Long-Term Climate Change Mitigation in Kazakhstan in a Post Paris Agreement Context

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Key messages

- The energy targets of the Strategy 2050 and the Green Economy Concept of Kazakhstan are compatible with the least-cost 25% emissions reduction pathway. In other words, a 25% emissions reduction target, rather than a 15% reduction target as currently proposed, is feasible for Kazakhstan.
- Renewable energy reaches 50% of the electricity generation mix, the rest is attributed to gas-fired power plants.
- A coal ban is not sufficient; emission reduction strategies must be also supported by carbon pricing and market mechanisms to promote zero emission sources.
- A TIMES model disaggregating the energy system of Kazakhstan in 16 sub-national regions is used for this study.

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1 Introduction

Kazakhstan ratified the Paris Agreement and its nationally determined contribution (NDC) is a 15% reduction in greenhouse gas emissions (GHG) as an unconditional target and 25% reduction as conditional target by 2030 compared to the level of 1990 (UNFCCC 2016a). The 25% conditional target is subject to additional international investments, access to the low carbon technologies transfer mechanism, green climate funds and flexible mechanism for economy in transition countries. Historical trends show a steadily increasing level of emissions over the last decade, with an average annual growth rate of 3.7%, already exceeding in 2014 the net GHG emissions of the unconditional NDC 15 target by 7% (Fig. 1). From the recent GHG emissions trends it can be concluded that progress towards achieving even the unconditional NDC 15 target is not sufficient and the mitigation actions are inadequate.

The Climate Action Tracker (2017) indicates that Kazakhstan's unconditional NDC commitment (−15%) in 2017 is not consistent with holding the increase in average global temperature to below 2 °C and is instead consistent with warming between 2 and 3 °C. According to the World Energy Outlook 2016, Eastern Europe/Eurasia region (where Kazakhstan belongs to) will be required to reduce its CO_2 emissions by 50% by 2030 and 58% by 2040 compared to 1990 level in the 450 Scenario (IEA 2017). This points out that Kazakhstan may be required to take a more ambitious emissions reduction target, depending on the burden sharing method. The implications of the conditional NDC (−25%) target have not previously been studied for Kazakhstan. This chapter addresses this knowledge gap. More ambitious targets (−50, −100%) have not been discussed previously in the country.

Kazakhstan has experienced a rapid economic development since the year 2000, and in 2016 the country was rated as an upper-middle-income country; its GDP per capita reached 7700 USD (World Bank 2017). Due to poor building insulation, low coverage by energy infrastructure (gas and district heating) in some of its regions

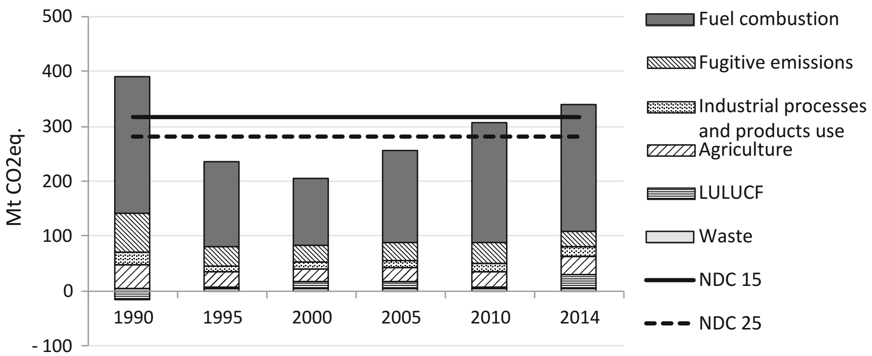

Fig. 1 Historical GHG emissions trend in Kazakhstan and the NDC cap (UNFCCC 2016b)

and large income inequalities, households are affected by energy poverty, more particularly energy affordability and lack of access to clean fuels. 28% of surveyed households spent more than 10% of their income on energy in 2013 (Kerimray et al. 2017a). There is high reliance on unsustainable fuels: 40% of households used coal, mainly for heating purposes in low-efficiency stoves (Kerimray et al. 2017a). There could be large incidence of insufficient thermal comfort values, but there are no data to quantify these values. Economic development (reduction of income inequality) and satisfaction of the demand for energy services have been higher priority in the country, compared to the climate change mitigation (Government of the Republic of Kazakhstan 2014; Tengrinews 2017). In this regard, taking into account current policies and long-term strategic documents, as well as the need to increase contribution to climate change mitigation, we considered the NDC 25 target as a possible main target for Kazakhstan rather than the NDC 15 target.

Previous energy system modelling studies for Kazakhstan focused on the unconditional target (NDC 15) and focused mostly on the mid-term analysis (2030) (Kerimray et al. 2016; Sarbassov et al. 2013; Kerimray et al. 2015; Suleimenov et al. 2016; PMR 2016). This study explores for the first time, the more ambitious the NDC 25 reduction target, under a longer time horizon (2050). As there is no official national long term GHG emissions reduction pledge by 2050, we assume in this chapter that it extends beyond 2030–2050. These scenarios serve as a benchmark for how the NDC targets can be achieved at least cost.

