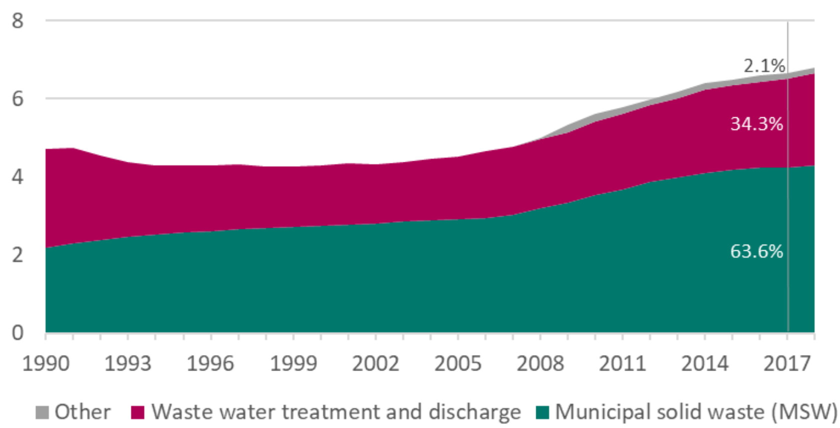
Table 2-9
Characteristics of the waste management sector in Kazakhstan

	2017
Total production, billion USD	1.04
Value added, billion USD	0.52
Share in total value added, %	0.3%
Share in employment, %	0.9%
Share in total emissions, %	2%

Data: Bureau of National Statistics, (MEGNR RK, 2020)

Since 1994, GHG emissions from waste have been rising (Figure 2-7). About two thirds of GHG emissions from the sector originate from municipal solid waste (MSW) and one third from wastewater treatment. Waste generation and, thus, GHG emissions are rising because of population growth and the increase in waste generation per capita. In 2018, 69% of solid waste was landfilled while only 18% was sorted for recycling. Moreover, though the share of wastewater treatment was high at 86.8% in 2018, the sludge remaining after treatment (around 20% dry matter) is deposited in sludge pads and landfills (MEGNR RK, 2020).

Figure 2-7
GHG emissions from the waste sector in 1990-2018, Mt CO_2-eq



Data: (MEGNR RK, 2020)

Both the separate collection of different MSW streams (e.g., paper, glass, organic waste) and the pre-sorting of MSW before disposal, are currently almost absent, which increases the waste intake of landfills. In 2019, about a quarter of settlements had some form of separate collection system and just below 15% had some sorting mechanism of MSW (Kazinform, 2019). Hence, reuse and recycling of waste as well as energy recovery from waste combustion remain very low. Estimations show that about 37% of the MSW generated (around 2 million tonnes per year) could be used to produce biogas, but the utilisation of waste for bioenergy production is practically non-existent (EBRD, 2017).

Most landfills are in poor condition. In 2018, Kazakhstan counted over 3 thousand MSW landfills, of which 16% met the environmental regulations. Most landfills have exhausted their capacities and require recultivation (MEGNR RK, 2020). Several adjustments to the regulatory framework have been made in recent years to reduce the quantities of waste disposed of in landfills and ban certain waste completely from landfill disposal.[30] However, low MSW tariffs render investments in waste management projects economically unviable and hinder the implementation of regulatory requirements.

The situation is similar for wastewater, with insufficient provision of sewage treatment plants in cities and large urban-type settlements. In 2016, 39 out of 102 such settlements had no wastewater treatment plants at all (Targets for the Protocol on Water and Health, 2017), while the condition of the existing wastewater treatment plants is poor, with depleted equipment and often outdated technologies and treatment methods. Moreover, with few exceptions, infrastructure is lacking for sludge treatment and disposal. This includes not only the sludge collection and dewatering facilities, but also disposal sites, i.e., sludge ponds, landfills, and biological treatment facilities. Currently, the sludge from sewage treatment plants is not treated but collected and buried in sludge pads or landfills, irrespective of the organic content. Moreover, dewatering of sludge is not always carried out, and water containing about 1-2% of sludge is poured not only in sludge ponds or landfills, but also in open ponds, causing their increased eutrophication.

As with the organic part of MSW, the use of sludge for biogas production could reduce waste GHG emissions and produce renewable energy. Currently, the only sludge utilisation complex of sewage treatment plants in Kazakhstan operates in Shymkent. It includes digesters, boiler house, gas holders, sludge mixing chambers, and a sludge dewatering and disinfection unit. By processing the sludge from the sewage treatment, about 500 kWh (4.38 GW per year) of renewable electricity and 840 kWh (7.35 GW per year) of renewable heat are produced. This led to the reduction of GHG emissions by 3.7 kt CO_2-eq per year. The expansion of such projects to other cities and settlements in Kazakhstan is indispensable for decarbonisation in the waste sector.

[30] The waste banned from landfilling includes: mercury-containing lamps and devices, scrap metals, waste oils and liquids, batteries, and electronic waste since 2016; plastic, paper, and glass since 2019; construction and food waste from 2021.

About 2% of GHG emissions of the waste sector arise from medical waste. About half of medical waste is non-hazardous and is landfilled like MSW (ME RK, 2019). The other half constitutes epidemiologically hazardous waste, which is incinerated using low-power incinerator units or, in their absence, burned in hospital boiler rooms if available.[31] The ash from incineration is buried in landfills. However, medical waste is handled by about 200 firms in Kazakhstan, which so far neither report on the waste collected nor on the methods of disposal.

[31] Radioactive waste constitutes less than 0.005% and is subject to special collection and disposal.

3 The analytical modelling framework, scenarios, and pathways to 2060

The modelling framework applied for assessing the transition to a desirable low-carbon future employs a hybrid TICS-KAZ model consisting of three interlinked state-of-the-art economic and technological models: TIMES-KAZ, CGE-KAZ, and SD-KAZ. In addition, building on the modelling results for reaching net zero GHG emissions, a financing model of the electricity system of Kazakhstan was devised to analyse the instruments for attracting green investments into the power sector. This section describes in each subsection the three stand-alone models, the resulting hybrid model, and the LEDS scenarios analysed, while the financing model of the power sector and financing scenarios are introduced in Section 6.2.

3.1 The bottom-up TIMES-KAZ model

The TIMES-KAZ model was developed using the TIMES (an acronym for *The Integrated MARKAL-EFOM*[32] *System*) model generator, which provides a technology-rich basis for estimating the dynamics of energy systems over a long-term, multi-period time horizon. TIMES is usually utilised for the analysis of the entire energy sector, and the scope of the model extends beyond purely energy-oriented issues, to the representation of environmental emissions related to the energy system. In addition, the model is well suited for analysing energy-environmental policies, as it explicitly outlines technologies and fuels, with their technical and economic parameters, in all sectors of energy production, conversion and end use.

TIMES computes a partial equilibrium on energy markets, i.e., it determines the flows of energy and materials as well as their prices in such a way that the suppliers of energy produce exactly the amounts that the consumers are willing to buy in each region that is included in the model. This equilibrium feature is present at every stage of the energy system: primary energy forms, secondary energy forms, and energy services. The economic objective is the maximisation of the total surplus, defined as the sum of suppliers' and consumers' surpluses.

TIMES-KAZ is a single-region multi-period model, developed for Kazakhstan to analyse alternative developments of the energy sector under different scenarios and with a time horizon up to 2060. Methodologically, TIMES-KAZ is a least-cost optimisation model, in which a target level of emissions and a number of further constraints are set and a linear optimisation algorithm is used to find an energy system that will satisfy these constraints, be technologically feasible

[32] MARKAL – MARKet ALlocation model (Fishbone & Abilock, 1981; Fishbone, et al., 1983; Berger, et al., 1992) and EFOM (van der Voort, 1984) are two bottom-up energy models that inspired the structure of TIMES.

and have the lowest cost. Thus, the constraints represent the country-specific limits, within which the model can select optimal technologies and the extent of their use. In other words, most of the assumptions are expressed in terms of either lower or upper limits on the use of certain technologies or technological solutions the model is allowed to use. This implies that, on the optimal path, some indicators will not equal the set limits.

The TIMES-KAZ has the following dimensions:

Structure: The Reference Energy System (process / flow relationships from supply to demand) was designed and implemented to allow the analysis of long-term energy and climate dynamics, while also providing the capability to present several mitigation and energy efficiency options and measures. The supply and use of fossil and renewable energy sources are represented by a rich set of technologies, and on the final demand side, eight industrial sectors (major ones with further sub-sectoral differentiation), the residential and the tertiary sectors, agriculture (including forestry and fishery), and four transportation modes (further divided into passenger and freight transport) are distinguished.

Geography: the energy demands in the residential and the tertiary sectors are split along four climatic zones of Kazakhstan to reflect the respective differences in the heating demand in buildings.

Time horizon / granularity: the new TIMES-KAZ covers the period between 2017 and 2060. The base year was set to 2017, the most recent year (at the moment of compilation) with the richest statistical information allowing for both the stand-alone and the hybrid version of the model. The model was re-calibrated with the most recent energy balance and sectoral data (as of 2020) and further checked and processed to obtain a self-consistent representation of the entire system for the starting year 2017. The intra-annual representation of the system was also refined to enable better representation of key technologies such as wind, solar, advanced heaters, storage, etc. The model covers four seasons and six periods of the day, resulting in a total of 24 time slices.

Solver / algorithm: the TIMES-KAZ was designed as a mixed-integer linear programming problem (MILP), as some variables (e.g., size of power plants) are restricted to be integers. Integer linear programming formulations provide a more accurate tool for the representation of specific investment decisions / installations, even though they require higher computational efforts.

Extended database to run Net Zero Emissions scenario: a set of recent and enhanced low-carbon technologies in all transformation (e.g., hydrogen) and final consumption sectors was added to the model. A wide array of sources was used for these technologies and for an overall update of the Reference Energy System for the TIMES-KAZ, ranging from official statistics published by the Bureau of National Statistics and sectoral ministries, to international databases and literature (e.g., JRC and Danish Energy Agency technology databases), and to extensive stakeholder and expert consultations during the whole modelling process.

3.2 The top-down CGE-KAZ model

Computable general equilibrium (CGE) models use actual economic data to provide a theoretically consistent analysis of how an economy might react to changes in external factors such as policy or technology. A CGE model consists of equations describing model variables and behaviour of economic agents as well as a database consistent with these model equations. The equations are based on neo-classical economic theory, assuming cost-minimising behaviour by producers, balanced and perfectly competitive markets, and household demands based on the maximisation of utility.

CGE models have a clear policy orientation and capture both direct and indirect inter-sectoral and inter-temporal effects induced by policy changes. They are, therefore, useful whenever the economy-wide effects of changes in a particular policy instrument or of specific sectoral investments need to be estimated. CGE models are widely used in the analysis of the economic effects of climate change mitigation policies and measures.

CGE-KAZ – the model of Kazakhstan's economy – represents the behaviour of all relevant players in the economy based on microeconomic foundations, including firms producing different commodities, private households, the government (i.e., public household), the investment bank (or investor who carries out gross capital formation), and the single-region external sector (flows of real exports, real imports, balance of payments and current account). The model covers all products and services in the economy, aggregated into 34 types of activities out of the standard national input-output tables from the Bureau of National Statistics. The model also covers factor markets and allows the tracing of changes in the accumulation of production factors and, as a result, the projection of future structural changes of the entire economy. An additional module was developed to account for emissions from industrial processes, which are strongly dependent on the output of the respective sectors and not captured elsewhere in the hybrid model.

The CGE-KAZ model is implemented in the General Algebraic Modelling System (GAMS) and can be used in two structurally similar versions: a static and a dynamic one. The hybrid TICS-KAZ model uses the dynamic version of the CGE-KAZ model, since it provides much more valuable insights for the elaboration of climate-related policies and enables the alignment of economic development with the dynamic TIMES-KAZ and SD-KAZ models.

A key element of a CGE model in general and a key data input in the CGE-KAZ model is a social accounting matrix (SAM), which covers monetary flows between all institutions and markets in the model. Most parameters of the model are calibrated from this single database. The model's database is fully consistent with the official statistics on the economy of Kazakhstan, in particular the national accounts data and, as additional sources, the National Inventory Report (NIR) and the national energy balance (NEB).

The main purpose of the model is to contribute to the understanding of the economy-wide consequences of different mitigation and decarbonisation policies as well as to monitor the effectiveness of green growth policies. By assuming the development of key drivers such as population growth, energy efficiency improvements, total factor productivity improvements or world commodity prices, the CGE-KAZ model is able to generate different economy-wide and sectoral growth paths with detailed effects on, inter alia, gross domestic product (GDP), gross value added, output, domestic product and input prices, as well as energy and GHG emission levels.

The model simulates the development of the national economy of Kazakhstan over the period of 44 years, starting from 2017 up to 2060. Hence, it is able to assess medium-term (2015-2030) and long-term (2030-2060) consequences of different combinations of mitigation actions and polices.

3.3 The system dynamics models (SD-KAZ)

System dynamics modelling is used to frame, understand, and discuss complex issues and problems. It represents an aspect of systems theory and is based on the recognition that the structure of any system – the many circular, interlocking, sometimes time-delayed relationships among its components – is often as important in determining its behaviour as the individual components. The primary elements of system dynamics diagrams are feedback, accumulation of flows into stocks, and time delays. A simple map of a system with all its constituent components and their interactions can be represented qualitatively with causal loop diagrams (CLDs). For a more detailed quantitative analysis, CLDs serve as a point of departure to inform the development of stock and flow models. The models simulate, based on their structure and interconnections, the systems' evolution over time. In contrast to optimisation models, like TIMES-KAZ, which search for pathways to a predefined target, SD models generate "what if" scenarios, operating with policies / interventions applied to the existing system in order to analyse how the system would react to them.

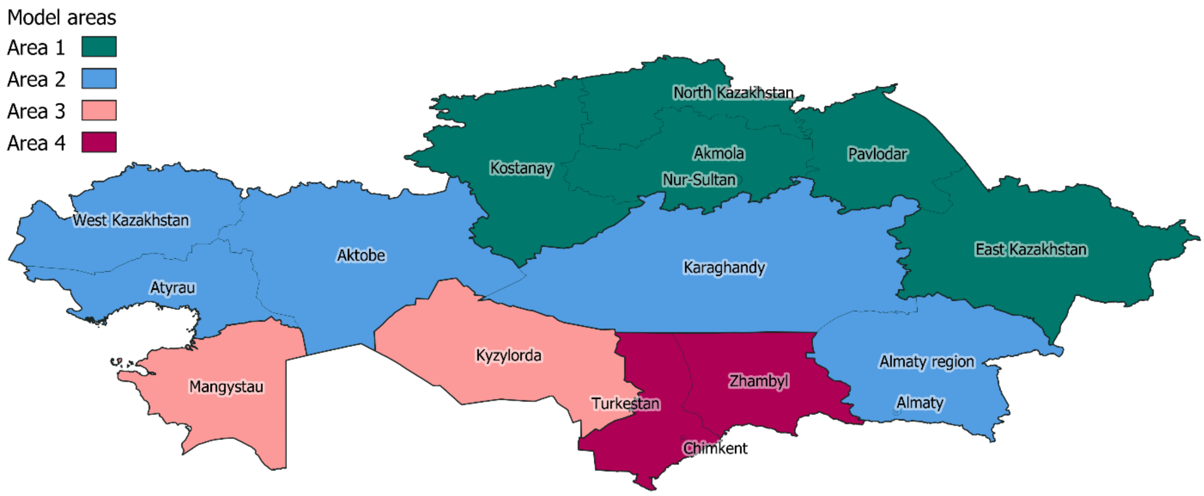
The SD-KAZ model is a customised system dynamics model developed specifically to assist the creation of the LEDS of Kazakhstan. The model is customised to the context of Kazakhstan, a process that started with the creation of sectoral CLDs and continued with the customisation of the stock and flow model. Both have been informed by local stakeholders and data. Unlike single-year calibrations of TIMES-KAZ and CGE-KAZ, the dynamic SD-KAZ was calibrated with data from 2000-2017.

Five sectoral models have been created within SD-KAZ covering the following sources of GHG emissions in depth: (1) agriculture, (2) residential buildings, (3) coal mining, (4) private and public road passenger transport, and (5) waste management. Each model describes in detail the respective sector and its specific structure and dynamics; hence the models rely on different types of information and data sources.

The **agriculture** sectoral SD model was developed for analysing climate-change related losses in agricultural production as well as emissions from land use, land use change and forestry (LULUCF) and from agriculture. The model is designed to simulate agricultural production in four geographic areas in Kazakhstan using precipitation data pertaining to each of them. In addition, the agriculture model differentiates between crop and livestock agriculture. The model operates with 12 time slices to capture seasonality of agricultural production.

The four geographical areas defined according to the climatic zones and the respective regions (oblasts) are illustrated in Figure 3-1. Area 1 corresponds to predominantly humid continental climate with warm to hot summers and cold winters. It includes most of Kazakhstan's forests and steppe. Area 2 corresponds to predominantly cold semi-arid climate with warm to hot dry summers and cold winters. It is mostly covered by semi-deserts and deserts, though dry steppe is also present in the north of the area. In area 3, cold desert climate predominates, with hot dry summers and cold dry winters. As such, the area features semi-deserts in the north and deserts in the south. Finally, area 4 corresponds to humid continental climate with dry hot summers, relatively mild winters, and significant precipitation differences between seasons. A large part of the area is mountainous, while the rest is mostly covered by deserts.

Figure 3-1
Geographical areas of the SD-KAZ model



Source: Own presentation, base map: GADM

The **buildings** SD model specifies the geographical representation of the agriculture SD model and it is used to forecast building-related costs according to building type and area. All output indicators are calculated per square meter (m^2), for all buildings, and for each geographical area. Among others, output indicators capture the cost of heating, electricity use, and building-related outcomes, such as employment and income, air pollution and GHG emissions.

The **coal** sector SD model captures coal production, costs, revenues as well as coal-related social and environmental outcomes such as employment, GHG emissions and health impacts of coal combustion. Accounting for the high concentration of coal production in Kazakhstan, the coal SD model does not differentiate between regions and, instead, simulates scenarios at the country level.

The **transport** sector SD sector model is set up to provide information on passenger car and bus transport indicators, both for the whole transport system and per vehicle. It includes capital, operation and maintenance costs of private and public transport, as well as externalities related to congestion, accidents, and health impacts. These are calculated at the national level and for the four geographical areas presented earlier, and include various types of vehicles. The core focus area for the transport sector is based on the Avoid-Shift-Improve paradigm: improving the stock of private vehicles while reducing the necessity for their use, especially in urban areas, creating synergies for mobility and health.

Finally, the **waste** sector SD model tracks different waste flows to analyse the outcomes of several intervention options (e.g., recycling and reuse, waste to energy, wastewater treatment, organic fertiliser production) on GHG emissions, employment creation and economic activity.

The model is set up at the national level and differentiates between organic waste, paper, plastics, glass, metals, and mixed solid waste as MSW types, two types of agricultural waste as well as wastewater.

3.4 The hybrid TICS-KAZ model

Each of the distinct models developed for this analysis is devised to answer a specific set of questions and uses methods appropriate for this purpose. Top-down models – like the CGE-KAZ model – represent a system by providing a general overview while abstracting from specific details. For example, the CGE models represent an entire economy based on a relatively small number of aggregate variables and equations. In contrast, bottom-up models focus on specific parts of a system which they capture in detail. For example, the bottom-up TIMES model is technology-explicit and focuses on the energy sectors of an economy.

This means that, like any models, each of the stand-alone models used in this analysis focuses on a certain sphere of development in Kazakhstan, taking others as exogenous predictions. Replacing these exogenous predictions with results delivered by other models, which specifically focus on these spheres, can significantly improve the quality of data each model uses and, overall, provide more informative results. For example:

- The CGE model makes very simple assumptions about how energy suppliers behave. Information from the TIMES-KAZ model about the most effective way of delivering energy services improves the treatment of energy suppliers' behaviour in the CGE-KAZ model. Among other things, TIMES provides a consistent dataset on the future energy mix and the needed capacity investments. TIMES is especially well suited for the backcasting approach for exploring the optimal pathway towards a future target, whereas CGE relies on pre-determined pathways to project their economic effects in the future.
- The economic projections from the CGE-KAZ model can be used to inform TIMES-KAZ on the dynamic development of macroeconomic variables such as GDP and energy service demands by economic activity, which are otherwise taken by TIMES as exogenously given. CGE-KAZ ensures macroeconomic equilibrium, the compatibility of the allocation of resources, and the consistency of all prices, including energy prices, with the projected demands.
- The SD-KAZ models examine selected sectors in detail, provide more accurate projections of sectoral development for CGE-KAZ and in turn benefit from the macroeconomic and energy

system information out of the optimisation models, CGE-KAZ and TIMES-KAZ.[33] Furthermore, the SD models are used to quantify externalities related to each of the systems analysed and hence enable the assessment of not just investment, costs, and revenues but also of environmental and societal impacts of development decisions. This allows the evaluation of the value-for-money of investments, in addition to the traditional cost-benefit assessment.

Thus, integration between models delivers significantly better information to policy makers in terms of both modelling accuracy and the broader scope of indicators. It allows better assessment of low-carbon policies' feasibility and the impacts on economic growth, required investment, and of other socio-economic indicators.

The strengths and weaknesses of the bottom-up and the top-down modelling approaches have led to a wide range of hybrid modelling efforts that combine economic comprehensiveness of top-down models with the technological explicitness of bottom-up models. Böhringer & Rutherford (2008) distinguish three broader categories of hybrid modelling approaches:

- Independently developed bottom-up and top-down models are linked (soft linking);
- A focus is put on one model type (either bottom-up or top-down) and a "reduced form" representation of the other is used;
- The models are completely integrated based on the development of solution algorithms, which allow for jointly solving both models.

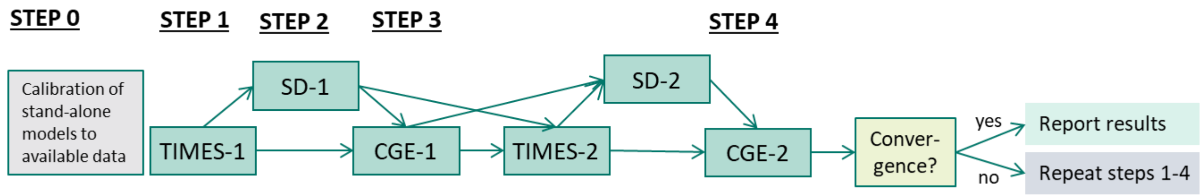
In this analysis, a "soft-linking" approach is applied. This means that all models remain applicable in their stand-alone versions and that no modification of models' structures is necessary. Instead, the models are used to inform each other in areas which would otherwise be left out of the scope of the analysis and assumed as exogenous. In comparison to augmenting one or more of the models and establishing a superstructure for an integrated assessment, this approach puts certain limitations on the degree to which the models can be aligned with each other. However, there are significant operational advantages to such soft linking, including higher transparency and level of detail as well as model flexibility for other policy cases in the future, which increases the model's sustainability.

The high-level schematic process of linking the TIMES-KAZ, CGE-KAZ and SD-KAZ models is presented in Figure 3-2. The process starts with the reference (baseline) scenario, which later serves as a basis for modelling the policy scenarios (here – decarbonisation pathways), and a

[33] In fact, in many instances, SD-KAZ, which was built specifically for this analysis, was already in its development phase explicitly linked to inputs from the other two models.

calibration of each stand-alone model to the respective statistical data and, where applicable, official forecasts of future development (Step 0 in Figure 3-2).

Figure 3-2
High-level schematics of the integration process



Source: Own presentation

The integrated model run then starts with the TIMES-KAZ model, which delivers the relevant information on the energy system to the CGE-KAZ and the SD-KAZ models (Step 1 in Figure 3-2). These data replace the projections taken as exogenous in the stand-alone CGE-KAZ and SD-KAZ models (e.g., from national or international literature or by extrapolating the existing trends).

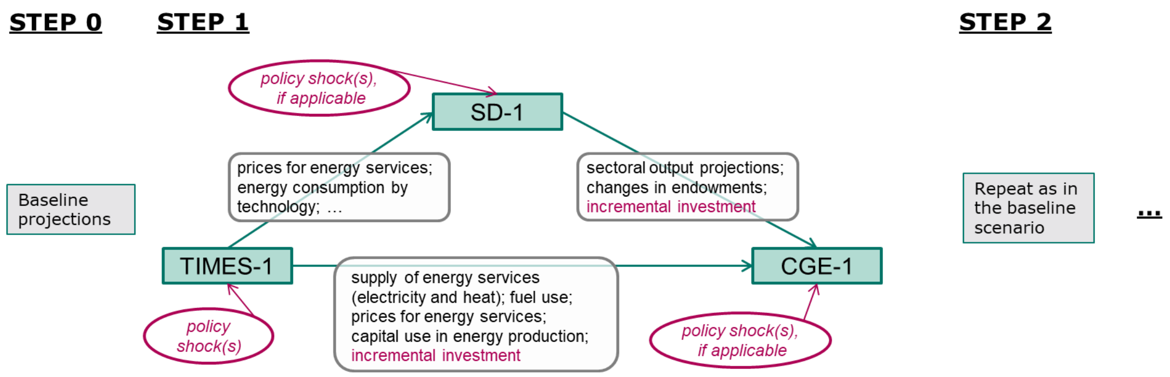
Large amounts of data are transferred particularly from TIMES-KAZ to CGE-KAZ, and the two models cannot "communicate" directly with each other due to their structural differences and, thus, require an additional step of data processing before information from the TIMES-KAZ model can be used in the CGE-KAZ model. To resolve this challenge, a specific data exchange file was set up for this task, serving as an effective and compact data exchange tool between the two models. It includes the aggregation of sectors and technologies and, where necessary, the smoothing of the time dimension from multi-year time periods in TIMES to the corresponding annual developments of CGE. Data processing is largely automated using Excel VBA, which operates with a structural description of input (raw) and output (processed) data by the user and provides a high level of flexibility for model adjustment or extension (e.g., changing the time horizon or sectoral coverage). An additional benefit of automation with customised structural description is that it also enables the extraction and interpolation of variables not necessary for the data exchange between the two models but valuable for further analyses (e.g., sectoral emission levels).

After the data exchange is complete, in step 2, the SD-KAZ model is rerun first and then delivers inputs to CGE-KAZ and relevant information back to TIMES-KAZ. Next, CGE-KAZ is updated with information from both other models and in turn supplies them with updated macroeconomic projections (Step 3 in Figure 3-2).

At this point, the first iteration is completed, and the second iteration starts again with TIMES-KAZ. When the round of data exchange is complete and the second iteration of CGE-KAZ is done, an evaluation of the three models is conducted to assess whether their results change significantly compared to the previous iteration (Step 4 in Figure 3-2). If a set of predefined convergence criteria between the models is reached, the results for the hybrid TICS-KAZ can be reported. Otherwise, the iterations are repeated until the convergence is achieved.

The results, which are obtained from the hybrid model for the reference (baseline) scenario, serve as a basis for the analysis of policy scenarios in the stand-alone models. The integration process in policy scenarios is very similar to the reference scenario. It again begins with the TIMES-KAZ model, which is the first to apply policy shock(s) according to the design of the respective target scenario (Figure 3-3). When the results are shared with SD-KAZ and CGE-KAZ, they use these data as exogenous parameters *and* apply the models' own policy shocks. From the second iteration, the integration process continues as outlined above.

Figure 3-3
Integration process in policy scenarios



Source: Own presentation

3.5 Scenarios analysed

The assessment of the transition pathways towards the low-carbon or carbon-neutral future of Kazakhstan is based on two scenarios. The scenario development included intensive stakeholder consultations in 2020 and 2021. Both scenarios consistently and explicitly incorporate the already known ambitious international efforts to limit global warming to 1.5°C, such as the Green Deal in the European Union or the decarbonisation pledges of most countries to achieve net zero carbon emissions by 2050 or, in the case of China, by 2060. Such international climate change efforts will reduce global demand for fossil fuels, emission-intensive industrial products, and other tradable goods. This shift in demand will have a profound effect on the economy of Kazakhstan. The two analytical scenarios[34] are:

Business as usual: The business-as-usual (BAU) scenario describes a hypothetical development path of the economy by extrapolating past developments, policy decisions made and trends observed in Kazakhstan to the future and assumes that presently existing policies will remain in place throughout the entire period. In short, no additional decarbonisation efforts will be made and no specific targets are set for 2030 or 2060. The BAU scenario is not to be understood as a forecast (i.e., most realistic development) of the economy, but rather as a benchmark for comparing the results of the decarbonisation scenarios and as a motivation for policy action by the government.

Net zero emissions: In the net-zero-emission (NZE) scenario, efforts are actively pursued in Kazakhstan to reach both the targets stipulated by the Paris Agreement and the pledge of Kazakhstan to reach carbon neutrality by 2060. Future efforts include increasingly market-based policies, improved regulatory policies and significant public investment. The conditional NDC target of 25% emission reduction relative to the 1990 level will be met by 2030. By 2060, Kazakhstan reaches a net zero GHG emission balance economy-wide, so that almost all GHG emissions are avoided and the remaining unavoidable GHG emissions are either captured and stored or used directly at the source or sequestrated in carbon sinks like vegetation and soils.

Against the background of swift technological progress and massive research efforts on climate-friendly technologies, it is important to note that the modelling results presented in this report outline a potential pathway to a future carbon neutrality based on currently known technologies and projections about their costs and commercial availability. In the long term, reaching carbon neutrality entails the use of technologies, which are not yet commercially available or even known. In this regard the International Energy Agency stated that "in 2050, almost half the reductions come from technologies that are currently at the demonstration or prototype phase" (IEA, 2021, p. 15). At the same time, the direction of technological change and, even more so, technologies no longer viable in a zero-emission world are already known, and so the modelling results presented below deliver important insights into the necessary transformations towards carbon neutrality in Kazakhstan.

[34] In the course of the project work 2 additional scenarios were elaborated, labelled as Green economy (GE) and deep decarbonisation (DD) scenarios. They differ regarding the climate ambition and fit between the BAU and NZE scenarios. Some figures are presented for information in the appendix.

4 The macroeconomic assessment of decarbonisation

4.1 Decarbonisation and economic growth

The following analysis compares how projected long-term economic growth paths of Kazakhstan will differ across the BAU and the NZE scenarios.

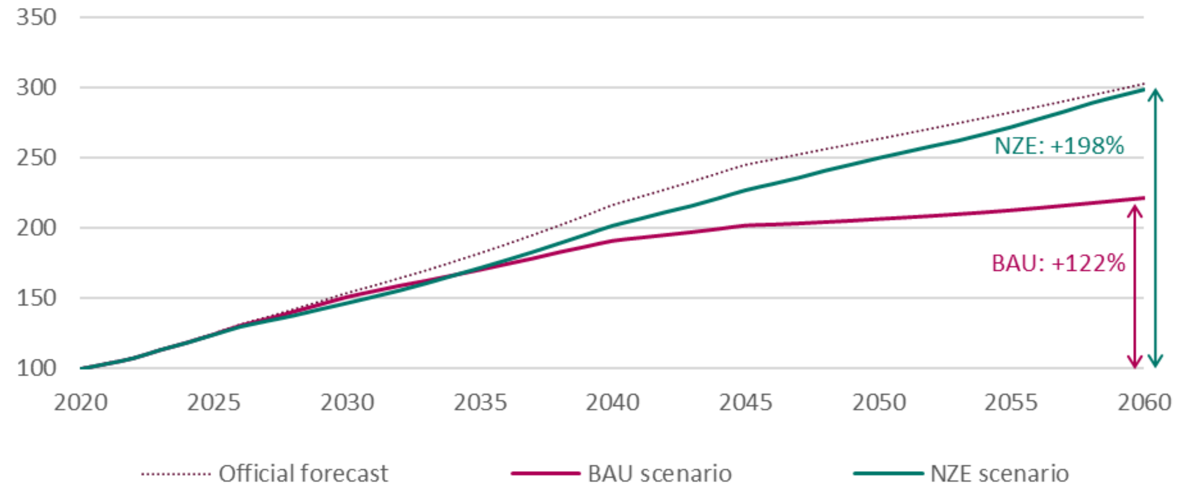
The current official forecast on economic growth by the Ministry of National Economy of the Republic of Kazakhstan does not yet anticipate the consequences of international climate action for Kazakhstan and projects an increase of Kazakhstan's GDP until 2060 by +202% (see the dotted line in Figure 4-1).

In modelling the BAU scenario, the impact of climate policies outside Kazakhstan is accounted for, including the EU-CBAM and the decline of market prices for fossil fuels. Thus, in the BAU scenario the economy will expand less than in the official forecast: by +122% until 2060.

In the NZE scenario, reaching climate neutrality in Kazakhstan by 2060 requires massive investments, which in turn will be driving strong economic growth up to +198%.

The corresponding figures for GDP per capita are at present USD 9.3 thousand (in 2017), while by 2060 they reach USD 14.9 thousand in the BAU scenario and USD 20.2 thousand in the NZE scenario.

Figure 4-1
GDP growth (2020 = 100) in the current projection and the BAU and the NZE scenarios

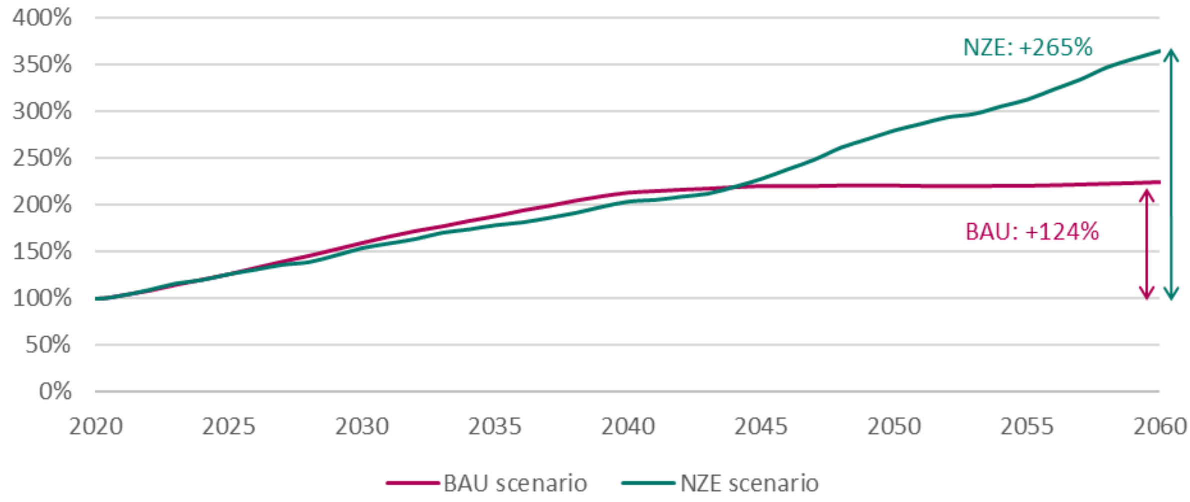


Source: Own calculations

The investment-driven economic development will increasingly require market-oriented framework conditions in order to be attractive for capital and financial markets, as well as for investments by domestic and foreign companies and private households. In order to initiate the development, the government should clearly signal its firm commitment to carbon neutrality by quickly getting the implementation of suitable measures and policies underway, for example by implementing a roadmap for a coal phase-out.

In both scenarios, household consumption increases until 2060 but with different dynamics. In the BAU scenario, the consumption growth is close to zero starting from 2040 (Figure 4-2). In contrast, the increase in the NZE scenario will be initially marginally lower than in BAU between 2027 and up to 2044, due to high domestic investment activities which take resources out of consumption, However, from 2045 onwards the net gains significantly outperform the improvements in BAU.

Figure 4-2
Change in real household consumption, 2020 = 100%

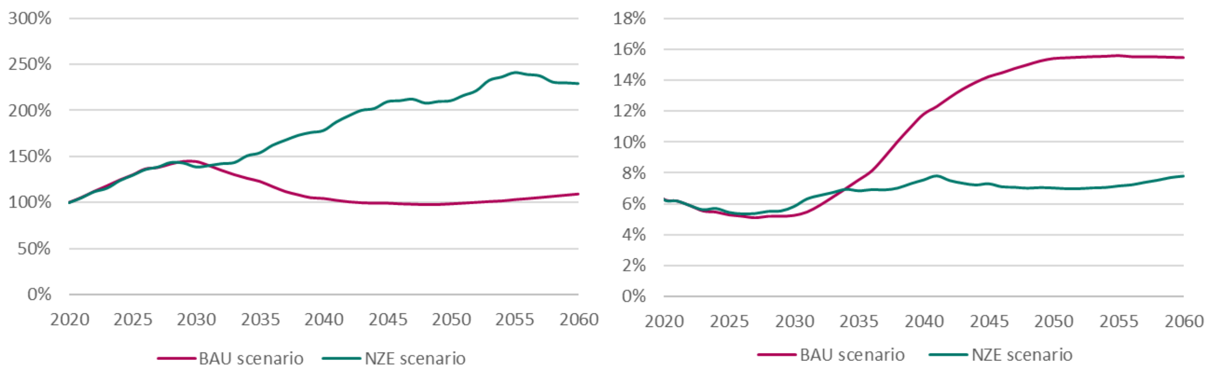


Source: Own calculations

4.2 Assessment of investment needs

The transition to the net-zero-emission development requires massive investment into new and state-of-the-art low- or no-carbon technologies. Moreover, high efforts to continuously attract investment in decarbonisation will be necessary. Figure 4-3 shows in the left panel the investment levels in the two scenarios, relative to 2020. In the BAU scenario, due to poor investment attractiveness of the economy, investments decline from 2029 onwards reaching an all-time low around 2045, followed by a slight increase afterwards. In the NZE scenario investment levels are continuously high and, despite 2-3 short weakening periods, follow a steady upward trend over the entire modelled time horizon (Figure 4-3, left panel).

Figure 4-3
Economy-wide capital investment by scenario, 2020 = 100% (left) and share of government in total investment, % (right)



Source: Own calculations

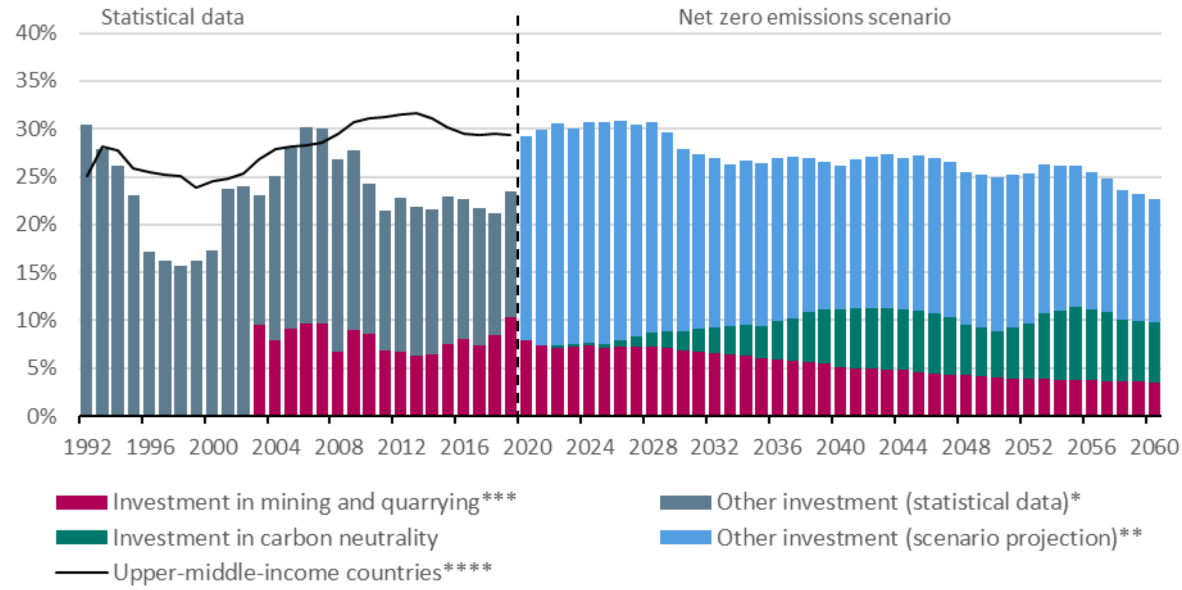
In the BAU scenario, the continuation of the present high-carbon economy increases the risks of stranded (fossil) assets. Worsening terms of trade and declining export revenues will reduce the profitability of affected industries, while at the same time the government will need to spend more scarce funds for investment but at the expense of other priorities (Figure 4-3, right panel). Around 2050, over 15% of all investment in the economy will have to be supplied by the government in the BAU setting, which is twice the current share.

The situation is very different in the NZE scenario, as the economy will be more attractive to private investors. Despite the significantly higher necessary investment volumes, the government share in climate-friendly investments supporting the transition towards net zero emissions will remain stable at below 8%. In the medium-term (2025 to 2035), when the readiness of private investors to provide finance is still relatively low, the share of government in total investment is somewhat higher in the NZE scenario than in the BAU scenario. Thus, continuous efforts to attract private investment should be prioritised.

It is important to emphasise, however, that a large part of "low- or no-carbon" investments will be made instead of high-carbon projects. This replacement effect implies, that when a worn-out carbon-intensive installation (e.g., coal-fired power plant) needs to be replaced "anyway", then only the additional cost of building and operating a new low-carbon installation, instead of a new carbon-intensive installation, is considered driven by policies to reach net zero emissions. This significantly reduces the amount of the necessary additional investment into decarbonisation. This is illustrated in Figure 4-4, which compares the historical investment levels as a share of GDP and the projection until 2060 in the NZE scenario. The main findings from the comparison are as follows:

1. In the last decades, the ratio of investment to GDP in Kazakhstan has been, with few exceptions, consistently lower than the average of the peer group of upper-middle-income countries[35].
2. In the past, a large share of the investments (marked red in Figure 4-4) was allocated to mining and quarrying industries, which are traditionally carbon-intensive.
3. In the NZE scenario, carbon-intensive investments are increasingly avoided and investment funds are diverted into low- and zero-carbon activities: Relative to GDP, the green investment in the NZE scenario will require a share of investment similar to what is currently directed towards mining activities. Mining will have to be significantly reduced in order to achieve carbon neutrality by 2060.

Figure 4-4
Economy-wide investment as a share of GDP (statistical data and NZE projection), %



* Until 2003, total investment including mining and quarrying
** Scenario data can slightly differ from World Bank data due to different accounting of reinvested profits
*** Statistical data until 2019, scenario projection from 2020
**** Countries with GIP per capita between USD 4096 and USD 12695

Data: World Bank, Bureau of National Statistics (1992-2019), own calculations

4. Given the current enormous depletion of the capital stock in Kazakhstan, investment levels will have to increase substantially until 2030 independently of decarbonisation efforts (compare to Figure 4-3, left panel). However, if green technologies, instead of high-carbon

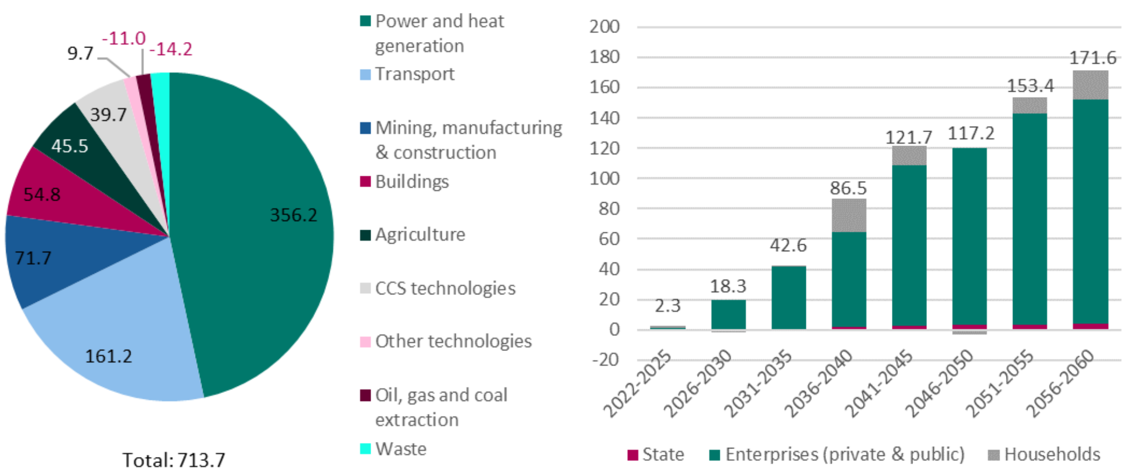
[35] The World Bank classifies countries with per capita income levels ranging from 4096 to 12695 USD as upper-middle-income countries.

technologies, are selected to replace the outdated equipment, these investments will contribute to significantly reducing GHG emissions without the necessity to steer additional investment specifically towards decarbonisation. The accumulated net additional (incremental) investment required for reaching carbon neutrality is estimated for the 40-year period from 2022 to 2060 at a total of around USD 714 billion in the NZE scenario. Given that the expected total savings of GHG emissions over the same period amount to 9.76 Gt CO_2-eq, the average decarbonisation price is relatively low at 73.1 USD/t CO_2-eq.

5. Overall, the investment share of GDP in the NZE scenario does not significantly exceed the historical levels in Kazakhstan. In the most intensive investment phase until 2030, the investment share of GDP reaches up to 31%, which is slightly above the upper-middle-income group average and the investment levels in Kazakhstan in 2006-2007. After 2028, the investment share of GDP declines and, already by 2050, returns to the current levels.

The redistribution of investments across sectors is further illustrated in the left panel of Figure 4-5. It presents the necessary incremental (additional) investment by sector in the NZE scenario, compared to the BAU scenario. By far the largest investment is needed in power and heat generation with USD 356 billion (50%). The total investment share necessary for transport is 23% (corresponds to USD 161 billion), for industry – 10% (in total almost USD 72 billion), for buildings – 8% (or nearly USD 55 billion), and for agriculture – 6% (USD 45.5 billion). Reaching the carbon balance in the NZE scenario also requires investments USD 39.7 billion into technologies of carbon capture and storage.

Figure 4-5
Cumulative necessary incremental investment by sector (left) and by five-year periods (right), 2022-2060, USD billion



Source: Own calculations

At the same time, investments in fossil fuel extraction will be consistently lower than in the BAU scenario, marked in Figure 4-5 with minus USD 11 billion. This decline in investment is aligned with the falling demand for fossil fuels both internationally and domestically, the phase-out of coal production and the projected peak of oil and gas extraction in 2035.

In addition, waste management is emerging as a new sector in the economy in both scenarios, although reducing costs in the NZE scenario, mostly due to significant reduction of waste creation, will lead to the overall lower investment volume than in the BAU scenario, marked with minus USD 14.2 billion in Figure 4-5.

When comparing investments over time by dividing the investment horizon into five-year periods (Figure 4-5, right panel), it is evident that the volume of incremental investment in the NZE scenario continuously increases until 2060. This is because the least-cost emission reduction investments are made early on and more expensive measures are implemented later, and much stronger efforts are necessary to achieve further emission reductions.[36] Over the next 40 years, the annual incremental investment in the NZE scenario is projected to be on average USD 18.3 billion above the investment levels in the BAU scenario, which corresponds to 5% of GDP.

Figure 4-5 also shows that most investments are made by enterprises and households. This illustrates the role of households and incentivised private investment in decarbonising the economy and ultimately reaching carbon neutrality. Thus, the main role of the government in this process is to create an enabling regulatory environment and to support the development of the necessary financial and physical infrastructure. Direct public investments into achieving net zero emissions will constitute only a small share of total investment. However, attracting sufficient private investment in the decarbonisation of power and heat generation, of steel, cement and aluminium production – especially in the relatively early stages – will require a consistent set of strategies and policies.

[36] This is based on present estimations of the future cost of technologies. This will certainly be subject to change over the next decades, and it seems safe to assume that costs for some technologies will decline or new technologies will be developed and marketed.

Box 4-1
Carbon-free private passenger transport and changes in direct household expenditures

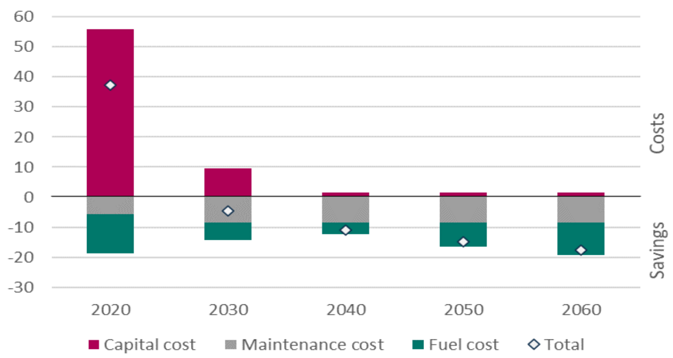
Private household expenditures will be affected by full decarbonisation as well, especially in individual passenger transport, but also buildings and household appliances. But a significant share of spending for achieving net zero emissions will be made by private households when replacing old with new and more energy-efficient vehicles and appliances, and by switching to zero-carbon equipment, which in turn will generate savings on energy goods and services.

An illustrative example is provided by the switch from internal combustion engine (ICE) cars to electric vehicles (EV). Currently, sales prices of EVs are higher than those of comparable ICE vehicles. Roughly recalculated into monthly rates over the assumed vehicle lifetime of 20 years, the higher sales price of EV increases the cost of car ownership on average by USD 56 per month compared to a gasoline vehicle. But after deducting the savings on fossil fuels, the total current car ownership cost of EV is about USD 37 per month higher than that of combustion engine vehicles. Furthermore, EVs have significantly less wear-prone parts, and so the operational cost for maintenance and repair of EV, compared to ICE vehicles, will be lower as well.

Over the next 5 years, the expected large-scale roll-out of EVs will eventually lead to a convergence of sales prices of electric and combustion-engine vehicles for both new and used cars elsewhere, and later on in Kazakhstan as well. At the same time, future savings on operational and fuel costs will remain an advantage of EVs. As a result, by 2030 the total cost of driving EVs will be lower than that of ICE vehicles, and this cost advantage will increase over time (Figure 4-6).

So far, oil prices in Kazakhstan do not reflect the cost of GHG emissions from fossil fuel combustion. If the latter would be internalised with carbon taxes, the advantage of switching to EV would emerge earlier on and the differences in cost would be even larger.

Figure 4-6
Difference in the cost of car ownership for electric versus gasoline vehicles (positive = cost is higher for electric vehicles), USD per month



Source: Own calculations

Hence, switching to electric vehicles will not only be environmentally beneficial but will also allow households to save on mobility expenditure. A precondition for the switch to EVs is the sophisticated roll-out of charging infrastructure for EVs. This will resemble the past roll-out of mobile communication. Initially, wealthier consumers in densely populated urban areas will be connected and benefit first, while later on technology and infrastructure will be also become increasingly available in less affluent or less populated areas. But eventually, and similar to today's mobile communication network, the charging infrastructure will cover large parts of Kazakhstan.

5 Sectoral decarbonisation pathways

This section presents the transformation pathways for the sectors emitting or removing greenhouse gases according to the guidelines of the IPCC as outlined in Section 1.4.

The historical GHG emission levels, the projections for the BAU scenario and the NZE targets are shown in Table 5-1. The largest source of emissions in Kazakhstan is the combustion of fossil fuels. It accounted with 317 Mt CO_2-eq for 83% of net total GHG emissions of 382 Mt CO_2-eq reported in 1990. In 2017, the emissions from fossil fuel combustion were at approximately the same level. In the BAU scenario, the GHG emissions from fuel combustion would exceed the 1990 level in 2030 and continue to rise until 2060 to reach 362 Mt CO_2-eq. This would imply an increase of GHG emissions of 9% compared to the 1990 level.

Table 5-1

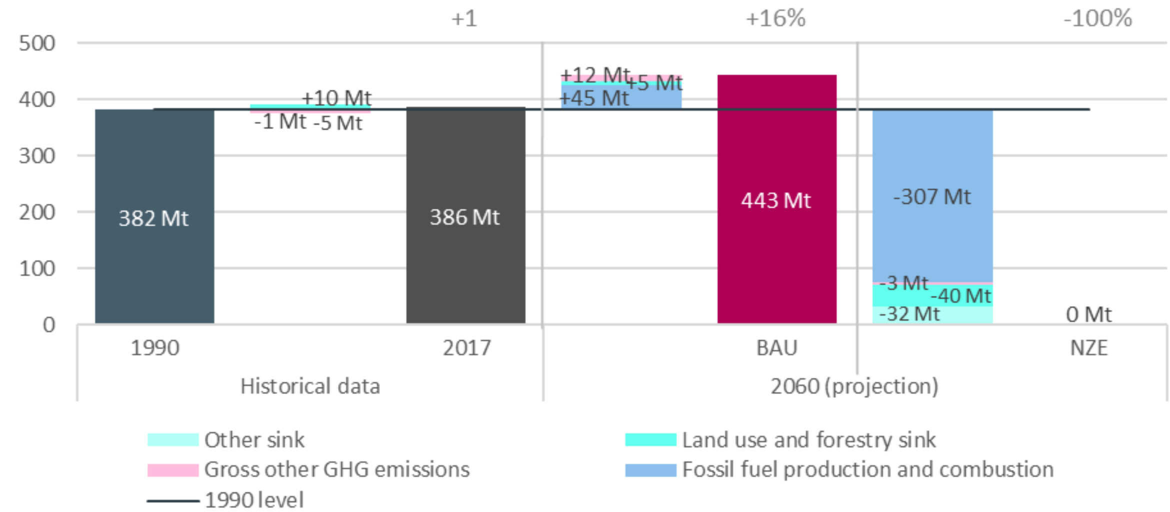
Reported GHG emissions in 1990, 2017 and scenario targets for 2025, 2030 and 2060, Mt CO_2-eq (% of total)

	1990	2017	2025	2030	2060
Baseline scenario (BAU)					
CO_2 from fuel combustion	317 (83%)	316 (82%)	332 (81%)	357 (82%)	362 (82%)
Fossil fuel CO_2 per capita (tons)	19 (5%)	18 (5%)	0 (0%)	17 (4%)	14 (3%)
Gross other GHG emissions	69 (18%)	63 (16%)	78 (19%)	84 (19%)	80 (18%)
Total gross GHG emissions	386 (101%)	379 (98%)	410 (100%)	440 (101%)	442 (100%)
Land use and forestry sink (-) / emissions (+)	-4 (-1%)	6 (2%)	-2 (0%)	-4 (-1%)	1 (0%)
Net GHG emissions	382 (100%)	386 (100%)	408 (100%)	437 (100%)	443 (100%)
Net zero emissions (NZE)					
CO_2 from fuel combustion	317 (83%)	316 (82%)	322 (83%)	230 (80%)	10 (13%)*
Fossil fuel CO_2 per capita (tons)	19 (5%)	18 (5%)	0 (0%)	11 (4%)	0 (1%)*
Gross other GHG emissions	69 (18%)	63 (16%)	77 (20%)	74 (26%)	66 (87%)*
Total gross GHG emissions	386 (101%)	379 (98%)	399 (102%)	304 (106%)	76 (100%)*
Land use and forestry sink (-) / emissions (+)	-4 (-1%)	6 (2%)	-9 (-2%)	-18 (-6%)	-43 (-57%)*
Other carbon sinks (-)			0 (0%)	0 (0%)	-32 (-43%)*
Net GHG emissions	382 (100%)	386 (100%)	389 (100%)	286 (100%)	0 (0%)*

* Gross GHG emissions are used for comparison of sectoral contribution, as net emissions are zero

Data: Kazakhstan 2020 Common Reporting Format (CRF) Table (emissions in 1990, 2017); World Bank (population 1990); Economic Research Institute, Kazakhstan (population 2017-2050), own calculations.

Figure 5-1
Components of emission reduction in 2017 and 2060, relative to 1990, Mt CO_2-eq



Data: Kazakhstan 2020 Common Reporting Format (CRF) Table (emissions in 1990, 2017), own calculations.

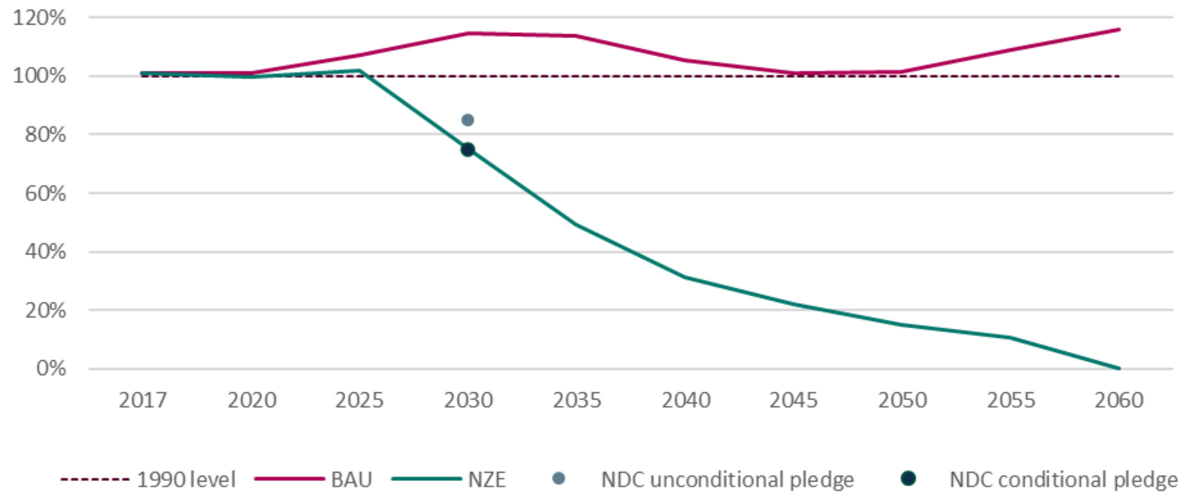
In the NZE scenario, the path to reducing GHG emissions from fuel combustion is steeper. In the mid-term, emissions from fuel combustion are projected to decline to 230 Mt CO_2-eq in 2030, followed by a strong contraction afterwards, reaching 10 Mt CO_2-eq in 2060 – a reduction of 97% compared to 1990.

The total emissions captured in the category "Gross other GHG emissions" will increase in the BAU scenario, while remaining relatively stable in the NZE scenario. These emissions include emissions from industrial processes, agriculture, and waste management.

Figure 5-2 shows the total net GHG emissions relative to 1990 and in comparison with the NDC emission reduction pledge for 2030. In the BAU scenario, the total GHG emissions in Kazakhstan would reach 15% above the 1990 level in 2030 and, after a short-lived weakening, again increase to 16% above the 1990 benchmark in 2060, which is far beyond the levels of Kazakhstan's international pledges. In the NZE scenario, on the contrary, the GHG emissions decline early on and converge to the conditional NDC target of a 25% reduction compared to the 1990 levels in 2030. By 2060, the GHG emissions are reduced to net zero in the NZE scenario, meaning that any remaining emissions are absorbed in natural carbon sinks or through new technologies.

Figure 5-2

Scenario emission pathways and the NDC 2030 pledge, % of the 1990 level

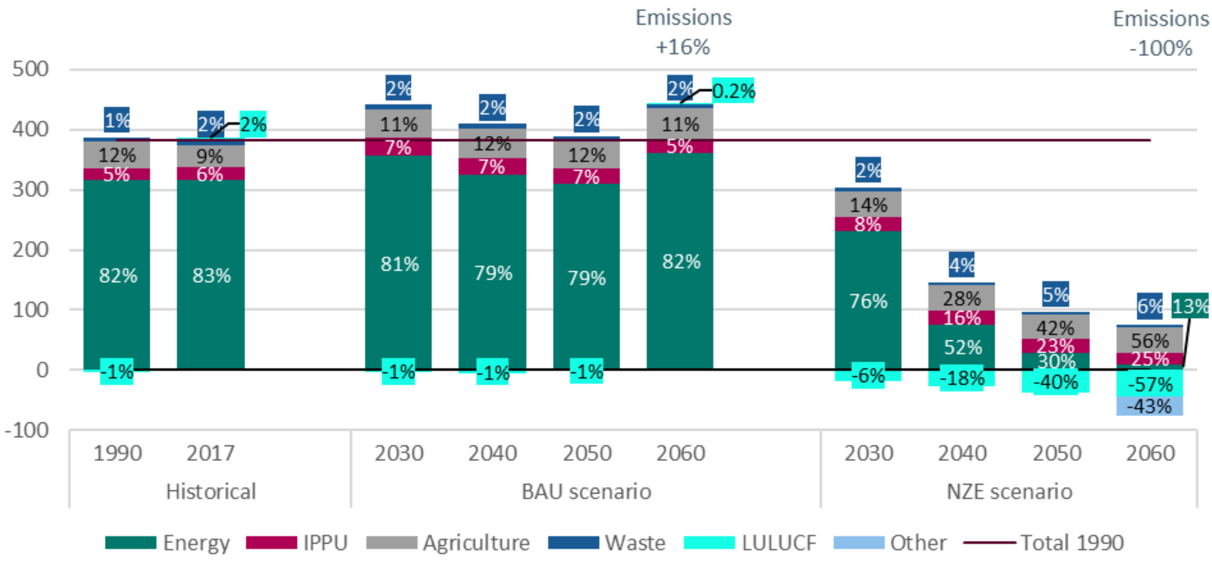


Source: Own calculations

Most GHG emission reductions need to be achieved in the energy sector by downscaling fossil fuel combustion (Figure 5-3). This requires both steep improvements in energy efficiency in transmission, distribution and final demand, and a switch to non-fossil fuels in the primary energy supply. The application of carbon absorption technologies like carbon capture and storage (CCS) will be required in the NZE scenario for the enhanced decarbonisation of the energy sector and industrial processes (IPPU).

Figure 5-3

Contribution of IPCC sectors to overall emission levels historically and in scenario projections, Mt CO2-eq



Source: Own calculations

At the same time, the planned expansion of agricultural livestock production runs counter to the GHG emission reduction in other sectors and hence the relative share of agriculture of presently 9% of gross total GHG emissions (in 2017) increases slightly to 11% by 2060 in the BAU scenario and reaches 56% in the NZE scenario (Figure 5-3). At the same time, the CO_2 absorption capacity of carbon sinks of 1% in 1990 rises until 2060 to reach 57% in the NZE scenario. The sharp increase is achieved through both the decline in gross GHG emissions and steep improvement of carbon sequestration in land use, land use change and forestry (LULUCF).

The next section analyses in more detail the emissions from the combustion of fossil fuels, i.e., the oxidation of carbon when fossil fuels (i.e., coal, oil, natural gas) are burned. The UNFCCC classifies any emissions from fuel combustion as emissions from the energy sector. Consequently, the following section will discuss not only how the supply of energy will change in order to achieve deep decarbonisation and ultimately carbon neutrality, but also how the transformation in the energy sector is intertwined with secondary energy conversion and the final demand for energy.

5.1 Energy sector

Under the UNFCCC classification, the energy sector comprises primary energy extraction, transport, conversion into secondary energy (e.g., power, heat, hydrogen), transmission and distribution, and final demand for energy services by transport, buildings, agriculture, and industry.[37] The energy sector also accounts for fugitive emissions from primary energy extraction, transmission, and distribution. Consequently, at present virtually all economic activities contribute to emissions in the energy sector.

The decarbonisation and transition to a carbon-neutral energy sector requires three elements, which will lead to fundamental changes in the energy sector:

1. The decarbonisation of the primary energy supply;
2. The decarbonisation of electricity and heat; and
3. The decarbonisation and highly efficient end use of energy in buildings, transportation, agriculture, and industry.

Achieving the ambitious carbon neutrality target will demand a profound transformation of the whole energy sector in Kazakhstan. The fundamental changes required in the energy sector can

[37] Primary energy originates from natural resources, both non-renewable or renewable. The sources of primary energy include oil, coal, peat, shale, natural gas, waste, nuclear, hydro, biomass, wind, solar, and geothermal energy. Secondary energy is a carrier of energy, such as electricity, heat, gasoline, diesel, hydrogen, or biofuels.

be illustrated with Sankey diagrams, which provide a schematic high-level view illustrating the differences between the current and the decarbonised energy system.

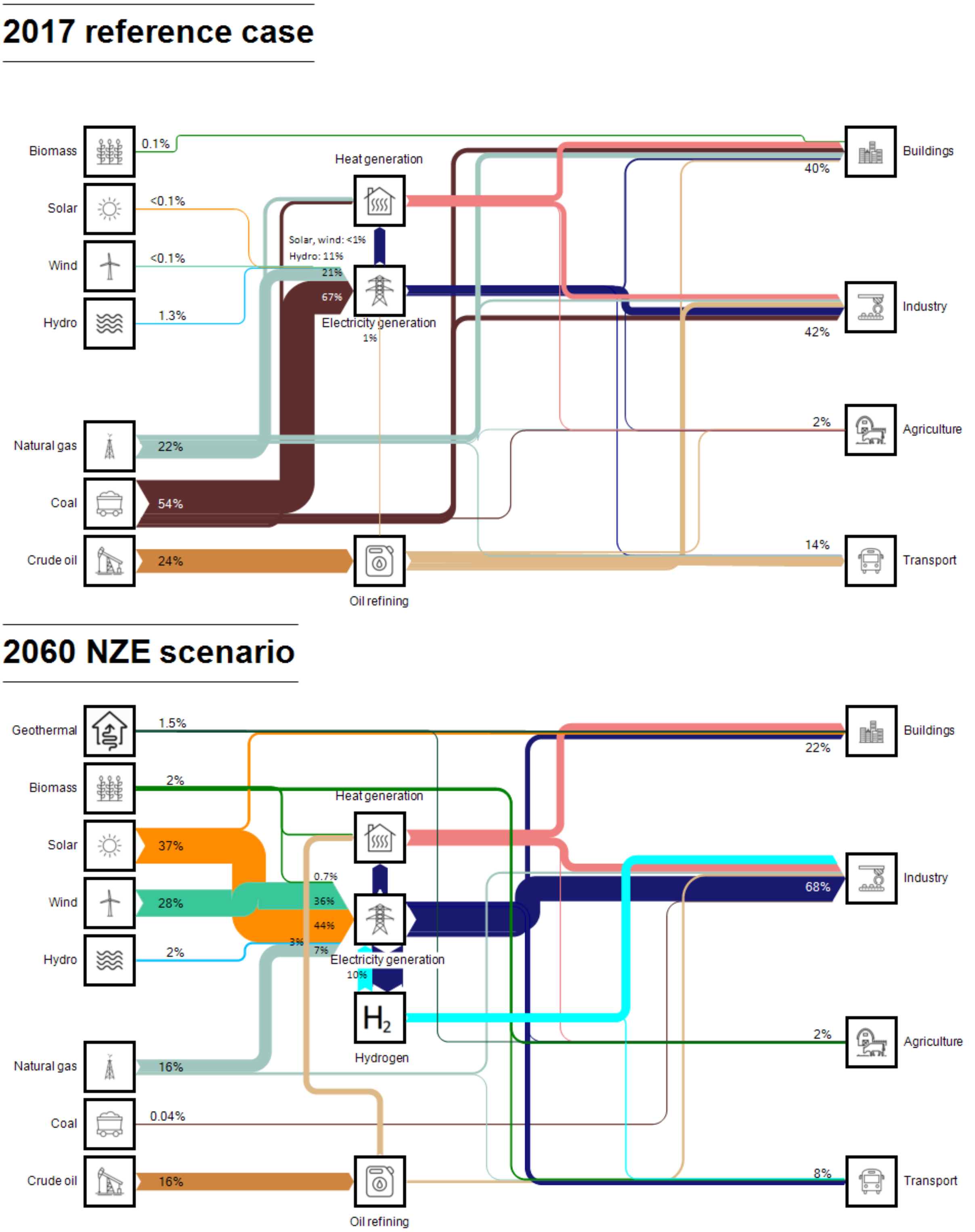
In Figure 5-4, the current structure of the energy sector is shown in the upper panel, the lower panel demonstrates the 2060 energy system in the NZE scenario.[38] The arrows represent the major flows of energy from primary supply to end use, whereby the width of the arrows is proportional to the magnitude of the flows. In each panel, the primary energy supplies are shown on the left side, conversion processes in the middle, and final energy consumption on the right. All final energy consumption is allocated to the four categories of buildings, transport, industry, and agriculture. In the present structure of the energy sector, the three fuels on the bottom left side (i.e., primary energy supply) and the broad arrows connecting them to secondary energy conversion and final demand illustrate the heavy dependence on carbon-intensive fossil fuels.

The Sankey diagrams illustrate that a transition to carbon neutrality in Kazakhstan by 2060 will require a profound transformation of the entire energy sector, from primary energy supply to final use. The consequences of the three main elements of decarbonisation – energy efficiency, net-zero-carbon electricity and heat generation, and fuel switching to electricity and other low- or no-carbon fuels – are readily visible when comparing the figures:

1. In general, both primary supply and final energy use are reduced in the carbon-neutral system of 2060, relative to the BAU scenario.
2. Compared to the present system, oil, coal, and gas are supplanted by renewable energy sources, while coal is almost completely phased out.
3. Renewable energies gain more significance, as wind, solar, geothermal, and biomass account for increasing shares in the primary energy supply. In the NZE scenario, on-shore wind and solar become the main sources for power generation.

[38] For comparison of the 2060 structure between the scenarios, see Figure A- 10 in the Appendix.

Figure 5-4
Sankey diagram for Kazakhstan in 2017 and NZE projection for 2060[39]



Source: Own calculations

[39] The percentages around electricity generation show shares of electricity produced from each source (as opposed to the shares of the respective energy inputs, which are higher for combustion fuels due to conversion losses).

4. Electrification is increasingly dominating final energy use, driving out fossil fuel combustion.
5. Conversion processes like biomass refining (for biogas, biodiesel, and biokerosene) and the production of green hydrogen substitute fossil fuels in final demand, especially in applications which are difficult to electrify, e.g., in water and air transport or in the production of aluminium, cement, and steel.
6. Carbon capture and storage (CCS) is only a bridge technology towards a fully decarbonised and 100%-renewable future. Not only are CCS technologies cost- and energy-intensive, but they also require storage capacities for the captured carbon dioxide, which eventually impede both the scale and duration of CCS use.

The key elements of energy transition are summarised in Table 5-2:

Table 5-2
Comparison of the current and the decarbonised energy system by sector

Sector	Current energy system	Decarbonised energy system
Electricity	Heavily dominated by coal	Renewables, CCS
Transportation	Oil-dominated	Electricity, hydrogen, biofuels, end-use efficiency
Buildings	Coal and natural gas dominated heating	Electrification, end-use efficiency, renewable heat
Industry	High demand for fossil fuels	Electrification, end-use efficiency, hydrogen, CCS

Source: Own presentation

5.1.1 Decarbonisation pathways in the energy sector

The scenario analysis and the development of decarbonisation pathways in the energy sector were conducted by using the 2021 update of the TIMES-KAZ model. The TIMES model searches for a technologically feasible but least-cost pathway towards a set goal, i.e., the level of emission reduction in this application. The assumptions then represent the country-specific limits within which the model can select optimal technologies and the extent of their use. Therefore, most of the assumptions are expressed in terms of either technological solutions the model is allowed to use or lower and/or upper limits on the use of certain technologies. The TIMES-KAZ model entertains a wide set of assumptions and sets the respective limitations and targets for 2060 (for a list of assumptions, see Table A- 2 in the Appendix).[40]

In the BAU scenario, the model is not constrained with regard to emission levels, and so, the GHG emissions in the energy sector are projected to increase until 2030. Between 2030 and 2045,

[40] This implies that, on the optimal path, some indicators will not equal the set limits. For example, in the NZE scenario, an upper limit is set on nuclear power capacity. However, nuclear power is an expensive option and, if less expensive zero-carbon sources are available (e.g., renewables), the latter will be chosen and the optimal pathway may not include nuclear power generation at all. Similarly, there is a lower limit on the share of renewables in power generation, but their actual share may well exceed that limit, if it leads to higher technical and economic efficiency.

GHG emissions will decrease slightly, because of a slowdown in economic growth, a reduction in fossil fuel production (after reaching the peak in oil extraction), incremental energy efficiency improvements from the renewal of capital stock, and the wider use of renewable energy sources for electricity generation. After 2045, the energy efficiency improvements slow down and continued increase in coal production for heat, power, and hydrogen production will cancel them out, leading to increasing emission levels. Thus, in the BAU scenario, the total GHG emissions in the energy sector may reach 107% of the 1990 level in 2030 and 109% in 2060. This corresponds to 17.5 and 13.8 t CO_2-eq of GHG emissions per capita, respectively.

In the NZE scenario, the GHG emissions from the energy sector were strictly limited in accordance with the scenario design and assumptions to fulfil the conditional NDC target and the climate neutrality pledge. The GHG emissions from the energy sector were restricted to be 31% lower compared to the 1990 level in 2030, so that the conditional NDC goal of a 25% economy-wide GHG emission reduction can be achieved. In 2060, GHG emissions were set to be 97% below the 1990 level, which corresponds to a reduction of emissions to 0.4 t CO_2-eq per capita.

Taking into account the currently available technological solutions at presently known investment costs as specified in the TIMES-KAZ model, reaching strictly zero emissions in the energy sector is not technologically and economically feasible. It was, therefore, assumed that the remaining 3% of emissions will be reduced with the help of either natural carbon sinks in other sectors or new technologies, currently not commercially available.[41]

The set restrictions for the NZE scenario in the TIMES model trigger a profound transformation of the energy sector. The volume and structure of primary supply and final energy demand varies considerably both over time and between the scenarios (see Section 5.1.2 and 5.1.4).

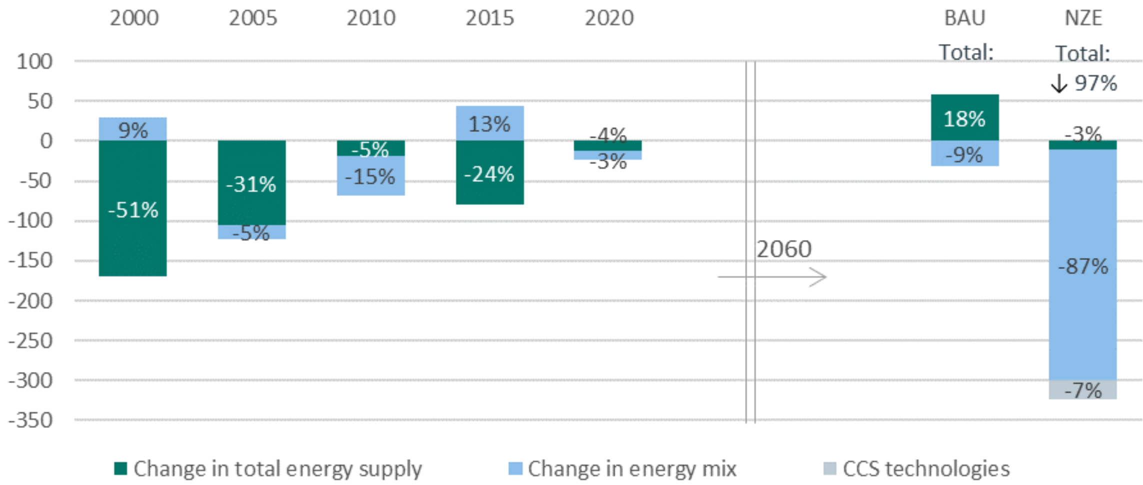
The largest emission reduction in the energy sector is achieved through changes in the energy mix by shifting the energy supply towards more sustainable energy sources, i.e., transition towards the use of electricity and heat, instead of direct combustion of fossil fuels, and the increased use of natural gas and renewables. This leads to a decrease of GHG emissions by 9% in the BAU scenario and 87% in the NZE scenario (Figure 5-5).

[41] As per IEA (2021), most of the global emission reductions until 2030 can be achieved with already available technologies, however, about half of the emission reductions to reach global net zero in 2050 will be achieved with technologies presently in demonstration or prototyping stages. It can be expected that, in the future, more efficient and less costly solutions will be available, which will allow full decarbonisation in the energy sector.

Carbon capture and storage (CCS) is important for decarbonising the combustion of natural gas, permitting, in the NZE scenario, 7% of additional GHG emissions reduction. The use of CCS technologies will be essential for the decarbonisation of the power and heat sector and of industrial processes.

Figure 5-5

Decomposition of the overall change in energy emissions relative to 1990 (1990 level = 0) into change in energy supply, change in energy mix, and carbon capture and storage, Mt CO_2-eq



Source: Own calculations

Table 5-3

GHG emissions from fuel combustion and energy industries by sector, Mt CO_2-eq

		BAU scenario				NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Power and heat generation	102.8	133.8	113.9	91.0	106.7	78.7	8.2	2.0	0.1
Gross emissions	*102.8*	*133.8*	*113.9*	*91.0*	*106.7*	*78.7*	*60.8*	*31.2*	*20.1*
CCS	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-52.6*	*-29.2*	*-20.0*
Other energy industries	70.2	42.3	38.7	44.5	63.4	24.8	19.2	8.9	4.9
Agriculture	3.6	2.6	2.8	2.9	3.0	2.5	2.3	0.0	0.0
Industry	35.8	44.1	40.6	46.0	52.0	35.3	10.2	1.0	0.8
Gross emissions	*35.8*	*44.1*	*40.6*	*46.0*	*52.0*	*35.3*	*14.5*	*5.6*	*4.0*
Carbon capture & storage	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-4.3*	*-4.6*	*-3.3*
Buildings	28.8	24.6	24.7	24.2	24.1	12.6	3.1	0.5	0.0
Transport	24.4	26.0	27.8	28.1	27.8	22.2	15.2	10.0	1.8
Other	50.5	83.4	75.8	72.3	84.6	53.8	17.7	6.8	2.3
Total	**316.0**	**356.8**	**324.2**	**309.0**	**361.6**	**229.9**	**75.9**	**29.2**	**9.9**

Source: Own calculations

The largest emitter – power and heat generation – has also the largest potential for emission reductions. It generates the largest emission savings in all scenarios. In the NZE scenario, net GHG emissions from power and heat generation will be reduced from the current 102.8 Mt CO_2-

eq to just 0.1 Mt CO_2-eq in 2060, becoming essentially carbon-neutral[42]. This is achieved through change in the fuel mix and the use of CCS technologies capturing 99.5% of the remaining emissions from fossil-based power plants in 2060 (see Section 5.1.3 for more detail).

GHG emissions from fuel combustion in industry will steadily increase in the BAU scenario. Comparatively, it will be increasingly possible to decarbonise industrial production in the NZE scenario, and gross industrial energy-related GHG emissions will shrink from the current 35.8 Mt CO_2-eq to 4 Mt CO_2-eq (-89%) by 2060. After 2030, industry also introduces CCS technologies allowing to put underground additional 3.3 Mt CO_2-eq in 2060.

The next three subsections will analyse the decarbonisation along the three stages of energy flows in the energy system in more detail: energy production (primary energy supply), conversion (power, heat generation and potentially hydrogen), and final use by buildings, transport, industry, and agriculture.

5.1.2 Primary energy supply

Improvements in energy efficiency and shifts to low-carbon technologies in the power and heat sector and the end use of energy will induce profound changes in the primary energy supply.

The overall volume of total primary energy supply will increase substantially by 2060 relative to the 1990 level in the BAU scenario but will remain close to the 1990 level in the NZE scenario (Figure 5-6 / Table 5-4)[43]. Compared to the BAU scenario, in the NZE scenario the total primary energy supply in 2060 is lower by 18%. While in the BAU scenario coal still retains a significant though smaller share in the primary energy supply even in 2060, it almost completely disappears from the energy balance in the NZE setting as it is substituted primarily with renewable energy sources. (Figure 5-6 / Table 5-4, see also Figure A- 12 in the Appendix).

[42] The TIMES-KAZ model was developed and calibrated by early 2021, and so it relies on the 2020 national inventory submission for emission data. While the 2022 submission has somewhat redistributed the emissions between the categories within the energy sector, the total was almost unchanged. For presenting the 1990 and 2017 data in this section, the 2022 submission was used.

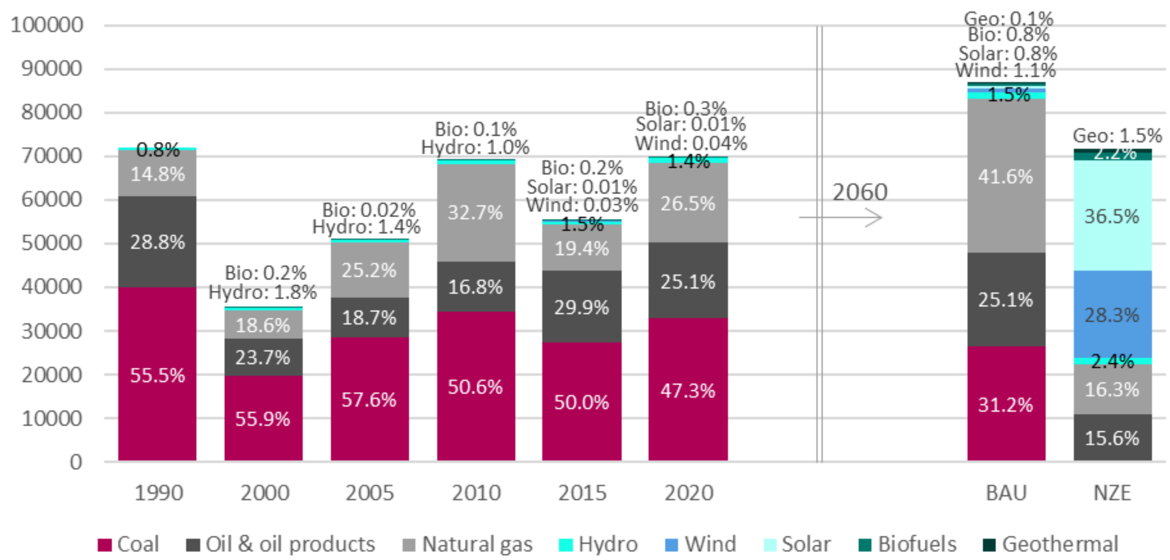
[43] (Small) reduction in TPES through electricity exports is not shown in Figure 5-6.

Table 5-4
Total primary energy supply (TPES) by fuel type, ktoe

		BAU scenario				NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Coal	35006	32861	25680	20233	26474	14143	4404	440	31
Oil and oil products	15368	20095	21154	21308	21334	18952	12464	11572	10876
Natural gas	14001	24339	28408	36543	35356	24365	27906	17390	11373
Renewables	1114	1462	2213	3459	3693	6195	16632	35499	49489
Electricity import (+) / export (-)	-375	-682	-830	-978	-1956	-682	-830	-978	-1956
Total	**65113**	**78076**	**76625**	**80565**	**84901**	**62973**	**60576**	**63923**	**69813**

Source: Own calculations

Figure 5-6
Changes in total primary energy supply (TPES) by source, ktoe



Source: Own calculations

Considering that 90% of the current coal production in Kazakhstan (in physical volume) is comprised of thermal coal[44], avoiding extraction of thermal coal and the related fugitive emissions alone can decrease emissions from mining by about 80% (20 Mt CO_2-eq) in 2060 in the NZE scenario. Adding the emissions saved by phasing out the coal combustion (see also discussion in Section 5.1.3 and 5.1.4) will have a profound impact on the reduction of total emissions.

In the BAU scenario, natural gas will become the dominating energy source by 2060, covering over 40% of the total primary energy supply. In the NZE scenario, it will cover just about 16% of

[44] Thermal coal is used solely for combustion to generate electricity or heat in nearby powerplants. Coking coal can be chemically processed and used for industrial applications.

the total primary energy supply, significantly less than wind or solar resources. The total share of renewable energies will increase from 2% in 2020 to 4% in 2060 in the BAU scenario and 71% in the NZE scenario. This increase is primarily driven by the massive expansion of solar and onshore wind energy, but also by a growing share of biomass and geothermal energy.

These changes in the energy mix are mirrored in the use of primary energy for electricity and heat generation and their direct combustion in industry, transport, and buildings. After a closer look at the consequences and benefits of the coal phase-out in the next subsection, Section 5.1.3 will present in detail the transformations in the power and heat sector.

Deep dive: The coal phase-out

Currently Kazakhstan is among the world's largest producers of coal, with proven coal reserves of 34.2 billion tonnes (4% of the world reserves). About two thirds of the coal reserves are comprised of brown coal, the rest – of hard coal (Kalmykov & Malikova, 2017). Coking coal, currently constituting 10% of the total production volume is mined in the Karaganda basin in Central Kazakhstan. At current levels of production, the coal reserves would last for up to 300 years[45].

However, decarbonisation requires to transform the economy towards low-carbon development and eventually reaching net carbon neutrality. The pursuit of this goal needs to be underpinned by near-term policies and measures. This implies a phase-out of fossil fuels, no new investment into unabated fossil assets, and a necessity to keep remaining fossil reserves in the ground. Among the fossil energy sources, coal is by far the most emission-intensive and, at present, it dominates the Kazakh energy sector, and power and heat generation in particular. Therefore, no low-emission development in Kazakhstan will be possible without an almost complete phase-out of coal from the energy mix. Moreover, a delay or avoidance of the coal phase-out would undermine overall investor trust and interest in both the (fossil-dominated) power sector and - in the presence of unused lucrative opportunities in this sector - also less financially attractive decarbonisation investments in other sectors.

The coal sector's direct share in the country's employment is rather small with 0.5%, and it accounts for a similar share of the total value added (Table 5-5). About a quarter of the produced coal is exported to neighbouring countries. The export of thermal hard coal to Russian thermal power plants constitutes over 75% of all coal exports.

[45] It should be acknowledged that renewable energy sources like wind and solar power do not face such restrictions and will be available in Kazakhstan beyond 300 years.

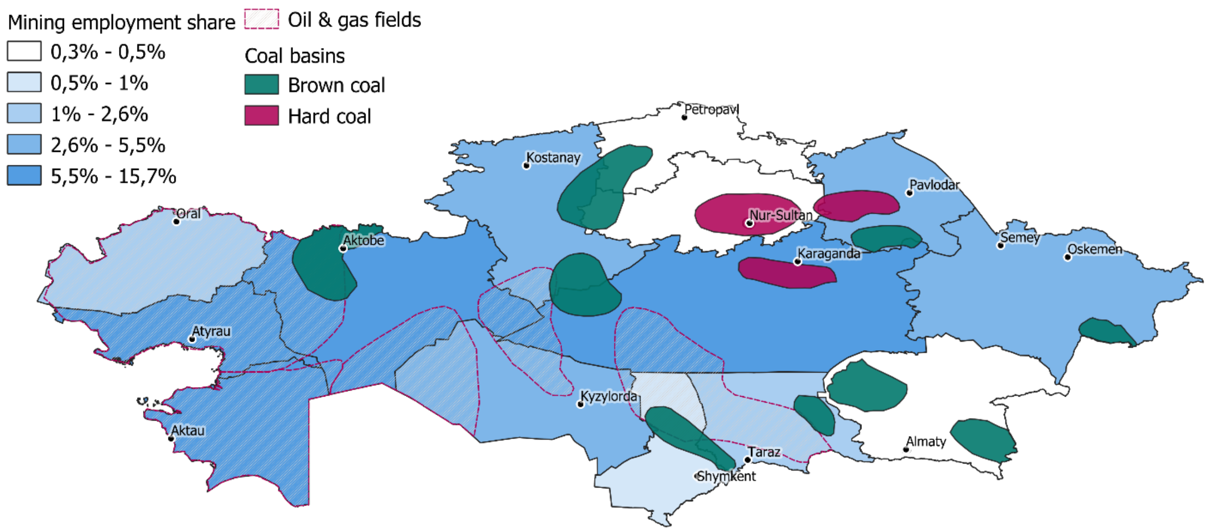
Table 5-5
Characteristics of the coal sector in Kazakhstan

	2017
Total production, billion USD	1.49
Value added, billion USD	0.79
Share in total value added, %	0.5%
Share in employment, %	0.5%
Export share in sector production, %	26%
Production volume, Mt	112.3
Share of hard coal, %	84%
Share of coking coal, %	10%

Data: Bureau of National Statistics

The major coal reserves are concentrated in a few basins located at a distance from gas and oil reserves. The largest deposits are around Karaganda and Nur-Sultan (Figure 5-7). In some regions and cities, the local economy is centred around coal extraction and combustion for power generation and industrial production. This shapes a perception that ending coal mining and use is next to impossible without serious social and economic challenges in the respective regions. However, the gasification projects, e.g., in the Almaty region, indicate that other fuels are available. Therefore, the coal phase-out will be an ambitious but necessary and achievable task.

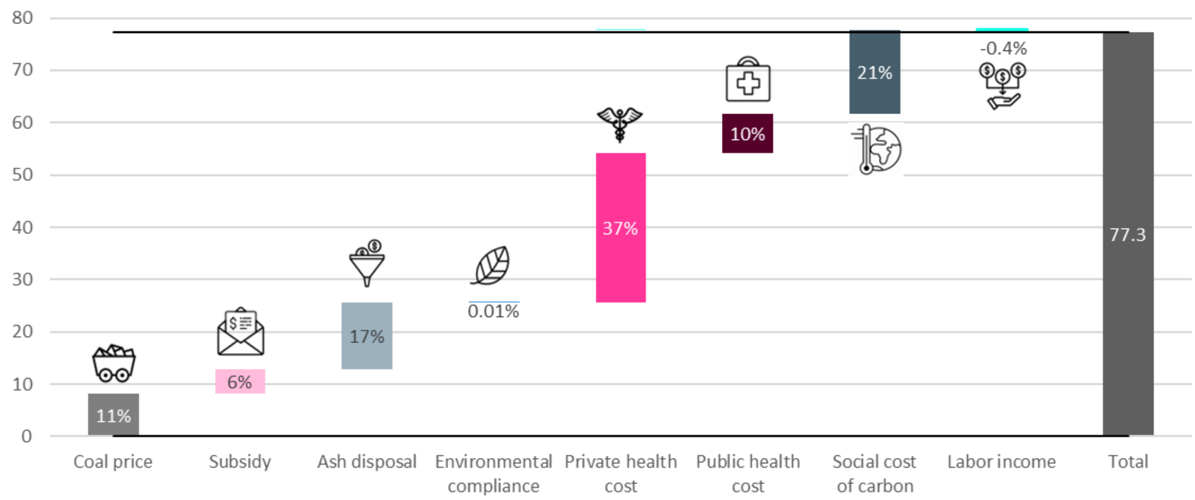
Figure 5-7
Coal basins in Kazakhstan



Data: Bureau of National Statistics; Base map: GADM

The current overall cost of coal production and combustion is already larger than the profits and income generated by the coal sector. In Figure 5-8, the societal costs of coal combustion are delineated, which also include the expenses and lost income resulting from coal pollution as estimated by the SD-KAZ model. Unlike other fuels, combustion of solid fuels like coal emits not only a variety of polluting gases but also harmful particles and dust. Moreover, ash disposal after combustion adds to the costs that can be avoided by using other fuels. Accounting for these additional expenses and the costs borne by the population and the government (subsidies, health cost) increases the cost of coal many times over (on subsidies, see also Box 5-1). Even though coal production itself also generates some labour income (marked with a negative sign, i.e., as a benefit in Figure 5-8), the indirect costs combined and accrued outside the coal sector reach USD 50 per ton of coal extracted, while coal sector profits only constitute USD 6.8 per ton of coal. This already overall negative impact of coal does not even include the climate-related damages from extracting and burning coal and the related GHG emissions, which can incur costs as high as USD 15.9 per ton of coal.[46]

Figure 5-8
Total societal cost of domestic coal production in 2017, USD per t of coal extracted



Source: Own calculations

At the 2017 production level, the indirect costs of coal would add up to about USD 6 billion, which is seven times the USD 790 million of value added in the whole sector (Table 5-5).
While the phase-out of coal will be at the expense of local economies, triggering substantial structural changes, the benefits from reduced pollution and diminished climate effects will be significant and more evenly distributed across Kazakhstan. For example, the reduction in pollution-related health costs will be beneficial to all. At the same time, it should be noted that

[46] The damages from burning coal are estimated as *social cost of carbon*. Social cost of carbon is related to GHG emissions and estimates the economic value of the impacts caused by extra GHG emissions over the lifetime of respective gases, including the "non-market" impacts on the environment and human health.

most of the quality-of-life benefits (such as clean air and improved health) will accrue directly to the transforming regions.