Coal is currently widely used in power plants (74% of electricity generated with coal) and in the domestic heating appliances (40% of households use coal) in Kazakhstan. Therefore, emissions reductions are not possible without urgent actions on substantially reducing coal use across all sectors of the economy. This chapter goes further than previous work by analysing the implications of phasing-out coal (with a coal-ban scenario) in Kazakhstan by 2050 as an additional contribution from Kazakhstan towards achieving "well below 2 degrees world".

The TIMES-based sub-nationally disaggregated 16-region energy system model for Kazakhstan was employed in this study. The need for regionally disaggregated analysis for Kazakhstan is mainly driven by spatially heterogeneous conditions of the national energy system and different dynamic factors of its regions. Due to the absence of data on thermal comfort and unmet demand values, energy poverty was not explicitly modelled. The results of the study can be used for development of a low-carbon development program for Kazakhstan and to inform actions to be undertaken for fulfillment of the NDC targets.

2 Policies for Energy Transition and GHG Emissions Reduction in Kazakhstan

Kazakhstan has introduced many policies and measures domestically over the last 5–7 years to promote penetration of renewable energies and to improve energy efficiencies (Kerimray et al. 2017b, c). The law 'On Energy Saving and Improving Energy Efficiency' was adopted in 2012. Since its enactment, many industrial and buildings energy audits have been conducted and a regulatory framework for energy efficiency has been introduced. A law promoting the use of renewable energy resources was introduced in 2009, with fixed feed-in tariffs adopted initially, and renewable energy auctions later in 2017.

Kazakhstan is the first country in Central Asia that has launched an emissions trading scheme (ETS) in 2013. It involves 140 big companies (including oil and gas), mining and chemical industry, covering around 50% of country's CO_2 emissions. However, industry involvement and trading activity has been very weak, which could be partly due to the economic recession. Thus, in the first year of ETS (2014), just 32 transactions were completed with an average price of 1.67 USD/tonne and in its second year, 40 transactions took place for a total of 1.98 Mt (<1% of all tonnes capped under the system) with the average price of USD2.06 (IETA 2016). In 2016, trading and penalties for non-compliance were suspended until January 2018, to give time to make amendments to the ETS, although annual reporting and verification requirements remain in place. The ETS suspension was due to high resistance of industries and concern of the negative impact of the ETS on the economic growth associated with lack of flexibility of "historical" allocation methods to production levels. It is planned to restart ETS with new allocation methods (benchmarking) and trading procedures.

Despite existence of policies and measures, changes in the energy mix are slow: renewable energy penetration is still low (less than 1% without accounting for biomass) and there were no significant energy intensity reductions for any sectors between 2010 and 2014 (except for oil and gas), resulting in the positive trend in growth of GHG emissions (Kerimray et al. 2017c).

Strategic documents on energy development of Kazakhstan suffer from the lack of integrated approach and consistency. According to the "Strategy-Kazakhstan-2050": the new political course of the state" by 2050, 50% of energy consumed in Kazakhstan should be supplied through renewable and alternative energy sources. While the strategic document "Fuel-energy complex development concept till 2030", adopted in 2014, implies that coal will remain to be the main fuel for power generation in Kazakhstan (Government of the Republic of Kazakhstan 2014). Reduction of coal share in the fuel mix, actions towards achieving ambitious 2050 goals, as well as emissions reduction measures, are not indicated in the "Fuel-energy complex development concept till 2030".

Energy system models provide a comprehensive description of possible scenarios for development of the energy system by considering intertemporal, interregional and intersectoral relations and thus, may assist decision makers to take systemic interdependencies of the energy sector into consideration.

3 TIMES-Kazakhstan Multi-regional Model

The TIMES-Kazakhstan multi-regional model represents all steps of an energy chain region by region: from an extraction of primary resources to their supply to primary energy markets, from transformation of primary energy carriers to their transmission and distribution to the final energy-use sectors, from use of final energy commodities to satisfaction of end-users demand for energy services (Suleimenov et al. 2016).

The optimisation paradigm used here is energy system cost minimisation with perfect foresight. The modelling time horizon is from base year (2011) to (2050). The model for Kazakhstan is calibrated for the year 2011 with the data provided by the regional Energy Balances (Kazmaganbetova et al. 2016; Kerimray et al. 2017c). Regional representation corresponds to administrative division of the country: 14 regions and 2 cities: Astana (capital) and Almaty (ex-capital, financial centre).

The model is one multi-regional model with 16 regions which are allowed to trade energy forms through the existing and new infrastructures (pipelines for crude oil and natural gas), through electrical grids and via land transport (oil products and coal) depending on regional demand for energy. Capacities of the existing infrastructures are used to describe the maximum level of "tradable" energy between pairs of regions. New capacities of energy infrastructure between regions is endogenous to the model, investment costs and possible routes were described. The capital cost for new gas pipeline infrastructure (described in the model as one of the technology investment options) was obtained from the recently constructed gas pipeline Beineu-Bozoi-Shymkent at 7 mln USD/(TJ*km).

CO_2 emissions from combustion are tracked using the emission coefficients per "fuel", according to the IPCC guidelines (based on the carbon content of each fuel) and the national inventory of emissions.

The technology database was inherited from national (single region) TIMES-Kazakhstan model, using the latest updated version by Nazarbayev University Research and Innovation System (Kazakhstan) under the Project funded by Partnership for Market Readiness (2015–2016).