Box 5-1
Energy subsidies

Different definitions of what constitutes a subsidy are in use. The OECD cites the definition of subsidies as specified in the Agreement on Subsidies and Countervailing Measures (ASCM) under the WTO. The definition includes financial contributions by a government or any public body, such as direct or potential direct transfers of funds, foregone government revenue, provision of goods and services, or payments to funding mechanisms. It also includes any form of income or price support in the sense of Article XVI of GATT 1994. The latter refers to export or import of goods and covers such mechanisms as domestic price setting, reduced domestic transport charges, tax exemptions, etc.

The International Energy Agency (IEA) extends the definition of price support beyond the focus on international trade and, methodologically, uses the *price-gap approach* to estimate subsidies of fossil fuels. The price gap is the amount by which the average end-user prices paid by consumers fall short of the reference prices that correspond to the full cost of supply. The existence of the price gap indicates the presence of a subsidy. For Kazakhstan, the IEA estimates the overall value of fossil-fuel subsidies at USD 6.6 billion in 2019, or 3.6% of GDP. Of those, USD 2.2 billion correspond to coal subsidies (IEA, 2021). This is equivalent to USD 18.97 per tonne of coal extracted. Hence, the estimate of USD 4.65 per tonne of coal presented in this section and based on OECD (2014) is a conservative one.
The price-gap approach was further synthesised with the narrow OECD definition of subsidy to provide a comprehensive set of measures for monitoring the progress on the SDG target 12.c, which is to *rationalise inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions*. As per UNEP, OECD and IISD (2019), the subsidy categories are:

- Direct transfer of funds
- Induced transfers (price support)
- Tax expenditure, other revenue foregone, and under-pricing of goods and services
- Transfer of risk

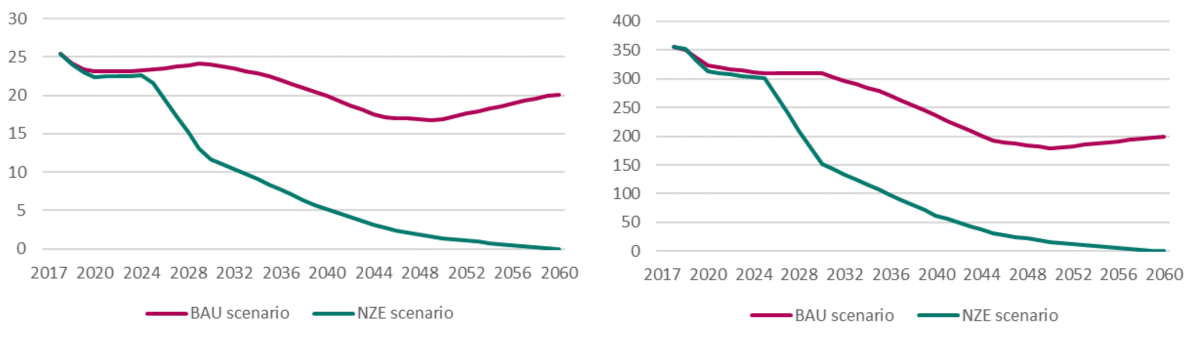
While the OECD labelled this broader definition as *support* in order to distinguish it from the narrow WTO definition, most international organisations use the term *subsidy*, especially in the context of fossil fuel subsidies.

Thermal coal production will decline and will eventually need to disappear to reach deep decarbonisation and ultimately climate neutrality of the Kazakh economy. In the BAU scenario, projecting a revival in coal use after 2050, a marginal reduction in profits in the coal sector is estimated, from a total of USD 769 million in 2017 to USD 767 million in 2060. The phase-out of coal production and coal-powered electricity generation in the NZE scenario will lead to a steep decline in profits (see also Table A- 5, Table A- 6 in the Appendix). By 2060, the profits in the NZE scenario will be insignificant at USD 0.3 million.

Similarly, employment from coal extraction will shrink and then recover slightly in the BAU scenario, reaching around 20 thousand jobs by 2060 from presently 25.4 thousand jobs – a net decline of 21% (Figure 5-9, left panel). In the NZE scenario, it is expected that under 30 jobs will remain in the sector by 2060. The remaining coal – around 47 kt in 2060 – will be consumed by industry. A similar trend is projected in employment related to coal-fired power generation.

The decline in the number of coal-related jobs has an impact on the total labour income generated by the sector. In the BAU scenario, coal-related employment is projected to continue generating over USD 14.4 million yearly in labour income by 2060. In the NZE scenario, the income generated by the coal sector will soon start to decline at an accelerated pace. On average, the envisaged reductions in coal extraction and use for power generation will lead to an income reduction of around USD 9.1 million per year over the next 40 years.

Figure 5-9
Employment from coal extraction, thousand persons (left) and per-capita total societal cost of coal extraction and combustion, USD (right)



Source: Own calculations

At the same time, the phase-out of coal generates significant benefits at the societal level concerning the cost of air pollution caused by coal extraction and use. As a result, the number of people with respiratory diseases will be reduced and, hence, the cost of treating such diseases will be reduced along with the losses in working time and labour productivity. Depending on the modelling approach, the NZE scenario generates cumulative net societal savings between

USD 18 billion and as much as USD 133 billion between 2020 and 2060 (see also Table A- 5, Table A- 6 in the Appendix). To put this figure into perspective, this corresponds to reducing the per-capita societal cost of coal extraction and combustion from the current USD 356 (in 2017) to USD 0.1 in 2060 in the NZE scenario (Figure 5-9, right panel). Thus, even in the most conservative calculation, the avoided health costs far outweigh the losses in employment income in the coal sector.

Furthermore, coal-related GHG emissions and, as a result, the social cost of carbon are projected to decline as well. In the BAU scenario, the total coal-related social cost of carbon amounts to USD 849 million in 2060, while it declines to USD 0.1 million in the NZE scenario.

In short, the continuation of coal extraction and coal combustion is reducing the overall welfare of Kazakhstan significantly. Moreover, the overall gains from the coal phase-out by far outweigh the resources necessary to replace it, for example, with renewable energy sources. Taking into account the recent increase in electricity tariffs for households – which currently stand at USD cent 2.9 per kWh of coal-powered electricity[47] - at this level, the tariffs set by administrative decree are not sufficient for covering the capital costs in full. It should be noted that almost all coal-powered electricity in Kazakhstan is generated in power plants built decades ago, whose capital costs have long been written off and whose capital stock urgently needs to be renewed.

By comparison, the average 2020 auction prices for renewable power installations, which include capital expenditures, were USD cent 4.5 per kWh for new hydro, USD cent 4.8 per kWh for solar, and USD cent 5.7 per kWh for on-shore wind power.[48] In comparison to 2018, the auction prices decreased by 4% for wind power installations and by 34% for solar power installations. This reflects the significant price decreases within the last decade in most energy markets around the globe. The fundamental driver of this development is that renewable energy technologies follow learning curves, implying that the price per unit of capacity decreases as the cumulative globally installed capacity grows. This is different from electricity production from fossil fuel sources, which is based on long-established technologies and, thus, does not follow learning curves anymore.

At first glance, the comparison of coal-based electricity tariffs with the 2020 auction prices for renewables implies that renewable energies are between 55% and 96% more expensive than "cheap" coal-based electricity generation.

[47] Based on tariffs set in (ME RK, 2021)

[48] Based on data by (Financial Settlement Center for RE, n.d.)

At the 2020 level of production, the complete replacement of coal-powered electricity generation with renewables would increase the total expenditure on electricity to somewhere between USD 1.5 billion and almost USD 2 billion.[49] However, the real 2020 subsidies for coal production and use of around USD 0.49 billion need to be deducted from this amount. Further USD 0.8 billion of direct government expenses related to the health consequences of coal production and use should be deducted, as the health situation of the affected population is projected to improve over time. So, to put this into perspective, removing the coal subsidies and redirecting the state support towards renewables, plus avoiding the annual coal-related health costs borne by the government, would cover most of the additional electricity expenditures resulting from a full substitution of coal-based electricity with power generated solely from renewable energies.

Importantly, this cost reduction results from avoided costs and, therefore, does not pose a financial burden on the society or the state. Moreover, it does not yet account for the additional benefits resulting from reduced private health costs and social costs of carbon. This balance tips even more in favour of renewables when the capital costs for retrofitting the existing and constructing new coal-fired power plants are considered.

To summarise, the phase-out of coal will deliver substantial net benefits to the Kazakh economy and to society as a whole. The comprehensive technological and infrastructural changes in the energy system will entail significant employment impacts for fossil fuel workers and their communities. The social impact on the affected local economies needs to be softened by means of a just transition. including combining elements of targeted social transfers to affected households, retraining and other skill improvements of the shed labour force, transfers to local budgets compensating for losses of revenue, and special programmes and stimuli for the creation of new non-fossil jobs.

[49] The actual amount will depend on the mix of the different renewable energy sources. The lower limit of USD 1.53 billion is tentative and corresponds roughly to the mix of renewables in the NZE scenario in 2060 (43% wind, 53% solar, 4% hydro).

5.1.3 Secondary energy conversion: Power and heat sector

The supply of electricity and heat is a crucial part of the energy system and, in many sectors, the basis for economic activity. At the same time, the power and heat sector in Kazakhstan is characterised by relatively low efficiency and high GHG emissions. The potential for GHG emission reduction is huge. Even in the BAU scenario, modernisation of equipment and moderate changes in the energy mix are expected to reduce the GHG emissions from fuel combustion in power plants and combined heat and power units (CHPs), though relatively mildly – by 25% compared to the 1990 level. On the other end of the spectrum, the NZE scenario projects a far-reaching transformation in electricity and heat generation essentially reaching net emission neutrality in 2060, with a 99.9% reduction in GHG emissions, relative to 1990. Such massive reduction will be possible through:

- the gradual phase-out of coal-powered generation of energy as the coal-fired power plants reach the end of their designed lifetime;
- increased focus on renewable energy sources, in the long run supported by the expansion of electricity storage systems;
- active deployment of carbon capture and storage in the remaining power plants that combust fossil fuels after 2030.

In the decarbonised future, the transformation of the power and heat sector will be driven by the changing technological mix in the generation of electricity and heat on the one hand, and by the growing demand for electricity from other decarbonising sectors on the other. While in the BAU scenario the increase in electricity generation over the next 40 years is relatively modest, the implementation of the NZE scenario requires a six-fold expansion of electricity production relative to the current level and up to three times the amount of energy generation relative to the BAU scenario, reaching over 643 TWh by 2060 (Table 5-6).

In electricity production, coal-fired power generation maintains a dominant position for a long time in the BAU scenario, and only towards the end of the period it is projected to decrease to 30.9 TWh (19% of total generation). However, in the NZE scenario, a steady downward trend in the share of coal-fired power generation is expected up to its complete disappearance in 2055. Importantly, this process is linked to the current high capital stock depletion in coal-fired power generation and the replacement with renewable energy sources, primarily solar and on-shore wind generation. In the NZE scenario, by 2060 solar energy will account for up to 44% of all electricity generation and 53% of renewable electricity, and on-shore wind for 36% and 43%, respectively. In the long run, the use of renewables will be accompanied by electricity storage systems (such as utility-scale battery installations), which will allow the regulation of the electricity supply and better integration of renewables into the power grid.

Table 5-6
Electricity generation by fuel type, TWh

		BAU scenario				NZE scenario			
	2017	2030	2040	2050	2060	2030	2040	2050	2060
Coal TPP and CHP	68.9	78.4	57.3	29.0	30.9	34.2	13.4	0.3	0.0
Oil CHP	0.8	1.0	1.5	1.5	0.8	0.5	0.2	0.1	0.0
Natural gas TPP and CHP	21.8	39.3	51.6	78.2	100.3	40.2	79.0	62.8	44.3
Hydrogen TPP and CHP	0	2.7	0.0	0.0	0.0	0.0	0.0	23.0	62.9
Biomass	0	0.0	0.0	0.0	0.0	0.0	0.5	3.3	4.7
Hydro	11.2	12.0	17.2	21.2	15.3	23.2	23.2	25.4	19.5
Solar	0.2	0.5	2.1	5.9	8.2	17.7	50.7	158.3	282.5
Wind	0.3	1.0	2.5	8.6	10.6	21.0	98.3	192.9	229.5
Total	**103.2**	**135.0**	**132.2**	**144.3**	**166.1**	**136.9**	**265.3**	**466.1**	**643.4**

Source: Own calculations

The increased supply of power from different sources like wind and solar is also mirrored in the corresponding increase in the flexible and so adjustable to electricity demand gas-fired and hydro power generation. Hydro-powered generation will increase by 74% in the NZE scenario, compared to the current level, reaching 19.5 TWh by 2060. The production of electricity by gas-powered thermal power plants (TPPs) and combined heat and power units (CHPs) will almost quadruple, reaching 107.2 TWh by 2060, of which 62.9 TWh, or 59%, will be generated from hydrogen combustion. For plants combusting fossil fuels, the cogeneration of power and heat in the CHPs will especially come into focus. Moreover, after 2030, CCS technologies will be actively used to capture GHG emitted from fuel combustion in TPPs and CHPs, which, in 2060, will enable the elimination of 19.3 out of the remaining 19.4 Mt CO_2-eq of GHG emissions in the NZE scenario.

5.1.4 Final energy demand

In the NZE scenario, improvements in energy efficiency that prevent excessive energy use will be significant in all sectors. Such improvements include, for example, better thermal insulation and the use of modern energy-efficient appliances in buildings, modern fuel-saving vehicles in transport, and the gradual replacement of industrial equipment at the end of its lifetime with newer, energy-efficient technology. In the NZE scenario, a substantial decline in the final demand for energy is observed for buildings and transport (Table 5-7). Energy demand will increase in agriculture and industry as a result of the projected strong growth of production and income. However, as will be discussed in Section 5.1.4.3, there are substantial gains in energy efficiency in industry indicating that decarbonisation measures will make it possible to decouple economic growth from energy demand.

Table 5-7
Final energy demand / demand for energy services (FEC) by sector, ktoe

	BAU scenario					NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Agriculture	862	983	1040	1066	1099	999	1133	1223	1362
Industry	16686	21830	22306	26208	30713	21362	26599	32759	37188
Buildings	16951	15565	16596	17761	18863	12485	10982	11461	11823
Transport	5529	8872	9447	9546	9491	7791	6424	5613	4385
Total	**40028**	**47249**	**49390**	**54581**	**60165**	**42637**	**45139**	**51056**	**54757**

Source: Own calculations

The decarbonisation scenarios will require a massive shift away from fossil fuels and, thus, the maximum possible transition of final energy consumption to secondary types of energy – primarily electricity and heat – as well as low- and zero-carbon fuels (Table 5-8). While currently electricity and heat together account for about 30% of energy consumption, they will cover over two thirds of energy consumption in 2060 in the NZE scenario. The share of fossil fuels, on the contrary, will decline from the current 69% to 6%, driven primarily by the phase-out of coal and the decreasing levels of oil and gas use despite the growing economy. Moreover, final demand will also shift towards the use of low-carbon fuels such as biofuels and hydrogen in applications where switching to electricity is still difficult. It is worth noting that in the BAU scenario natural gas, oil products and coal will be used for hydrogen production, while in the NZE scenario gas will only be relevant in the mid-term. Instead, hydrogen will be completely produced with electricity starting from 2050 (compare Sankey diagrams in Figure 5-4 and Figure A- 10). Another technological improvement in the NZE scenario will be the use of CCS technologies in the industry.

Table 5-8
Final energy demand / demand for energy services (FEC) by fuel, ktoe

	BAU scenario					NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Coal	9307	6077	5004	5297	6427	2212	407	218	30
Oil and oil products	12574	14237	14884	15318	15642	13400	6904	3777	1790
Natural gas	5622	10460	11431	12248	12103	9259	6568	3062	1635
Electricity	6545	8182	7939	8843	9634	8841	13836	20720	25497
Heat	5917	7912	9121	10708	12029	7115	9889	10589	11246
Biomass	63	322	363	449	889	441	3670	5558	6333
Solar	0	0	0	0	0	0	191	958	1194
Geothermal	0	38	39	51	56	39	364	865	1051
Hydrogen	0	22	609	1666	3385	1331	3310	5309	5979
Total	**40028**	**47249**	**49390**	**54581**	**60165**	**42637**	**45139**	**51056**	**54757**

Source: Own calculations

The following subsections will provide a more detailed discussion of the transformations in transport, buildings, and industry.

5.1.4.1 Transport

GDP and population growth as well as urbanisation are the main drivers for the expansion of the transport sector and their impact will persist over the next decades. Especially cities face challenges in meeting the expanding mobility demands. At present, the transport sector is almost exclusively fuelled by fossil energy and is therefore a major source of GHG emissions. This points to the significant potential for reducing carbon emissions generated by transport. Guiding principles for the energy transition in transport are provided by the "Avoid-Shift-Improve" (ASI) approach which aims at achieving significant GHG emission reductions, reducing energy consumption and congestion:

- Avoid: the integration of land-use planning and transport as well as the optimisation of passenger and cargo traffic and the improvement of public transport infrastructure will make it possible to *avoid* unnecessary individual motorised traffic;
- Shift in transport modes: The modal shift in passenger transportation means *switching* from private to public transport, to non-motorised travel (walking, cycling) where possible, and from air transport and roads to railroads for long-distance travel.
- Improve: Gradual *replacement* of currently used high-carbon transportation technologies with more efficient and low-/zero-carbon fuels through the electrification of railroads, intensive renewal of the vehicle fleet, increasing the shares of biofuels, CNG and LPG, and electric vehicles for commercial and private use, and switching to (green) hydrogen for long-distance overland cargo transport. This improvement is supported by the rather short designed lifetime of transport equipment. Besides locomotives, almost all vehicles in use will be renewed by 2060.

This subsection will primarily focus on land transport, which - with a share of 86% - is the main source of transport GHG emissions in Kazakhstan. Overall, the development of the transport sector should follow the "Avoid-Shift-Improve" (ASI) framework[50]. The first action area within this framework is to avoid and reduce the need for motorised travel itself. This can be achieved on different levels, from digitalisation and the use of online services to city planning that ensures mixed zoning. For example, both buying goods online and having shopping malls nearby (as opposed to separated downtown and residential areas) would reduce the need to travel. The second action area is to shift to more environmentally friendly modes of transport, such as the use of trains instead of air transport for long-distance travel, the use of public transport, cycling,

[50] See Figure A- 15 in the Appendix for a comprehensive overview of the ASI elements.

electric scooters and walking instead of driving in cities. For such modal shifts, city planning and infrastructure development are crucial prerequisites. Finally, the third action area is to improve the energy and emission efficiency of transport modes. This can be done, for example, by switching to renewable energy (electricity, biofuels, hydrogen), instead of fossil fuels, and through renovation of the fleet and the modernisation of existing vehicles (e.g., retrofitting exhaust filters or converting diesel vehicles to burning natural gas). This step needs to be combined with avoidance and a modal shift.

In the modelling, the first two action areas are operationalised through decreasing the use of private transport and increasing shares of public transport at a given income level.[51] This causes, in all scenarios, a decline in kilometres travelled per capita with private vehicles and an overall increase in the share of public transport, relative to the current level. In the NZE scenario, the share of public transport increases also in comparison to the BAU scenario, while the travel volume of private transport remains close in both scenarios (see Figure A- 16 in the Appendix). While measures to shift mobility to public transport increase the share of public transport and reduce demand for private mobility, there is a rebound effect due to rising income levels. The strongly growing household income after 2030 in the NZE scenario leads to an increase in demand for (private) mobility. As a result, travel volume of private vehicles in the NZE scenario surpasses the level of the BAU scenario around 2035, though in the long run it remains well below the 2017 level (-14% in 2060) and only slightly higher than the BAU level (+4%). Moreover, the expansion of public transport outpaces that of private transport, and the already high share of public transport reaches 83% in 2060 in the NZE scenario, which is 7 percentage points higher than in 2017 and 2 percentage points higher than in BAU.

Furthermore, the decarbonisation scenarios project significant improvements in the energy and emission efficiency of transport, so that final energy consumption and GHG emissions from transport are reduced significantly. Whereas the BAU scenario projects a continuous increase up to 2060, in the NZE scenario energy demand declines steadily and is 45% lower in 2060 compared to the current level, and 54% lower relative to BAU (Table 5-9). This drop will primarily be achieved through the massive decline in energy demand from passenger cars, the renewal of the transport fleet and the optimisation of passenger and freight flows. It is expected that on average 2-5% of the vehicle fleet will be renewed every year in the NZE scenario.

[51] Especially for the "avoid" action area, there are significant limitations to capturing the possible measures in the higher-level TICS-KAZ framework, due to their variety and granularity. This is why these two major proxies were selected, acknowledging that more potential benefits can arise from the avoid and shift strategies.

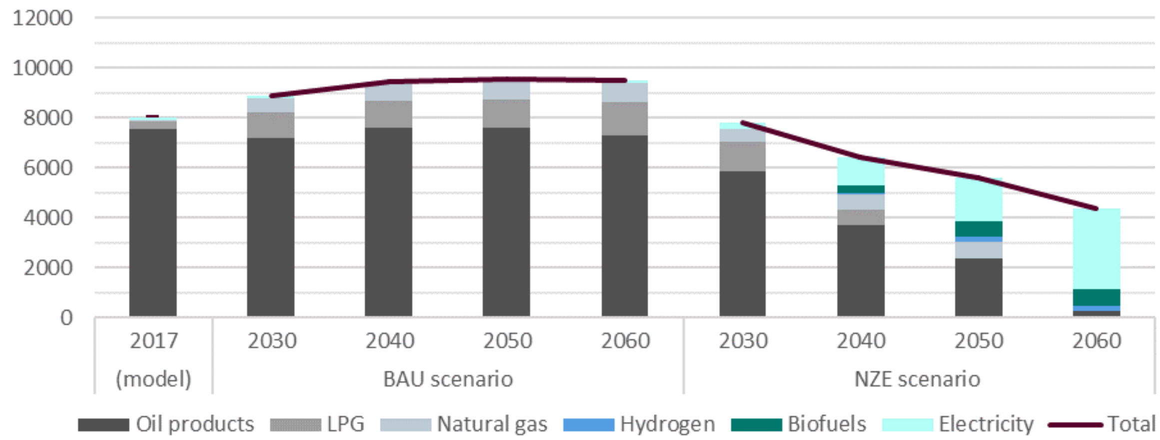
Table 5-9
Final energy demand in the transport sector by transport type, ktoe[52]

	2017 (model)	2017 (update)	BAU scenario 2030	2040	2050	2060	NZE scenario 2030	2040	2050	2060
Cars	3746	2566	4270	4231	4221	4094	3431	1765	1065	939
Other road transport	3440	2357	3499	3874	3832	3809	3281	3328	3192	1937
Railway transport	376	459	498	616	704	761	491	568	539	602
Other transport	451	147	604	725	789	827	587	763	817	906
Total	**8014**	**5529**	**8872**	**9447**	**9546**	**9491**	**7791**	**6424**	**5613**	**4385**

Source: Own calculations

The other significant source of emission reduction in the transport sector is the fuel switch away from oil products (Figure 5-10). In the BAU scenario, liquid oil products will remain the dominant fuel, complemented by LPG and natural gas.

Figure 5-10
Final energy demand in the transport sector by fuel type, ktoe



Source: Own calculations

Comparatively, in the NZE scenario LPG and natural gas are completely phased out and the use of other oil products is reduced by 97%, amounting to just 6% of total energy demand by 2060. Instead, the main energy source in 2060 is electricity, which accounts for 74% of total energy demand in transport. It will be used actively in both the road transport and through the widespread electrification of railways. The deployment of biofuels (16% of total energy demand)

[52] The *model* value for 2017 corresponds to the first version of the IEA-format energy balance in Kazakhstan issued in 2020, which was used in the model calibration in 2020-2021, while the *updated* 2017 value relates to the latest (third) revision of the energy balance as of February 2022. While in other sectors the changes between the versions were relatively small, in transport the total consumption was revised downwards significantly.

The division into cars and other road transport in the updated 2017 values is indicative only and based on the model data.

and hydrogen (5%) is expected primarily for transport modes that cannot be electrified, such as water and air transport.

Deep dive: Societal cost of road passenger transportation

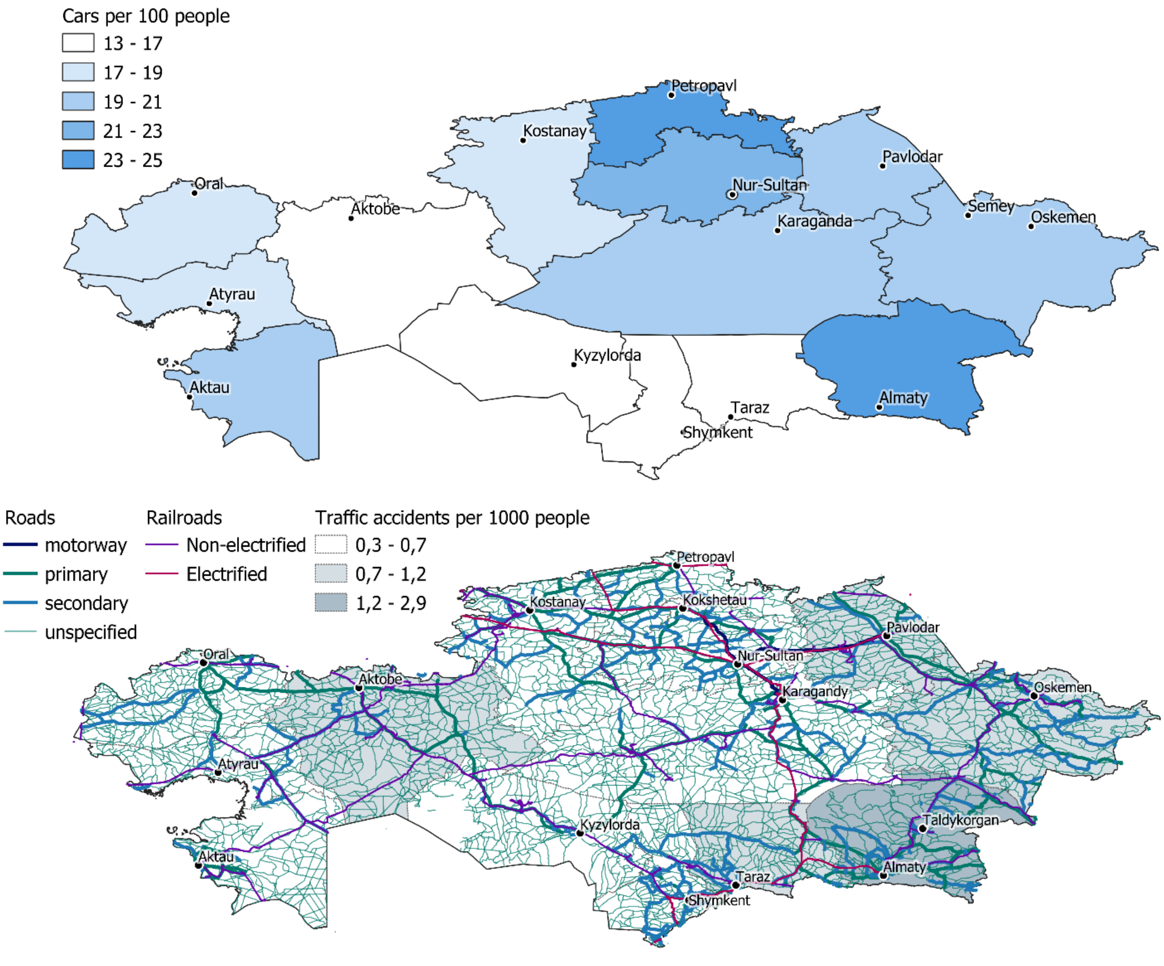
Car ownership by both households and firms as well as passenger road transport tripled over the last 15 years. In 2017, every fifth resident owned a car, while private ownership is mostly clustered around larger cities (see Figure 5-11). At the same time, the road system is mainly comprised of lower capacity roads, with motorways covering less than 10% of total road length. The road coverage has been growing at a much slower pace than traffic, with only a 7%-increase in the last 15 years (mostly regional and municipal roads). As a result, traffic accidents and traffic congestion have intensified substantially[53]. Current low fuel prices do not cover the social and climate costs of transport and distort consumption towards extensive use of private transport and fossil-intensive mobility.

The modelling scenarios for passenger road transport focus on the renewal of the vehicle fleet and the fuel switch from conventional diesel and gasoline towards electric vehicles. The projected size and structure of the car fleet by scenario is illustrated in Figure 5-12. While in the BAU scenario most of the car fleet is composed of gasoline and bi-fuel cars in 2060, the NZE scenario projects complete electrification of private transport by 2060. For buses, the diversification and modernisation of the bus fleet shrinks demand for fossil fuels and contributes to reducing transport-related energy emissions. The NZE scenario further assumes a shift towards public transport and a decline in the travel volume per capita at a given income level. Nevertheless, this reduction is offset by the growing population and increasing incomes after 2035, which in turn is reflected in terms of car numbers and total travel volumes.

[53] Based on data from Bureau of National Statistics.

Figure 5-11

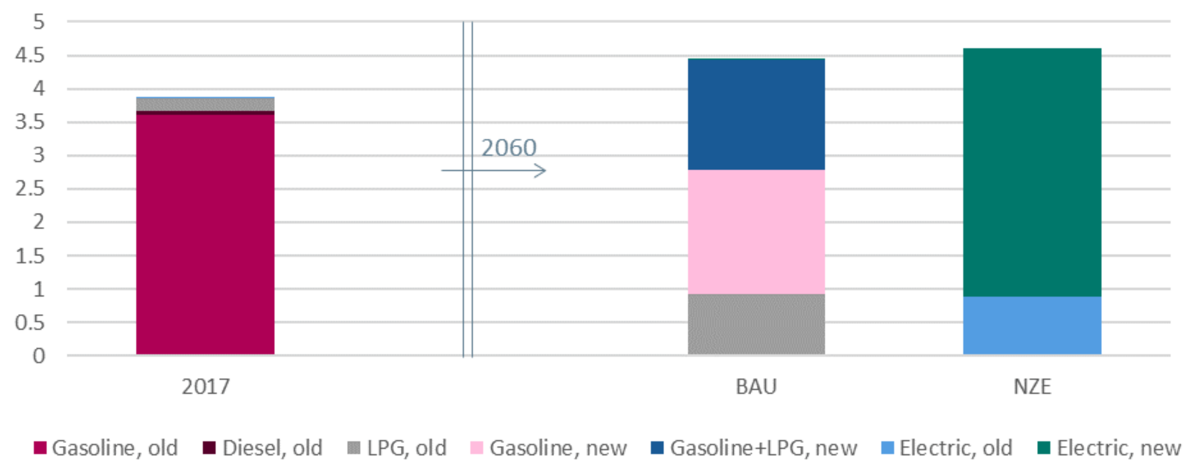
Car ownership, cars per 100 residents (upper panel) and traffic accidents, accidents per 1000 residents (lower panel) by region in 2017



Data: Bureau of National Statistics; Road maps: OpenStreetMap, Global Roads Open Access Data Set; base map: GADM

Figure 5-12

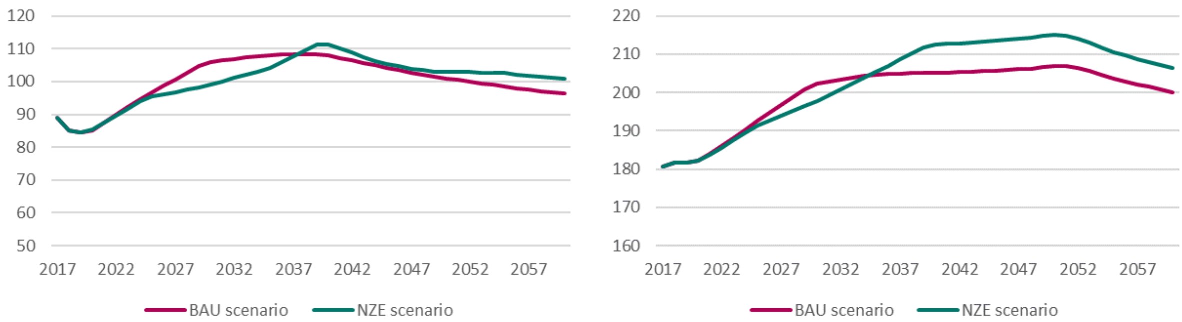
Current and projected structure of the passenger car fleet, million cars



Source: Own calculations

The change in total travel volume leads to a temporary reduction in the total number of accidents in the NZE scenario compared to the BAU scenario (Figure 5-13, left panel). The number of accidents is also reduced through the purchase and use of newer vehicles (as opposed to using vehicles that are more than 10 years old) and the expansion of public transport.[54] Moreover, the decline in total travel volume (reductions in vehicle-km travelled) contributes to improved travel speed and less congestion, relative to the BAU scenario (Figure 5-13, right panel). This reduces the congestion delay per vehicle and the total cost of time spent in congestion in urban areas. Starting 2035, the rising incomes and, as a result, the higher demand for mobility, lead to an increase in both the number of traffic accidents and congestion, though the difference between the BAU and the NZE scenarios will remain fairly small. These results indicate that additional policies and strategies will be necessary in order to slow down the expansion of private transport as population incomes grow.[55]

Figure 5-13
Number of traffic accidents per 100 000 people (left panel) and congestion delay per vehicle in urban areas, hours per year (right panel)



Source: Own calculations

The transition in passenger transportation will have beneficial social impacts because of the reduction of negative externalities.[56] In the NZE scenario, the increase in congestion and the number of accidents after 2035 will generate an increase in externalities by USD 13 billion between 2021 and 2060, relative to BAU. However, technology switching to low- and zero-carbon

[54] Newer vehicles are assumed to have a lower average number of accidents. At the same time, the average number of accidents per vehicle within one age group is assumed to remain constant over time, as the scenarios assume no improvements in transport infrastructure. If improvements in traffic safety follow the historical trends, the future number of accidents would be lower than currently projected.

[55] Such additional strategies, which could include, for example, changes in regulations as well as city planning and zoning (pedestrian zones, bus and bicycle lanes, paid parking, bans on certain vehicle types, etc.), were out of scope of the model.

[56] An externality is a cost or benefit of an economic activity experienced by an unrelated third party and not financially incurred or received by its producer. It can be positive (benefit) or negative (cost).

transport will reduce externalities related to high-emission vehicles, such as air pollution, noise, as well as the health and social cost of carbon. The respective savings accumulate to USD 75 billion between 2021 and 2060 in the NZE scenario, or on average USD 1.9 billion annually. Thus, the modelling results suggest that, by 2060, the net avoided externality costs may accumulate to USD 62 billion.

The annual value of negative externalities related specifically to private cars is presented in Table 5-10 for both scenarios and for selected years. While negative externalities will increase in the BAU scenario in most categories, a reduction across almost all categories is projected in the NZE scenario. Taking into account the rebound effects, the total annual negative externalities will decline until 2060 by 5% relative to 2017 in the NZE scenario and by 15% relative to the BAU scenario, while carbon-related externalities will decline by 37-100%, relative to BAU. The major reasons are the electrification of transport and the expansion of the public transport network.

Table 5-10

Annual negative externalities from passenger cars, billion USD

		BAU scenario				NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Cost of air pollution	1.83	1.34	0.95	1.31	1.33	1.11	0.34	0.03	0.02
Cost of noise	1.18	1.09	0.88	1.11	1.07	1.04	0.75	0.71	0.68
Social cost of carbon	0.34	0.39	0.38	0.38	0.37	0.31	0.10	0.00	0.00
Cost of respiratory disease	0.95	1.04	1.01	1.02	1.00	0.82	0.35	0.12	0.11
Cost of urban effects	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Economic value of traffic accidents	8.04	9.04	9.31	9.33	9.38	8.62	9.82	9.85	9.78
Value of time lost due to congestion	1.96	2.70	2.79	2.87	2.78	2.52	3.07	3.17	2.99
Total annual externalities of cars	**14.38**	**15.67**	**15.40**	**16.09**	**16.01**	**14.49**	**14.51**	**13.96**	**13.66**

Source: Own calculations

It is important to note that both conventional costs and negative externalities change depending on the vehicles considered. The externalities are lower for more modern and low-carbon vehicles. Moreover, their total cost of ownership by 2060 will be aligned with the current cost of internal combustion engine vehicles. The operating costs will be lower, due to reduced maintenance and energy costs, generating net savings for households. The savings in operating costs could exceed USD 230 per vehicle per year in the NZE scenario.

5.1.4.2 Buildings

Currently, the modernisation and extension of the buildings stock and improvement of energy efficiency in buildings are among the most prioritised areas of development in Kazakhstan.[57] Therefore, even in the BAU scenario a significant reduction in GHG emissions from buildings is expected in the future. By 2060, GHG emissions are projected to fall by 49%, relative to the 1990 level. However, even such significant a decrease does not exhaust the emission reduction potential. In the most ambitious NZE scenario, buildings will become carbon-free by 2060. The main policy interventions driving such reduction include:

- Ambitious measures to improve energy efficiency in buildings, such as thermal insulation, the use of energy-efficient appliances, modern heating systems, energy use controls, etc.;
- The deployment of renewable energy sources and efficient technologies for space and water heating, such as modern gas and electric boilers, solar PV, and solar water heating;
- The modernisation and decarbonisation of central heating and more intensive use of electricity and central heating by the commercial sector and households, instead of direct combustion of fossil fuels or wood.

Buildings belong to the largest sources of GHG emissions and are, therefore, of most importance for emission reduction. The emissions in residential and non-residential buildings are associated with energy use by the commercial sector and households, i.e., consumption of electricity, heat, and the direct use of primary energy (e.g., for cooking, individual heating, etc.).

The decarbonisation of the buildings sector is driven by the switch from fossil fuel-based heating towards renewables-based energy and more efficient technological equipment. Consequently, the total energy mix is different for the scenarios analysed.

In the BAU scenario, the emissions from buildings are expected to decline as a result of existing modernisation programmes and a reduced share of coal in energy generation, because generation capacities are extended with renewable energy and gas-fired power plants. Therefore, overall emissions in the buildings sector are projected to decrease by 16% relative to the 2017 level and 49% relative to the 1990 level. In the NZE scenario, residential buildings will become carbon-free by 2060, non-residential buildings – already by 2050. The buildings sector will achieve net-zero emissions as a result of increasing energy efficiency and the use of central heating, electricity for heating purposes, and renewable energy sources.

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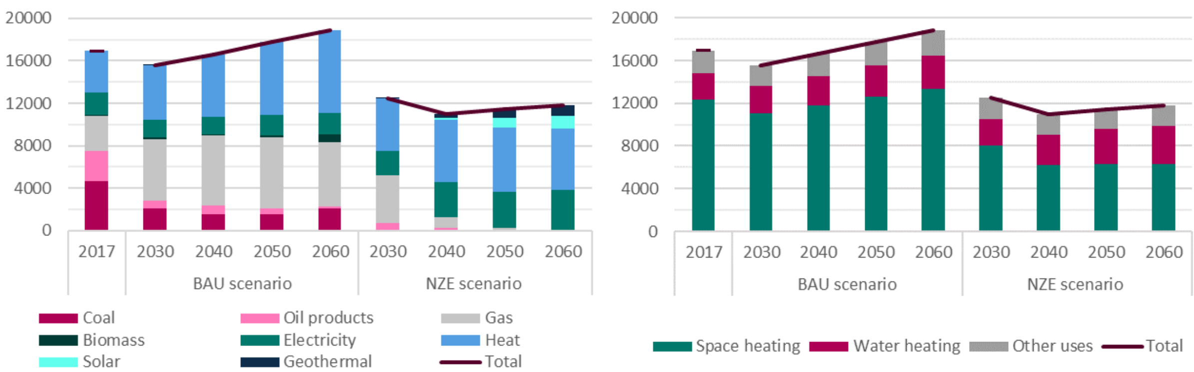
[57] See, e.g., (Government of Kazakhstan, 2018) and (Government of Kazakhstan, 2019).

This trajectory is mirrored by the structure of final energy consumption in the sector. Coal use is expected to decrease significantly in all scenarios, with direct coal combustion in buildings completely vanishing in the NZE scenario already by 2030 (Figure 5-14, left panel). It will be replaced by natural gas, electricity, and heat. In 2060, the energy demand in buildings will be almost completely covered by electricity and central heating, the rest will be fulfilled by solar (10%) and geothermal (8%) energy.

Moreover, the thermal modernisation of buildings and introduction of new heating technologies will also manage to substantially decrease the energy demand for heating purposes (Figure 5-14, right panel). In the NZE scenario, heating will only account for just over half of total energy demand in 2060.[58] In fact, most of the savings in energy demand will result from more efficient heating.

Figure 5-14
Final energy demand in buildings by fuel (left panel) and by end use (right panel), ktoe



Source: Own calculations

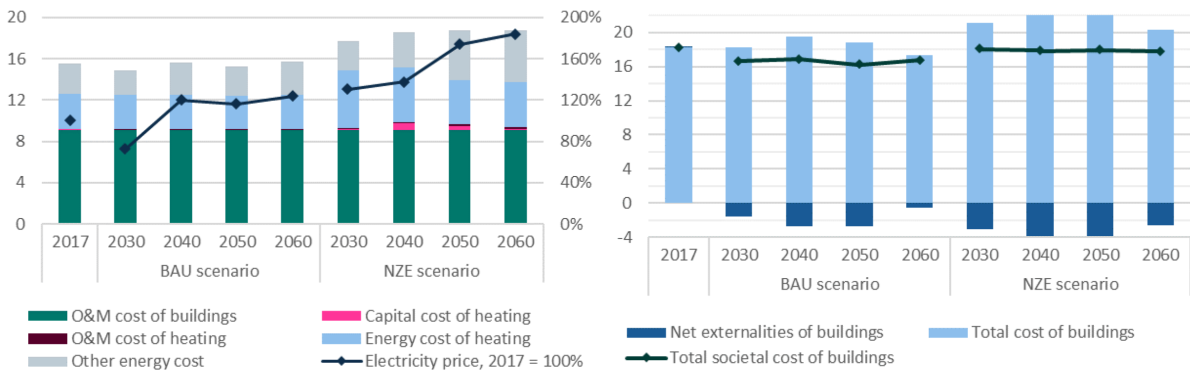
Deep dive: Societal cost and benefits from reducing energy demand and GHG emissions of buildings

The decarbonisation of the Kazakh economy requires a significant increase in energy prices to reflect the cost of investment, maintenance, and carbon emissions. This will have profound impact on all sectors, including public, commercial, and residential buildings. Energy efficiency improvements like the thermal modernisation of buildings and the implementation of new efficient technologies will alleviate the impact of price increases by reducing energy consumption (see also Figure 5-14) and the associated negative societal costs of fossil fuel combustion in buildings.

[58] In fact, Figure 5-14 may even overestimate the share of space heating in total energy demand, as mixed technologies, which can be applied for both, space and water heating or heating and air conditioning, are classified under space heating as well.

In the left panel, Figure 5-15 breaks down the average cost of buildings into the maintenance cost of a building itself, the capital and operating costs of the heating systems, and energy expenditure, calculated per square meter of living space.[59] In both scenarios, the cost of buildings is expected to increase slightly. In the NZE scenario, the cost per square meter of living space in 2060 increases by USD 3.24 per year compared to the current level, or by USD 2.83 relative to the BAU scenario. This is driven almost exclusively by the rising prices of energy: in the NZE scenario, the total energy cost is USD 3.10 higher than in 2017, of which USD 0.62 are contributed by heating and USD 2.02 resulting from other energy sources such as lighting, appliances, cooking as well as ash disposal from coal burning.

Figure 5-15
Annual cost of buildings per m² (excluding the construction cost of new buildings), USD, and electricity price, 2017 = 100% (left) and total societal cost of buildings per m², USD (right)



Source: Own calculations

Importantly, this is the result of restructuring the energy system as a whole, with spill-over effects between sectors. In fact, modernisation and switching to new technologies significantly dampen the negative impact of a price change through the reduction of energy consumption. Without this reduction – at energy demand levels corresponding to the BAU scenario and energy prices of the NZE scenario – the total annual energy cost could become as high as USD 17.68 per m². This is an increase by USD 11.14 relative to BAU, almost four times the projected USD 3.10 increase in total energy cost in the NZE scenario.

Decarbonisation measures not only help offset the price impacts, but also reduce negative externalities and societal costs (Figure 5-15, right panel). The average cost of negative

59 The capital cost of construction is excluded, i.e., only the average cost of running an existing building is represented. The average is taken over the stock of buildings in the respective year. Capital cost of heating systems is included, as their lifetime is less than that of buildings, i.e., heating systems in a building might be replaced several times before the building is demolished. For comparability, their capital cost is annualised over their lifetime.

externalities, which affect all families and especially those currently using coal-fired heating, will decline by up to USD 2.03 per m^2 per year.[60] Therefore, overall, the societal cost of buildings will decline slightly by 2060. At the same time, in some periods, this additional positive impact may not fully compensate for the increase in energy costs. As such, active government involvement is necessary to both support socially vulnerable groups and to accelerate modernisation and maintain the decarbonisation ambition.

5.1.4.3 Industry

The decarbonisation of industry will require large-scale decoupling of industrial growth from fossil fuel use. Although some modernisation efforts are being made, the continuing dependence of growth on energy will lead to the doubling of GHG emissions from energy use in industry by 2060 in the BAU scenario, compared to 1990 levels. In contrast, in the most ambitious NZE scenario, net GHG emissions decline by 96% in 2060, relative to the 1990 level, and by 98% relative to 2017. This is projected despite the massive expansion of industrial production, demonstrating the additional gains in energy efficiency and low-carbon energy use. This will be a result of sectoral transformation along several dimensions:

- As in other sectors too, ambitious measures to improve energy efficiency will lead to a significant slowdown in the growth of energy demand and, consequently, of GHG emissions, despite rapid growth in production;
- Technological modernisation will change the energy mix substantially, with a shift towards the use of electricity and heat, but also the active use of renewable fuels such as hydrogen and biofuels;
- In the long run, industry too will deploy CCS technologies in applications, where combustion of fossil fuels cannot be avoided.

In the IPCC common reporting format, the energy sector also covers fuel combustion by industry. Industry comprises the manufacturing, mining, and construction sectors. However, construction and non-energy mining only contribute a small portion of the group's emissions, and so, this section will primarily focus on manufacturing.

[60] In the SD-KAZ model, the costs and externalities of residential buildings are captured for different geographic areas and types of buildings (e.g., detached or multiapartment, various heating systems). The average cost of negative externalities per square meter presented here is calculated by aggregating the externalities on the country level (across geographies and building types) and dividing them by the total building stock in the respective year. The total annual and cumulative externalities on the country level can be viewed in Table A- 13 and Table A- 14 in the Appendix, respectively.

The decarbonisation pathway in industry is characterised by an increasing decoupling of economic growth from energy use. In the BAU scenario, emissions from fuel combustion in industry will further increase, doubling by 2060 relative to the 1990 level. In contrast, in the NZE scenario, gross emissions are relatively stable until 2030 and fall steeply after 2030, as all sectors except the chemical industry, primarily ferrous and non-ferrous metallurgy and mining, reduce GHG emissions significantly (Table 5-11). As a result, in 2060 gross emissions will be 77% lower than in 1990 and 92% lower than in the BAU scenario.

Table 5-11
Emissions from fuel combustion in industry by sector, Mt CO2-eq

		BAU scenario				NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Ferrous metallurgy	19.9	19.8	18.3	20.0	21.2	9.8	1.8	1.9	0.9
Non-ferrous metallurgy	7.6	2.6	1.8	1.9	2.9	2.1	1.5	0.9	0.4
Chemical industry	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Food industry	0.7	0.8	0.9	1.0	1.0	0.8	0.5	0.0	0.0
Mineral production	3.4	4.9	4.9	5.3	5.4	5.0	4.8	2.8	2.6
Mining and quarrying	2.7	9.5	9.0	10.4	12.1	9.6	3.9	0.0	0.0
Other industries & construction	0.9	6.5	5.8	7.3	9.4	8.0	1.9	0.0	0.0
Total	**35.8**	**44.1**	**40.6**	**46.0**	**52.0**	**35.3**	**14.5**	**5.6**	**4.0**
Carbon capture & storage	0.0	0.0	0.0	0.0	0.0	0.0	-4.3	-4.6	-3.3
Net total	**35.8**	**44.1**	**40.6**	**46.0**	**52.0**	**35.3**	**10.2**	**1.0**	**0.8**

Source: Own calculations

Moreover, in the NZE scenario, carbon capture and storage (CCS) technologies will be introduced starting 2030, enabling the capture of up to 4.6 Mt of CO_2. By 2060, the NZE scenario foresees the capture of 81% of the remaining emissions. As a result, industry will be close to net zero in 2060, with net emissions from fuel combustion in industry being 96% lower than in 1990 and 99% lower than in the BAU scenario.

This GHG emission reduction is achieved by increasing energy efficiency in industry and especially by changes in the energy mix. Table 5-12 presents the changes in the energy intensity of selected industries (measured as energy consumption per USD of output).

Table 5-12
Energy intensity (per USD of output) of selected industries, MJ/USD

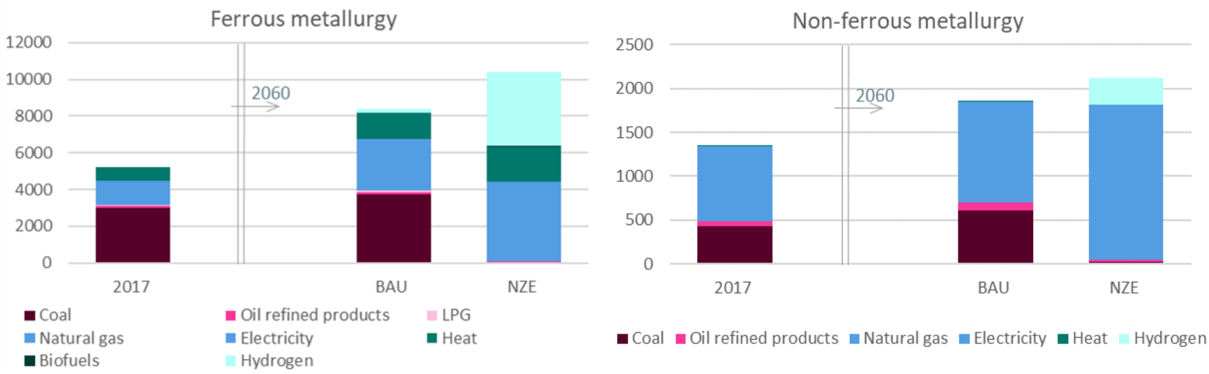
		BAU scenario				NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Mining and Quarrying	9.6	9.3	8.4	9.4	10.2	9.2	7.6	7.8	8.1
Food industry	1.7	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.4
Ferrous metallurgy	28.1	21.6	19.0	19.7	19.9	18.8	14.8	15.9	15.4
Non-ferrous metallurgy	5.7	4.7	3.8	3.9	4.2	4.6	3.1	2.7	2.6
Chemical industry	18.8	12.2	12.3	14.5	16.8	13.4	14.2	19.9	17.5
Mineral products	21.6	18.8	15.6	15.8	14.7	19.3	15.8	17.4	17.3

Source: Own calculations

Gradual replacement of worn-out equipment will result in energy efficiency gains in most industries in both scenarios. In the NZE scenario, however, the efficiency gains are significantly higher, with energy intensity in 2060 declining to a level up to 38% lower than in the BAU scenario and up to 55% lower than in 2017.

A significant share of emission reductions results from the changing energy mix. Coal, the major energy source for ferrous metallurgy and one of the main energy sources for non-ferrous metallurgy currently and in the BAU scenario (Figure 5-16), will be substituted with hydrogen, electricity, and heat in the NZE scenario. By 2060, steelmaking completely shifts to hydrogen-based direct reduction of iron (DRI) for iron ore processing or metal scrap as an alternative input source, with both then processed to steel in electric arc furnaces (EAF). Similar shifts towards more sustainable energy mixes are expected in other sectors as well (see also Figure A- 22 in Appendix). Some industries, like the food and mining industries, will even be able to become carbon-neutral by completely switching to electricity, heat, and hydrogen (compare Table 5-11).

Figure 5-16
Final energy demand in metallurgy by fuel type, ktoe



Source: Own calculations

5.2 Industrial processes and product use

Greenhouse gas emissions from industrial processes and product use (IPPU) arise from chemical reactions or the physical transformation of materials during industrial production. Therefore, GHG process emissions are recorded separately from GHG emissions caused by fuel combustion. While some emissions are a result of the use of solvents and other components, the majority of IPPU emissions are caused by the production processes of basic materials like minerals and metals.

Reduction of IPPU emissions would require significant transformations both on the demand and the supply sides. The main elements of such transformations include:

- Reduction in consumption of basic materials through improved product design and the use of alternative materials;
- Increased recycling to reduce the need for raw material processing as the main contributing factor to emissions from IPPU;
- Adoption of new, zero-carbon production technologies.

Decarbonisation of industrial process emissions requires significant changes on both the demand and the supply side. This includes the substitution of carbon-intensive primary products like cement, steel, or aluminium with other emission-free or less emission-intensive products. At the same time, the use of emission-free and less emission-intensive technologies for producing the basic materials (e.g., hydrogen in steel production) and in combination with carbon capture and storage also have the potential of reducing the carbon footprint. This subsection will provide examples of decarbonisation best practices for the three major IPPU emitters: steel, aluminium, and cement production.

On the demand side, the two main action areas are material efficiency and the use of alternative materials, which both reduce the need for primary production. Material efficiency includes changes in the design of products, so that their lifetime is prolonged, less material is needed for production, or the components of the product can be recycled. The emission reduction potential of the two action areas differs across sectors.

For example, in the aluminium production, efficient recycling can decrease demand for primary aluminium and reduce total emissions by 27% by 2050 relative to today, despite the expected growth in demand for aluminium products (IAI, 2021). Using steel scrap in combination with electric arc furnaces (EAF) can reduce the carbon intensity of steel production by up to 83%, which would also allow the decrease of emissions even with rising demand (BHP, 2020). This is because recycling of metal scrap requires much less energy and skips the step of smelting the metal from the ore, the process during which process emissions occur. If renewable sources of energy are used, producing aluminium or steel from scrap can become completely carbon-neutral.

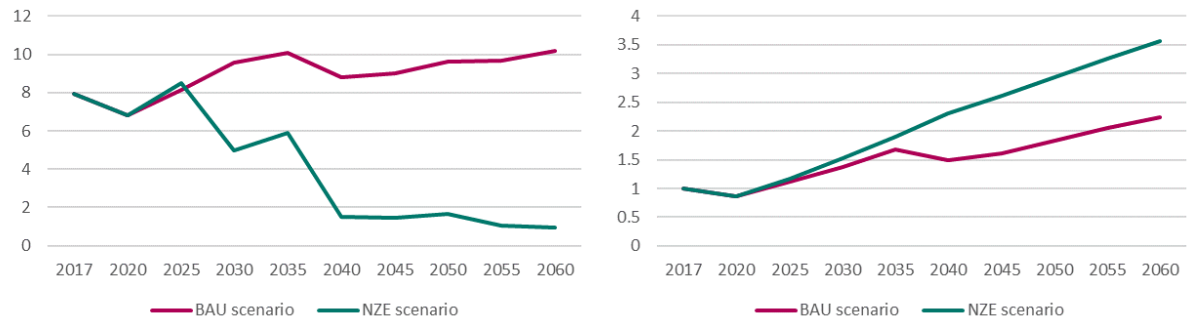
In cement production, on the other hand, the focus is rather on the use of alternative building materials such as cross-laminated timber, and improving architectural design. These shifts can constitute 9% and more of the total reduction potential in cement production (including energy use). This reduction potential is as large as that of using clinker substitutes to produce cement (Czigler, Reiter, Schulze, & Somers, 2020).

On the supply side, the reduction of process emissions will require deployment of novel technologies. For example, in metal production, technologies avoiding the oxidation of ores using carbon and heat (the process causing CO_2 emissions) will play a crucial role. In aluminium production, eliminating carbon in smelting by using inert anodes can reduce direct (energy and process) emissions from the sector by 15% (IAI, 2021). In steel production, the use of direct reduced iron (DRI) based on natural gas already significantly reduces IPPU emissions by 30% compared to the outdated blast furnaces and basic oxygen furnaces and by 42% compared to coal-based DRI technologies (BHP, 2020). Using (green) hydrogen for DRI, combined with electric arc furnaces on renewable energy, provides the possibility of carbon-neutral steel production.

The importance of the technology mix in process emission reduction is well illustrated by the projected transformation in iron and steel production in Kazakhstan. Figure 5-17 shows the change in process emissions from iron and steel production in the two scenarios resulting from technology shifts and compares is it to the production levels.[61]

[61] Only CO_2 emissions were analysed. The scenarios focus on technology choices in the full production cycle from iron ore to steel and assume the same amount of steel scrap the model can use for steel production (up to 40%). Large-scale economy-wide modernization of equipment will generate significant amounts of metal scrap and can help reduce the demand for iron ore processing and, therefore, IPPU emissions. However, the estimation of the amount of steel scrap potentially available for recycling was out of scope of the current model.

Figure 5-17
Projected carbon dioxide process emissions in iron and steel production, Mt CO_2 (left) and production levels, 2017 = 1 (right)



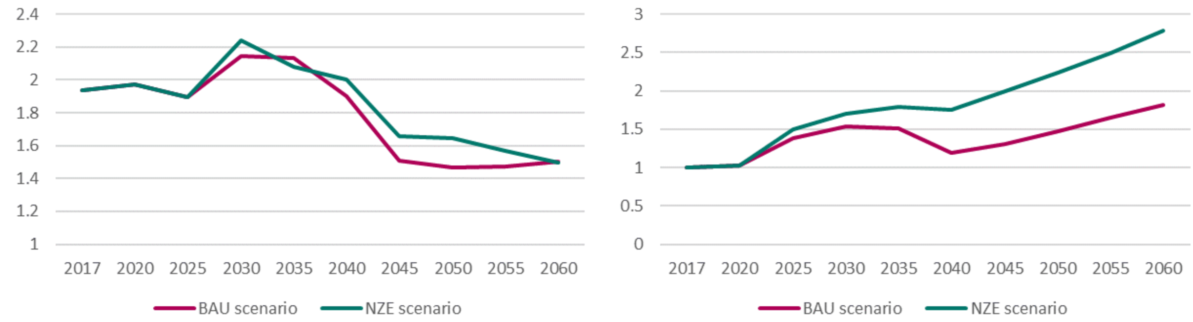
Source: Own calculations

In the BAU scenario, the steel production in basic oxygen furnaces with an intermediate step of extracting pig iron from the ore in blast furnaces will continue to constitute a significant share of total steel production. This process creates significant emissions during the ore reduction process and, as steel production grows, so will the process emissions. By 2060, the process emissions from iron and steel production in the BAU scenario will be 28% higher than in 2017 and 12% lower than in 1990 due to the very high level recorded in 1990. In the NZE scenario, however, a major shift towards gas- and then hydrogen-based DRI technologies is projected in two steps between 2025 and 2045. This sharply reduces the GHG process emissions, though slight emission growth can be observed between 2030 and 2035 due to rising production. After 2040, almost all remaining iron ore processing with blast furnaces is phased out in favour of DRI, which stabilises IPPU emissions from steel production despite continuously increasing output. In 2060, the process emissions from iron and steel production in the NZE scenario are projected to be 90% lower than in the BAU scenario, 88% lower than in 2017 and 91% lower than in in 1990. Similarly, the current processes of aluminium production in Kazakhstan do not use the latest available technologies. In the BAU scenario, the adoption of improved technologies will gradually begin starting 2030, as the existing equipment approaches the end of its economic lifetime. Combined with staggering production growth, this will reduce process emissions by around 23% relative to the 2017 level (Figure 5-18).[62] The NZE scenario is characterised by significantly higher production levels, to be achieved through the replacement of the existing equipment and capacity expansion with modern low-emission technologies. As a result, there is a downward trend in process emissions, while the total volume of emissions mostly remains

[62] The modelling was performed before the latest CRF version was released in April 2022, which massively downscaled the IPPU emissions from aluminium production. See Appendix (Figure A- 25) for discussion.

close to the BAU level. In 2060, the emissions are 23% lower than in 2017 and 1% lower than in the BAU scenario.[63]

Figure 5-18
Projected process emissions from aluminium production, Mt CO_2-eq (left) and production levels, 2017 = 1 (right)



Source: Own calculations

In cement production, most process emissions result from burning limestone (calcium carbonate) to remove carbon and produce lime (calcium oxide) and eventually clinker. This single chemical reaction is a major contributor to global carbon dioxide emissions. Changing the composition of cement, i.e., reducing the share of clinker in cement, has the potential to decrease process-related emissions by 30% (IEA & CSI, 2018).

A noteworthy recent approach is the production of so-called carbon-cured concrete. By exploiting the ability of cement to absorb CO_2, this approach involves injecting CO_2 into cement during production, which not only allows storing CO_2 in the final product but also improves the physical characteristics of cement. This could significantly reduce the carbon footprint of cement production and even create demand for the carbon captured in other sectors. Jointly, carbon capture and storage (CCS) technologies and the use of carbon-cured concrete have the potential to reduce emissions from cement production by 48% (Czigler, Reiter, Schulze, & Somers, 2020)'[64]

Technologies to capture and use or store CO_2 (CCUS) will continue to play a significant role in other sectors as well. It is estimated that CCUS technologies can reduce direct emissions by 35% in aluminium production and by 60% in steel production (IAI, 2021; BHP, 2020). Overall, it is noteworthy that many of the decarbonisation options for industrial processes involve updating

[63] No comparison to the benchmark year 1990 could be made, as aluminium IPPU emissions in Kazakhstan are only reported from 2007.

[64] Since CCS technologies are accounted for in the modelling of the energy sector and other approaches mentioned are not yet available in Kazakhstan, IPPU emission reduction pathways were not modelled for cement production.

equipment and restructuring production in a way that splits production processes or enables easily upgrading the equipment from low- to zero-carbon processes (e.g., switch from natural gas to hydrogen in DRI). Therefore, even when some technologies are still expensive for some producers (e.g., hydrogen-based DRI or CCS in cement plants), transitory technologies (such as natural gas-based DRI) and process adjustments (like injecting CO_2 in cement, to be later sourced with own CCS) lay the groundwork for completely eliminating process emissions in these sectors.

5.3 Agriculture, forestry, and other land use

The agriculture, forestry, and other land use (AFOLU) sector differs from other IPCC sectors in that it not only releases GHG emissions but has also the potential for carbon sequestration through soils and vegetation. Increasing the absorptive capacity of carbon sinks in forests and other ecosystems is therefore a significant aspect of decarbonisation. Similar to CCS technologies, carbon sequestration in AFOLU can ease the pressure to achieve deep decarbonisation and ultimately carbon neutrality in sectors where zero-carbon technologies are not yet commercially available.

Emission trajectories in AFOLU are different in the two subcategories of agriculture and land use. The growth in agricultural production will lead to increasing emissions in all scenarios, though decarbonisation measures will slow down this trend in the policy scenarios. The category of land use, land use change, and forestry (LULUCF) is a net carbon sink in all decarbonisation scenarios, with significantly higher absorption capacity relative to the 1990 level. The major decarbonisation measures include:

- Increased ambitions for sustainable crop agriculture and livestock management;
- Improvements in irrigation;
- Sustainable forest management and afforestation programmes.

Unlike the TIMES-KAZ model, which selects the optimal pathways within the limits assumed, with the aim of reaching a target outcome (emission level), the SD-KAZ model treats the scenario assumptions as target policies and estimates the prospective outcomes. An overview of the assumptions made for the scenario analysis is presented in Table 5-13. The assumptions include not only national and regional policies but also changes in the world climate.[65] Changes

[65] Changes in the world climate can affect agriculture and forestry, as they influence precipitation patterns and, thus, water availability and soil loss. The climate scenarios used in the modelling correspond to the IPCC Representative Concentration

in land use (LULUCF) constitute measures for reforestation and restoration of degraded forest land (including sustainable management practices). In agriculture, the expansion of sustainable agriculture practices is a prerequisite, especially improved livestock management and higher irrigation coverage (see also Box 5-2).[66]

Table 5-13
Assumptions in the AFOLU sectors

Assumptions	**BAU**	**GE**	**DD**	**NZE**
Carbon sequestration in carbon sinks (LULUCF)				
Reforestation (2 billion trees plan), 2020-2025, million ha/year	1.3	1.3	1.3	1.3
State-driven reforestation programmes, 2020-2030, total, million ha	-	0.7	0.7	0.7
State-driven reforestation programmes, 2040-2050, total, million ha	-	-	-	0.7
Additional sequestration (state-driven), t CO_2/ha per year	-	11.9	11.9	11.9
Sustainable management of degraded forests, 2020-2026 (GE,DD), 2020-2040 & 2050-2060 (NZE), total, million ha	-	1.3	1.3	1.95
Additional sequestration (state-driven), t CO_2/ha per year	-	6	6	6
Private afforestation programmes, 2020-2026, total, million ha	-	0.05	0.05	0.05
Private afforestation programmes, 2031-2035 & 2041-2045, total, million ha	-	-	-	0.1
Additional sequestration (private), t CO_2/ha per year	-	11.9	11.9	11.9
Additional sequestration per hectare of sustainable cropland, t CO_2/ha per year	0.357	0.357	0.357	0.357
Reduction of emissions from agricultural production				
Climate scenario	RCP4.5	RCP4.5	RCP4.5	RCP4.5
Sustainable agriculture				
Share of agriculture land under sustainable management	30%	30%	60%	100%
Labour intensity increase in sustainable agriculture	10%	10%	10%	10%
Price premium in sustainable agriculture	40%	40%	40%	40%
Reduction in soil erosion on sustainably managed cropland	100%	100%	100%	100%
Fertiliser use				
Precision fertiliser application	0%	0%	60%	80%
N_2O emissions per kg nitrogen from organic fertilizer, g N_2O/kg N	15.7	15.7	7	7
Livestock production (% of total livestock population)				
Adoption rate: improved livestock feeding practices	30%	30%	40%	60%
Adoption rate: reduction in time to slaughter	30%	30%	40%	60%
Irrigation coverage (% of cropland)				
Area 1	3.2%	10%	15%	15%
Area 2	15.9%	30%	40%	40%
Area 3	80%	90%	100%	100%
Area 4	80%	90%	100%	100%
Reduction in pre-harvest losses	-	-10%	-30%	-30%

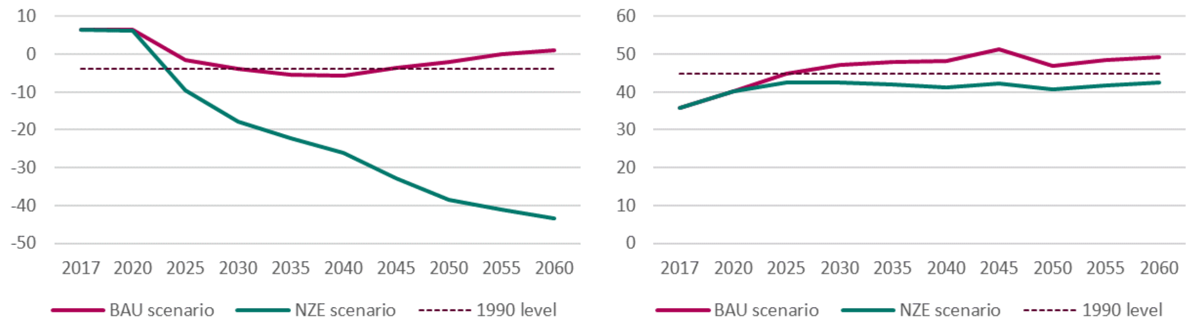
Source: Own presentation

Pathways (RCPs). These are scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover. RCP4.5 corresponds to a scenario, in which the global temperature increase is likely to remain below 2 °C by mid-century.

[66] If not indicated otherwise, the implementation of all interventions is assumed to follow a linear trajectory. For example, if an adoption increases from 10% in the year 2020 to 20% in the year 2030, the model assumes that one additional percent per year will be implemented between 2020 and 2030 respectively (e.g., 11% in 2021, 12% in 2022, etc.).

The projected GHG emissions from agricultural production for the BAU and the NZE scenarios are presented in the right panel of Figure 5-19 and in Table 5-14. In the BAU scenario, total GHG emissions from agriculture are projected to increase from the current 35.7 Mt CO_2-eq per year to 49.1 Mt CO_2-eq by 2060. In the NZE scenario, the emission intensity resulting from agriculture is progressively reduced and total agriculture GHG emissions in 2060 are estimated at 42.4 Mt CO_2-eq per year, which is a reduction of 14% in annual emissions compared to the BAU scenario.

Figure 5-19
Total emissions in LULUCF (left) and agriculture (right), Mt CO_2-eq



Source: Own calculations

Table 5-14
Emissions from LULUCF and agriculture, Mt CO_2-eq

	BAU scenario					NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
LULUCF									
Settlement land	-3.4	-3.7	-3.9	-4	-4.3	-3.7	-3.9	-4	-4.3
Cropland	30.4	21.2	18.5	21.9	25.1	20.3	15.4	11.8	10.5
Grassland	-17.8	-9.9	-9.9	-9.8	-9.8	-9.9	-9.9	-9.8	-9.8
Forestry	-2.9	-11.4	-10.3	-10	-9.9	-24.4	-27.8	-36.3	-39.8
LULUCF total	**6.4**	**-3.9**	**-5.6**	**-2**	**1.1**	**-17.8**	**-26.1**	**-38.4**	**-43.4**
Agriculture									
Enteric fermentation	18.7	26.9	28.3	29.7	30.6	24.9	25.1	26.2	26.9
Manure management	3.1	4	4.4	4.7	5	3.6	3.6	3.4	3.6
Agricultural soils	13.9	16.1	15.5	12.4	13.5	14.1	12.4	11	11.9
Agriculture total	**35.7**	**47.1**	**48.2**	**46.9**	**49.1**	**42.6**	**41.1**	**40.6**	**42.4**

Source: Own calculations

In terms of carbon absorption, changes in land use will turn LULUCF again into a net sink. In the BAU scenario, net absorption first occurs in 2024, while in the NZE scenario it starts in 2022 as a result of additional reforestation ambitions. However, in the BAU scenario, the increase in emissions from agricultural soils will again reduce total LULUCF CO_2 absorption and turn the sector into a net emitter of 1.1 Mt CO_2 per year by 2060.[67] Nevertheless, this represents a net emission reduction of 5.3 Mt CO_2 between 2017 and 2060. In the NZE scenario, the absorption capacity of the sector is increased significantly and maintained throughout the projection period. The LULUCF sector plays a crucial role and is projected to absorb 43.4 Mt CO_2 in 2060, which will cover all GHG emissions from agricultural production and somewhat relieve the emission reduction pressure in other sectors.

Box 5-2
Sustainable agriculture

FAO **(2014, p. 12)** defines sustainable agricultural development as "the management and conservation of the natural resource base, and the orientation of technological change in a manner that ensures the attainment of continued fulfilment of human needs for present and future generations. Sustainable agriculture conserves land, water, and plant and animal genetic resources, and is environmentally non-degrading, technically appropriate, economically viable and socially acceptable". Sustainable agriculture practices are adopted to increase soil and livestock productivity, reduce pre-harvest losses and minimise the use of chemical fertilisers. Concrete examples of sustainable agriculture practices include (but are not limited to) crop rotation and diversification, planting of cover crops, the integration of livestock and crop agriculture in order to benefit from their synergies, or the adoption of agroforestry practices.

Existing research also shows that sustainable agriculture practices contribute to reducing climate impacts on agricultural productivity. For example, sustainable agriculture practices are assumed to reduce topsoil erosion from precipitation, which maintains agriculture productivity relative to conventional agriculture practices.

In the current analysis, organic agriculture is defined as a subset of sustainable agriculture in which sustainable agricultural production is certified, and is also formally acknowledged as such. The modelling, however, covers sustainable agriculture in general, whether certified or not, and so organic production is used as an example.

Sustainable agriculture management practices contribute 13% to the avoided emissions in the NZE scenario, compared to BAU, totalling up to 223 Mt CO_2-eq of emissions between 2021 and 2060. This is driven by advances in livestock management, such as improved feeding practices, reduced time to slaughter and the collection of manure for fertiliser and bioenergy production.

[67] For more details on the projected development of GHG emissions by land use category see Figure A- 27 in the Appendix.

As a result, GHG emissions from enteric fermentation will fall in 2060 by 12% in the NZE scenario compared to the BAU scenario, and emissions from manure management will decrease by 29%. Improved soil management is also expected to reduce the GHG emission intensity of crop farming. Thus, despite the significant increase in crop production (up to 85% higher in the NZE scenario in 2060 compared to BAU), emissions from agricultural soils will decline by up to 12% in 2060 compared to the BAU scenario. Improved soil management will also reduce soil erosion. While soil erosion is to a large extent climate-induced (as it depends on precipitation and wind), sustainable agriculture techniques can significantly slow this process down, e.g., by using cover crops. Thus, soil erosion over the next 40 years is estimated to be lower by 37% in the NZE scenario compared to the BAU scenario, which supports carbon sequestration by the soil and reduces emissions per hectare of agricultural land by 41%.

Moreover, sustainable agriculture and improved irrigation coverage contribute to reducing the impact of water scarcity on crop productivity. In the BAU scenario, total losses of agricultural produce resulting from climate change are expected to increase from 13.1 Mt per year in 2017 to up to 19.1 Mt per year, or about 40% of crop production, by 2060. In the NZE scenario, the share of crop losses is progressively reduced, and climate-change induced losses fall to 15.6-16.9 Mt per year (19% of crop production, or -7% to -12% relative to BAU). Hence, investments in sustainable agriculture and resilience to climate change provide two-fold benefits: they not only reduce emissions from agriculture and contribute to climate change mitigation but also raise productivity in the sector.

This implies that the envisaged measures will also contribute to increasing employment in agriculture. In the BAU scenario, employment in agriculture is expected to rise from the current 1.3 million jobs (in 2017) to around 1.75 million jobs in 2060. In the NZE scenarios, additional 122 thousand jobs are projected by 2060. This is equivalent to an increase in employment by 7% relative to the BAU scenario.

Deep dive: Potential for bioenergy generation from agricultural waste

Agricultural waste refers to organic waste from agricultural production. It includes animal manure, residues from slaughtered livestock, crop residues, waste from the processing of dairy products, and waste from oilseed processing. A significant portion of agricultural waste is used for soil mulching, as fertiliser, animal feed, and livestock bedding, and is also partially incinerated. However, a large share of waste remains unused and, if not treated lead to the decay of the organic components, and the emission of methane and carbon dioxide.

The unused plant residues are often incinerated as fuel in boiler houses. Since 2015, over a hundred biomass boilers were installed in the Northern part of Kazakhstan. The use of biomass for heat generation replaced 23 thousand tonnes of thermal coal, saving around USD 670 thousand in fuel cost (ZM KZ, 2020).[68]

A more energy efficient use of agricultural waste is the controlled decomposition in anaerobic digestion plants to produce biogas for heating and power generation. This reduces waste and GHG emissions, and the fuel switch allows for a reduction in expenditure for fossil energy. The solid residues of anaerobic digestion can be used as an organic fertiliser, potentially replacing chemical fertilisers to some extent.

The current diffusion of bioenergy technologies in Kazakhstan is low. By the end of 2019, only three large biogas plants with a total capacity of 2.42 MW were operating in the country. In 2019, they produced 6.5 million kWh, or 0.2% of all renewable electricity in the country.[69] Investment in bioenergy generation capacities is hindered by the low cost of fossil energy sources and a lack of investment support and incentive programs to stimulate the use of biomass and agricultural waste for energy production.

The projection of agricultural production until 2060 also allowed for the estimation of the quantities of agricultural waste and the respective calorific values, i.e., the potential for bioenergy generation across regions and for the different scenarios (see Table 5-15). The total bioenergy generation potential is projected to increase in both scenarios due to the growing production in agriculture. The potential generation capacity by 2060 will be 20 GW in the BAU scenario, while it progressively grows in the NZE scenario to reach 32 GW by 2060. This is an increase of 59% relative to the BAU scenario. In addition to agricultural waste, there is also significant potential for bioenergy production from sewage sludge from wastewater treatment plants.

Table 5-15
Potential generation capacity for bioenergy from waste in Kazakhstan, MW

	BAU scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Crop residues	9277	10307	11334	12038	10500	13435	17680	22602
Manure	516	563	614	657	876	1333	1843	1970
Slaughtering residues	121	132	144	154	121	132	144	154
Other waste: Sewage sludge	5722	6257	6805	7253	5722	6257	6805	7253
Total	**15636**	**17260**	**18898**	**20102**	**17219**	**21157**	**26473**	**31979**

Source: Own calculations

[68] Energy cost recalculated at the average 2017 exchange rage (1 USD = 326 KZT).

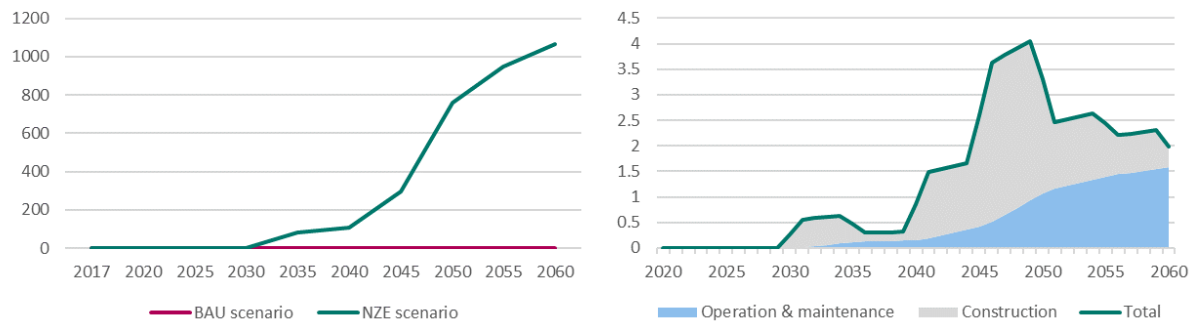
[69] Based on data from Bureau of National Statistics.

The main drivers for bioenergy in the NZE scenario are the availability of crop residues and animal manure. Firstly, due to the increased crop production from sustainable agriculture and reduced pre-harvest losses, the quantities of agricultural residue will be 88% higher by 2060 compared to the BAU scenario. Secondly, improved manure management practices increase the availability of manure for bioenergy production. While in the BAU scenario, only 17% of the estimated amount of manure is assumed to be collected, this figure rises 51% in the NZE scenario. As a result, the amount of manure available for reuse triples relative to the BAU scenario.

Not all waste will be converted into bioenergy, as manure is also used for mulching or as fertiliser, and the investment into biogas plants is weighted against the potential energy cost savings. Thus, in the BAU scenario, no bioenergy is generated, while in the NZE scenario there is an uptake of biogas production, with total added capacity reaching over 1 GW by 2060 (Figure 5-20, left panel).

The roll-out of bioenergy generation from waste will increase employment. The employment effects in the NZE scenario are shown in Figure 5-20, right panel. After peaking in 2049 at about 4 thousand jobs, by 2060 around 2 thousand jobs in the NZE scenario will be related to bioenergy. These include employment in construction, maintenance, and operation of the plants, as well as the preparation of feedstocks. The spike in employment is created through construction employment related to the acceleration of capacity additions between 2040 and 2050.

Figure 5-20
Additional biogas generation capacity, MW (left) and resulting employment in the NZE scenario, person (right)



Source: Own calculations

Finally, almost all types of biomass can be developed for use as biogenic fuel, either as a main product or a by-product. Different processing steps are necessary depending on the type of biomass. Processes such as methane fermentation (biogas), alcoholic fermentation (ethanol), pyrolysis or oil extraction (vegetable oil) with subsequent transesterification (biodiesel) may be necessary, or, as with wood, biomass can also be used directly. It is mostly used in systems that are operated in an identical or similar way to fossil fuels, such as boilers and combustion engines. However, such uses would require detailed analysis on the intersection of different sectors and consideration of various sustainability concerns and were, therefore, out of scope of the SD-KAZ model.

5.4 Waste sector

The waste sector is responsible for the methane (CH_4) and carbon dioxide (CO_2) emitted by the anaerobic decomposition of organic waste and sludge disposed of in solid waste disposal sites or by the handling of wastewater under anaerobic conditions.[70] In addition, the incineration of waste produces emissions of CO_2, CH_4 and N_2O. The current waste management system of Kazakhstan is largely dominated by landfilling and the incineration of waste. Decarbonisation of the waste sector requires a deep sectoral transformation and a large-scale roll-out of material recycling and energy recovery. The main measures for a decarbonised waste management system are:

- Accelerated implementation of full coverage by MSW collection and sorting;
- Reduction in waste and wastewater generation and improved technologies of wastewater treatment, including biogas generation;
- Increase in the share of waste recycled and composted for both environmentally friendly waste management and an establishment of a circular economy.

The decarbonisation scenarios in the waste sector take into account regulations related to waste streams, costs associated with waste management, and emissions from waste. The policy assumptions for the four scenarios are outlined in Table 5-16. The scenarios consider increasing ambitions for waste management in line with the waste management hierarchy.[71] In particular, landfilling of waste will to a large extent be replaced with more sustainable waste management strategies by 2060. The assumptions for the BAU scenario were aligned with current expert projections of the future development of Kazakhstan's waste management sector.[72] While the

[70] Landfill gas, which consists of methane and carbon dioxide at roughly equal shares and typically also contains a small amount of other components like nitrogen, oxygen, ammonia, or non-methane organic compounds, though their combined share usually does not exceed 5%.

[71] EPA classifies waste management strategies from most to least environmentally preferred: source reduction and reuse (avoidance of waste); recycling and composting (circular economy); energy recovery (waste combustion for renewable energy to replace fossil fuels); and treatment and (landfill) disposal as the least preferred option.

[72] The current scenario assumptions do not consider the landfill ban for various materials that was introduced from 2021. Compliance to the ban would require full sorting and recycling of materials banned from landfills and the disposal of organic

share of the most environmentally friendly waste treatments such as recycling and composting are expected to increase in this scenario, energy recovery through waste combustion still remains an important factor. In contrast, the decarbonisation scenarios assume much higher ambitions with respect to the reuse and recycling of waste as opposed to landfilling and combustion. They also assume a faster implementation of full MSW collection and a reduction in waste generation per capita.

Table 5-16
Assumptions on policy targets for 2060 in the waste sector

Policy / technology	BAU	GE	DD	NZE
Wastewater production	0%	-20%	-40%	-40%
Waste generation per capita	0%	0%	0%	-40%*
Technology cost	-20%	-20%	-40%	-40%
MSW collection: first year of 100% coverage	2050	2045	2040	2040
MSW recycling**	55%	70%	85%	85%
MSW composting***	15%	30%	70%	70%
MSW energy recovery****	33.5%	33.2%	23.5%	25.1%
MSW landfilling	Residual	Residual	Residual	Residual
Sewage sludge treatment (biogas)	-	30%	40%	40%

* Not applicable to industrial waste as part of “other waste”
** Organic waste and other waste are excluded from recycling
*** Composting is only assumed for organic waste
**** Energy recovery from organic and non-organic non-recyclable waste. For organic waste, energy recovery and composting compete, whereby priority is given to composting, which has lower emissions, relative to energy recovery

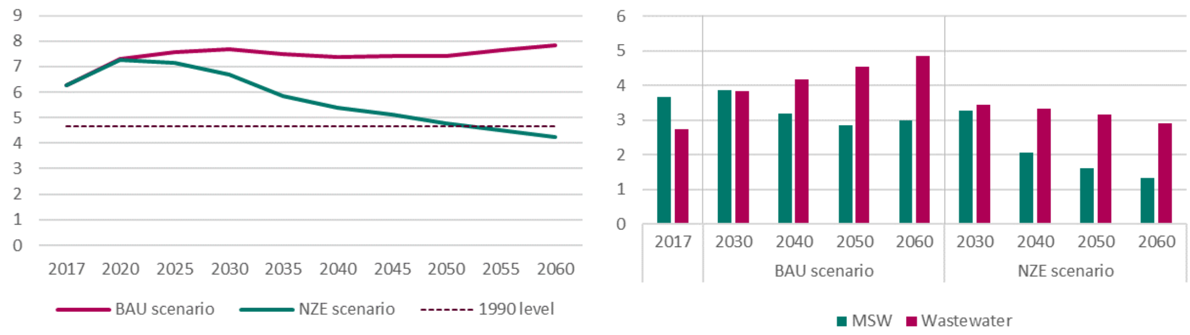
Source: Own presentation

The improvements in waste management and, in the NZE scenario, the decrease in waste generation will significantly reduce emissions from the waste sector. In the BAU scenario, total waste-related emissions increase from the current 6.4 Mt CO_2-eq to 7.85 Mt CO_2-eq by 2060 (Figure 5-21, left panel), a net increase of 23% relative to 2017. There is a temporary emission reduction from 2025, which is completely driven by the improved management of municipal solid waste (Figure 5-21, right panel). However, in the long run the positive impact is offset by the growing population and the resulting waste accumulation.

waste through composting and energy recovery, which experts deemed infeasible due to a lack of capacity for managing the additional waste loads.

Figure 5-21

Total projected GHG emissions from waste (left) and GHG emissions by waste type for selected years (right), Mt CO_2-eq



Source: Own calculations

In the NZE scenario, however, reductions in waste generation per capita and higher ambitions in both MSW and wastewater management contribute to reducing emissions at a much faster rate. As a result, total emissions will decline to 4.23 Mt CO_2-eq, which corresponds to a reduction of 34% relative to 2017.

In Table 5-17, GHG emissions are disaggregated by the mode of treatment.[73] The decline in total MSW emissions is driven by a gradual elimination of the open dumping of waste and an almost complete elimination of waste disposal in landfills. These reductions more than offset the slight growth in GHG emissions from the increased use of organic waste for composting and energy recovery. A growing share of MSW collection increases GHG emissions from waste collection over time, but in the NZE scenario, emissions from collection stabilise as a result of reduced waste generation. Furthermore, these emissions are offset by the reduction of emissions from open dumping as well.

Table 5-17

MSW emissions by management mode, Mt CO_2-eq

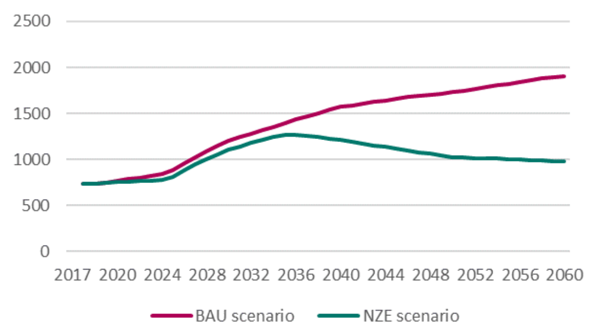
		BAU scenario				NZE scenario			
	2017	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Collection	0.18	0.23	0.32	0.39	0.42	0.23	0.29	0.29	0.27
Composting	0.00	0.01	0.02	0.03	0.03	0.02	0.08	0.09	0.10
Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste to energy	0.00	0.80	1.11	1.34	1.59	0.93	1.39	1.04	0.77
Landfills	1.39	1.00	1.08	1.09	0.97	0.77	0.29	0.20	0.18
Open dumping	2.09	1.81	0.65	0.00	0.00	1.32	0.00	0.00	0.00
Total	**3.66**	**3.85**	**3.19**	**2.85**	**3.00**	**3.27**	**2.06**	**1.61**	**1.32**

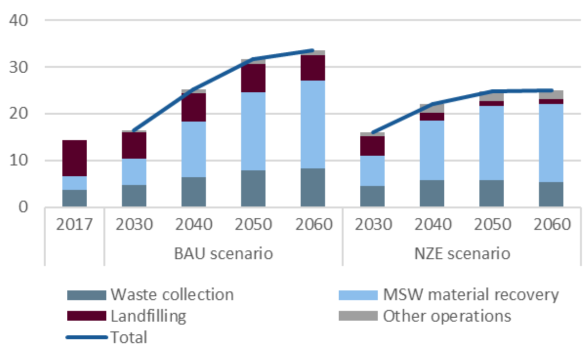
Source: Own calculations

[73] The change in MSW generation and in waste management shares by management mode can be viewed in Figure A- 29 and Figure A- 30 in the Appendix.

Unlike in MSW management, no improvements are expected in wastewater generation and treatment in the BAU scenario due to low ambition and investments. The amount of wastewater generated is projected to increase by 42% from 670 million m³ per year in 2017 to approximately 954 million m³ per year in 2060, without any change in the rate of treatment or methods. Thus, emissions from wastewater substantially increase in the BAU scenario (Figure 5-21, right panel). In the more ambitious NZE scenario, however, a shift towards more water-efficient appliances and machinery leads to a significant reduction in wastewater – by 15% in 2060 relative to 2017, or by 40% relative to the BAU scenario. Moreover, a change in the treatment of sludge from wastewater is expected, with increased use of sludge for biogas production. This not only reduces GHG emissions from wastewater but also increases renewable energy generation, thus reducing the use of fossil fuels and additionally contributing to a reduction in emissions from energy use. Improved waste collection and the transition from landfilling to recycling and energy recovery increase waste management costs. However, unlike in the BAU scenario, in the NZE scenario the total waste management cost does not increase continuously. Instead, the peak is reached in 2036, after which the costs decline again (Figure 5-22, left panel). This is due to both the overall falling technology costs for waste management, declining waste generation rates and higher recycling rates in this scenario (generating scale economies). In fact, turning waste into a resource would often also generate profits, which would increase the benefits from recycling beyond GHG emission reduction.[74]

Figure 5-22
Total cost of MSW management, million USD (left) and employment in waste management, thousand persons (right)





Source: Own calculations

[74] Material recycling constitutes a sector connected to but distinct from waste management, and explicit modelling of cost and revenue streams in waste recycling was, therefore, out of scope of the SD-KAZ model.

The increase in waste management cost should be weighed against the additional employment needed for the transformation of waste management. In all scenarios, employment in the waste sector is expected to increase considerably, and its structure will also change significantly (Figure 5-22, right panel). In the BAU scenario, waste sector employment is forecast to more than double from about 14.3 thousand jobs in 2017 to 33.6 thousand jobs in 2060, with 16% of those jobs still relating to landfilling operations. In the NZE scenario, the growth in waste sector employment is more modest as the amount of waste is expected to decrease significantly. Still, by 2060, employment is projected to increase to around 25 thousand jobs, which is 75% higher than in 2017. The main contributor in the NZE scenario to jobs is the increased recycling of materials, which more than offsets the reduction in jobs in landfilling and accounts for 66% of sector employment in 2060. Additional employment from using waste, including agricultural waste, for bioenergy generation should also be considered and will constitute about 4 thousand jobs at its peak and 2 thousand jobs in 2060 in the NZE scenario (see also the Deep dive in Section 5.3).