3.1 Electricity and Heat Generation Sector

The electricity and heat generation sector in the base year (2011) represents all power and combined heat and power plants, region by region, by input fuel type and calibrated according to data from KEGOC (Kazakhstan Electricity Grid Operating Company) for 2011. The existing stock is dominated by coal-fired plants, low efficiencies, and low shares of renewables (hydro). For the future years, the retirement of existing stock and new capacities is fully endogenous to the model. Electric power transmission and distribution losses of Kazakhstan's grid was around 7%.

In Kazakhstan the renewable energy potential is high and it exceeds the projected energy demand (Karatayev et al. 2016). Hydro, solar and wind technologies were assumed to have three levels of costs, depending on the region. The regions with the highest wind speed and high solar insolation were assumed to have the lower end of technology cost. The regions with lower renewable potential were assumed to have high medium and high technology cost. As there were no studies on renewable energy technology costs for Kazakhstan, it was assumed as described in the Table 1.

3.2 Demand Projections

The model includes various demands for energy services categorised by sector (for example, industries, types of transport, household and commercial processes: washing, drying, cooking, heating, hot water supply, lighting, etc.). Each energy service demand has its own macro-economic or physical output driver. Correlation factors for associating energy service demand to their drivers were inherited from the national model (PMR 2016) and assumed to be the same across the regions. Energy service demands are assumed here to be "inelastic" to prices for energy, due to the absence of data on price elasticities. Projections of drivers of energy demand is described by Suleimenov et al. (2016).

3.3 Export and Import Assumptions

Kazakhstan has significant fossil fuel resources and is a net exporter of energy and energy products. One of the pillars of the national strategy is to minimize energy imports. According to the energy balance of Kazakhstan, most of the energy commodities consumed are supplied from domestic production, with the exception of oil products (due to insufficient capacity of domestic oil refineries).

Existing import/export from/to abroad are also taken into consideration in the model and projected over the time horizon based on the following assumptions:

Table 1 Investment cost of solar, wind and hydro, USD_{2013}/W

	Low cost	Medium cost	High cost
Hydro	3	6.6	9.6
Solar	1.57	1.62	2.22
Wind	1.44	1.68	2.76

(a) Minimum level of crude oil export is equal to the base year net export (2000 PJ) till 2030; (b) Natural gas export level decreases twice in 2030 from the level of the base year, allowing the system to supply gas to domestic users which is consistent with the adopted Law "On gas and gas supply" (2012), setting priority of gas supply to domestic users; and (c) Export level for coal decreases by 25% from the base year (540 PJ). Trade of oil products, electricity and biomass is endogenous to the model, with exogenously defined import and export prices.

4 Scenarios

TIMES 16-region model employed in this study cover only fuel combustion related emissions. Thus, projections for sectors not related to fuel combustion (e.g. waste; industrial processes and products use; land use, land-use change and forestry, fugitive emissions from fuels) were obtained from the previous study funded by Partnership for Market Readiness (PMR 2016). The results of "with measures" scenario was taken. Upper limits on fuel combustion emissions take into account these other emissions.

The model was run for four scenarios: Business as usual (BaU), unconditional and conditional NDC targets, and coal ban (Table 2). The NDC scenarios inherit all the key characteristics of a reference case (key assumptions about the gas production profile, energy self-sufficiency plan, gas network development, etc.), and add an emission reduction target to the decision problem. The system can respond to the constraint through investing in higher efficiency technologies, and/or different fuels, energy infrastructure (gas pipeline, electricity network, district heating system) in some or in all regions. The underlying assumption is that there is an (endogenous) allocation of an emission reduction among regions and sectors based

Table 2 Scenario runs

Scenario	Description
BaU	The BaU (business as usual) scenario is the least cost solution of the energy system without any specific environmental target
NDC 15	Least cost solution of the energy system with the constraint on total GHG emissions from fuel combustion to the amount of 199 Mt CO_2 equivalent for the entire time horizon (until 2050), which is equivalent to 80% of emissions in the year 1990. With GHG emissions for sectors not related to fuel combustion accounted, total GHG emissions correspond to 85% relative to 1990 levels
NDC 25	Least cost solution of the energy system with the constraint on total GHG emissions from fuel combustion in the amount of 174 Mt CO_2 equivalent for the entire time horizon (until 2050), which is equivalent to 70% of 1990 levels. With GHG emissions for sectors not related to fuel combustion accounted, total GHG emissions correspond to 75% relative to 1990 levels
Coal-ban	Total coal consumption is reduced by 20% in 2020, by 60% in 2030 and by 100% in 2050 compared to the base year

on a cost-effectiveness approach to equalize the marginal cost of CO_2 eq. emissions across the regions.

5 Results

5.1 *High Abatement Potentials, Coal Ban Alone Is Insufficient*

Without any targets (the BaU Scenario), the GHG emissions from fuel combustion increases by 47% by 2050 compared the base year level due to rising demand for energy services and low technology/fuel improvements (Fig. 2). In 2050, GHG emissions in BaU scenario exceed the NDC 25 by 184 $MtCO_2$ eq. Cap on GHG emissions has resulted in the fuel switch and improving efficiencies in technologies and processes. Coal ban has resulted in GHG emissions reductions by 153 $MtCO_2$ eq. in 2050 (compared to BaU), however, it exceeds the NDC 25 since coal is substituted by fossil fuels rather than renewable, pointing out the need for additional actions for achieving GHG emissions reductions. Most of the GHG emissions reductions are realized through abatement of CO_2, in particular in the power sector (Fig. 2).

Due to necessity for investments in the energy system, CO_2 price reaches 36–59 USD per tonne in 2030 and 209–281 USD per tonne in 2050 (Table 3). These prices apply to all sectors. ETS sectors (upstream, industry and power generation sectors) are collectively responsible for 75% of total GHG emissions reductions in 2050 in the NDC 25 compared to BaU. This demonstrates that sectors covered by ETS have the highest abatement potential at the lowest cost.

Coal continues to dominate in the BaU scenario (from the current share in the TPES of 55–63% in 2050). In the NDC 25 scenario, share of coal in the TPES reduces to 12% and share of gas increases from the current share of 20–52% in 2050 (Fig. 3). There is an investment to the gas pipeline construction to the regions, which currently do not have access to network gas in alternative scenarios. Total final consumption reduces by 27% in the NDC 25 in 2050 compared to the BaU case.

As a result of the replacement of existing inefficient coal-fired power plants with new gas and renewable based generation, the efficiency of energy transformation processes (measured as TFC/TPES) increases and reaches 80% in 2050 in the NDC 25 scenario (compared to the existing 54%).

5.2 *Focus on Power Generation: Less Coal, Less CHP*

Without any climate policy actions (BaU), coal continues to dominate the fuel mix for electricity and heat generation (70% in 2050), while in the NDC 25 scenario it is almost fully phased out (0.3%). Share of gas in electricity generation reaches 50%,

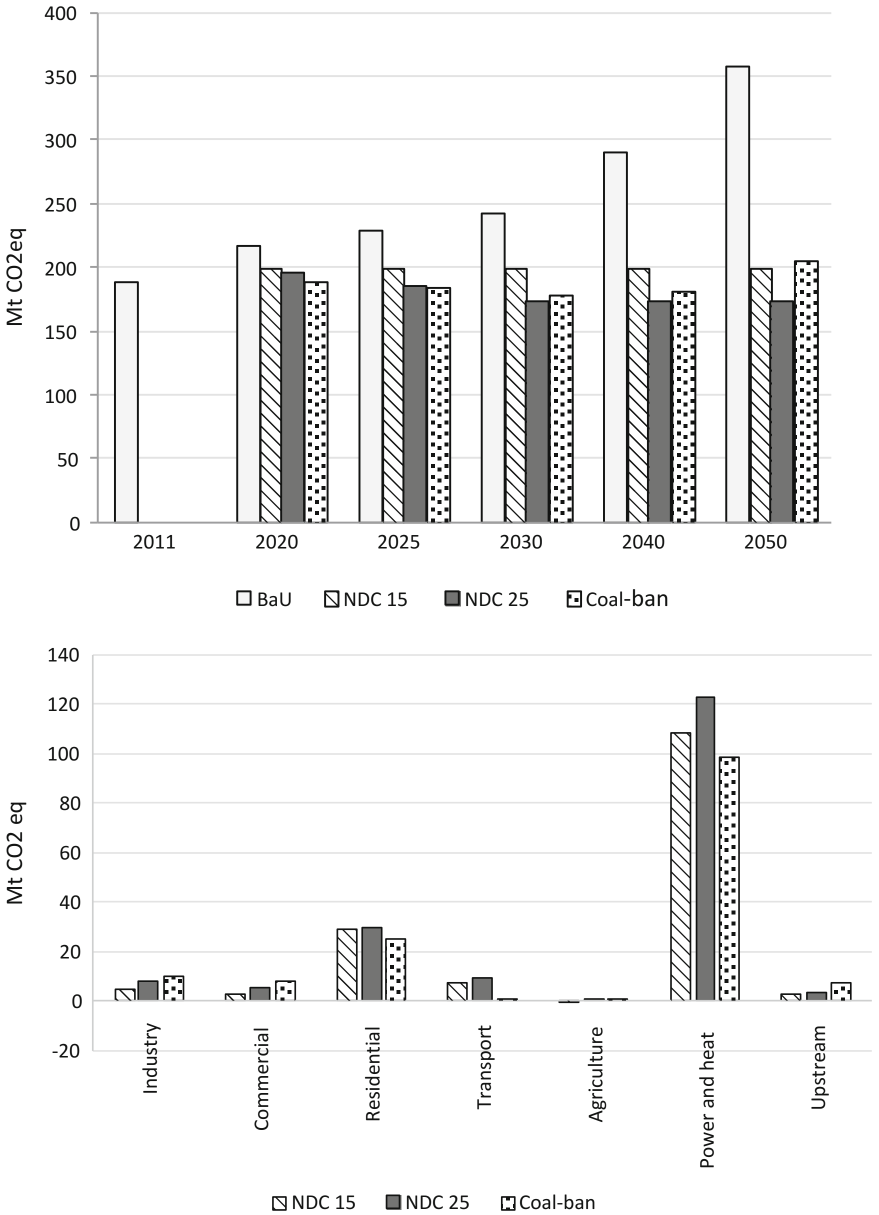

Fig. 2 Total GHG emissions from fuel combustion (top) and CO_2 emissions reduction by sectors compared to the BaU scenario in 2050 (bottom)