6 Financing decarbonisation: Power sector

As outlined in Section 4.2, the massive scale of transformation in the economy will require large investments, of which the majority is required in the power sector. Moreover, most investments will need to be made by the producers. This section analyses how to stimulate these investments through the lens of required electricity prices. The analysis combines different instruments to achieve the economically viable transformation of the power sector, such as:

- tariff policies;
- carbon pricing; and
- measures to reduce the cost of capital and attract green finance.

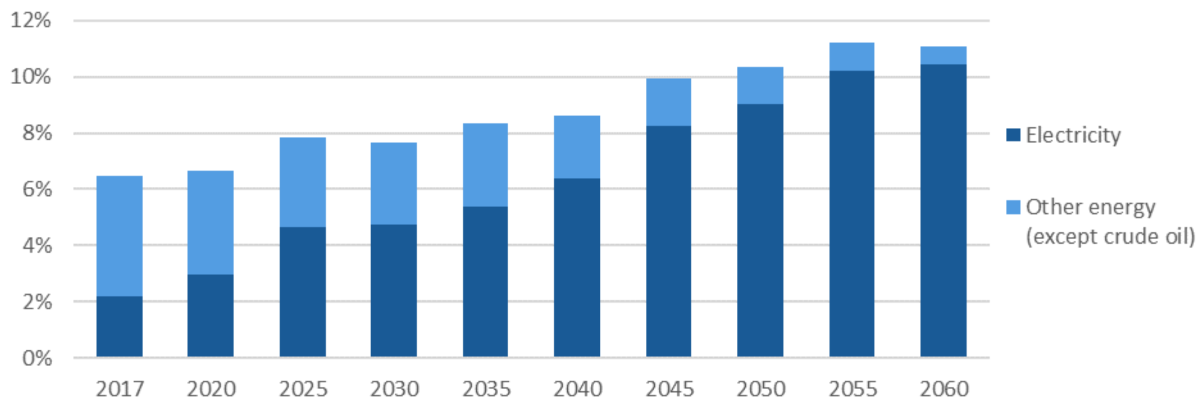
The economically optimal tariff policy will allow markets to determine electricity prices that cover all operational, capital, and environmental costs of power generation in Kazakhstan. The resulting price increase can be cushioned with government financial support from carbon pricing and by attracting international support. At the same time, the transition in the power sector should be socially just protecting vulnerable groups of society.

This section provides an analysis of the different instruments to attract green investments for the transformation towards net zero emissions, with a special focus on the power generation sector. The choice of the power sector is driven by the following considerations:

- It requires major structural changes for achieving net zero emissions, with a shift from emission-intensive coal-based to renewables-driven power generation and the use of CCS for any remaining fossil fuel combustion (see also Section 5.1.3).
- This profound transformation requires massive investments – half of the economy-wide total investment needs – and will cause increasing costs in the power system, mainly due to costly technologies like electricity storage and CCS (see also Section 4.2).
- The power sector is a prime example of at present regulated tariffs in Kazakhstan, which discourage energy saving, energy efficiency improvements and private investment into sustaining and expanding electricity generation capacities. Economic viability of the power sector will require revision of the tariff policies, which is a sensitive issue for the final consumers of electricity (households and industry).

The analysis of the necessary instruments to stimulate private investment is carried out through the lens of required cost covering prices. To cover the investments for the transition to net zero emissions in the power sector, a significant increase in electricity prices relative to the current level will be necessary. This trend is reflected in the total cost of energy. Overall, rising demand for electricity, switching to renewables and the extensive use of energy storage and of CCS for the remaining fossil assets will lead to higher capital and operating costs associated with the power system. Total economy-wide expenditure on electricity is expected to increase five-fold, from about 2% of GDP in 2017 to over 10% of GDP by 2060 (Figure 6-1). However, this increase has to be weighed against the decreasing consumption of other - mostly fossil - energy, which is replaced by electricity. The share of electricity costs in total energy consumption will almost triple between 2017 and 2060, and so the share of total energy spending in GDP is projected to rise gradually from 6.5% in 2017 to 11.1% in 2060. This is close to the global average when fuel prices are high[75] and well below the energy spending share in China and South Korea[76].

Figure 6-1
Electricity and total energy costs relative to GDP, %



Source: Own calculations

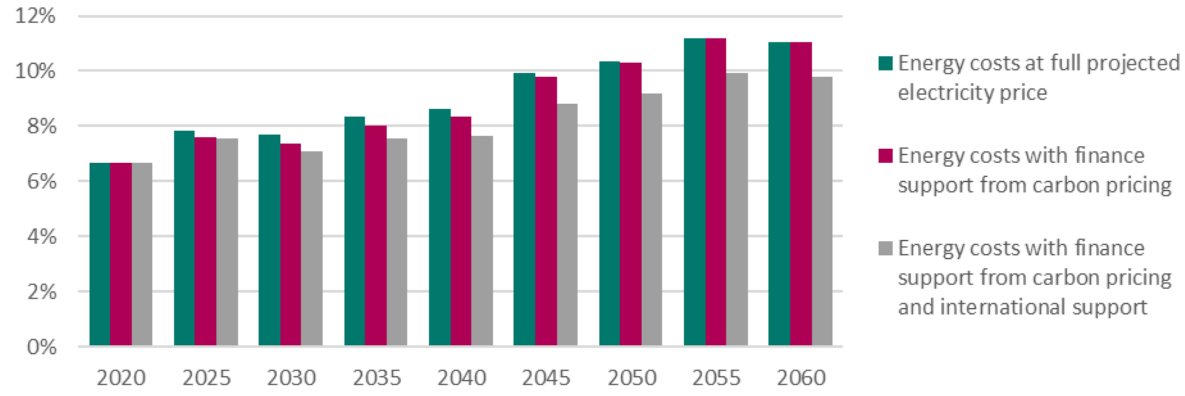
This significant increase is primarily driven by technological changes in industrial processes and fast-growing electricity demand in industry after 2030. The government has several possibilities to further reduce the overall economic impact of the power system transformation. For example, using part of the revenues from carbon pricing to support green investment in the power sector can help stabilise the total cost of energy relative to GDP until 2030. In addition, engaging with international investors and institutions to secure low-interest green investments can significantly reduce the energy costs in the mid- to long term. It would limit the growth of relative energy spending, so that the share of energy costs in GDP reaches just below 10% by 2060 (Figure 6-2).

[75] For example, global spending on energy as a share of GDP reached about 10% in 2008-2011 and is expected to reach as high as 13% in 2022 (THUNDER SAID ENERGY, 2022).

[76] In China and South Korea, the share of energy spending in GDP has consistently exceeded 10% in the last decades, reaching up to 15-18% between 2005 and 2012 (Zhaoyuan & Ishwaran, 2020).

Compared to the overall economic impact, households will be affected much less by the costs of power system transformation, again due to fuel switching. The share of households in economy-wide electricity spending will steadily decrease from 2040 onwards, reducing their share in the total costs of the power system. Moreover, electrification processes in buildings and individual passenger transport will efficiently replace the use of other energy sources.

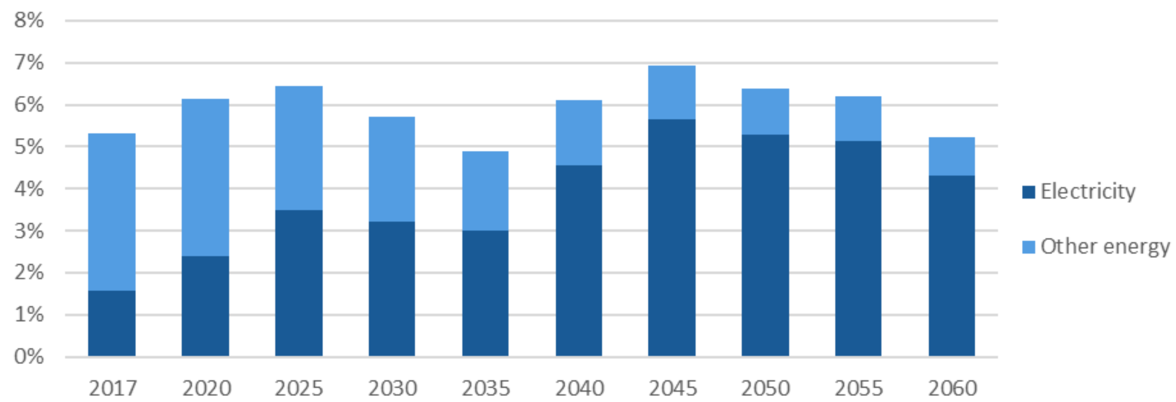
Figure 6-2
Total energy cost as a share of GDP under three policy options, %



Source: Own calculations

Figure 6-3 depicts the development of household electricity and total energy spending as a share of total household expenditure. In the long-term perspective, while the spending on electricity increases, total energy costs will remain fairly stable. This is because electricity will replace the use of fossil fuels for individual heating and transport. The small share of other energy spending in 2060 constitutes primarily of the costs of central heating and the remaining minor portion of gasoline private transport. Overall, there are two periods, around 2025 and 2045, when energy costs take a slightly higher share in total consumption.

Figure 6-3
Electricity and total energy costs of households relative to total household expenditure, %



Source: Own calculations

The first increase is associated with the necessary rise in electricity prices to account for the capital and environmental costs of the current energy system. It is cushioned by increasing energy efficiency and lower spending on other energy sources, leading to a reduction in the share of energy expenditure below the 2017 level by 2035.

The second period of rising energy spending reflects the costs of the massive scaling up of the power system and a push towards high shares of renewables. The same rise in costs is also visible economy-wide in Figure 6-1 above. For households, however, it is cushioned by the falling share of other energy spending and the use of energy-efficient electric equipment (e.g., heat pumps). As electricity prices stabilise after 2040 and the household share of total electricity demand declines against the growing demand from industry, electricity costs for households fall, and so does total energy spending relative to total consumption. By 2060, the total energy spending as a share of total consumption is projected to be just below the 2017 level. This example of price volatility related to the different investment cycles in the power sector would be perceived by business and households as an unpleasant uncertainty. Thus, regulatory policies to smoothen the price developments over time could be applied.

Moreover, also in periods of rising costs, the impact on consumption is relatively small. If total consumption expenditure were to remain unchanged despite higher electricity prices – i.e., if households would reduce other consumption instead of reducing savings to cover the extra energy cost – non-energy consumption would have to decline by up to 2% (in 2025). In terms of monthly consumption per capita, this corresponds to about USD 8 out of approx. USD 450 in 2025 and USD 14 out of approx. USD 865 in 2055. Policies could be pursued to further reduce these effects, as will be discussed in more detail in Section 6.4.

Overall, the results show that financing the transformation in the power sector through increased electricity prices is feasible. As will be shown in more detail below, the government has policies, options, and tools to reduce the economic effects of the price increase without additional costs to the public budget.

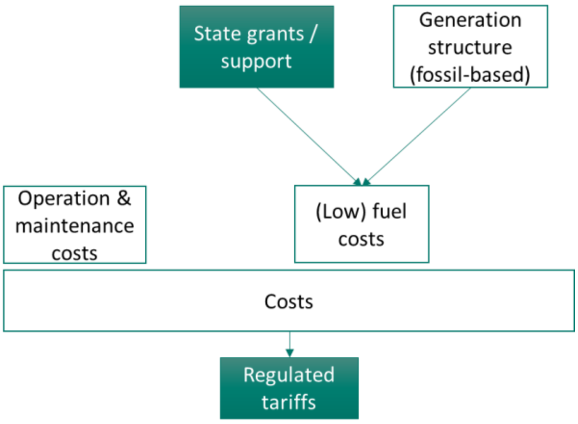
6.1 Sustainable financing mechanisms

6.1.1 Viability of the electricity system

The current techno-economic structure of the Kazakh electricity system is characterised by regulated tariffs and the implicit subsidisation of fossil fuels, which are consumed in the generation structure dominated by coal and gas (see also Box 5-1 on fossil fuel subsidies). The consumer tariffs in Kazakhstan averaged US cent 4.3 per kWh in 2021 (Bureau of National

Statistics, 2022). As illustrated in Figure 6-4, this tariff only covers operation and maintenance costs as well as fuel costs (Decree of the Minister of Energy, 2015).[77]

Figure 6-4
Techno-economic structure of the current electricity system



Source: Own presentation

The transformation of the Kazakh electricity system towards net zero emissions by 2060 requires significant investments in new renewable electricity generation capacities, expansion of the power transmission and distribution grid, and energy storage capacities.

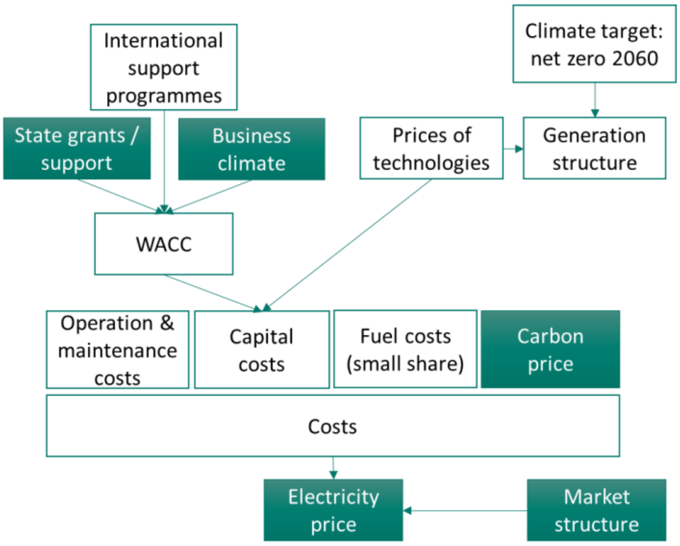
Most of these investments will be made by private investors seeking returns on their investments. To stimulate investment in the power sector, the revenues in the electricity system have to cover capital costs as well. If these capital costs are not covered by the electricity tariffs, the electricity system is not viable, because private investments in new capacities and retrofitting of existing generation capacities will not take place. To provide sufficient investments for maintaining and expanding the power system, the state would have to step in with public funds to finance new generation capacities directly or cover the difference between tariffs and actual costs, in order to attract domestic and international investors. Both options are economically inefficient and burden public budgets while diverting government spending from other policy areas.

Figure 6-5 outlines the main techno-economic cost determinants in an economically viable electricity system. To guarantee viability of the power system in its transition to net zero emissions, **electricity prices have to cover all system costs**, which comprise the *capital costs, variable and fixed operation and maintenance costs, fuel costs, and carbon prices* arising for all

[77] The tariff also includes carbon pricing if applicable, but at the current price of USD 1 per t CO_2 this component is negligible. In addition, it includes amortization of existing capital stock, but most power plants in Kazakhstan are old and already completely amortised. Thus, this component too plays only a marginal role.

technological components of the electricity system, such as *electricity generation facilities, the electricity distribution system,* and *electricity storage facilities*.

Figure 6-5
Techno-economic structure of the future electricity system



Source: Own presentation

While most of these parameters, such as prices for generation technologies and operation costs, are exogenously determined, governmental policies can directly and indirectly influence the characteristics of several important factors (green boxes in Figure 6-5).

Policy changes are needed to foster the transition of the electricity system and therewith its economic viability. This comprises a *phase out of currently existing fossil fuel subsidies*, especially for coal[78], a *re-framing of the tariff system*, an implementation of appropriate *carbon pricing,* and a variety of policies and measures to improve the business climate and *support the use of green finance instruments*.

6.1.2 Phase out of fossil fuel subsidies

According to IEA estimates, of the USD 6.6 billion of fossil fuel subsidies in Kazakhstan in 2019, USD 1 billion accrue to electricity and USD 2.2 billion were directed to coal subsidies (IEA, 2021). The latter figure corresponds to 1.2% of GDP and USD 18.97 per tonne of coal extracted. In the cost-benefit analysis of the coal phase-out (see Section 5.1.2), a rather conservative estimate of USD 4.65 per tonne of coal was used, based on OECD (2014).

The negative economic effects of fossil fuel subsidies in Kazakhstan are threefold:

[78] See Box 5-1 for discussion on fossil fuel subsidies.

- Firstly, they increase the relative price gap between conventional and renewable power generation, which leads to a competitive disadvantage for electricity generation from renewable sources. As a result, investments in renewable electricity capacities are not stimulated.
- Secondly, funding for fossil fuel subsidies eventually comes from the state budget and has distributional effects between different income groups that contradict the socio-political goals of the government, as more affluent consumers benefit more from fossil subsidies than poorer households.
- Thirdly, subsidisation stimulates overconsumption of the subsidised good. Hence, these subsidies impede the necessary transformation, are ineffective in their socio-political impact, and are also economically inefficient.

A complete phase-out of these subsidies is a necessity for achieving the defined net-zero target. Eliminating fossil subsidies should be among the first policy measures implemented when transitioning to net zero GHG emissions. By doing so, fuel prices will better reflect the actual costs of fuel production and consumption, and reduce the disproportions between different types of power generation.

6.1.3 Re-framing the tariff system

Payments for electricity, defined by the electricity prices, are the only income source for the entire power system. If the prices do not cover all costs, supply decreases and no investments flow in the installation of new and the retrofitting of existing generation facilities. So, transfers from the state budget must compensate for the financial gap. Still, the electricity system is not economically viable and cannot sustain operations over time without external public support.

Consequently, economically optimal prices should reflect the costs of electricity generation. However, generation costs vary depending on the season and time of the day. The reason for that is the time-dependent variation in the composition of power generation by different types of capacities, triggered by changes in demand, availability of generation facilities (e.g., due to maintenance), fuel prices, and the availability of renewable energy (especially at higher shares of renewables in the power system).

When prices are regulated, tariff-setting needs to foresee such variation in generation costs, which is associated with a risk of miscalculation. A more efficient and effective approach to handling the cost variation is the formation of prices in a market setting, where many electricity traders buy power from many generators and sell it to many consumers. Market competition guarantees that traders buy electricity from generators offering the lowest possible prices and sell it to final consumers at the lowest prices that ensure their own profitability. Furthermore, if (some) traders consistently have wrong expectations about the margin between changing generation prices and self-defined tariffs, their market exit has no negative effects on the market as a whole.

Framing the tariff system as a market process with as many as possible (and necessary) market actors, allows for an effective and efficient price formation process. On the one hand, it will guarantee the viability of the existing electricity system. On the other hand, because market competition among producers will induce the *merit order effect*[79], and renewable energy sources have significantly lower costs than fossil-based generation facilities, market pricing will stimulate the entry of market participants generating electricity from renewables.

The role of the state in such a system is two-fold: firstly, the state has to define the market design and ensure that the market process functions without failures, e.g., due to monopolies or illegal market arrangements. Secondly, the state has to protect vulnerable consumer groups if electricity prices rise. Ideally, such protection is imbedded within the overall targeted social transfer system (see also Section 6.4).

6.1.4 Carbon pricing

Pricing GHG emissions, either through emission permits in a market with a carbon cap or through carbon taxes, can help reduce emissions. Carbon prices generate three effects:

- They change the relative electricity prices of fossil and non-fossil generation capacities and increase the profitability of renewable electricity generation;
- Consequently, they decrease the demand for (and therewith supply of) fossil-based electricity generation; and
- They generate a constant stream of state budget revenues. The revenues compensate for the negative environmental and health effects of GHG emissions and can be used for direct climate policy action by the government and for compensating vulnerable electricity consumer groups (see also Section 6.4).

At present, the carbon price in Kazakhstan's Emission Trading System (ETS) of around EUR 1 (USD 1.13) per t CO_2 is too low to stimulate investments in renewables. The current update of Kazakhstan's NDC proposes an increase of the carbon price in the ETS to EUR 15 (USD 16.95)

[79] Merit order is a way of ranking electricity generation by ascending order of price, which in turn reflects the order of short-run marginal costs of production by different facilities. The merit order effect implies that, to cover electricity demand at any point, generation will first be dispatched from the facilities with the lowest marginal costs, while those with the highest costs will be the last to dispatch. Because wind and solar energy do not have the fuel component, they are placed higher in the merit order than gas or coal power plants.

per t CO_2 in 2023 and EUR 45 (USD 50.85) per t CO_2 in 2026. Among others, the ETS covers the power sector, and so these prices will apply to fossil-based electricity generation. For the following years, the NDC proposal is close to the carbon price trajectory suggested for emerging markets by the IEA in its report on reaching net-zero emissions in the global energy sector (Table 6-1).

Table 6-1
IEA net-zero scenario: CO_2 prices for electricity, industry and energy production, USD (2019) / t CO_2

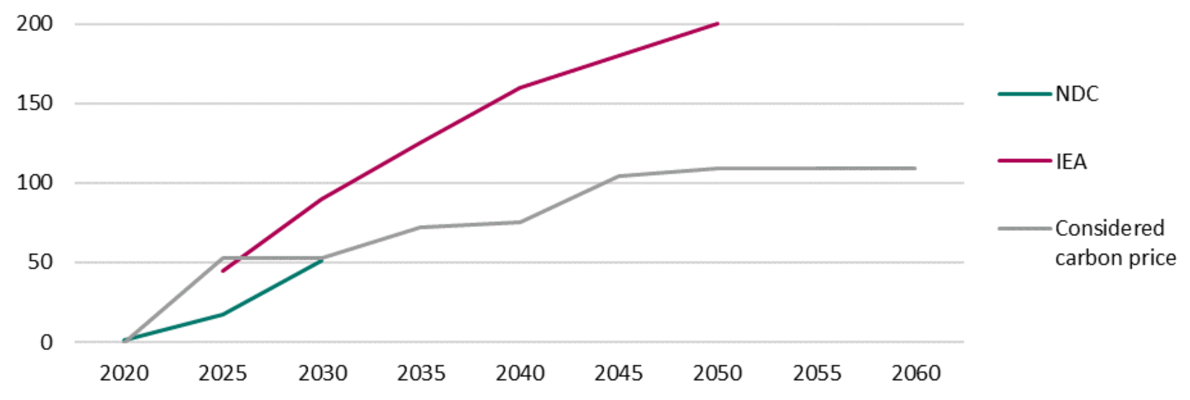
	2025	2030	2040	2050
Advanced economies	75	130	205	250
Selected emerging market and developing economies*	45	90	160	200
Other emerging market and developing economies	3	15	35	55

* Includes China, Russia, Brazil and South Africa
Source: IEA (2021)

Currently, no plans exist for the period after 2030. To effectively stimulate green investments in the power sector, however, the carbon price will have to continue rising after 2030. Internationally, the price reference is the IEA's projection of the carbon prices in advanced as well as emerging and developing economies that are required for reaching net zero energy emissions globally by 2050 (IEA, 2021).

Figure 6-6 compares three carbon price trajectories: the NDC plan of Kazakhstan until 2030, the IEA projection for emerging market and developing economies, and the lowest carbon price that is necessary for the market to prefer decarbonisation over "business as usual" in terms of system costs. Technically, the latter is the carbon price that equalises the cost-covering electricity price in both the BAU scenario and the NZE scenario.

Figure 6-6
Carbon price corresponding to NDC and IEA and the proposed carbon price, USD / t CO_2



Source: NDC, IEA and own calculations

Figure 6-6 shows that, after 2025, the NDC carbon price reaches the level needed to stimulate decarbonisation (about USD 50 per t CO_2). Furthermore, the IEA projection exceeds the required minimal carbon prices from 2030 onwards. In other words, a carbon price lower than the IEA projection would be sufficient to make the net zero pathway in the power sector more attractive than "business as usual". The necessary carbon price is close to the NDC level in 2030, afterwards it continues to rise gradually, suggesting plausible long-term targets for carbon pricing in the power sector in Kazakhstan. By 2050, it reaches USD 109 per t CO2, almost 50% lower than the IEA projection. This required carbon price is used as a reference value in the policy scenarios outlined in Section 6.2.

6.1.5 Further policy measures to reduce the increase in tariffs

6.1.5.1 Business climate

A market-oriented business climate is key for economic development, prosperity and attracting international investments. Therefore, the state has to frame the institutional environment consisting of a multitude of socio-economic and policy sub-systems, including the design of markets, the monetary system, legal frameworks, the tax system, the capital market, and many more. The specific design of all these systems and their reliability co-define the country-specific business climate. In addition, setting clear targets (including on climate policy), specifying frameworks and criteria for preferential treatment of green projects as well as providing timely information on future policy changes all contribute to reducing uncertainty for investors. This lowers the risk premium, the surcharge on investors' requested yield of capital to ensure profitability of investments in a specific country. Consequently, the better the business climate due to an appropriate institutional framework, the lower the risk premia, the weighted average costs of capital (WACC) and the costs of electricity generation.

Box 6-1
The weighted average cost of capital (WACC)

The WACC represents the average rate of return of an investment. Typically, physical investments – construction of a building, development of a wind park or foundation of a company – are funded by different sources of capital. In its simplest version, the funding consists of equity capital – capital that the new owner of a company possesses – and debt capital, such as bonds and bank loans. The cost of capital – the interest rate or yield – may differ between these two types of capital: the yield on equity (determined by profits) is higher than the interest on debt, because creditors can hedge risks over all assigned credits and have priority over capital owners in case of bankruptcy.

The WACC determines the average interest rate, whereby the interest rates for each funding source are weighted by its share in total investment. In more advanced variants of the WACC, funding-source specific taxes are considered too.

Interest rates of funding sources depend on a variety of technological, economic, and regional parameters, such as the type of capital good, the lifetime of the capital good (its use-time), exchange rate expectations, inflation expectations, the overall country risk, and the alternative risk-free investment options of an investor. If interest rates differ across funding sources, the capital structure of an investment becomes key for the average cost of capital (WACC). Moreover, because the capital costs co-determine the total costs of electricity generation, the WACC has a direct influence on the tariffs required to cover all costs of the power system (also called *cost-covering prices*).

Investors face differences in the WACC for renewables and conventional fossil capacities, which also vary across countries and regions. The estimated average WACC for investments in renewable energy capacities in emerging markets is about 8.16%, while that of investments in fossil generation capacities is 9.78% (Table 6-2).[80] The main reason for this gap is the difference in run-time and the time-dependency of risks between renewable and fossil capacities (Grubb, et al., 2017).

It is uncertain whether and to what extent the spread of WACC between renewable and fossil investments will increase in the future. A growing share of investors seek environmentally responsible investment options. In the US, the volume of "sustainable and responsible investments" has increased by the factor of four since 2010 and reached about 12 trillion USD in 2018 (US SIF, n.d.). The growing number of private and institutional investors looking for these

[80] There is no reliable information on Kazakhstan-specific WACCs. However, the emerging markets WACC for fossil generation capacities of 9.8 % aligns perfectly with the discount rate of 10 % assumed for the fossil-dominated power sector in Kazakhstan by USAID (2018).

types of investments might decrease the interest rates and therewith the costs of capital. At the same time, for institutional investors, funding fossil capacities might result in reputational damage, which decreases the supply of investment into fossil assets and increases the respective interest rates. In addition, global decarbonisation requires renewables to largely replace fossil-based generation in the future, which will turn fossil investments into stranded assets. This risk will further increase the WACC of fossil investments.

Table 6-2
WACC for selected regions and sectors

WACC	Germany	US	China	Emerging markets
Engineering / construction	3.72%	6.75%	6.76%	8.08%
Green & renewable energy	3.41%	5.14%	6.56%	8.16%
Insurance (general)	4.88%	5.41%	6.44%	5.23%
Investments & asset management	3.31%	5.09%	4.74%	6.27%
Oil / gas (integrated)	5.43%	5.32%	8.60%	9.78%
Power	3.22%	4.37%	6.04%	6.31%

Source: Grubb et al. (2017)

6.1.5.2 Targeted transfers funded with revenues from carbon pricing

Policy makers could earmark the revenues from carbon pricing for the targeted support of different economic actors both on the supply as well as on the demand side in the electricity market.

On the electricity supply side, investors can be supported with grants or interest subsidies. Both options result in lower capital costs (WACC) and therefore reduce the total power generation costs. As a result, the required prices for guaranteeing the viability of the electricity system will be lower (see Section 6.3.2).

On the demand side, revenues from carbon pricing can support specific consumer groups, such as low-income rural and urban households, who are especially vulnerable to increases in electricity prices (see Section 6.4)

6.1.5.3 International support for attracting green finance

The restructuring of the electricity system and the development of renewable energy generation in Kazakhstan will require substantial investments until 2060. Globally, investments in renewable electricity capacities are dominated by non-governmental funding, comprising 86% in 2019 (IEA, 2020), and it is foreseeable that Kazakhstan will need to attract large funds from international investors to decarbonise its economy.

Because market participants are increasingly incorporating environmental, social and governance (ESG) considerations and sustainability into their investment decisions (Moody's, 2020), an increasing share of capital is channelled in investments aiming at emission reduction and energy saving.

The two main sources of private funding for renewable electricity projects are equity capital and debt. Among debt-based instruments, green loans and green bonds are the main funding sources for "green" projects. Both are fixed-income debt instruments, but green loans are mainly short-term, while green bonds are more suitable for funding long-term climate and renewable energy projects. Currently, the global volume of green loans is about USD 33 billion, with the majority (USD 31 billion) situated in developed countries, but the market is growing rapidly (World Bank, 2021). In contrast, the volume of green bonds is 13 times larger. In line with the overall development of ESG finance, the market for green bonds has grown steadily from about USD 50 billion in 2015 (Bloomberg, 2019) to USD 433 billion in 2021 (Research and Markets, 2022). The market for green bonds is expected to continue growing, and renewable energy is becoming increasingly prominent as a funding beneficiary (Research and Markets, 2022), which is of importance to the power sector.

Compared to equity finance and standard bank loans, green bonds result in lower capital costs for two reasons: firstly, they are often backed by international institutions, which reduces risks, and secondly, green bond issuers focus not only on monetary gains but also on the environmental and social benefits of their projects. Kazakhstan can benefit from green bonds by either issuing its own bonds through the domestic financial system or by actively engaging international issuers of green bonds to invest in renewable energy projects in Kazakhstan.

International support, e.g., by development banks or international governmental organisations through grants or the provision of guarantees, can help attract green finance. Such international support lowers investment risks perceived by investors and therewith the interest rates (WACC). As a result, capital costs for investments in renewable energy capacities decrease, leading to lower electricity prices.

6.2 Financing model of transition

The analysis of the evolving energy systems in the BAU and the NZE scenarios applies cost-covering prices. While the focus of the analysis is on the NZE scenario, the comparison between the two scenarios provides valuable insights into the changing structure of the system costs and the carbon price necessary to stimulate investments into low- and zero-carbon technologies.

Cost-covering electricity prices reflect the average price for a unit of electricity that covers all costs along the value chain of electricity generation. These include capital costs, variable and fixed operation and maintenance costs, fuel costs, and carbon prices arising for all technological components of the electricity system, such as electricity generation facilities, the electricity distribution system, and electricity storage facilities. The concept of cost-covering electricity prices is suitable for determining the average price needed to allow the electricity system as a whole to operate *profitably*. Because cost-covering prices by definition reflect the costs of the system, they will differ from the prices that result from a market process or are observable to electricity consumers (e.g., tariffs or merit order pricing).[81]

The technological and economic evolution of the electricity system until 2060 differs substantially between the BAU and the NZE scenarios, due to the differences in the massive transformation towards electrification and renewables to reach net zero by 2060 (see also Section 5.1.3). This implies significant differences in the volume of new investments and in technologies that these investments target. Furthermore, changing fuel prices and fuel consumption lead to a transformation of cost structures. These factors change the cost-covering electricity prices over time and across scenarios, and this approach depicts how present investment decisions affect future electricity generation costs.

The financing model is directly based on the results of the bottom-up TIMES-KAZ model for the two scenarios, BAU and NZE. It uses the TIMES modelling results on the volume and structure of power generation and capacities, energy storage, and power grid expansion as well as operating costs by technology. To completely reconstruct the full cost of the power system, the TIMES data are complemented with fuel prices in line with IEA (2021) and capital costs of retrofitting existing capacities as per Tsiropoulos, Tarvydas, & Zucker (2018). In addition, to explore the policy options for supporting green investments in the NZE scenario, the model differentiates between the cost of capital for fossil and for green investments (see Box 6-1 in Section 6.1.5 for more information on the cost of capital).

Three policy scenarios are analysed for the NZE development pathway:

- In scenario one, the full cost of the power system is covered by the price of electricity. Following Grubb et al. (2017), the cost of capital (WACC) for renewable investments is set at 8.16%.
- The second scenario builds upon the first one and assumes that 50% of revenues from carbon pricing are used domestically for supporting the interest rates for investments in renewable power generation capacities.

[81] The cost-covering prices also do not depict variation in the levelized costs of electricity from different generation sources, which arises from different fuel inputs, ages of power generation facilities, or capital investment needs, because the focus is on the average final price.

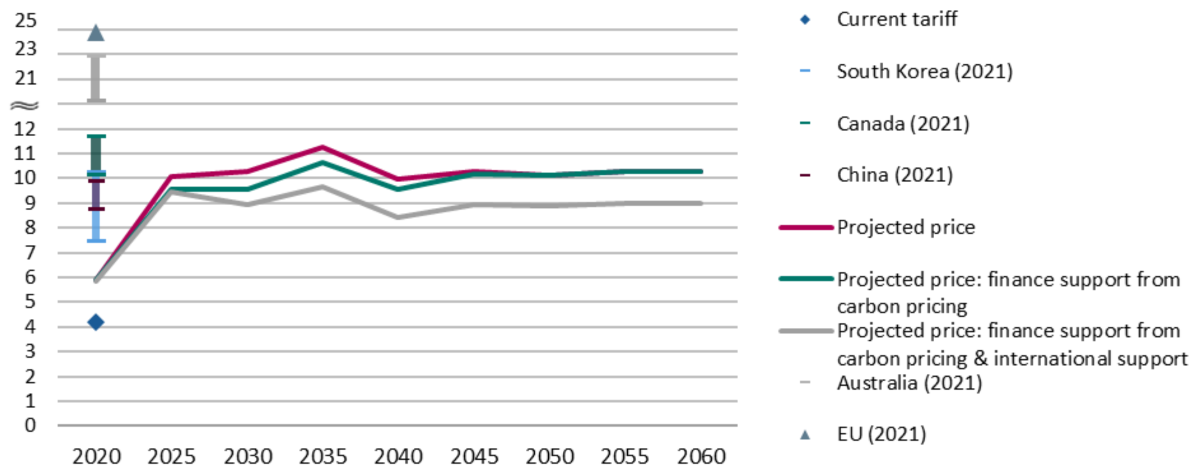
- In the third scenario, international funding support is added, which allows for a further reduction of the WACC of renewable investments by 2 percentage points.

In all three scenarios, the carbon price follows the NDC plan until 2030 and increases afterwards up to USD 109 per t CO_2 to equalise the cost-covering prices in the BAU and the NZE scenarios (see Section 6.1.4 for more detail).

6.3 Cost-covering electricity price and cost components

This section analyses the required cost-covering electricity prices corresponding to the necessary transition to a zero-emission economy in Kazakhstan by 2060 and their cost components for the three policy scenarios, as outlined in Section 6.2. The development of the cost-covering electricity prices is shown in Figure 6-7. The results indicate that, to cover the costs of the decarbonised power system, the long-term price has to increase to around US cent 10 per kWh in the first and the second scenarios and US cent 9 per kWh in the third scenario. This is still below the world average of US cent 13.9 per kWh for household users and US cent 13.4 per kWh for business users.[82]

Figure 6-7
Cost-covering electricity prices in the three scenarios, US cent / kWh



Source: Own calculations

Compared to the first scenario, finance support with revenues from carbon pricing allows the reduction of the cost-covering electricity price in the second scenario in the short to middle run. However, the revenues from carbon pricing decline with advances in the decarbonisation of the

[82] https://www.globalpetrolprices.com/electricity_prices/
With respect to the levels of electricity prices, Kazakhstan takes place 27 (out of 148 countries in the database), between Egypt and Afghanistan, as of March 2022.

economy, and hence the prices in the two scenarios converge after 2050. The largest effect is achieved in the third scenario, where reducing the cost of capital with the combination of revenues from carbon pricing and international support leads to lowering the required electricity prices by up to 16% (in 2040), relative to the first scenario.

6.3.1 Policy scenario 1: Cost-covering electricity price until 2060

As discussed in Section 6.1.1, the current electricity tariffs do not cover all costs of the system. The cost-covering price would have been around US cent 6 per kWh (40% higher than status quo) in 2020 (Figure 6-8 /

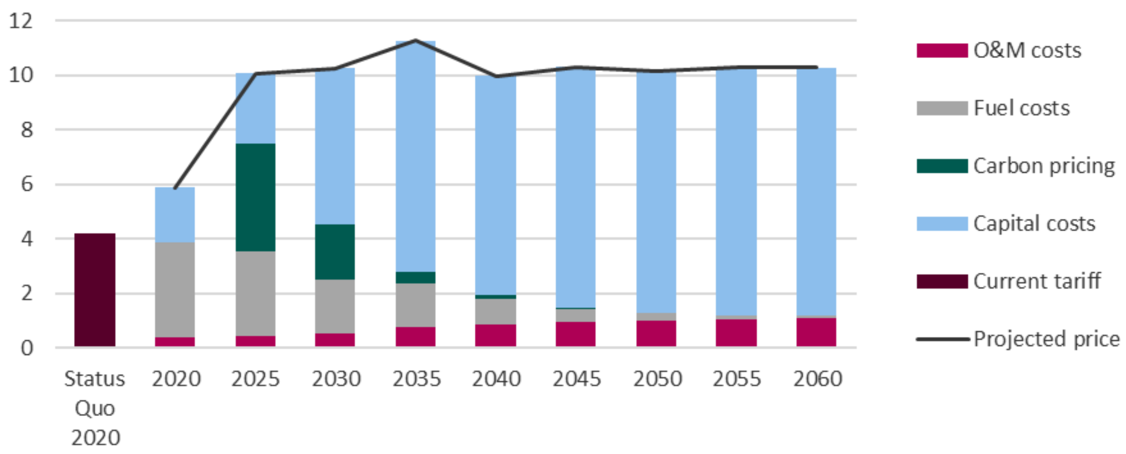
Table 6-3). As a meaningful carbon price is phased in, the cost-covering electricity price ("Projected price" in Figure 6-8) increases to about US cent 10 per kWh by 2025. Afterwards, the cost-covering price remains stable in the range of US cent 10-11 per kWh.

Table 6-3
Components of the cost-covering electricity price, US cent / kWh

	2020	2025	2030	2035	2040	2045	2050	2055	2060
O&M costs	0.4	0.5	0.5	0.8	0.9	1.0	1.0	1.1	1.1
Fuel costs	3.5	3.1	2.0	1.6	0.9	0.5	0.3	0.1	0.1
Carbon pricing	0.0	4.0	2.0	0.4	0.2	0.1	0.0	0.0	0.0
Capital costs	2.0	2.6	5.7	8.5	8.0	8.8	8.8	9.1	9.1
Total projected price	**5.9**	**10.1**	**10.3**	**11.3**	**10.0**	**10.3**	**10.1**	**10.3**	**10.3**
Status Quo tariff	4.2								

Source: Own calculations

Figure 6-8
Cost-covering electricity price and cost components, compared to the status quo tariff, US cent / kWh



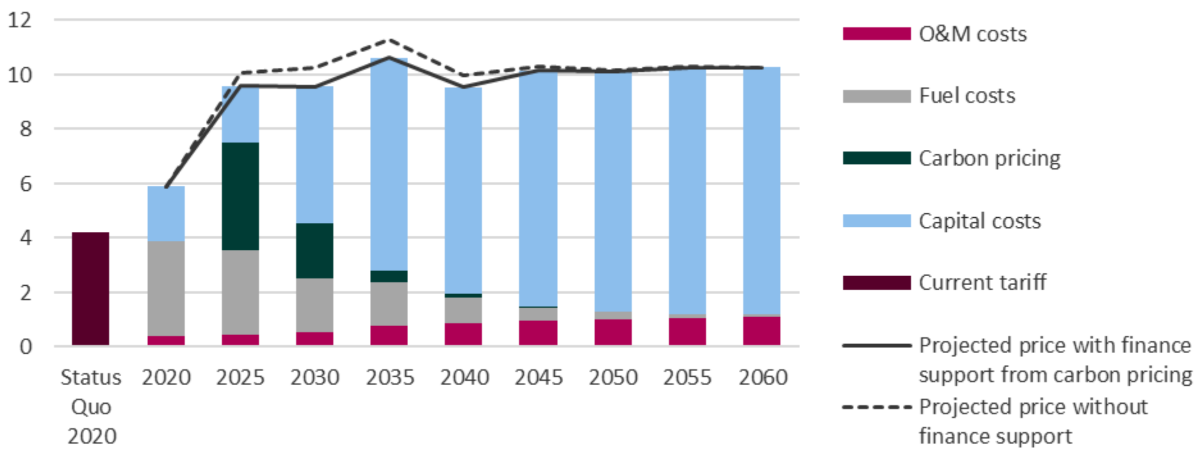
Source: Own calculations

The share of capital costs in the cost-covering price increases steadily to become the main component of the price by 2030, due to the ongoing investment into renewable generation capacities, grid expansion, and storage facilities. In contrast, the share of fuel costs decreases and is nearly zero in 2060, because of the phase-out of coal-fired power generation and the rising share of renewables, which do not have any fuel costs as wind and sunshine are provided free of charge (see also Section 5.1.3). Even though carbon prices increase until 2040, the total carbon payments are highest in 2025 and decrease afterwards as GHG emissions from the electricity system are diminished. Finally, the share of operation and maintenance (O&M) costs increases slightly due to the operation of renewables and storage facilities.

6.3.2 Policy scenario 2: Cost-covering electricity price with interest support from carbon pricing

The use of carbon revenues helps to soften the price growth in the medium term. In case 50% of the revenues from carbon pricing are used domestically to support the interest rates on investments into renewable electricity generation capacities, the cost-covering price ("Projected price with finance support from carbon pricing" in Figure 6-9) decreases by up to 6.7% in 2030, reaching US cent 10.6 per kWh at its peak in 2035. The reduction results only from lower capital costs, while all other cost components are equal to those in scenario 1.

Figure 6-9
Cost-covering electricity price with interest support from carbon pricing and cost components, compared to status quo tariff, US cent / kWh



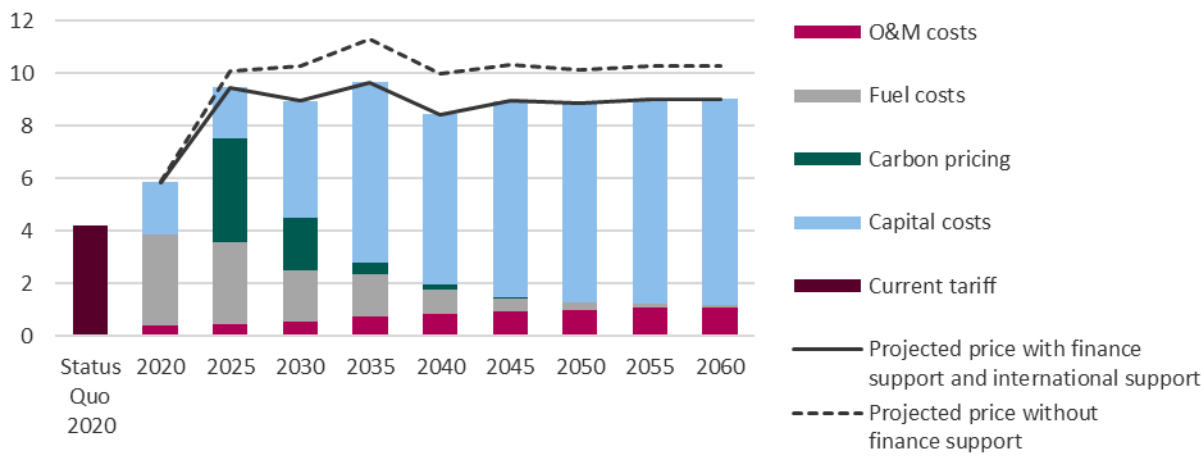
Source: Own calculations

The advantage in comparison to scenario 1 fades out by 2045, because the revenues from carbon pricing fall as the sector decarbonises. While around 2025-2030 carbon revenues provide a WACC reduction of up to 2 percentage points (from 8.16% to 6.16%), the effect diminishes to 0.5 percentage points from 2035 onwards and to nearly zero in 2060. Since the lifetime of new renewable capacities constitutes on average about 20 years, after which they will need to be replaced, this reduction in carbon revenues after 2030 will result in almost the same investment costs for these new facilities as in scenario 1.

6.3.3 Policy scenario 3: Cost-covering electricity price with interest support from carbon pricing and international interest support

The final scenario considers a further reduction of the overall WACC for investments in renewable energy sources by 2 percentage points, representing a WACC decrease from 8.16% to 6.16%. Together with support from carbon pricing this corresponds to an overall WACC reduction to 4.16-6.16% and leads to an additional reduction of capital costs over the whole period until 2060. The impact is substantial and is at its largest around 2040, when the high share of capital costs in the total electricity price coincides with still relatively high revenues from carbon pricing (Figure 6-10). Starting with a low relative difference of 6% in 2025, the gap between the cost-covering electricity price in scenarios 1 and 3 increases to 12% in 2030, peaks at 16% in 2040 and then stabilises again at 12-13%, as the carbon pricing component vanishes (compare with Figure 6-9).

Figure 6-10
Cost-covering electricity price with interest support from carbon pricing and international interest support and cost components, compared to status quo tariff, US cent / kWh



Source: Own calculations

A potential source for this type of WACC reduction is international public support schemes, such as funds from international development banks or from governmental donors and private funds that issue green bonds. Requirements for gaining such support were discussed in Section 6.1.5.3 and include reliable business climate and credible commitment to the implementation of climate targets, such as the NDC goals and the net-zero target for 2060.

6.3.4 Summarising remarks

This section highlights the interplay of the four elements of state action discussed in Section 6.1 and quantified above, which are necessary for financing the transition to net zero emissions in the power sector.

Firstly, to guarantee the viability of the power system without the need for additional governmental spending to cover investments, **tariffs must be equal to cost-covering electricity prices**. This means that **electricity prices should increase** significantly relative to their current level.

Secondly, the **electricity prices should reflect the environmental costs** of fossil-based power generation. This includes phasing out fossil fuel subsidies and introducing carbon pricing. The carbon price necessary to stimulate decarbonisation in the power sector reaches USD 109 per t CO_2 by 2050, which is half the level projected by the IEA of USD 200 per t CO_2 in 2050.

Thirdly, revenues from carbon pricing can be used to **support investments** in renewable capacities through grants or interest support. This would lower the necessary electricity price by 5-7% between 2025 and 2040. Furthermore, these revenues can reduce the prices for vulnerable consumer groups, as discussed in Section 6.4.

Finally, other than the direct financial effects, revision of tariff policy, carbon pricing and investment support can generate indirect effects. As discussed in Section 3, the **institutional framework** co-determines the business environment investors operate in and, consequently, affects the risk premia and interest rates. Additionally, investments in Kazakhstan can benefit from comprehensively defined institutional frameworks and active engagement with the international community through international support programs. This can significantly reduce capital costs and therewith the cost-covering price in the long run.

6.4 Support to vulnerable groups of society

Currently, the low electricity tariffs in Kazakhstan are considered a form of social policy to prevent energy poverty[83]. However, the universal provision of social benefits like low energy tariffs is vastly expensive and misallocates the largest part of social assistance to rich households, because poor households operate much fewer household appliances (like air conditioning,

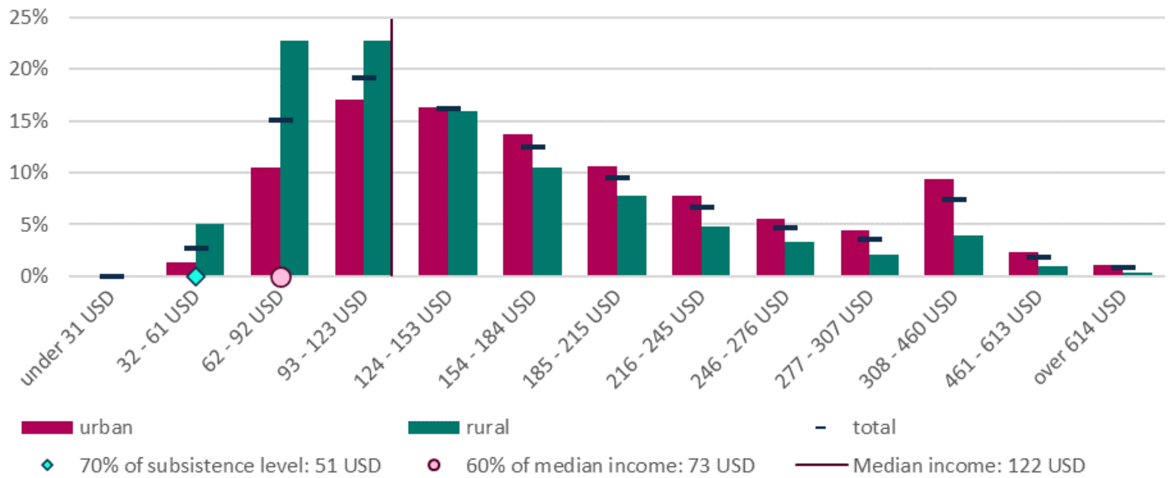
[83] IEA (2021) refers to energy poverty as a lack of access to modern energy. Close the term of "energy poverty", "fuel poverty" is accepted across the developed economies to describe a household's inability to afford basic standards of heat, power and light (Liddell, Morris, McKenzie, & Rae, 2012).

Some lobby groups and representatives of particular interests also argue that low energy tariffs are a competitive advantage of Kazakhstan. But this argument ignores that energy tariffs below cost cause misallocation, overconsumption and generate economy-wide welfare losses.

plasma TVs, washing machines, dryers, dish washers, freezers, etc.) and hence, poor households consume disproportionally less energy than others. Universal low-tariff schemes do not induce energy savings and often cause overconsumption and even waste of energy. The present power tariffs do not reflect the producer costs, leading to underinvestment in the power system, high environmental costs from the carbon-intensive power system, and reduced incentives to switch to renewable energy sources. Therefore, the low electricity tariffs come at high costs to society as a whole.

The misallocation of assistance through universally low tariffs is even more pronounced when the relatively low reported poverty rate in Kazakhstan is considered. Based on the absolute income threshold of 70% of the subsistence level, national statistics report just 2.7% of population to be living in poverty in 2017, with this number rising to 5.3% in 2020. If instead the relative threshold of 60% of median income is used, then about 10% of population can be considered poor, which is less than in most European countries.[84] The poverty rate is consistently higher in rural areas (compare income distribution in Figure 6-11). Based on these small shares of vulnerable population, a transition to market (cost-covering) prices, combined with targeted support to low-income households who are most affected by the energy transition, would significantly reduce the societal costs compared to universally low tariffs.

Figure 6-11
Population distribution in 2017 by monthly income used for consumption, %



Note: in 2017, subsistence level was almost equal to 60% of the median income.

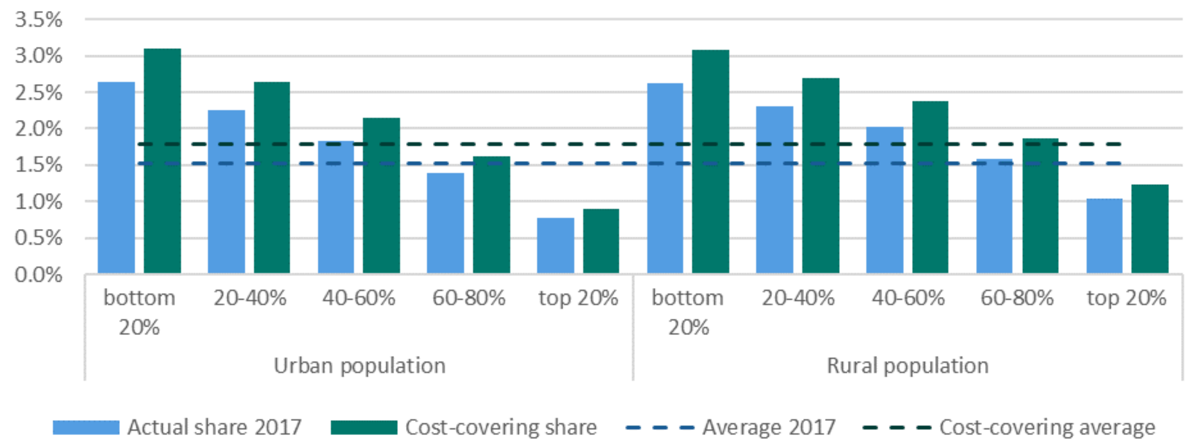
Data source: Bureau of National Statistics, (Forbes Kazakhstan, 2021)

[84] Data source: Forbes Kazakhstan (2021), comparison with European countries is based on World Bank data.

This consideration can be illustrated through the comparison of actual tariffs and cost-covering prices in 2017[85]: Figure 6-12 depicts, in blue, the actual shares of electricity spending in total household expenditure by income quintiles, divided into urban and rural population. In green, it shows how these shares would change if electricity prices were to rise in order to reflect all costs of the power system[86]. With the average electricity price of US cent 3.5 per kWh in 2017 on the one hand, and the 2017 cost-covering price of US cent 4.1 per kWh on the other, an increase by 17% is necessary to close this gap.

The average share of electricity expenditure across all households was 1.5% in 2017. It is the highest among households with lower incomes, both rural and urban, reaching over 2.5%. Consequently, an increase in tariffs to the cost-covering prices will affect them disproportionately, impacting the bottom 20% of households the most (Figure 6-12). In order to keep total expenditure unchanged, they would have to reduce all other consumption by 0.5%, whereas the top 20% of households would only need to reduce it by 0.1-0.2%.

Figure 6-12
Share of electricity costs in total household consumption in 2017 by income quintiles at actual tariffs and at cost-covering prices, %



Source: Own calculations

Assuming unchanged electricity consumption, the cost-covering price would increase total household expenditure on electricity by USD 230 million, from USD 1.33 billion to USD 1.56 billion. This reflects the costs of keeping tariffs low for all households in 2017. Of those, however,

[85] The example is based on the 2017 household survey and the social accounting matrix (SAM) for 2017, as used in CGE-KAZ modelling. The household survey is representative of different income groups, but covers only about half of total household expenditure, so the SAM, which covers the whole economy, is enhanced with the data from the survey to derive the expenditure volumes.

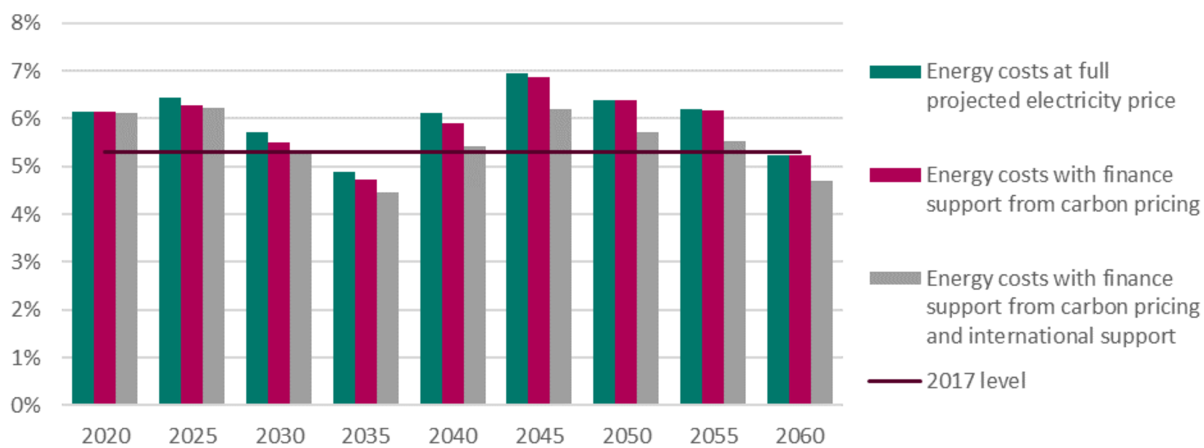
[86] For this counterfactual, it is assumed that electricity consumption will not change.

only USD 40 million (17%) are the additional costs accruing to the bottom 20% of households. In other words, increasing tariffs to the cost-covering level and providing targeted transfers to lower-income households, completely covering the price increase for them, would have cost about **one sixth** of the expense of keeping the tariffs universally low. Taking into account the low share of poor households (see above), the costs of supporting only those in poverty are even lower. This highlights that market pricing with targeted support is economically much more efficient.

As discussed above, over time an increase in electricity prices will be necessary to ensure economic viability and green transformation of the power sector. While reducing spending on other energy sources will mostly keep total energy spending (relative to total consumption expenditure) at about the same level as in 2017, in some periods the costs for households will increase if no additional measures are taken by the government.

Figure 6-13 compares how policies to reduce the overall cost of the power system, as discussed in Section 6.2, change the total costs of energy for households. In the short term, the use of half of state revenues from carbon pricing for investment support and securing international support for low-interest investments have almost equal-scaled impacts. Their combination allows to stabilise the share of total energy costs at just above 6% of total consumption expenditure and return it to the 2017 level or even lower in 2030-2040. The other half of carbon revenues can be employed, e.g., to directly support the population most affected by the rising electricity prices. Although the potential of carbon revenues substantially diminishes from 2035 onwards due to the falling share of fossil-based electricity generation, the modelling results of Section 6.2 suggest that, at proposed carbon prices, about USD 200-500 million could still be available annually until 2045 to split between investment and social support.

Figure 6-13
Energy costs as a share of total consumption under three policy options, %



Source: Own calculations

As the share of capital costs in the electricity price grows (compare Figure 6-8 in Section 6.3.1), securing low-interest green investments has increasing potential to reduce the overall cost of the power system. As a result, it allows the share of household expenditures on energy to be brought to approximately the 2017 level by 2055. In the absence of any support, up to 1.7% of expenditure would have been transferred from non-energy consumption to energy costs in 2055. However, with lower capital costs from state and international support, this amount is reduced to only 1%.

Taking into account the development of cost-covering electricity prices (Section 6.2) and energy costs relative to consumption expenditure (Figure 6-13), the targeted efforts to support vulnerable groups of society should focus on the near term, when the electricity price needs to rise to meet the cost-covering levels, and on the mid-term, when timely switching to energy-efficient electric equipment would both support decarbonisation in buildings and private transport and dampen the energy costs for households.

Importantly, it is necessary that sufficient time is provided to households to adapt to changes and plan their daily consumption and appliance purchases in line with the expected price changes. Sudden price shocks would lead to irritation and unacceptance among the population. Instead, **forward guidance** – the provision of information and the time-horizon of planned policy measures in advance – would help generate awareness and manage expectations. It would also provide preparatory time for the implementation of the policies, including setting up the support schemes and their monitoring.

There are various support measures that can relieve the burden on vulnerable households and help them adapt to the increasing electricity prices. As mentioned above, these measures can be at least partly financed through the redistribution of carbon revenues from the power sector.

To avoid energy poverty, **direct transfers** to cover a part of the electricity price for the poorest households can be put in place. Such transfers would be available to households already in energy poverty or in danger of energy poverty due to rising prices. They should however be limited to only cover a certain level of electricity consumption, in order to prevent wasteful use of energy.

Targeting specific households comes with administrative costs, and efficient targeting should minimise the two errors (Handrich & Betliy, 2008): under-coverage (lacking inclusion of the targeted households in the support programme) and leakage (coverage of non-targeted households by the support). One option is to perform so-called means testing – individual assessments of applicants' income and resources against a certain threshold, e.g., the poverty line. While this option ensures matching between the actual needs of poor households and the amount of support they receive, information collection and verification are associated with high cost and require high administrative capacity. An alternative option is to use proxy means testing, or indicator-based targeting. This procedure consists of two steps: first, statistical information on households is analysed to construct a poverty indicator based on a relatively small set of household characteristics; second, the households applying for social support provide the information necessary for calculating their poverty score and are assessed based on that score. Keeping the exact indicator formula undisclosed and automating score calculation can prevent fraud on households' side and due to instances of corruption. Overall, this approach lowers leakage and significantly reduces the administrative costs of information collection and verification.

A complementary measure to targeting, or an alternative in case targeting is too costly, is price segmentation based on electricity consumption. Taking into account that lower-income households consume disproportionally less energy (see above), setting lower prices up to a certain consumption threshold would implicitly favour poorer households and, overall, stimulate energy saving. A similar framework is already in place in current tariff-setting in Kazakhstan. The consumers are divided in three tiers, or "levels", based on their monthly electricity consumption (up to 100 kWh per person, 100-180 kWh per person, and over 180 kWh per person) and whether they use an electric stove for cooking. However, currently lower-tier groups are more strongly affected by price increases. For example, over 2017, the electricity tariffs increased on average by 2.7%, but the rise for level 1 (consumption less than 100 kWh per person) was 9.7% for households using electric stoves, while for level 3 (consumption over 180 kWh per person) it was just 0.6%.[87] An improvement of this framework will, for example, ensure that price increases are stronger for the upper-tier groups rather than the inverse. As technological energy efficiency is increasing over time, the thresholds defining the tariff groups will also need to be revised.

Besides direct transfers, increasing energy efficiency should be stimulated. To boost switching to energy-efficient and low-carbon appliances, **purchase support** can include direct subsidies as well as special credit conditions (e.g., reduced interest rates or state guaranties). In addition, information measures, such as labelling, should be rolled out.[88] Similar instruments as well as special **feed-in tariffs** can be applied to incentivise switching to **renewable energy sources**,

[87] Price changes between December 2016 and December 2017, based on consumer price data by Bureau of National Statistics.

[88] Steps are being made to promote energy efficiency (see, e.g., the project by UNDP, GEF and the Government of Kazakhstan, http://eesl.eep.kz/en/), but the awareness of population about the topics of energy efficiency and the benefits of energy-efficient appliances is still low (Kazinform, 2018).

especially in **rural areas**. Rural populations are often characterised by lower income levels and will be more strongly affected than urban population as electricity prices rise. At the same time, households in rural areas have to rely more on individual energy supply other than electricity (e.g., space and water heating), while decarbonisation would require widespread electrification of these uses. This would imply, especially in rural areas, a necessary increase in electricity consumption, coupled with rising prices. Own electricity production from renewable installations would dampen the growth of or even reduce electricity purchases from grid operators, thus easting this twofold pressure.

7 Conclusions and outlook

This report provides an analysis has the Republic of Kazakhstan can fulfil the countries pledge to reach climate neutrality by 2060. A future with net zero GHG emissions by 2060 in Kazakhstan is both technically possible and economically feasible. Achieving this goal will require deep structural changes throughout the entire economy and a fundamental transformation of the energy sector in particular. Carbon neutrality by 2060 will require the mobilisation of large investments. With redirecting current carbon investments towards low- or no-GHG-emitting technologies and with improving market-oriented framework conditions, the investment levels will be sustainable over the entire period leading up to 2060 and most of the time not exceeding historic investment-to-GDP ratios.

The continuation with business as usual will be associated with much higher costs to the economy and society alike. The pathway to carbon neutrality will require the switch to renewable energy, improved energy efficiency, and a reduction of consumption by increasingly employing principles of a circular economy.

Currently, the main obstacles to decarbonisation towards net zero emissions in Kazakhstan are a variety of regulated and low prices and tariffs in a number of sectors relevant for tackling climate change, such as energy and waste. The current low tariffs do not reflect the real economic, environmental, and social costs of use and consumption. Thus, market price signals of scarcity are distorted and incentives for more efficiency are lacking, causing misallocations and often conscious and unconscious wasteful handling of valuable resources (energy, raw and input materials, clean air, etc.). Low tariffs and prices prevent the amortisation of investments and the operation of energy-saving and zero-carbon equipment or even the investment in sustaining the existing capital stock.

Economically optimal policies allow markets to determine prices that will account for the relevant costs, encourage rational and prudent use of resources, and stimulate private investment in energy efficiency and fuel switching. The latter can be further supported by continuously improving the overall business environment and investment climate in Kazakhstan.

In the absence of market conditions, the second-best option for the government to stimulate investment into decarbonisation would be granting certain investors specific purchase agreements at predetermined prices and duration in order to ensure the profitability of particular investments. However, this approach is biased towards larger, well-connected investors and will reduce overall potential investments, compared to market conditions, as such specific agreements limit competition and innovation and create disadvantages for other investors, especially for small and medium enterprises (SMEs) and households in Kazakhstan. The less market forces are in operation, the more the government would need to step in. Given the large investment needs, this would require shifts in budget expenditures at the expense of other policy areas, creating trade-offs between decarbonisation and other socioeconomic priorities.

Achieving carbon neutrality is costly, but not acting would be detrimental to national welfare. This creates trade-offs, especially between current habit-driven consumption and investment to ensure future welfare. However, decarbonisation measures like the necessary exit from coal mining and combustion should not be understood as policies and measures at the expense of the current generation. The assessment of the coal phase-out and transformations in transport and buildings indicated that each avoided tonne of emissions and pollutants increases welfare, while energy saving and fuel switching create tangible benefits to households.

The present system of low tariffs and prices is justified with social concerns about preventing energy poverty and other disadvantages among the needy. However, poor households consume disproportionately much less of the low-tariff services and goods in comparison to more affluent households. Thus, these universal low-tariff schemes do not induce the rational use of scarce resources and often cause overconsumption and even waste of energy and other subsidised goods and services.

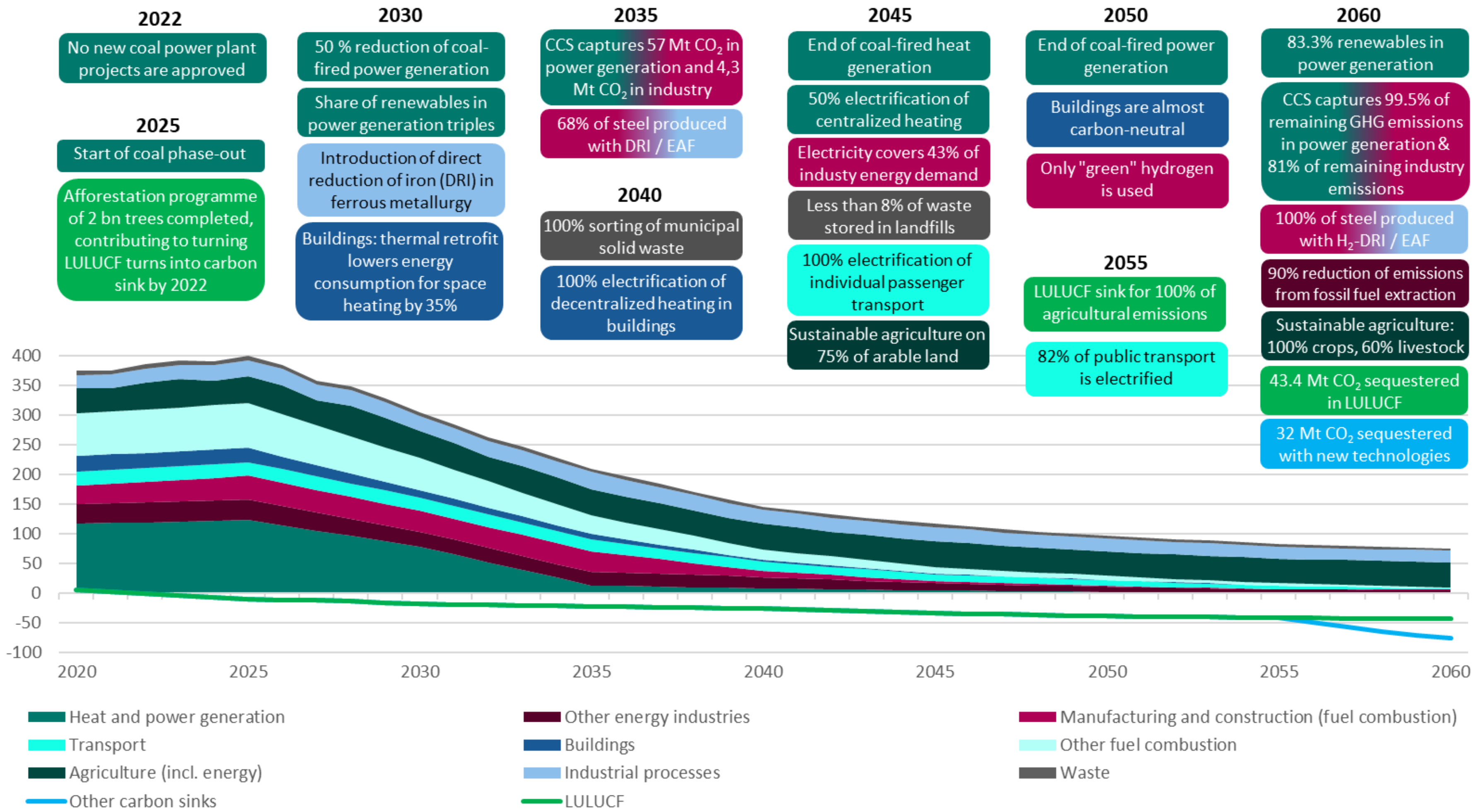
Instead, concerns about the financial burden of higher market prices on vulnerable social groups need to be addressed by policy makers with targeted social transfers to the identified groups.

At the same time, as the low tariffs do not reflect producer costs and negatively affect the environment, they come at a high cost to the society as a whole. Therefore, market prices with targeted social transfers to vulnerable groups increase resource efficiency and relieve the burden on the society without putting pressure on low-income households. The government has several instruments to cushion the effects of market pricing, in particular recycling the revenues from carbon pricing, improving framework conditions, and attracting international investment support in order to reduce the investment costs, which are then passed through to consumers.

Overall, a transition to carbon-neutral development comprises more than a reduction in GHG emissions. It is also a transition to a more sustainable and higher-quality lifestyle and economy. The Strategy “Kazakhstan-2050” and the Plan of the Nation “100 Concrete Steps” set ambitious transformative goals for society, state, and the economy. Many of them mirror the UN Sustainable Development Goals, which balance the economic, social, and environmental dimensions of sustainable development. The proposed path towards net zero by 2060 will

contribute to both and should be understood not as an alternative but as a complement to the "Kazakhstan-2050" strategy. The implementation of carbon neutrality is an important step on the way to realising the national vision and the Sustainable Development Goals in Kazakhstan.
The major milestones of the implementation of the net zero emissions scenario are summarised by 5-year-intervals in Figure 7-1.
The first milestone is reached when, after the government's decision to pursue the pathway towards net zero by 2060, the announcement is made that coal-fired power plants will no longer be approved. This will signal to the market, to domestic and foreign investors and firms, but also to the population the strong commitment to future carbon neutrality. This step will instantly turn renewable energies into more attractive investments and will help triple the renewable share in power generation by 2030.
By 2035, about two thirds of the steel production will be using direct reduced iron (DRI) in electric arc furnaces (EAF). By 2040, all decentralised heating in buildings will be electrified. Five years later, half of centralised heat supply will be electrified and coal-fired heating will be completely stopped. The last coal-fired power plant will stop production by 2050 and the buildings sector will be almost carbon-neutral by then.
By 2055, all GHG emissions from agricultural production will be sequestrated by the sector of land use, land use change, and forestry (LULUCF). In 2060, the share of renewables in power generation will exceed 83% and almost all remaining GHG emissions in power generation will be absorbed by technologies of carbon capture and storage (CCS). Natural sinks and new technologies will balance unavoidable GHG emissions, and the economy of Kazakhstan will reach a net zero emission balance.
The outlined milestones should not be seen as a forecast of future developments or a precise roadmap. Instead, they should be understood as an outline of potential pathways towards a future with a decarbonised economy. While the analysis presented above captures the major developments required for the transition to net zero emissions, its implementation in the course of the next decades will require regular monitoring and updating, as future changes need to consider both new technological advancements and changing global conditions. While presently available technologies can largely deliver the emission reductions necessary by 2030, deep – and full – decarbonisation in the long term will require development and market penetration of technologies which currently only exist as prototypes or pilot projects (IEA, 2021). Therefore, this pathway towards net zero by 2060 should be regarded as the first of a series of updates to be made on the way towards a climate-neutral future.

Figure 7-1
Major milestones of the pathway towards carbon neutrality



Source: Own presentation

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Appendix

The project work included initially the elaboration of four different scenarios for a low emission development strategy (LEDS) of the Republic of Kazakhstan, namely: the business as usual (BAU) scenario, the Green Economy (GE) scenario, the deep decarbonisation (DD) scenario and the net zero emissions (NZE) scenario. The four scenarios varied regarding the level of decarbonisation. In December 2020 the President of Kazakhstan made an international public pledge, that Kazakhstan will reach carbon neutrality by 2060. Therefore, the GE and DD scenarios were excluded from the main report. However, the results of the two scenarios omitted in the main report remain interesting and are reported in the appendix when suitable. The scenarios are defined as follows:

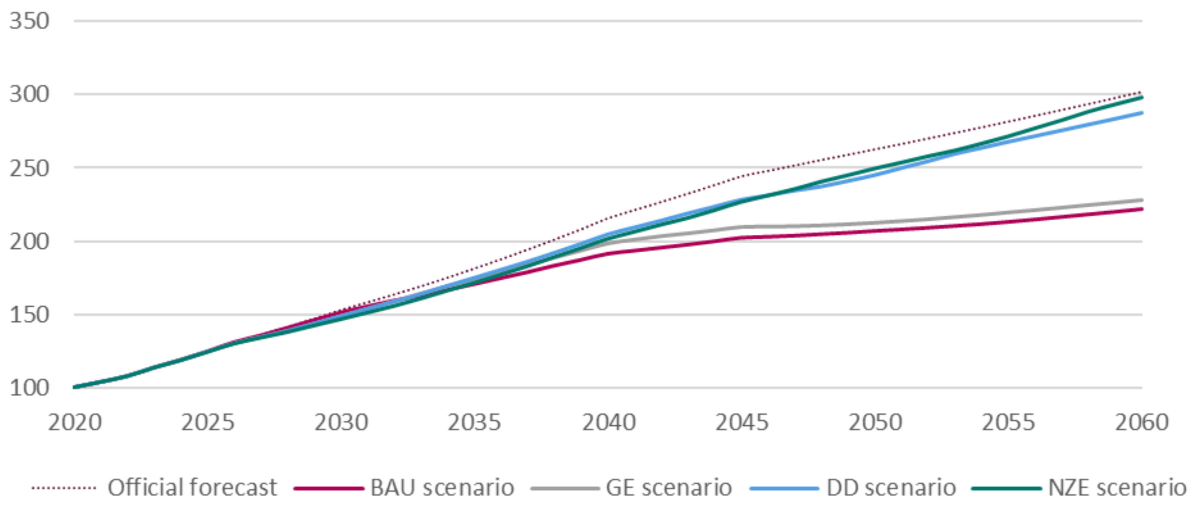
The **business as usual (BAU)** scenario describes a hypothetical development path of the economy by extrapolating past developments, policy decisions made and trends observed in Kazakhstan to the future under the assumption that presently existing policies will remain unchanged in place throughout the entire period. No additional decarbonisation efforts will be made and no specific targets are set for 2030 or 2060. The BAU scenario not a forecast (i.e., most realistic development) of the economy, but a benchmark for comparing the results of the other decarbonisation scenarios and as a motivation for policy action by the government.

The **green economy (GE)** scenario assumes that the international decarbonisation pledge of the Republic of Kazakhstan, as stipulated by the NDC and the Concept for transition of the Republic of Kazakhstan to Green Economy, and as approved in 2013, will be actively pursued. The unconditional NDC target of 15% emission reduction relative to the 1990 level is met by 2030. Additional market-based and regulatory policies will be adopted to stimulate green investment and energy efficiency but without extending public investment until 2030. The unconditional NDC target of 15% emission reduction is also fulfilled in the long term, but no further policies are implemented.

In the **deep decarbonisation (DD)** scenario introduces additional efforts to reach the targets stipulated by the Paris Agreement, including market-based policies, regulatory policies and public investment. Carbon neutrality will not be achieved. The conditional NDC target of 25% emission reduction relative to the 1990 level will be met by 2030 in the energy sector. The long-term emission target is a total emission reduction of 70% by 2060, relative to the 1990 level.

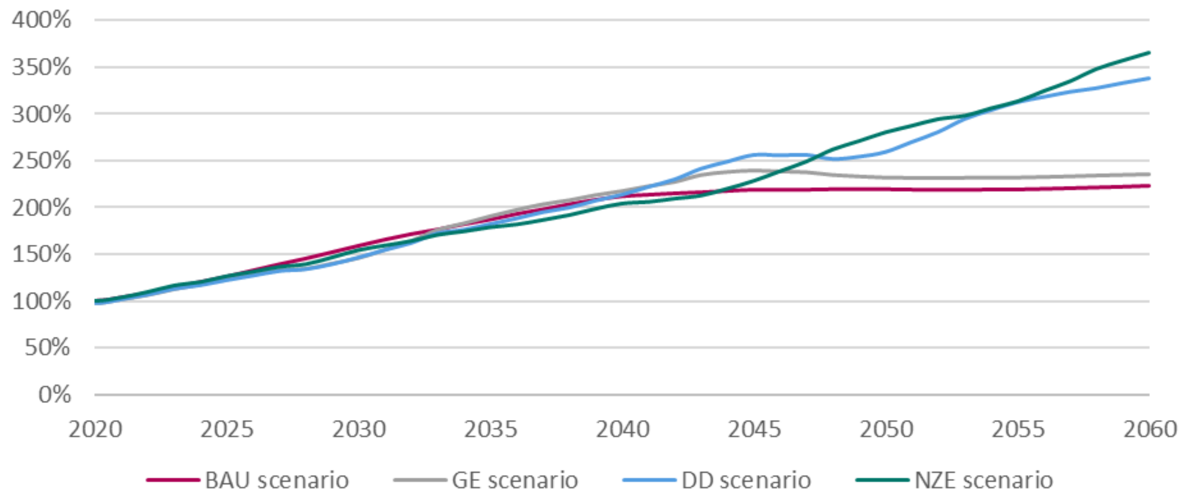
In the **net zero emissions (NZE)** scenario efforts are actively pursued to reach both the targets stipulated by the Paris Agreement and the pledge of Kazakhstan to reach carbon neutrality by 2060. Future efforts include increasingly market-based policies, improved regulatory policies and significant public investment. The conditional NDC target of 25% emission reduction relative to the 1990 level will be met by 2030. By 2060, Kazakhstan reaches a net zero GHG emission balance economy-wide, so that almost all GHG emissions are avoided and the remaining unavoidable GHG emissions are either captured and stored or used directly at the source or sequestrated in carbon sinks like vegetation and soils.

Figure A- 1
GDP growth (2020 = 100) in the current projection and the four scenarios



Source: Own calculations

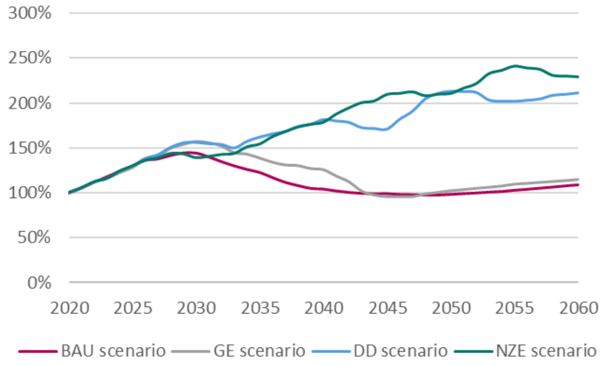
Figure A- 2
Change in real household consumption, 2020 = 100%, all scenarios



Source: Own calculations

Figure A- 3

Economy-wide investment by scenario, 2020 = 100% (left) and share of government in total investment, % (right), all scenarios



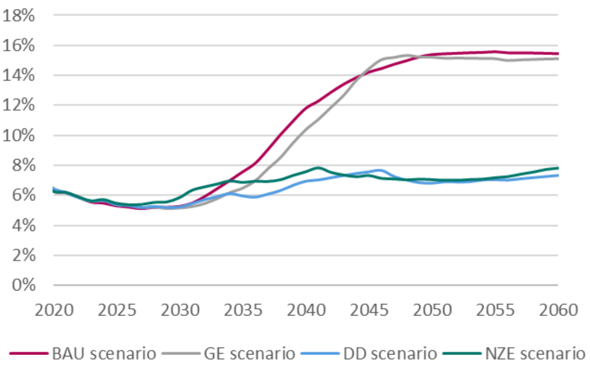
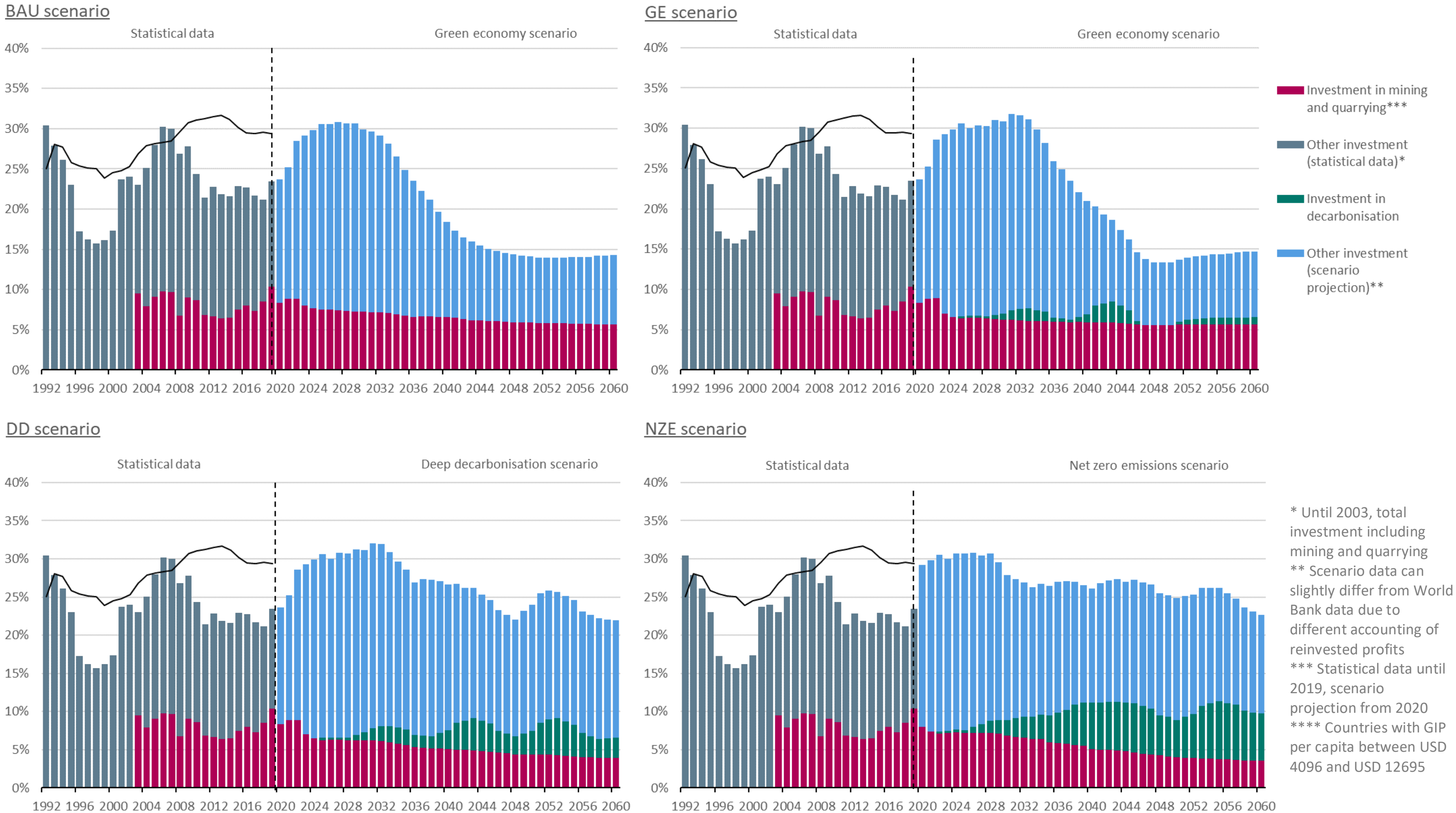


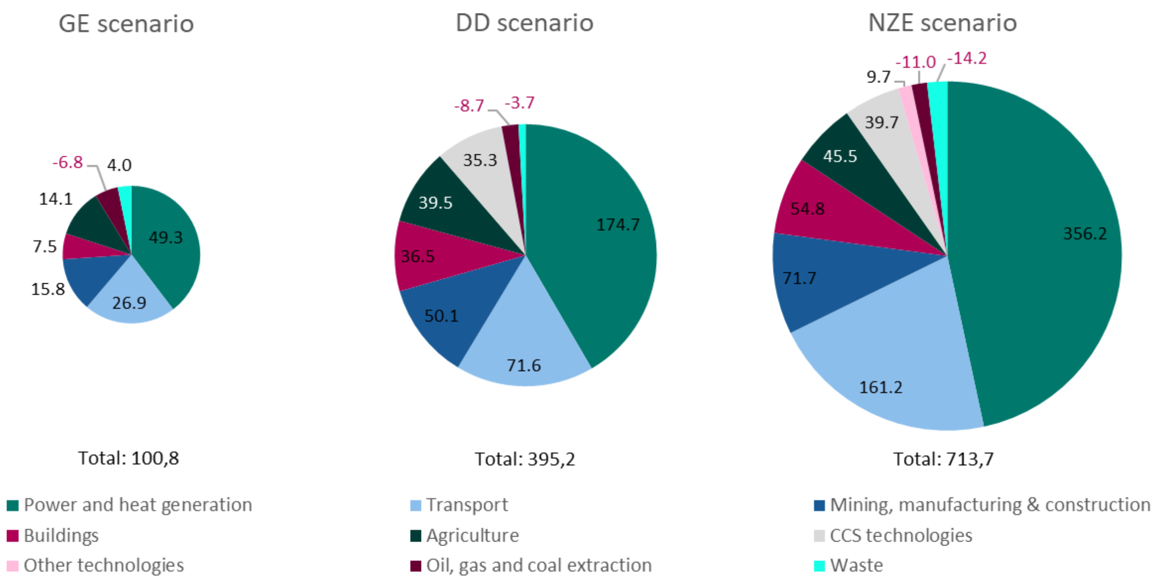
Figure A- 4
Economy-wide investment as a share of GDP by scenario, %, all scenarios



Data: World Bank, Bureau of National Statistics (1992-2019), own calculations

Figure A- 5

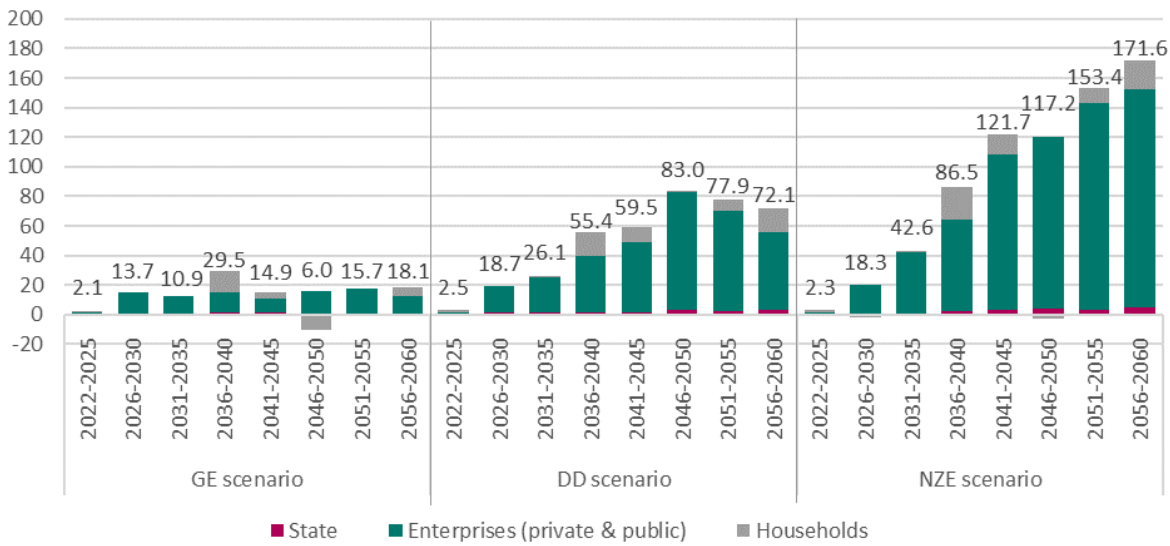
Cumulative necessary incremental investment by sector and scenario, 2022-2060, USD billion, all scenarios



Source: Own calculations

Figure A- 6

Cumulative necessary incremental investment by five-year periods, 2022-2060, USD billion, all scenarios



Source: Own calculations

Table A- 1

Reported GHG emissions in 1990, 2017 and scenarios targets for 2025, 2030 and 2060, Mt CO_2-eq (% of total), all scenarios

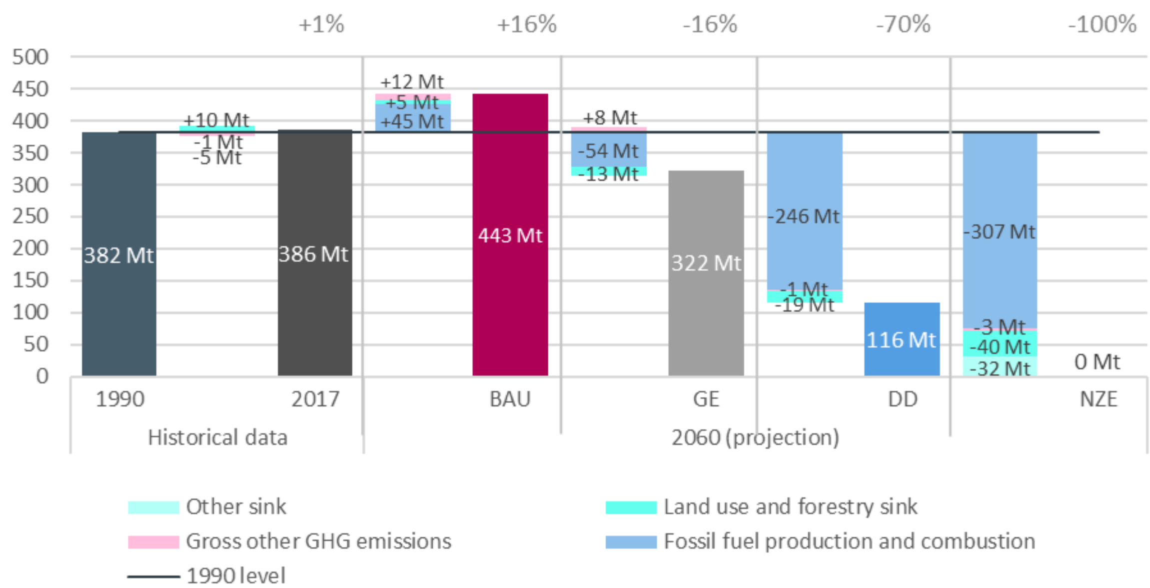
	1990	2017	2030	2060	2030	2060
			Baseline scenario (BAU)		Green economy (GE)	
CO_2 from fuel combustion	317 (83%)	316 (82%)	357 (82%)	362 (82%)	263 (80%)	263 (82%)
Fossil fuel CO_2 per capita (tons)	19.4	17.6	17.5	13.8	12.9	10.0
Gross other GHG emissions	69 (18%)	63 (16%)	84 (19%)	80 (18%)	83 (25%)	76 (24%)
Total gross GHG emissions	386 (101%)	379 (98%)	440 (101%)	442 (100%)	347 (105%)	339 (105%)
Land use and forestry sink (-) / emissions (+)	-4 (-1%)	6 (2%)	-4 (-1%)	1 (0%)	-17 (-5%)	-17 (-5%)
Net GHG emissions	382 (100%)	386 (100%)	437 (100%)	443 (100%)	330 (100%)	322 (100%)
			Deep decarbonisation (DD)		Net zero emissions (NZE)	
CO_2 from fuel combustion	317 (83%)	316 (82%)	230 (80%)	71 (61%)	230 (80%)	10 (13%)*
Fossil fuel CO_2 per capita (tons)	19.4	17.6	11.3	2.7	11.3	0.4
Gross other GHG emissions	69 (18%)	63 (16%)	76 (26%)	68 (58%)	74 (26%)	66 (87%)*
Total gross GHG emissions	386 (101%)	379 (98%)	306 (106%)	138 (119%)	304 (106%)	76 (100%)*
Land use and forestry sink (-) / emissions (+)	-4 (-1%)	6 (2%)	-17 (-6%)	-23 (-19%)	-18 (-6%)	-43 (-57%)*
Other carbon sinks (-)						-32 (-43%)*
Net GHG emissions	382 (100%)	386 (100%)	288 (100%)	116 (100%)	286 (100%)	0 (0%)*

* Gross GHG emissions are used for comparison of sectoral contribution, as net emissions are zero

Data: Kazakhstan 2022 CRF submission (emissions in 1990, 2017); World Bank (population 1990); Economic Research Institute, Kazakhstan (population 2017-2050), own calculations.