Table 3 Marginal CO_2 eq. price, USD/tonne

Scenario	2020	2025	2030	2035	2040	2045	2050
NDC 15	11.5	25.1	36.0	40.6	62.7	137.3	208.5
NDC 25	12.0	46.2	58.6	89.5	171.7	181.3	280.5

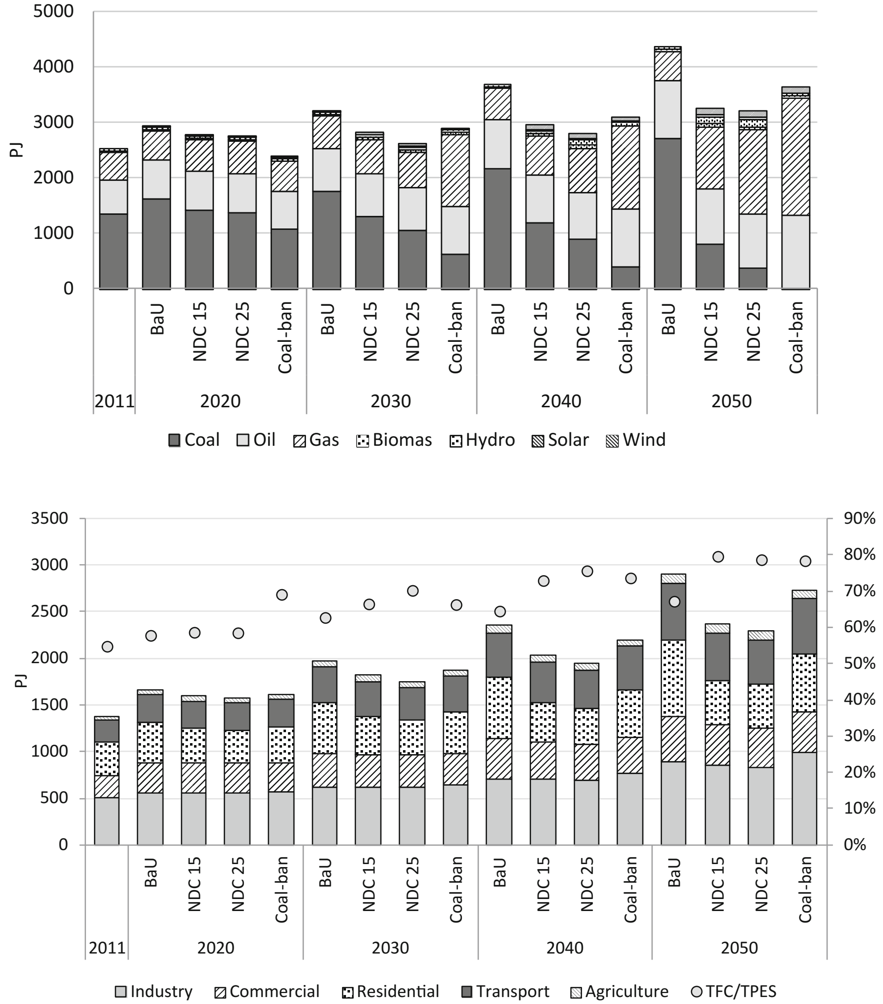

Fig. 3 Total primary energy supply (TPES), PJ (top) and total final consumption (TFC), TJ by sectors and TFC/TPES (bottom)

with the remaining 49% provided by the renewable energy sources in 2050 in the NDC 25.

The total installed capacity of coal fired power plants is 13 GW in 2050 in the NDC 25, while 5.9 GW only of which is utilized (new coal-fired CHP plants generate heat and electricity). By 2050 there will be a substantial installation of renewable energy sources reaching to 14 GW of wind, 10 GW of hydro and 9 GW of solar in the NDC cases. Renewable energy potential at the lowest costs is fully utilized in the NDC scenarios. Additional emissions reduction needed for the NDC 25 (compared to the NDC 15) is achieved by replacement of remaining coal-based capacity with gas. The cost for building gas infrastructure depends on the region (distance). Thus, the regions located at the longest distance from gas production regions are provided with gas in the NDC 25 and the coal ban scenario. In the coal ban scenario most of the electricity is generated with gas (73%), indicating that gas is the most economically viable substitution for coal when the emissions constraint is not imposed (Fig. 4).

Current production of electricity in Kazakhstan is largely dependent on coal-fired power plants with limited possibility of quick start-up and hot standby. In all alternative scenarios, the gas network is constructed in the northern and central regions, with installed capacity of gas power plants reaching 16 GW in northern and central Kazakhstan in 2050, thus providing necessary back up for variable renewable energy sources (wind, solar).

Due to high demand for heating (cold climate conditions), currently, CHP generation capacity makes up a large share of total installed capacity, providing 42% of the total electricity generation and 55% of the total district heating generation. In the BaU scenario, CHP (mainly coal based) provides up to 72% of electricity generation in 2050 and satisfies most of the heat demand (65%). While in the NDC cases CHP plants (mainly gas based) generate up to 47% of the electricity (due to utilisation of renewable energy sources). Production of district heat by CHP plants increases in all scenarios, by 79–87% compared to base year level.