Figure A- 7

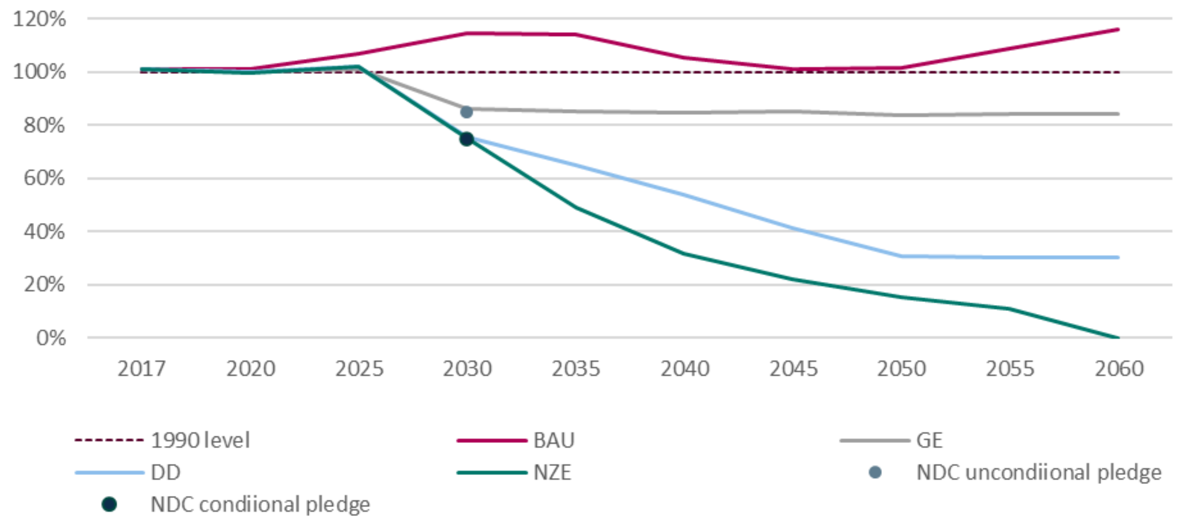
Components of emission reduction in 2017 and 2060, relative to 1990, Mt CO_2-eq, all scenarios



Data: Kazakhstan 2022 CRF submission (emissions in 1990, 2017), own calculations.

Figure A- 8

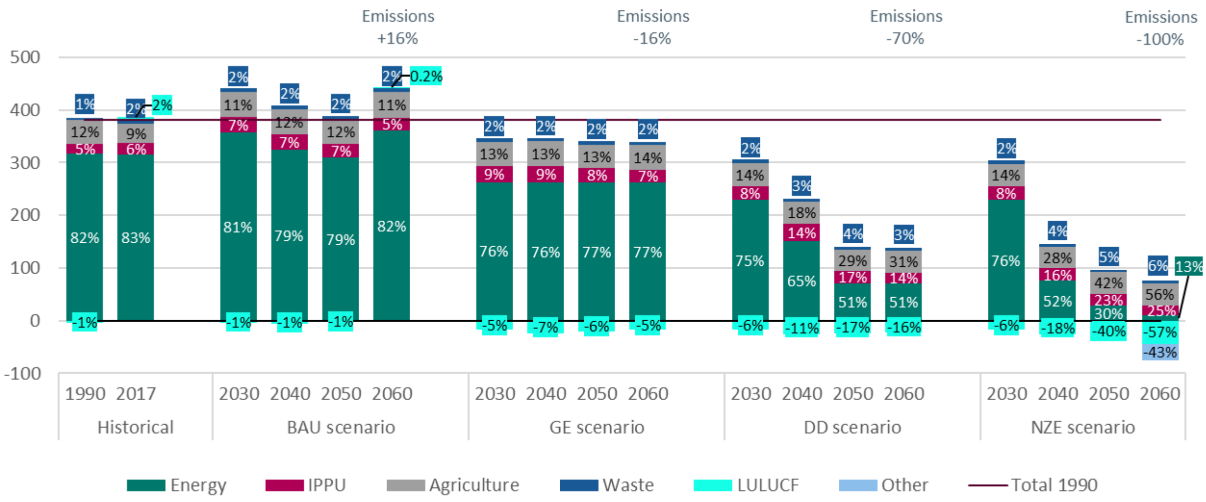
Scenario emission pathways and the NDC 2030 pledge, % of the 1990 level, all scenarios



Source: Own calculations

Figure A- 9

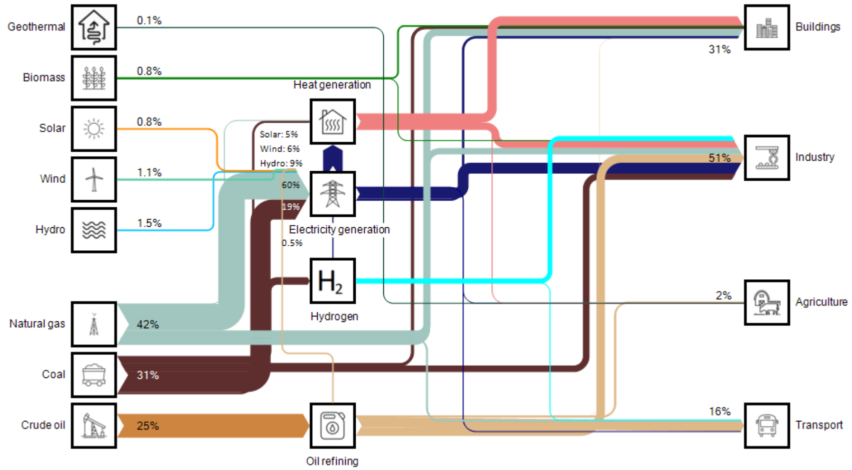
Contribution of IPCC sectors to overall emission levels historically and in scenario projections, Mt CO_2-eq, all scenarios



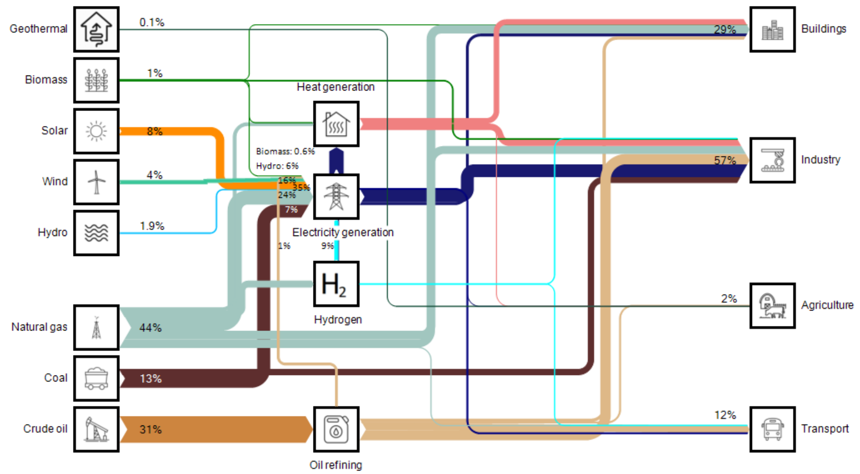
Source: Own calculations

Figure A- 10
Comparison of Sankey diagrams in the four scenarios

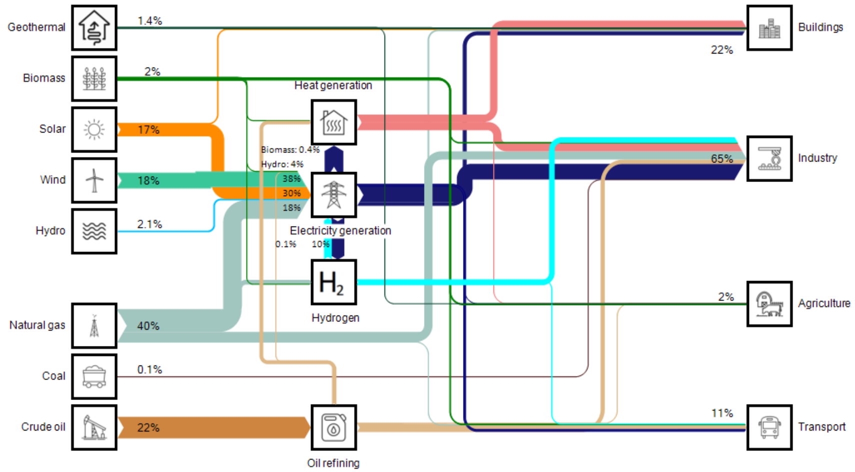
2060 BAU scenario



2060 GE scenario



2060 DD scenario



2060 NZE scenario

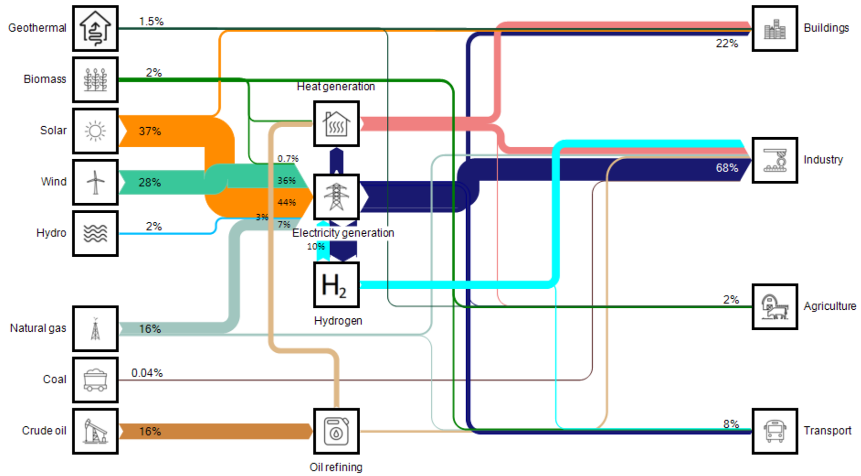


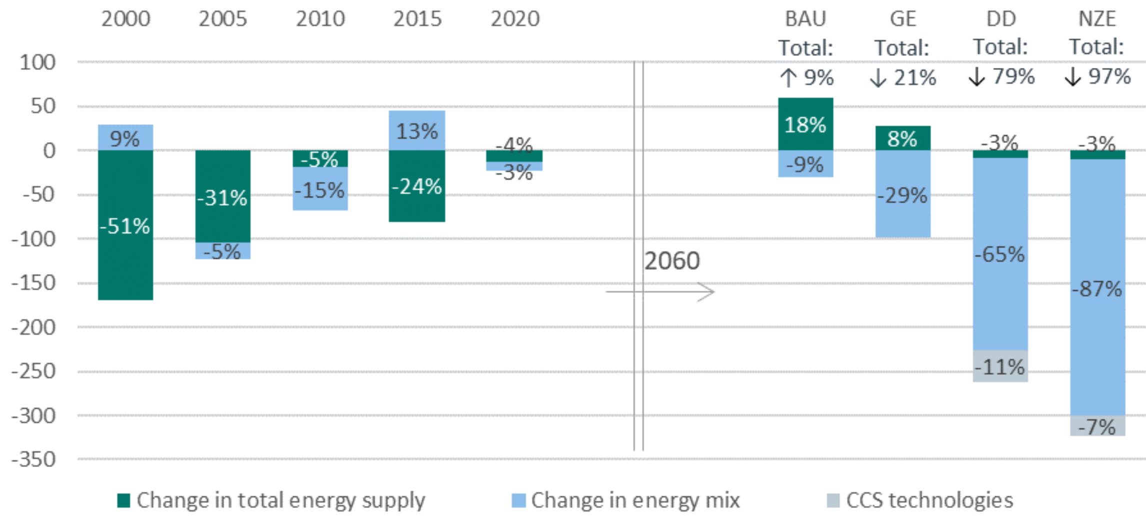
Table A- 2
Assumptions of the TIMES-KAZ model for 2060 by scenario

Policy / technology	BAU	GE	DD	NZE
Energy sector				
GHG emissions, reduction from the level of 1990 (primary target)	-	21%	78%	97%
Minimum share of RE in electricity generation	10%	30%	30%	30%
Minimum share of gas-fired power plants in electricity generation	25%	0%	0%	0%
Maximum share of gas-fired power plants in electricity generation	65%	70%	70%	70%
Minimum share of hydrogen power plants in electricity generation	-	10%	10%	10%
Maximum hydro power plants capacity, GW	3.35	3.35	3.35	3.35
Maximum biomass and biogas CHP capacity, GW	0.6	5	5	5
Possibility to use coalbed methane for electricity production	no	yes	yes	yes
Maximum nuclear power plant capacity, GW	-	2.6	2.6	2.6
Minimum wind power plant capacity, GW	1.7	4.6	4.6	4.6
Minimum solar power plant capacity, GW	0.66	1.7	1.7	1.7
Maximum residential rooftop solar power plant capacity, GW	1	10.2	10.2	10.2
Maximum industrial rooftop solar power plant capacity, GW	1.14	11.38	11.38	11.38
Maximum commercial rooftop solar power plant capacity, GW	0.9	5.57	5.57	5.57
Maximum agricultural rooftop solar power plant capacity, GW	0.312	3.12	3.12	3.12
Electricity transportation & distribution losses	14.9%	10%	10%	10%
Maximum share of heat plants in district heat generation	-	60%	60%	60%
Decrease in heat losses	no	yes	yes	yes
Decrease in electricity losses	yes	yes	yes	yes
Buildings				
Minimum efficient street lighting technologies	30%	30%	30%	30%
Minimum share of new energy efficient residential buildings (new and retrofitted)	80%	84%	84%	84%
Maximum share of new energy efficient residential buildings (new and retrofitted)	92%	100%	100%	100%
Minimum share of new energy efficient public buildings (new and retrofitted)	85%	89%	89%	89%
Maximum share of new energy efficient public buildings (new and retrofitted)	95%	100%	100%	100%
Additional support for the use of heat pumps and solar PV	no	yes	yes	yes
Phase-out of household coal stoves	no	yes	yes	yes
Transport				
Minimum CNG use as a vehicle fuel, billion cm	1	1	1	1
Electrification of rail transport	yes	yes	yes	yes
Minimum share of low-emission fuels in aviation	-	75%	75%	75%
Minimum share of new vehicles in first registrations (as opposed to used vehicles)	65%	90%	90%	90%
Maximum share of private electric and hydrogen vehicles	25%	100%	100%	100%
Prohibition of new ICE cars in 2035	no	yes	yes	yes
Industry				
Maximum share of metal scrap in steel production	40%	40%	40%	40%
Maximum share of metal scrap in aluminium production	50%	50%	50%	50%

Note: The TIMES model is an optimisation model, i.e., it searches for a least-cost, technologically feasible pathway to a given target – in this case, a certain level of GHG emission reduction. To do this, linear programming methods are employed under a set of assumptions. The assumptions of the model are constraints, taking into account the national conditions in Kazakhstan, within which the model can choose the optimal technologies and the degree of their use. Therefore, most of the TIMES assumptions are expressed in the form of either minimum / maximum limits on the use of certain technologies or technological solutions that the model is allowed (or not) to use in a certain scenario. The respective technologies are then selected if their use is the best solution to reach the required emission reduction. This means that, on the optimal trajectory, some indicators will not be equal to the limits listed in this table. E.g., in the NZE scenario, the minimum share of renewables in electricity generation is set at 30% in 2060, but their optimal share reaches over 80% (see also Section 5.1.3).

Figure A- 11

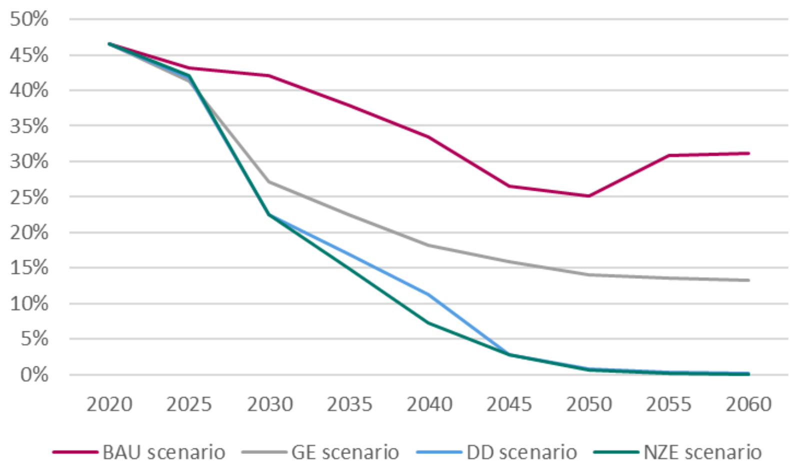
Decomposition of the overall change in energy emissions relative to 1990 (1990 level = 0) into change in energy supply, change in energy mix, and carbon capture and storage, Mt CO_2-eq, all scenarios



Source: Own calculations

Figure A- 12

Share of coal in total primary energy supply, %, all scenarios



Source: Own calculations

Table A- 3

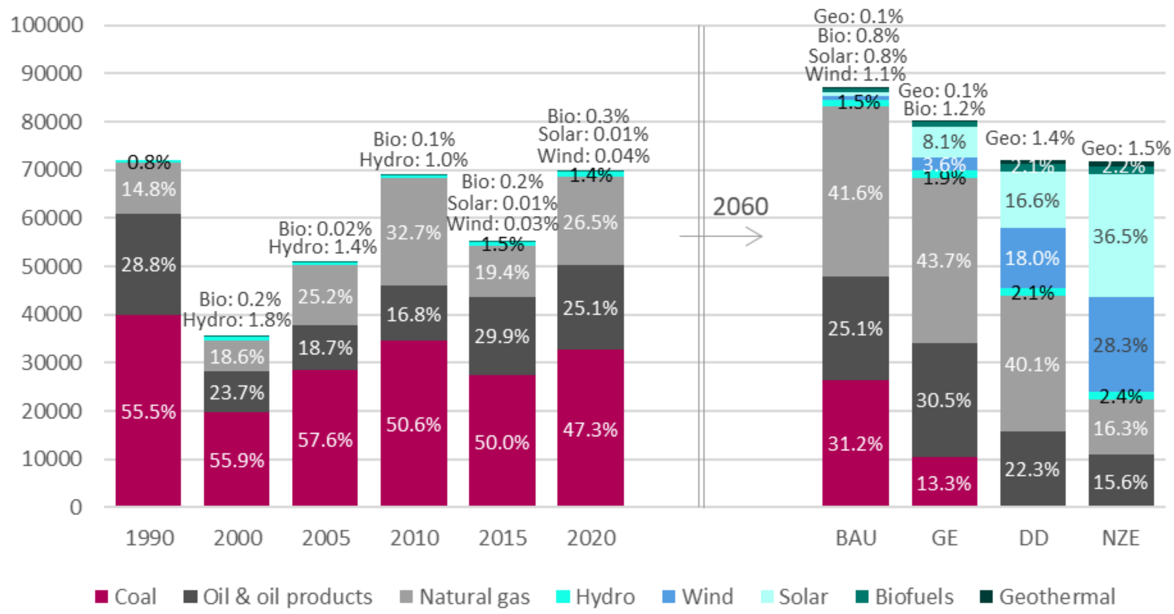
GHG emissions from fuel combustion and energy industries by sector, Mt CO_2-eq, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Power and heat generation	102.8	133.8	106.7	86.3	58.0	78.5	2.9	78.7	0.1
Gross emissions	*102.8*	*133.8*	*106.7*	*86.3*	*58.0*	*78.5*	*35.5*	*78.7*	*20.1*
CCS	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-32.6*	*0.0*	*-20.0*
Other energy industries	70.2	42.3	63.4	27.9	37.0	25.1	18.8	24.8	4.9
Agriculture	3.6	2.6	3.0	2.6	2.9	2.5	0.5	2.5	0.0
Industry	35.8	44.1	52.0	44.6	60.8	34.5	16.1	35.3	0.8
Gross emissions	*35.8*	*44.1*	*52.0*	*44.6*	*60.8*	*34.5*	*20.6*	*35.3*	*4.0*
Carbon capture & storage	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-4.5*	*0.0*	*-3.3*
Buildings	28.8	24.6	24.1	17.5	24.3	13.3	3.3	12.6	0.0
Transport	24.4	26.0	27.8	22.8	18.5	22.3	12.7	22.2	1.8
Other	50.5	83.4	84.6	61.6	61.5	53.8	16.6	53.8	2.3
Total	**316.0**	**356.8**	**361.6**	**263.3**	**263.0**	**229.9**	**70.8**	**229.9**	**9.9**

Source: Own calculations

Figure A- 13

Changes in total primary energy supply (TPES) by source, ktoe, all scenarios



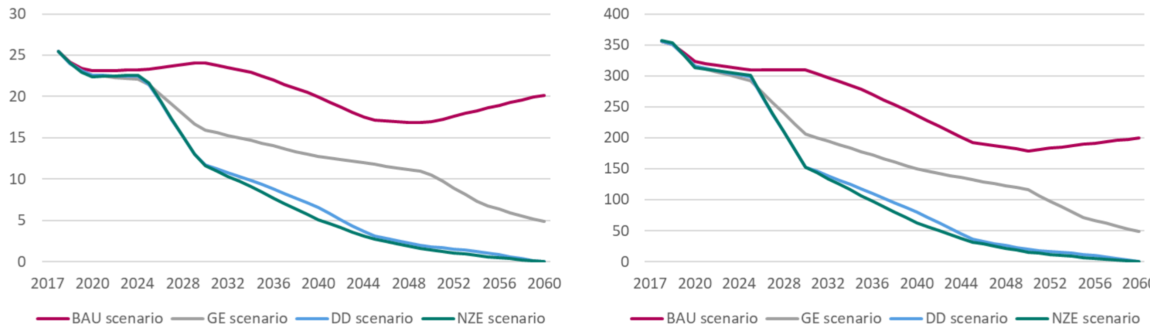
Source: Own calculations

Table A- 4
Total primary energy supply (TPES) by fuel type, ktoe, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Coal	35006	32861	26474	18089	10378	14129	83	14143	31
Oil and oil products	15368	20095	21334	18698	23837	18291	15677	18952	10876
Natural gas	14001	24339	35356	25112	34140	24817	28153	24365	11373
Renewables	1114	1462	3693	5583	11681	6009	28236	6195	49489
Electricity import (+) / export (-)	-375	-682	-1956	-682	-1956	-682	-1956	-682	-1956
Total	**65113**	**78076**	**84901**	**66801**	**78080**	**62564**	**70193**	**62973**	**69813**

Source: Own calculations

Figure A- 14
Employment from coal extraction, thousand persons (left) and per-capita total societal cost of coal extraction and combustion, USD (right), all scenarios



Source: Own calculations

Table A- 5
Annual CBA coal sector, million USD, all scenarios

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Costs and revenues																
Profits from coal mining (coal mining GDP)	878	779	694	767	697	605	544	116	471	296	121	0.7	471	260	94	0.3
Total cost of coal mining	303	253	210	251	373	297	252	114	405	232	63	1.0	404	181	49	0.4
Annual cost of rail-based coal transport	62	51	43	51	41	33	28	13	30	17	4.7	0.1	30	14	3.7	0.03
Real subsidy payments for coal production	516	431	358	429	172	137	116	53	0	0	0	0	0	0	0	0
Annual cost of environmental compliance	0.62	0.45	0.23	0.24	0.27	0.15	0.09	0.09	0.23	0.08	0	0	0.23	0.06	0	0
Externalities																
Positive externalities																
Labour income from coal mining	17	15	12	14	12	9.2	7.8	3.5	8.6	4.9	1.3	0.0	8.6	3.8	1.1	0.01
Labour income coal power generation	2.4	2.1	1.3	1.8	2.3	1.3	0.4	0.9	2.2	1.0	0.2	0.8	2.2	1.1	0.2	0.9
Negative externalities																
Social cost of carbon from coal mining operations	1894	1407	776	849	845	491	313	269	693	230	21	0.3	683	186	17	0.1
Total health cost of coal combustion	841	702	583	698	559	445	378	171	416	239	65	1.0	415	186	51	0.4
Total private cost of coal-related respiratory diseases	3165	2641	2194	2628	2103	1676	1421	644	1564	898	244	3.7	1560	699	191	1.4
Coal health cost valuation approaches																
Emission-based																
Total cost of coal-power related emissions	1037	757	382	408	453	254	143	153	389	127	1.9	0	383	104	1.9	0
Direct government health care expenditure and indirect impacts																
Total societal cost of coal-related respiratory diseases	6310	5266	4375	5239	4193	3341	2832	1284	3117	1790	486	7.5	3110	1394	381	2.8
Direct health cost incurring from coal-related respiratory diseases	841	702	583	698	559	445	378	171	416	239	65	1.0	415	186	51	0.4
Indirect cost incurring from coal-related respiratory diseases	5469	4564	3791	4540	3634	2895	2454	1112	2702	1551	421	6.5	2695	1208	331	2.5
Population-based																
Health costs of respiratory diseases related to coal consumption	1152	961	798	956	765	765	765	765	569	327	89	1.4	568	254	70	0.5

Source: Own calculations

Table A- 6
Cumulative CBA coal sector, billion USD, all scenarios

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Costs and revenues																
Profits from coal mining (coal mining GDP)	9.5	18	25	32	8.8	15	21	24	8.2	12	14	14	8.2	12	13	14
Total cost of coal mining	3.2	6.0	8.2	11	4.0	7.3	10	12	4.8	7.9	9.1	9.4	4.8	7.6	8.6	8.8
Annual cost of rail-based coal transport	0.7	1.2	1.7	2.1	0.6	0.9	1.2	1.4	0.5	0.8	0.9	0.9	0.6	0.8	0.8	0.9
Real subsidy payments for coal production	5.5	10	14	18	3.7	5.2	6.5	7.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Annual cost of environmental compliance	0.006	0.012	0.015	0.017	0.005	0.007	0.008	0.009	0.005	0.006	0.007	0.007	0.005	0.006	0.006	0.006
Externalities																
Positive externalities																
Labour income from coal mining	0.2	0.3	0.5	0.6	0.2	0.3	0.3	0.4	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
Labour income coal power generation	0.03	0.05	0.07	0.09	0.03	0.05	0.06	0.06	0.03	0.05	0.05	0.06	0.03	0.05	0.05	0.06
Negative externalities																
Social cost of carbon from coal mining operations	20	36	46	55	15	21	25	28	15	19	20	20	15	18	19	19
Total health cost of coal combustion	9.0	17	23	29	7.9	13	17	19	7.5	11	12	12	7.5	10	11	12
Total private cost of coal-related respiratory diseases	34	63	86	110	30	48	64	73	28	40	45	46	28	39	43	44
Coal health cost valuation approaches																
Emission-based																
Total cost of coal-power related emissions	11	20	25	29	8.2	12	14	15	8.1	10	11	11	8.0	10	11	11
Direct government health care expenditure and indirect impacts																
Total societal cost of coal-related respiratory diseases	67	125	171	220	59	96	127	145	56	80	90	92	56	78	86	87
Direct health cost incurring from coal-related respiratory diseases	9.0	17	23	29	7.9	13	17	19	7.5	11	12	12	7.5	10	11	12
Indirect cost incurring from coal-related respiratory diseases	58	109	149	191	51	83	110	126	49	70	78	80	49	68	74	76
Population-based																
Health costs of respiratory diseases related to coal consumption	12	23	31	40	11	18	23	27	10	15	16	17	10	14	16	16

Source: Own calculations

Table A- 7
Electricity generation by fuel type, TWh, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Coal TPP and CHP	68.9	78.4	30.9	38.0	14.5	34.8	0.0	34.2	0.0
Oil CHP	0.8	1.0	0.8	0.9	2.1	0.6	0.2	0.5	0.0
Natural gas TPP and CHP	21.8	39.3	100.3	40.0	50.9	38.4	70.2	40.2	44.3
Hydrogen TPP and CHP	0	2.7	0.0	0.0	19.5	0.0	37.5	0.0	62.9
Biomass	0	0.0	0.0	0.8	1.2	1.6	1.6	0.0	4.7
Hydro	11.2	12.0	15.3	19.3	13.5	23.2	17.4	23.2	19.5
Solar	0.2	0.5	8.2	15.8	73.9	13.6	115.1	17.7	282.5
Wind	0.3	1.0	10.6	21.0	33.1	21.0	146.8	21.0	229.5
Total	**103.2**	**135.0**	**166.1**	**135.9**	**208.8**	**133.2**	**388.7**	**136.9**	**643.4**

Source: Own calculations

Table A- 8
Final energy demand / demand for energy services (FEC) by sector, ktoe, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Agriculture	862	983	1099	989	1096	989	1235	999	1362
Industry	16686	21830	30713	22271	33640	21232	36958	21362	37188
Buildings	16951	15565	18863	13926	17097	12668	12234	12485	11823
Transport	5529	8872	9491	7972	6983	7808	6155	7791	4385
Total	**40028**	**47249**	**60165**	**45158**	**58815**	**42696**	**56581**	**42637**	**54757**

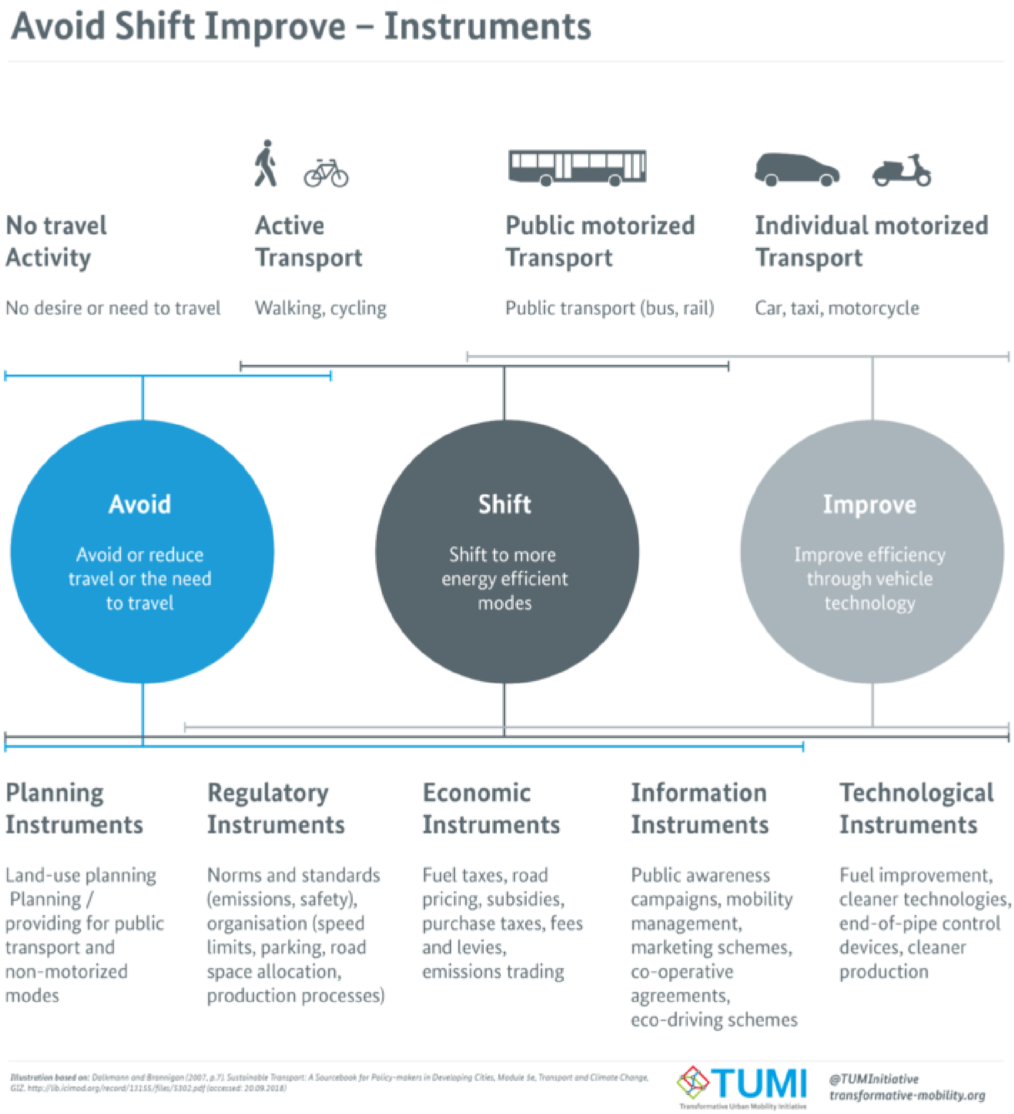
Source: Own calculations

Table A- 9
Final energy demand / demand for energy services (FEC) by fuel, ktoe, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Coal	9307	6077	6427	4393	4514	1952	80	2212	30
Oil and oil products	12574	14237	15642	13357	17542	13238	7179	13400	1790
Natural gas	5622	10460	12103	10691	13861	9994	8798	9259	1635
Electricity	6545	8182	9634	8493	13146	8470	17607	8841	25497
Heat	5917	7912	12029	7679	8376	7002	11654	7115	11246
Biomass	63	322	889	358	744	406	5639	441	6333
Solar	0	0	0	0	0	0	513	0	1194
Geothermal	0	38	56	38	58	205	964	39	1051
Hydrogen	0	22	3385	150	574	1428	4147	1331	5979
Total	**40028**	**47249**	**60165**	**45158**	**58815**	**42696**	**56581**	**42637**	**54757**

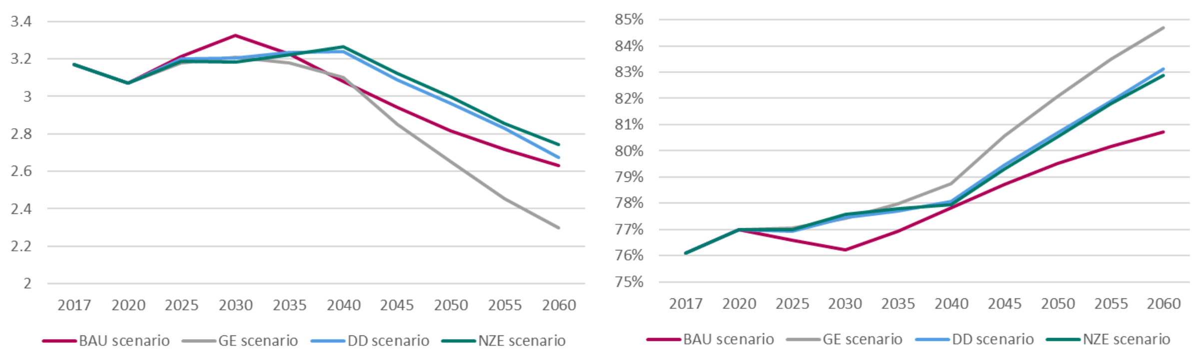
Source: Own calculations

Figure A- 15
Elements of the Avoid-Shift-Improve approach



Source: https://www.transformative-mobility.org/publications/avoid-shift-improve-instruments

Figure A- 16
Annual travel volume of private vehicles, thousand km per capita (left) and travel-volume based share of public transport, % (right), all scenarios



Source: Own calculations

Table A- 10

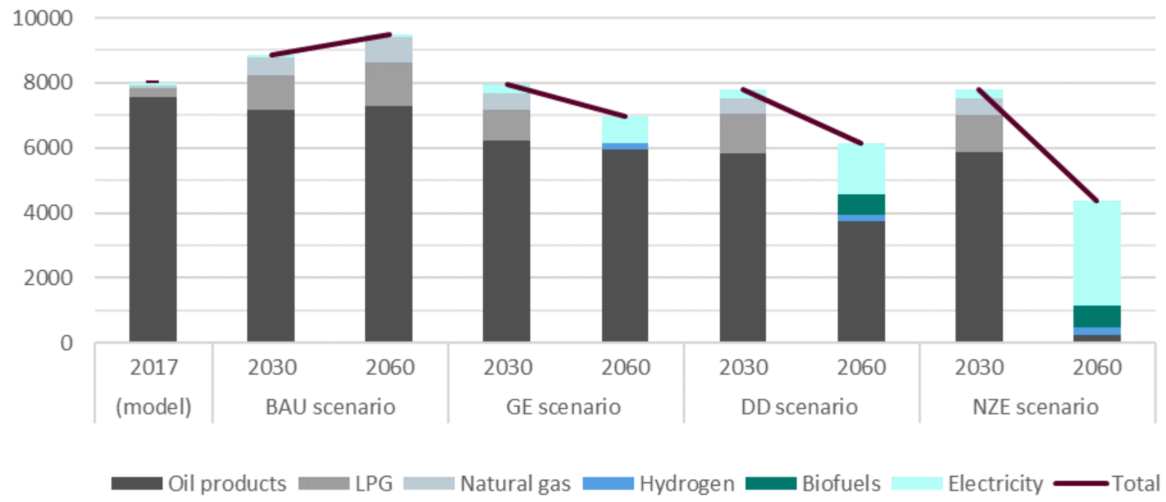
Final energy demand in the transport sector by transport type, ktoe, all scenarios

	2017 (model)	2017 (update)	BAU scenario 2030	BAU scenario 2060	GE scenario 2030	GE scenario 2060	DD scenario 2030	DD scenario 2060	NZE scenario 2030	NZE scenario 2060
Cars	3746	2566	4270	4094	3520	786	3429	916	3431	939
Other road transport	3440	2357	3499	3809	3353	4455	3292	3563	3281	1937
Railway transport	376	459	498	761	498	887	494	696	491	602
Other transport	451	147	604	827	600	855	593	981	587	906
Total	**8014**	**5529**	**8872**	**9491**	**7972**	**6983**	**7808**	**6155**	**7791**	**4385**

Source: Own calculations

Figure A- 17

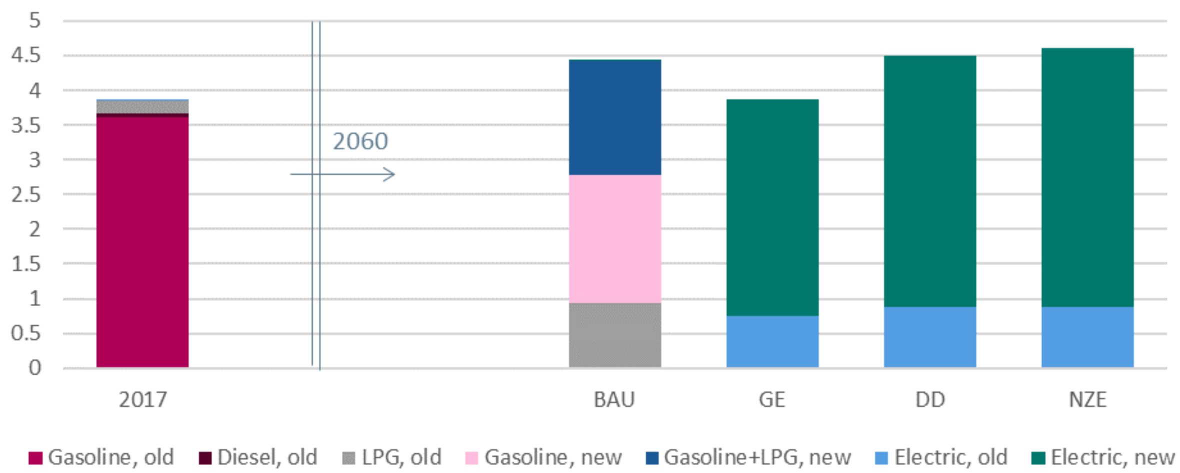
Final energy demand in the transport sector by fuel type, ktoe, all scenarios



Source: Own calculations

Figure A- 18

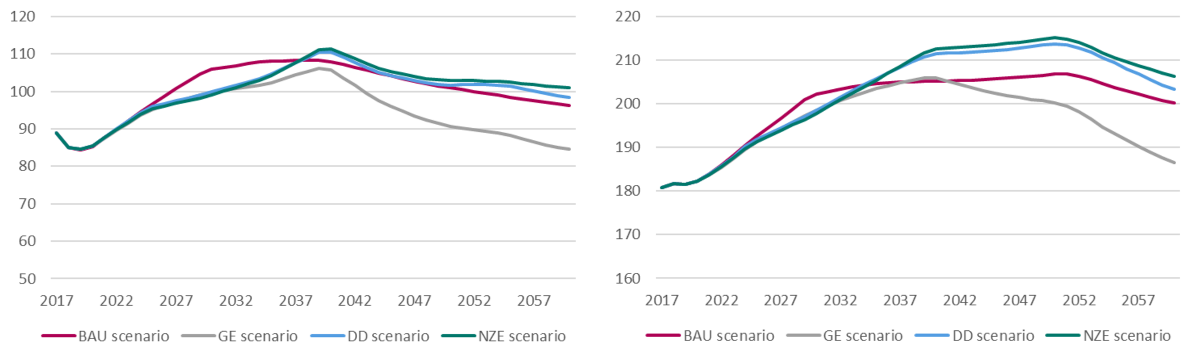
Current and projected structure of the passenger car fleet, million cars, all scenarios



Source: Own calculations

Figure A- 19

Number of traffic accidents per 100 000 people (left panel) and congestion delay per vehicle in urban areas, hours per year (right panel), all scenarios



Source: Own calculations

Table A- 11
Annual CBA transport, million USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Positive externalities																
Revenues from buses	4070	4448	4844	5178	4070	4448	4844	5178	4070	4448	4844	5178	4070	4448	4844	5178
Labour income bus maintenance	3.5	3.5	3.7	4.0	3.5	3.7	4.1	5.2	3.5	3.8	4.2	5.3	3.5	3.8	4.2	6.0
Negative externalities																
Value of time lost in congestion	2015	2351	2696	2795	2553	2828	2615	2266	2545	3027	3119	2876	2518	3067	3174	2992
Value of traffic accidents	7473	8301	9041	9306	8691	9329	8708	8190	8674	9740	9742	9536	8615	9821	9851	9781
Cost of noise from cars	1153	1121	1086	881	1110	774	627	569	1047	746	701	663	1041	753	709	680
Cost of urban effects cars	70	75	79	78	77	79	74	67	77	82	82	78	76	83	83	80
Cost of air pollution from cars	1659	1510	1343	945	1220	459	22	19	1104	347	25	22	1106	341	25	22
SCC from private vehicles	351	376	387	382	323	153	38	23	314	109	2	1	314	97	1	0
Cost of respiratory diseases cars	961	1019	1039	1009	846	367	106	89	821	355	119	103	821	351	120	106
Cost of noise from buses	5.2	5.6	5.9	6.6	6.1	7.0	8.1	9.1	6.1	7.0	7.6	6.4	6.1	6.6	6.5	4.7
Cost of urban effects from buses	1.3	1.4	1.5	1.6	1.5	1.7	2.0	2.3	1.5	1.8	2.1	2.4	1.5	1.8	2.1	2.4
Cost of air pollution from buses	257	258	274	310	283	330	386	534	283	331	312	188	283	276	173	10
SCC from buses	52	56	60	68	62	72	84	97	62	72	72	36	62	63	46	0
Cost of respiratory disease from buses	141	149	160	181	165	193	225	270	165	194	196	130	165	171	136	49