In the NDC scenarios, heat only plants reduce district heat generation substantially (by 92%) compared to the base year level. This occurs as a result of significant heat savings in the residential sector (up to 77% in the NDC 25) and the switch to individual heating systems (natural gas, electricity) in the residential and commercial sectors.

Biomass is not deployed in any scenarios, because of limited biomass potential in Kazakhstan (low level of large agriculture industries, limited stock of forests available only in certain regions).

5.3 Focus on Final Consumption Sectors: Large Changes in the Residential Sector

The residential sector is affected the most among end-use sectors by the emissions constraint, with total final consumption of this sector reducing by up to 43% (compared to the BaU scenario). There is a complete phase-out of coal in the residential sector in the NDC cases (from the base year level 104 to 0 PJ in 2050). In the NDC scenarios, the least cost energy system incorporates significant building

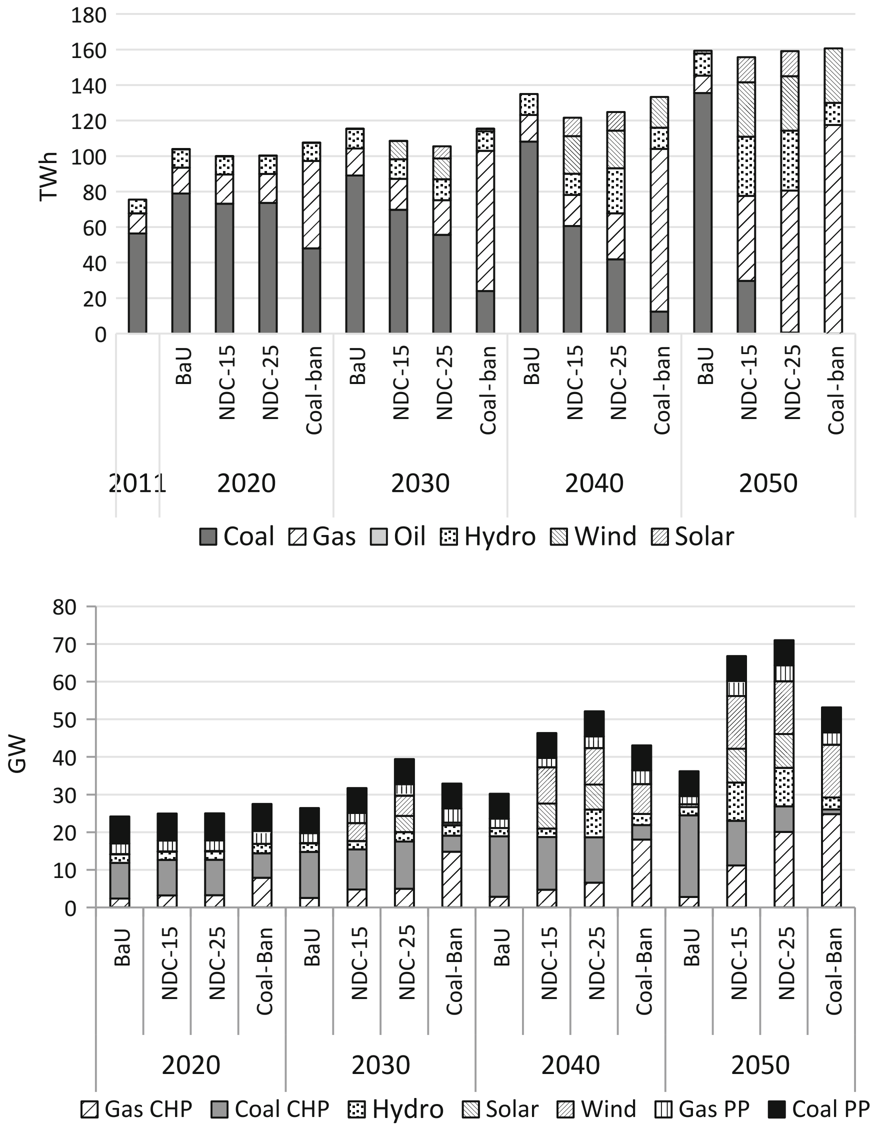

Fig. 4 Electricity generation by fuel type (top) and total installed capacity of power and CHP plants (bottom)

energy retrofit measures in the residential sector (e.g. insulation of walls, replacement of windows), which result in the reduced demand for heating by 32–46% in 2030 and by up to 77% in 2050. Along with building energy retrofit measures, coal is replaced by natural gas, electricity and LPG in the NDC scenarios. Additional emissions reductions in the NDC 25 (compared to the NDC 15) are achieved by additional heat savings, which are higher by 43% and 24% in 2030 and 2040, respectively.

In the transport sector, total consumption reduces by 22% by 2050 in the NDC 25 compared to the BaU scenario, as a result of switch to more efficient heavy trucks, light trucks and light duty vehicles. Thus, diesel oil consumption reduces 29% in the NDC 25 compared to the BaU scenario in 2050. Gasoline consumption reduces by 39% in the NDC 25 compared to BaU scenario in 2050.

In the industry sector, total consumption reduces in the NDC 25 by 6% compared to the BaU scenario in 2050. There is a fuel switch from coal to natural gas, electricity and district heating.