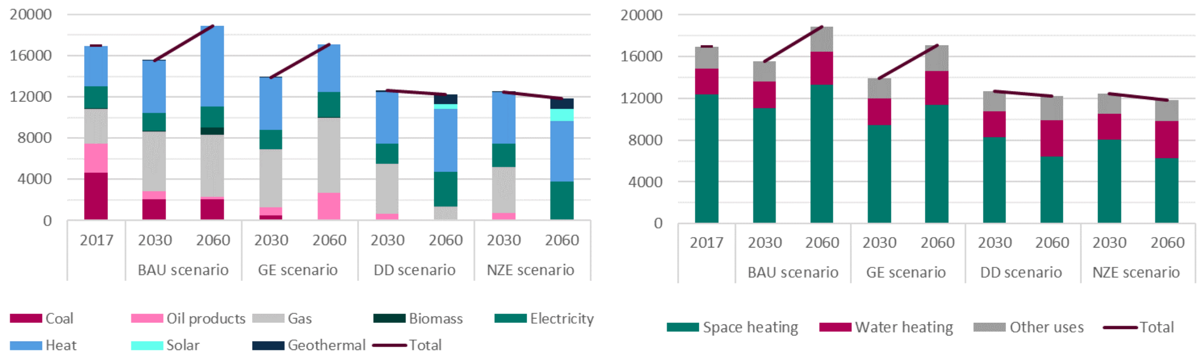
Source: Own calculations

Table A- 12
Cumulative CBA transport, billion USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Positive externalities																
Revenues from buses	43	86	132	183	43	86	132	183	43	86	132	183	43	86	132	183
Labour income bus maintenance	0.04	0.07	0.11	0.15	0.04	0.07	0.11	0.16	0.04	0.07	0.11	0.16	0.04	0.07	0.11	0.17
Negative externalities																
Value of time lost in congestion	26	54	82	110	25	52	79	104	25	53	84	114	25	53	84	115
Value of traffic accidents	91	183	276	370	90	180	270	354	90	182	280	376	89	182	280	378
Cost of noise from cars	12	22	32	43	12	22	29	35	12	21	28	35	12	21	28	35
Cost of urban effects cars	0.8	1.6	2.4	3.2	0.8	1.6	2.4	3.0	0.8	1.6	2.4	3.2	0.8	1.6	2.4	3.3
Cost of air pollution from cars	17	28	39	52	17	25	26	26	16	23	23	24	16	23	24	24
SCC from private vehicles	4.1	7.9	12	15	3.8	6.3	7.0	7.3	3.8	6.0	6.3	6.3	3.8	5.9	6.1	6.1
Cost of respiratory diseases cars	11	21	31	41	10	16	18	19	10	16	18	19	10	16	18	19
Cost of noise from buses	0.1	0.1	0.2	0.3	0.1	0.1	0.2	0.3	0.1	0.1	0.2	0.3	0.1	0.1	0.2	0.2
Cost of urban effects from buses	0.02	0.03	0.05	0.07	0.02	0.03	0.05	0.07	0.02	0.03	0.05	0.07	0.02	0.03	0.05	0.07
Cost of air pollution from buses	2.9	5.8	9.1	13	2.9	6.0	9.6	14	2.9	6.0	9.4	12	2.9	5.9	8.0	8.6
SCC from buses	0.6	1.3	2.0	2.8	0.6	1.3	2.1	3.0	0.6	1.3	2.1	2.6	0.6	1.3	1.8	2.0
Cost of respiratory disease from buses	1.6	3.4	5.3	7.4	1.7	3.5	5.6	8.1	1.7	3.5	5.5	7.1	1.7	3.4	4.9	5.7

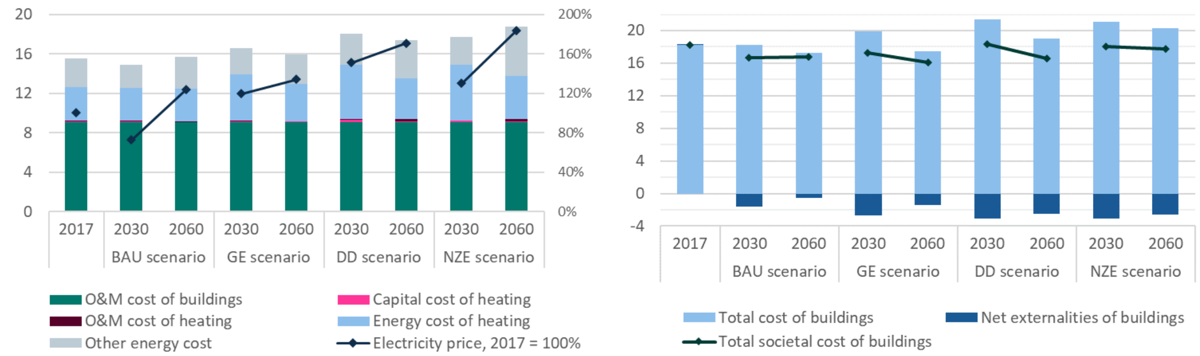
Source: Own calculations

Figure A- 20
Final energy demand in buildings by fuel (left panel) and by end use (right panel), ktoe, all scenarios



Source: Own calculations

Figure A- 21
Annual cost of buildings per square meter (excluding construction cost of new buildings), USD and electricity price, 2017 = 100% (left) and total societal cost of buildings per square meter, USD (right), all scenarios



Source: Own calculations

Table A- 13
Annual CBA buildings, million USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Investment and cost																
Investment in buildings	1330	1763	1811	1585	1330	1763	1811	1585	1330	1763	1811	1585	1330	1763	1811	1585
O&M cost buildings	3772	4152	4464	4798	3772	4097	4464	4798	3772	4097	4464	4798	3772	4097	4464	4798
Energy costs buildings	707	1202	1220	1421	1069	1284	1374	1575	1325	1374	1737	2054	1158	1483	2356	2642
Capital cost heating	18	25	20	25	34	29	22	45	147	31	378	89	48	361	229	88
O&M cost heating	22	22	23	27	23	21	24	27	34	31	88	99	23	55	91	109
Energy cost heating	1388	1544	1575	1756	1962	1689	1954	1973	2324	2114	2183	2191	2350	2388	2119	2298
Externalities																
Positive																
Labour income construction & maintenance	1643	2096	2161	1993	1643	2075	2161	1993	1643	2075	2161	1993	1643	2075	2161	1993
Labour income heating	37	45	43	48	46	43	42	51	53	41	77	46	44	70	54	44
Labour income coal extraction	0.46	0.40	0.42	0.57	0.09	0.03	0.09	0	0	0	0	0	0	0	0	0
Negative																
Total annual cost of air pollution from buildings	180	154	157	212	41	17	37	4	4.9	3.3	0	0	4.4	0	0	0
Annual social cost of carbon from buildings	885	773	673	835	579	546	593	623	484	354	66	67	495	87	19	0
Total public direct health cost of respiratory diseases from the use of coal-based technologies in an indoor environment	22	19	20	27	4.5	1.5	4.3	0	0	0	0	0	0	0	0	0

Source: Own calculations

Table A- 14
Cumulative CBA buildings, billion USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Investment and cost																
Investment in buildings	17	33	51	68	17	33	51	68	17	33	51	68	17	33	51	68
O&M cost buildings	40	80	123	170	40	79	122	169	40	79	122	169	40	79	122	169
Energy costs buildings	8.3	19	32	44	10	21	35	49	10	23	38	56	10	23	44	69
Capital cost heating	0.2	0.5	0.7	1.0	0.3	0.6	0.8	1.2	0.9	1.1	4.3	5.3	0.4	2.4	4.7	5.7
O&M cost heating	0.2	0.5	0.7	1.0	0.2	0.5	0.7	0.9	0.3	0.6	1.2	2.1	0.2	0.6	1.3	2.3
Energy cost heating	13	27	43	60	16	35	53	73	16	37	59	81	16	40	63	84
Externalities																
Positive																
Labour income construction & maintenance	20	39	61	82	20	39	61	81	20	39	61	81	20	39	61	81
Labour income heating	0.4	0.9	1.3	1.8	0.5	0.9	1.3	1.8	0.5	0.9	1.6	2.1	0.5	1.0	1.6	2.0
Labour income coal extraction	0.006	0.01	0.01	0.02	0.005	0.01	0.01	0.01	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Negative																
Total annual cost of air pollution from buildings	2.4	4.1	5.8	7.6	1.9	2.2	2.6	2.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Annual social cost of carbon from buildings	10	18	26	33	9	14	20	26	8.4	13	15	15	8.5	11	12	12
Total public direct health cost of respiratory diseases from the use of coal-based technologies in an indoor environment	0.3	0.5	0.7	0.9	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Source: Own calculations

Table A- 15

Output and emission intensity ranks in mining and manufacturing, 2017

Output rank	**Sector**	**Output, billion USD**	**Share in total output, %**	**Cumulative output share, %**	**Total emissions per USD of output, kg CO_2-eq**	**Emission rank**	**Share in emissions from industry, %**	**Cumulative emissions share, %**
1	Extraction of crude oil	30.25	11.8%	11.8%	0.00	**5**	36.6%	36.6%
2	Non-ferrous metallurgy	9.27	3.6%	15.4%	2.33	**2**	22.2%	58.8%
3	Food industry	7.87	3.1%	18.5%	0.09	17	0.7%	59.5%
4	Mining of non-ferrous metals	7.57	3.0%	21.5%	0.25	**10**	1.9%	61.5%
5	Ferrous metallurgy	7.22	2.8%	24.3%	2.33	**3**	17.3%	78.8%
6	Oil refining	3.44	1.3%	25.6%	1.01	**8**	3.6%	82.4%
7	Machinery	3.14	1.2%	26.8%	0.09	14	0.3%	82.7%
8	Other mining	2.78	1.1%	27.9%	0.25	11	0.7%	83.4%
9	Chemical industry	1.84	0.7%	28.7%	0.63	**9**	1.2%	84.6%
10	Mineral products	1.82	0.7%	29.4%	5.36	**1**	10.1%	94.6%
11	Coal extraction	1.49	0.6%	29.9%	1.17	6	1.8%	96.4%
12	Mining of iron ores	1.36	0.5%	30.5%	0.25	12	0.3%	96.8%
13	Other light industry	1.32	0.5%	31.0%	0.09	15	0.1%	96.9%
14	Extraction of natural gas	0.88	0.3%	31.3%	1.17	7	1.1%	98.0%
15	Other metallurgy	0.82	0.3%	31.7%	2.33	4	2.0%	99.9%
16	Paper, pulp and print	0.38	0.1%	31.8%	0.14	13	0.1%	100.0%
17	Other manufacturing	0.05	0.02%	31.8%	0.09	16	0.005%	100.0%

Source: Own work

Table A- 16
Emissions from fuel combustion in industry by sector, Mt CO2-eq, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Ferrous metallurgy	19.9	19.8	21.2	19.8	25.0	8.3	0.5	9.8	0.9
Non-ferrous metallurgy	7.6	2.6	2.9	2.5	2.2	2.5	1.3	2.1	0.4
Chemical industry	0.52	0.02	0.03	0.02	0.04	0.02	0.05	0.02	0.07
Food industry	0.7	0.8	1.0	0.7	1.6	0.7	1.3	0.8	0.0
Mineral production	3.4	4.9	5.4	4.8	6.6	4.9	5.1	5.0	2.6
Mining and quarrying	2.7	9.5	12.1	9.5	13.8	9.6	6.7	9.6	0.0
Other industries & construction	0.9	6.5	9.4	7.2	11.7	8.5	5.7	8.0	0.0
Total	**35.8**	**44.1**	**52.0**	**44.6**	**60.8**	**34.5**	**20.6**	**35.3**	**4.0**
Carbon capture & storage	0.0	0.0	0.0	0.0	0.0	0.0	-4.5	0.0	-3.3
Net total	**35.8**	**44.1**	**52.0**	**44.6**	**60.8**	**34.5**	**16.1**	**35.3**	**0.8**

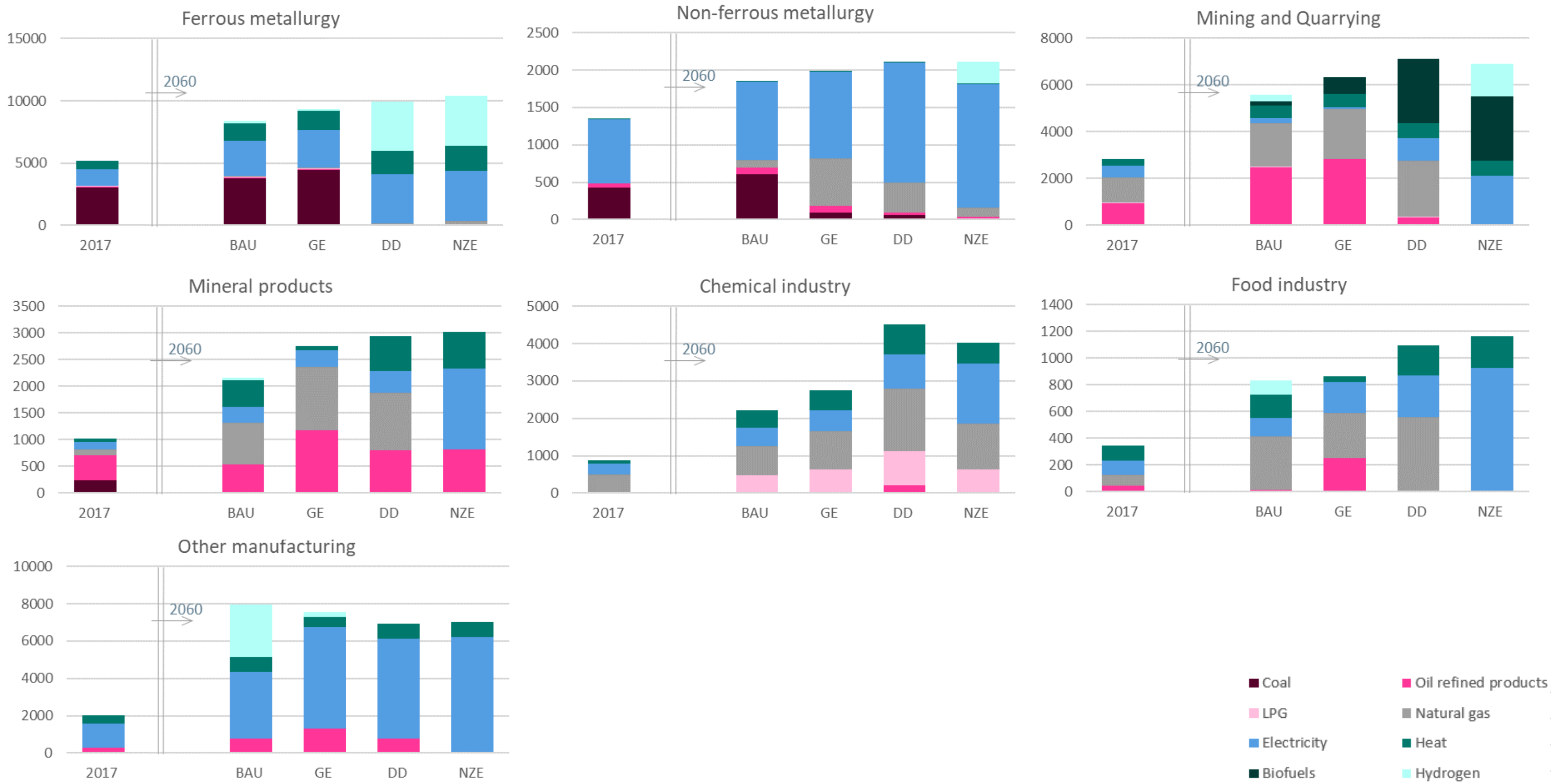
Source: Own calculations

Table A- 17
Energy intensity (per USD of output) of selected industries, MJ/USD, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Mining and Quarrying	9.6	9.3	10.2	8.8	11.1	8.9	8.0	9.2	8.1
Food industry	1.7	1.5	1.4	1.5	1.4	1.5	1.5	1.4	1.4
Ferrous metallurgy	28.1	21.6	19.9	21.7	21.7	17.7	14.3	18.8	15.4
Non-ferrous metallurgy	5.7	4.7	4.2	4.5	4.3	4.4	2.6	4.6	2.6
Chemical industry	18.8	12.2	16.8	12.2	18.3	12.7	18.2	13.4	17.5
Mineral products	21.6	18.8	14.7	18.7	18.4	18.7	16.7	19.3	17.3

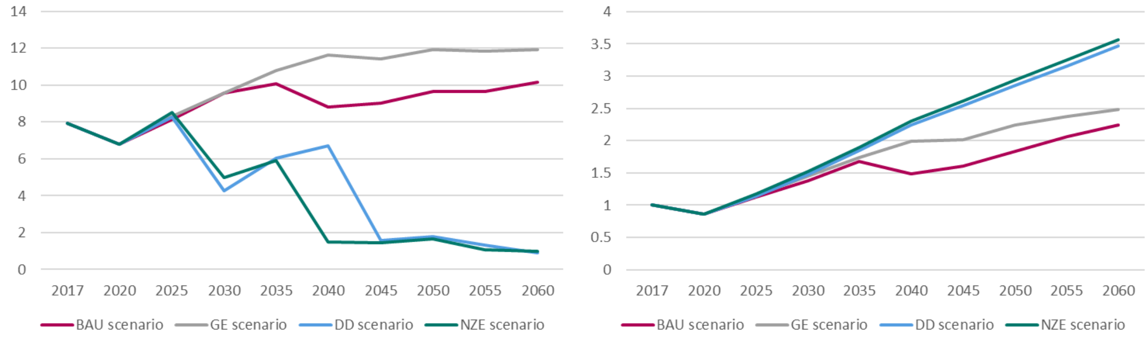
Source: Own calculations

Figure A- 22
Final energy demand in selected industries and fuel type, ktoe, all scenarios



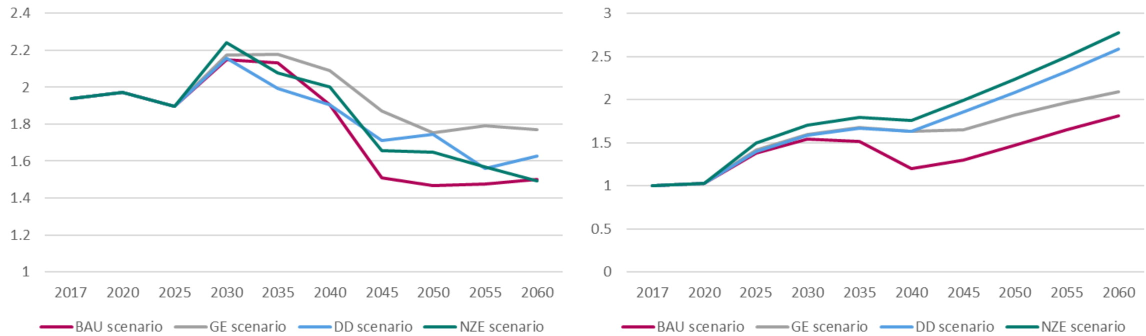
Source: Own calculations

Figure A- 23
Projected carbon dioxide process emissions in iron and steel production, Mt CO_2 (left) and production levels, 2017 = 1 (right), all scenarios



Source: Own calculations

Figure A- 24
Projected process emissions from aluminium production, Mt CO_2-eq (left) and production levels, 2017 = 1 (right), all scenarios



Source: Own calculations

IPPU emissions from aluminium production: 2022 CRF submission

In 2022, the IPPU emission values for aluminium production were significantly revised downwards following the data submission by the single producer of aluminium in Kazakhstan. As a result, the CO_2 emission factor of previously 5.11 t CO_2 / t Al was reduced to 1.44 t CO_2 / t Al in 2017. Taking into account the IPPU emissions from anode production, the total CO_2-intensity of aluminium would increase to 1.57 t CO2 / t Al. Similarly, the emission intensity for F-gases was reduced from 0.28 kg CF_4 / t Al to 0.17 kg CF_4 / t Al and from 0.03 kg C_2F_6 / t Al to 0.02 kg C_2F_6 / t Al.

The used CO_2 emission factor makes Kazakhstan one of the most emission-efficient producers of aluminium, putting it before the major aluminium producers in industrially advanced countries (Table A- 18).

Table A- 18

Emission factor per tonne of aluminium of major aluminium producers among the advanced countries and of Kazakhstan under 2020 and 2022 submissions

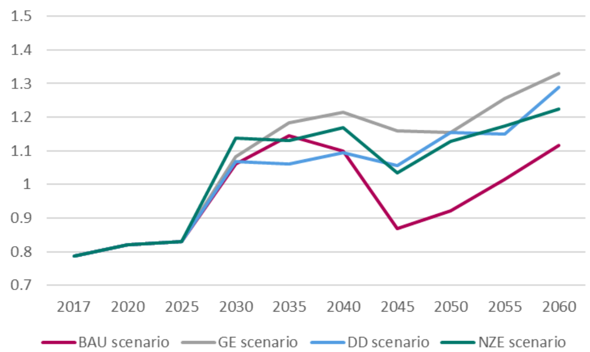
	CO_2 (t)	CF_4 (kg)	C_2F_6 (kg)
Australia	1.45	0.01	0.004
Canada	1.64	0.03	0.002
Norway	1.55	0.01	0.001
USA	1.63	0.13	0.04
Kazakhstan (NIR 2020)	5.11	0.28	0.03
Kazakhstan (NIR 2022)	1.44	0.17	0.02

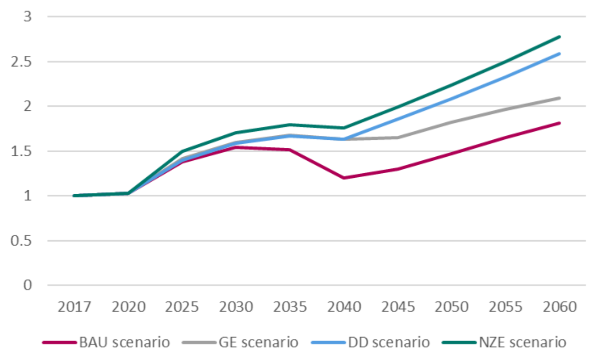
Source: 2022 NIR submissions of Australia, Canada, Norway, and USA, 2022 and 2020 NIR submissions of Kazakhstan

If the new emission factors are used, the emissions in the base year (2017) drop from 1.9 Mt CO_2-eq to under 0.8 Mt CO_2-eq and improvements in emission efficiency have significantly smaller impacts, so that rising production leads to an increase in total emissions (Figure A- 25). Process emissions will increase by around 42% relative to the 2017 level in the BAU scenario and by 69% in the GE scenario, where technological structure is similar, but production levels are higher. In the DD and the NZE scenarios, production levels increase much more (43% (DD) and 53% (NZE) higher than in BAU in 2060), but emission efficiency gains are also larger as more advanced technologies are employed. This puts the resulting total emissions between the GE and the BAU levels, at 64% (DD) and 56% (NZE) higher than in 2017 and just 16% (DD) and 10% (NZE) higher than in BAU.

Figure A- 25

Projected process emissions from aluminium production using the 2022 NIR version and the modelled technology mix, Mt CO_2-eq (left) and production levels, 2017 = 1 (right)

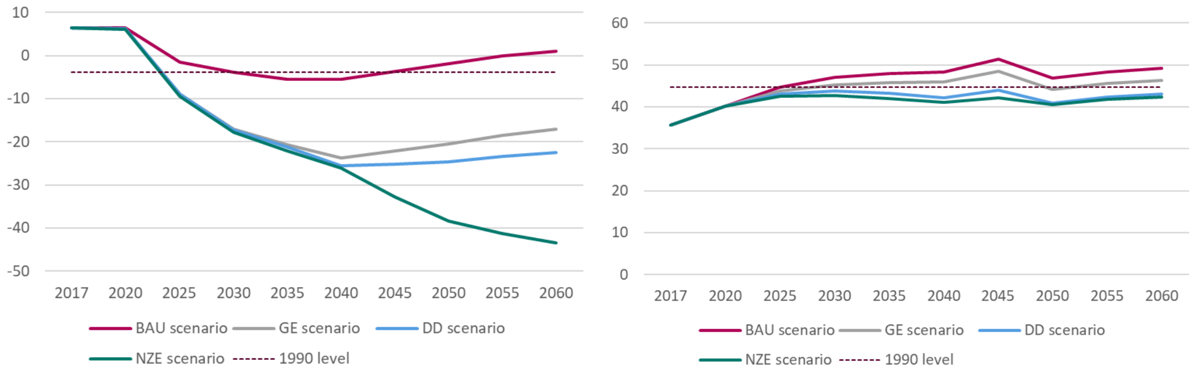




Source: Own calculations

Figure A- 26

Total emissions in LULUCF (left) and agriculture (right), Mt CO_2-eq, all scenarios



Source: Own calculations

Table A- 19

Emissions from LULUCF and agriculture, Mt CO_2-eq, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
					LULUCF				
Settlement land	-3.4	-3.7	-4.3	-3.7	-4.3	-3.7	-4.3	-3.7	-4.3
Cropland	30.4	21.2	25.1	21.0	23.7	20.9	18.2	20.3	10.5
Grassland	-17.8	-9.9	-9.8	-9.9	-9.8	-9.9	-9.8	-9.9	-9.8
Forestry	-2.9	-11.4	-9.9	-24.4	-26.6	-24.4	-26.6	-24.4	-39.8
LULUCF total	**6.4**	**-3.9**	**1.1**	**-17.1**	**-17.0**	**-17.2**	**-22.5**	**-17.8**	**-43.4**
					Agriculture				
Enteric fermentation	18.7	26.9	30.6	25.9	29.3	24.9	26.9	24.9	26.9
Manure management	3.1	4.0	5.0	3.8	4.2	3.6	3.6	3.6	3.6
Agricultural soils	13.9	16.1	13.5	15.5	12.8	15.3	12.6	14.1	11.9
Agriculture total	**35.7**	**47.1**	**49.1**	**45.2**	**46.3**	**43.8**	**43.0**	**42.6**	**42.4**

Source: Own calculations

Table A- 20

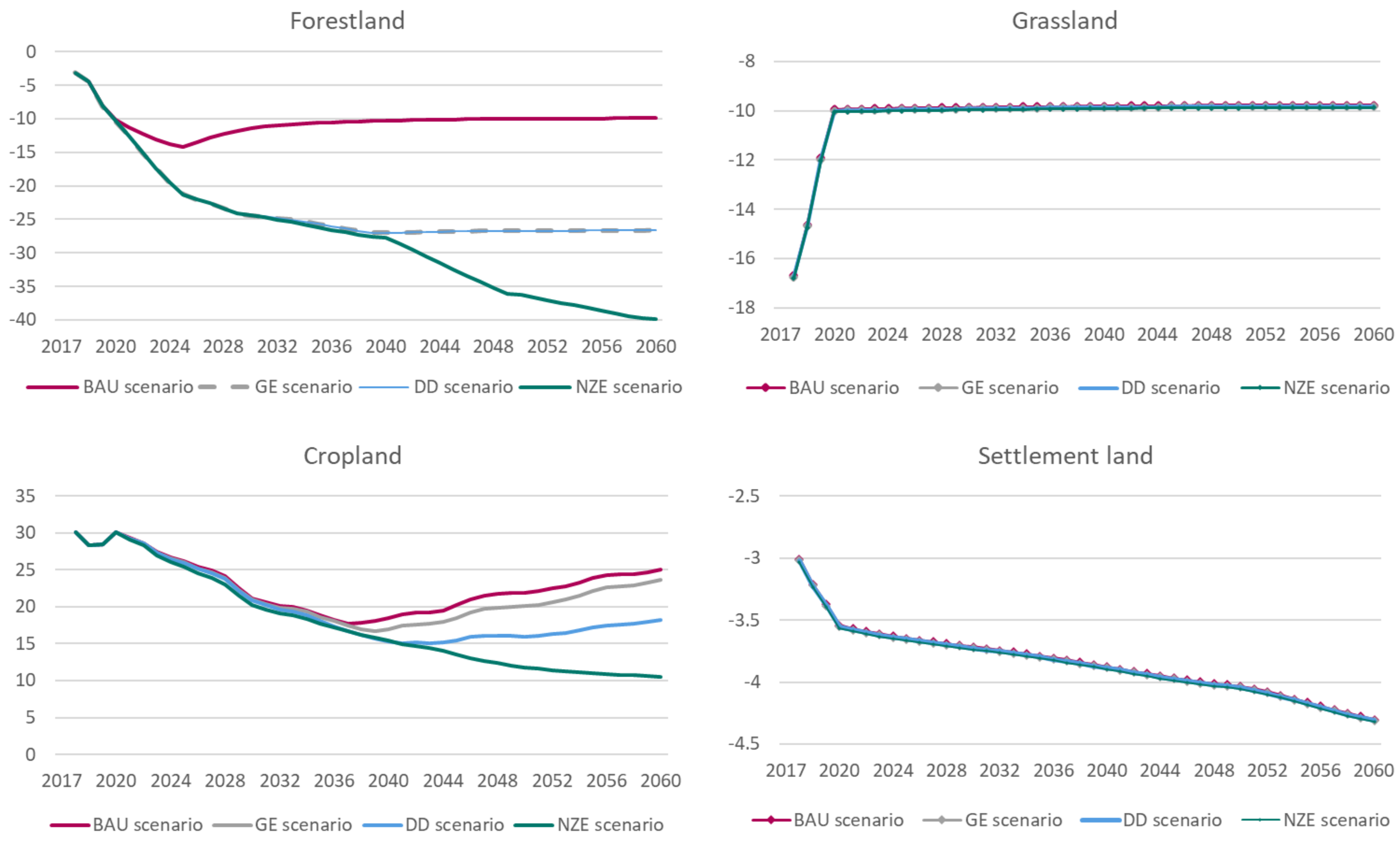
Potential generation capacity for bioenergy from waste in Kazakhstan, MW, all scenarios

	BAU scenario		GE scenario		DD scenario		NZE scenario	
	2030	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Crop residues	9277	12038	9694	13636	9950	17806	10500	22602
Manure	516	657	696	1313	876	1970	876	1970
Slaughtering residues	121	154	121	154	121	154	121	154
Other waste: sewage sludge	5722	7253	5722	7253	5722	7253	5722	7253
Total	**15636**	**20102**	**16233**	**22357**	**16669**	**27183**	**17219**	**31979**

Source: Own calculations

Figure A- 27

Land use emissions by land category, all scenarios, Mt CO_2-eq, all scenarios



Source: Own calculations

Table A- 21
Annual CBA agriculture, million USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Cost and revenues																
Crop production GDP	6753	7745	8833	9641	7178	8652	10099	11072	7408	9823	12943	15395	8150	11278	15841	20887
Profits lost due to climate change	2760	3109	3869	4269	2702	2972	3713	4149	2608	2858	3401	3966	2791	3265	3930	4884
Livestock GDP	4659	5088	5549	5929	4659	5088	5549	5929	4659	5088	5549	5929	4659	5088	5549	5929
Livestock profits lost due to climate change	7.9	8.6	9.4	10	7.9	8.6	9.4	10	7.9	8.6	9.4	10	7.9	8.6	9.4	10
Sustainable agriculture																
Capital cost	13	37	34	19	33	43	23	0	61	98	46	0	107	113	83	23
O&M cost	0.7	62	130	184	46	126	196	201	62	250	391	401	182	382	588	664
Irrigation																
Capital cost	16	16	16	16	26	35	32	31	27	40	49	43	27	40	49	43
O&M cost	45	46	47	47	59	82	91	92	60	88	120	125	60	88	120	125
Energy cost	22	44	32	28	40	67	62	64	52	79	104	125	46	79	120	135
Fertilizer																
Cost of inorganic fertilizer	684	555	406	228	579	378	196	79	549	193	0	0	384	23	0	0
Water																
Cost of water	612	748	598	508	703	1013	984	982	723	1124	1368	1466	723	1124	1368	1466
Cost of reforestation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cost of livestock emission reduction	4.9	118	250	389	108	229	370	516	215	448	606	766	215	448	606	766
Cost of low carbon interventions	0	0	0	0	1.5	0	0	0	1.5	0	0	0	6.7	13	0.7	0
Externalities																
Positive																
Labour income from agriculture	1923	1984	2045	2068	1937	2004	2065	2073	1941	2041	2124	2133	1977	2081	2183	2212
Negative																
Social cost of carbon agriculture	1460	1495	1454	1523	1402	1422	1371	1437	1359	1308	1267	1334	1321	1274	1259	1314

Source: Own calculations

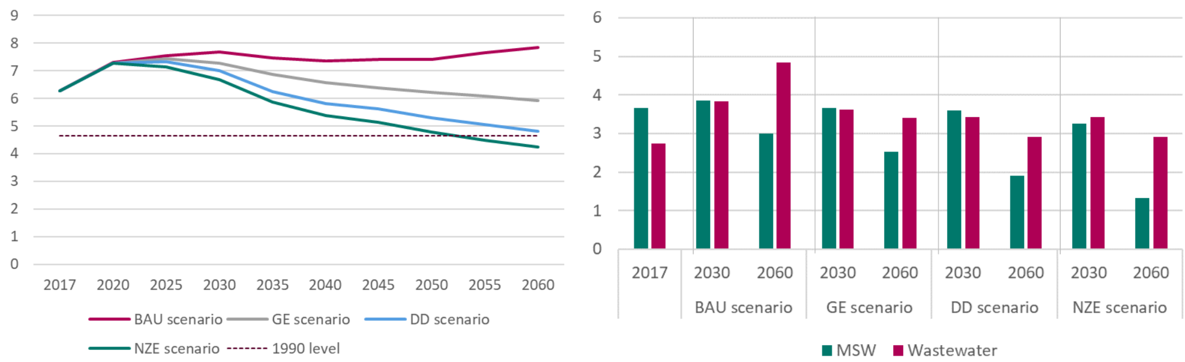
Table A- 22
Cumulative CBA agriculture, billion USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Cost and revenues																
Crop production GDP	69	140	223	318	71	149	243	352	72	157	272	417	75	172	308	495
Profits lost due to climate change	28	58	92	134	28	56	89	130	27	55	86	123	28	59	94	139
Livestock GDP	48	97	150	208	48	97	150	208	48	97	150	208	48	97	150	208
Livestock profits lost due to climate change	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4
Sustainable agriculture																
Capital cost	0.01	0.4	0.7	1.0	0.3	0.7	1.1	1.1	0.4	1.4	2.2	2.2	1.0	2.1	3.3	3.6
O&M cost	0.001	0.3	1.3	2.9	0.2	1.1	2.8	4.8	0.3	1.9	5.2	9.2	1.0	3.9	8.8	15
Irrigation																
Capital cost	0.2	0.3	0.5	0.6	0.2	0.6	0.9	1.2	0.3	0.6	1.1	1.5	0.3	0.6	1.1	1.5
O&M cost	0.5	0.9	1.4	1.9	0.6	1.3	2.1	3.1	0.6	1.3	2.4	3.6	0.6	1.3	2.4	3.6
Energy cost	0.2	0.5	0.9	1.2	0.4	0.8	1.4	2.1	0.4	0.9	1.8	3.0	0.3	0.9	2.0	3.3
Fertiliser																
Cost of inorganic fertiliser	4.7	11	16	19	4.2	9.0	12	13	4.1	7.8	8.3	8.3	3.4	5.2	5.2	5.2
Water																
Cost of water	6.2	12	18	24	6.7	14	24	34	6.8	15	28	43	6.8	15	28	43
Cost of reforestation	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Cost of livestock emission reduction	0.005	0.7	2.6	5.8	0.6	2.3	5.4	9.9	1.2	4.6	9.9	17	1.2	4.6	9.9	17
Cost of low carbon interventions	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5
Externalities																
Positive																
Labour income from agriculture	21	40	61	81	21	41	61	82	21	41	62	83	21	41	63	85
Negative																
Social cost of carbon agriculture	15	30	44	60	15	29	43	57	15	28	41	54	15	27	40	53

Source: Own calculations

Figure A- 28

Total projected GHG emissions from waste (left) and GHG emissions by waste type for selected years (right), Mt CO_2-eq, all scenarios



Source: Own calculations

Table A- 23

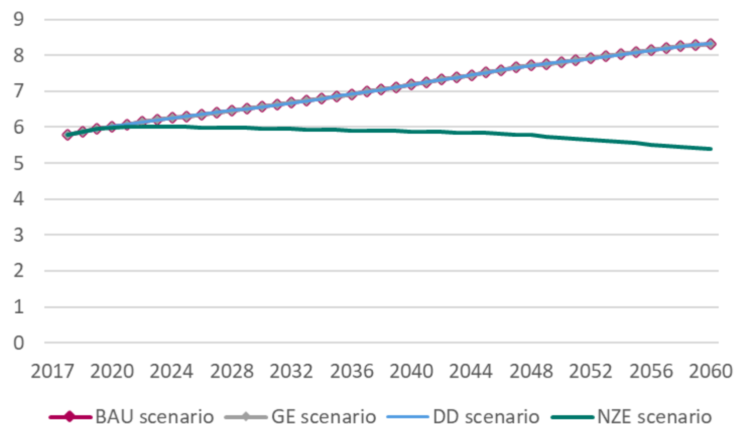
MSW emissions by management mode, Mt CO_2-eq, all scenarios

		BAU scenario		GE scenario		DD scenario		NZE scenario	
	2017	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Collection	0.18	0.23	0.42	0.25	0.42	0.25	0.42	0.23	0.27
Composting	0.00	0.01	0.03	0.01	0.06	0.02	0.17	0.02	0.10
Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste to energy	0.00	0.80	1.59	0.97	1.57	1.02	1.12	0.93	0.77
Landfills	1.39	1.00	0.97	0.93	0.48	0.84	0.21	0.77	0.18
Open dumping	2.09	1.81	0.00	1.50	0.00	1.46	0.00	1.32	0.00
Total	**3.66**	**3.85**	**3.00**	**3.66**	**2.53**	**3.59**	**1.90**	**3.27**	**1.32**

Source: Own calculations

Figure A- 29

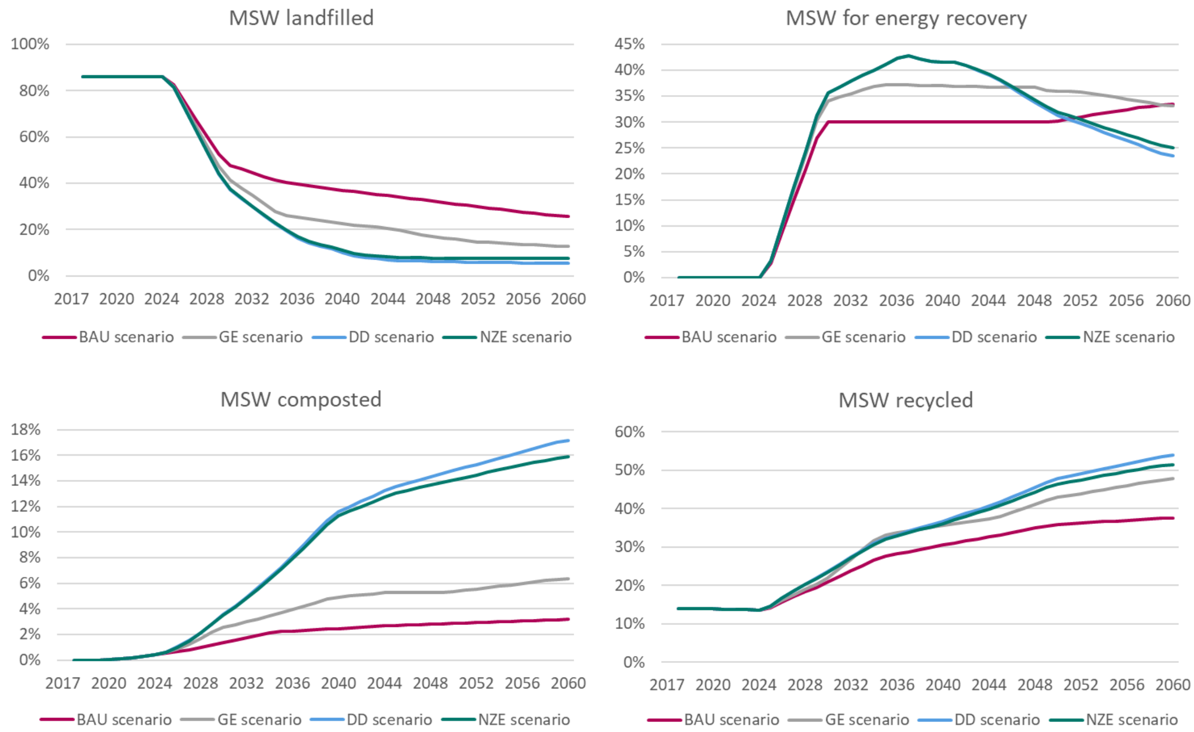
Total MSW generated, million tonnes, all scenarios



Source: Own calculations

Figure A- 30

Waste management share by waste management mode, %, all scenarios

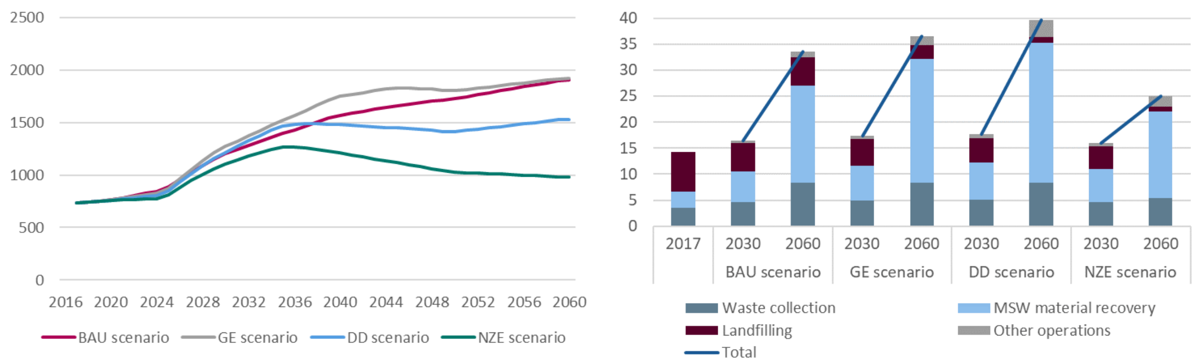


Note: In the NZE scenario, the shares of landfilling and energy recovery are somewhat higher than in the DD scenario, while the shares of composting and recycling are lower, despite the same level of ambition. This is a result of a reduction in waste generation in the NZE scenario, which is not applicable to industrial waste, part of "other waste". In other words, MSW appropriate for recycling or composting is reduced by more than other waste. This reduces slightly the shares of recyclable and compostable MSW in total MSW generation and, consequently, the shares of composting and recycling.

Source: Own calculations

Figure A- 31

Total cost of MSW management, million USD (left) and employment in waste management, thousand persons (right), all scenarios



Source: Own calculations

Table A- 24

Annual CBA waste sector, million USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Investment and cost																
Total costs	1185	1561	1722	1906	1250	1740	1799	1922	1191	1484	1408	1531	1085	1219	1028	979
Capital costs	772	1021	1125	1256	819	1161	1199	1280	784	1005	947	1028	715	825	690	655
O&M costs	413	540	596	649	431	579	600	643	406	478	461	503	370	394	338	324
Compost																
Compost production cost	0	0	0	0	2.2	5.9	16	17	5.4	17	39	41	5.4	17	39	41
Revenues from local compost sales	0	0	0	0	0.3	0.7	1.8	1.9	0.6	1.9	9.0	9.6	0.6	1.9	9.0	9.6
Revenues from compost exports	0	0	0	0	3.4	9.2	24	26	8.4	26	118	127	8.4	26	118	127
Avoided cost of fertilisers through compost	0	0	0	0	0.9	2.6	6.8	7.2	2.4	7.2	0.0	0.0	2.4	7.2	0.0	0.0
Pellets																
Pellet production cost	0	0	0	0	2.7	7.3	19	21	6.7	21	47	51	6.7	21	47	51
Revenues from pellets	0	0	0	0	7.1	19	50	54	18	54	125	133	18	54	125	133
Externalities																
Social cost of carbon from waste	219	207	204	214	209	180	168	159	202	155	138	125	190	141	122	106
Labour income from waste management	127	196	249	265	133	207	255	288	135	212	268	313	123	174	195	198
Labour income from bioenergy capacity	0	0	0	0	0.2	0.3	0.3	0.3	2.0	0.4	0.4	0.4	0.01	0.2	2.9	1.7

Source: Own calculations

Table A- 25

Cumulative CBA waste sector, billion USD

	BAU scenario				GE scenario				DD scenario				NZE scenario			
	2030	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**	**2030**	**2040**	**2050**	**2060**
Investment and cost																
Total costs	10	24	41	59	10	25	43	62	10	24	39	53	9.5	22	33	43
Capital costs	6.1	15	26	38	6.2	16	28	41	6.1	16	25	35	5.8	14	21	28
O&M costs	4.0	8.8	15	21	4.0	9.1	15	21	3.9	8.5	13	18	3.7	7.7	11	15
Compost																
Compost production cost	0	0	0	0	0.01	0.1	0.2	0.3	0.03	0.1	0.4	0.8	0.03	0.1	0.4	0.8
Revenues from local compost sales	0	0	0	0	0.001	0.01	0.02	0.04	0.003	0.02	0.06	0.16	0.003	0.02	0.08	0.17
Revenues from compost exports	0	0	0	0	0.02	0.1	0.2	0.5	0.04	0.2	0.8	2.1	0.04	0.2	1.0	2.3
Avoided cost of fertilisers through compost	0	0	0	0	0.005	0.02	0.1	0.1	0.01	0.06	0.1	0.1	0.01	0.06	0.1	0.1
Pellets																
Pellet production cost	0	0	0	0	0.01	0.1	0.2	0.4	0.03	0.2	0.5	1.0	0.03	0.2	0.5	1.0
Revenues from pellets	0	0	0	0	0.03	0.2	0.5	1.0	0.08	0.4	1.3	2.6	0.08	0.4	1.3	2.6
Externalities																
Social cost of carbon from waste	2.4	4.6	6.6	8.7	2.4	4.3	6.0	7.7	2.4	4.1	5.6	6.9	2.3	3.9	5.2	6.3
Labour income from waste management	1.4	3.0	5.3	7.8	1.4	3.1	5.5	8.2	1.4	3.2	5.6	8.5	1.3	2.9	4.7	6.7
Labour income from bioenergy capacity	0	0	0	0	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0	0.003	0.02	0.04

Source: Own calculations