In the commercial sector there is up to 15% reduction in the total final consumption. The share of coal in the commercial energy consumption (which is mainly used for heating) in 2050 decreases from the 25% in the BaU to 9% in the NDC 25. Coal is mainly replaced by natural gas and electricity. The share of gas increases from 7% in the BaU to 19% in the NDC 25 in 2050. The share of electricity rises from 27% in the BaU to 42% in the NDC 25.

5.4 *Implications for Energy Poverty*

Energy poverty (or unmet demand) indicator is not explicitly tested in the model due to lack of data. However, marginal prices for heating were analyzed to account for the affordability dimension of energy poverty, as heating is the highest end-use service in the residential sector in Kazakhstan. The NDC 25 scenario has resulted in an increase in the marginal price of useful energy for heating by 125% and 288% by 2030 and 2050 respectively compared to the BaU (Fig. 5). This clearly indicates that additional investment in technology and more expensive fuel results in increased costs for heating, which can have negative impact for population, particularly on low income and vulnerable households.

Despite the negative impact on energy affordability (which can be mitigated by appropriate policies), there is an improved access to energy infrastructure in the NDC 25. Gas pipelines are constructed to all regions without access to gas in the NDC 25. Coal is fully phased out in the residential sector.

6 Recommendations for Policy Makers

The overall target as set by Kazakhstan's "Strategy 2050" and the Green Economy Concept to reach 50% of renewable and alternative energy sources by 2050 is very close to the least-cost emissions reduction pathway (NDC 25) as demonstrated by modeling results here (49% of renewable energy sources by 2050). Comparing values for installed capacity by energy source in the Green Economy Concept with this study demonstrate similar installed capacities for gas (23–24 GW) and wind

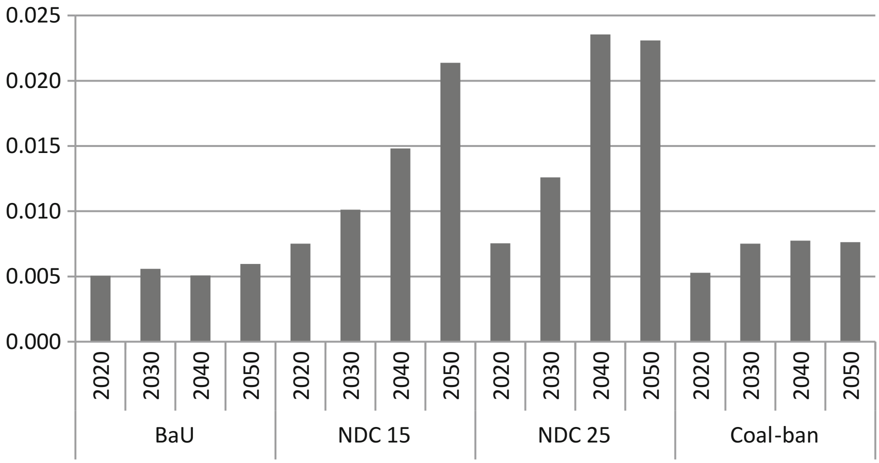

Fig. 5 Marginal price of useful energy for heating, USD/MJ

(14–15 GW). Capacity of coal power plants is also similar (5–6 GW) with the Green Economy Concept, as only 6 GW (out of 13 GW installed) is utilized in the NDC 25 scenario in 2050. The values for solar, hydro and nuclear are different (Table 4). According to the modeling results, nuclear power generation was not selected, while the renewable energy potential available at the lowest cost is fully utilized. Methodology, input data and assumptions used for the preparation of the Green Economy Concept and the Fuel-energy complex development concept till 2030 are not available for the public, thus making it challenging to compare assumptions and input data.

Compared to the results of the WEO 2017 for Eastern Europe/Eurasia region in the 450 scenario, Kazakhstan may need to reduce its fossil fuel power generation substantially more compared to the current study. Eastern Europe/Eurasia region have the following fuel mix for electricity generation in the 450 scenario: 30% nuclear, 21% gas, 27% hydro, 3% coal, with the remaining (46%) provided by renewable energy sources in 2040.

Table 4 Total installed capacity in 2050, GW

	The green economy concept	This study (NDC 15)	This study (NDC 25)
Gas	23	15	24
Wind	15	14	14
Solar	15	9	9
Coal	5	18	13 (5 GW utilized)
Nuclear	2	0	0
Hydro	4	11	11
Total	63	68	72

Coal has been used as an inexpensive and abundant resource for energy generation in the country. Due to the reduction of demand for coal globally and low export levels, the coal industry of Kazakhstan is mainly oriented for domestic use. The results presented here depict that the plan to increase coal consumption as set by the “Fuel-energy complex development concept till 2030” is not consistent with Kazakhstan’s climate pledge. The modeling results demonstrated that in 2030 there is a 25% reduction in the use of coal in the NDC 25 compared to the base year level. Fulfilling the NDC target would mean inevitable reduction/elimination of the consumption of coal. Carbon pricing and market mechanisms (such as ETS) can serve as an effective tool for achieving emissions reduction targets. Modeling results suggest that the ETS sectors contribute to the highest emissions reductions at the lowest cost, indicating that it can be an effective tool if it is appropriately designed and operated.

Kazakhstan has considerable gas supply potential, as it has its own gas reserves. Several possible routes for providing a gas to capital Astana city (with further extension to northern and eastern locations) have been discussed by the Government of Kazakhstan in the past. However, to date (2017), the investment decision for construction of a gas pipeline to northern and central regions has not been made yet. The results of this study suggest that the construction of gas pipelines to the northern, central and eastern regions of Kazakhstan is a necessary action to achieve emissions reduction targets as natural gas is the most economically feasible alternative to coal. Gas fired power plants can serve as a back-up capacity for balancing the system with high shares of renewable energy sources. “Coal to gas” strategy alone is not sufficient, as additional mitigation actions such as deployment of large shares of renewable energy sources (by up to 50%), energy efficiency improvements (heat savings in buildings, efficiency of transport technologies and early retirement of inefficient power plants) are necessary.

Despite the official announcements of Kazakhstan on its contribution to climate change mitigation (Ministry of Energy of the Republic of Kazakhstan 2017), high level officials stated that Kazakhstan will continue to rely on coal (as the least expensive fuel) and will not deploy alternative energy sources (due to its high cost) (Tengrinews 2017). Thus, compared to the current energy policies and mitigation actions which appeared to be inefficient, not fully implemented and sometimes contradictory, the actions proposed by these modeling results (NDC 25) are quite ambitious.

Negative implications of climate mitigation actions on energy affordability (due to higher prices) can be mitigated by providing subsidies on building energy retrofits, on clean technologies, with targeted support for low income and vulnerable population.

Analyses based on integrated energy and emissions modeling should be promoted and deployed in the country, to provide different views and pathways on the energy system development and to provide verification and comparison of the results.

7 Conclusion

Fulfilling the 25% emissions reduction target requires not only a coal ban but also the promotion of zero emission sources, which can be achieved by extending the gas network to the non-gasified regions, accelerated retirement of existing old and inefficient power plants and deployment of renewable energy sources. The share of renewable energy (including hydro) could represent half of the electricity generation mix. The remaining share should be attributed to gas-fired power plants. In other words, the overall target as set by Kazakhstan's "Strategy 2050" and "Green Economy Concept" to reach 50% of renewable and alternative energy sources by 2050 is very close to the least-cost 25% emissions reduction pathway.

Carbon pricing and market mechanisms (such as ETS) can be effective tools for climate change mitigation. Due to regulated (relatively low) energy prices, the future of the construction of gas pipelines largely relies on a strong political will to implement pricing reforms and/or allocation of funding from the Government. Additionally, a gradual coal ban across all sectors of the economy is a fundamental step towards achieving emissions reductions.

Coal is also fully phased-out in the residential sector in both NDC scenarios, in favor of natural gas, electricity and LPG, with substantial building energy retrofit measures. Mitigation actions in the transport sector include utilization of more efficient heavy trucks, light trucks and light duty vehicles, while in the commercial and public sector there is a substantial reduction of coal use in favor of gas and electricity.

Meeting the NDC target is technically possible, however, the corresponding abatement costs appear to be rather high at around 36–59 USD per tonne of CO_2 eq. by 2030 and 209–281 USD per tonne of CO_2 eq. by 2050 (if the NDC target is applied for 2050). Marginal price for heating increases substantially in the NDC 25, which can worsen energy affordability of households (if no actions supporting energy poor are taken).

The results of this work can be used by policy makers in formulating and justifying a climate mitigation roadmap.

Future studies need to be conducted to explore 40%, 50% or even higher emissions reductions compared to 1990 level by 2050. To provide more arguments necessary for energy transition, future studies are needed to quantify all external damage and costs of the existing energy system, consequences of climate change to the national economy and the health of population. Future studies should also be conducted to better quantify "unmet demand" based on Households Survey data of thermal comfort, indoor air temperature and behavioral issues. Finally, a finer representation of operating parameters of the power system (e.g. ramping rate, minimum up and down times) would be necessary to explore the full implications of the integration of renewable energy sources.

References

Government of the Republic of Kazakhstan (2013) Concept for transition of the Republic of Kazakhstan to green economy. http://gbpp.org/wp-content/uploads/2014/04/Green_Concept_En.pdf. Accessed 10 Oct 2017

Government of the Republic of Kazakhstan (2014) Fuel-energy complex development concept till 2030. https://tengrinews.kz/zakon/pravitelstvo_respubliki_kazahstan_premer_ministr_rk/promyishlennost/id-P1400000724/. Accessed 11 Oct 2017

IEA (2017) World energy outlook 2016

IETA (2016) Kazakhstan: an emissions trading case study. http://www.ieta.org/resources/2016%20Case%20Studies/Kazakhstan_Case_Study_2016.pdf. Accessed 7 Oct 2017

Karatayev M, Hall S, Kalyuzhnova Y, Clarke M (2016) Renewable energy technology uptake in Kazakhstan: policy drivers and barriers in a transitional economy. Renew Sustain Energy Rev 66:120–136

Kazmaganbetova M, Suleimenov B, Ayashev K, Kerimray A (2016) Sectoral structure and energy use in Kazakhstan's regions. In: 4th IET clean energy and technology conference (CEAT 2016), Kuala Lumpur, p 9(7). https://doi.org/10.1049/cp.2016.1266

Kerimray A, Baigarin K, Bakdolotov A, De Miglio R, Tosato GC (2015) Improving efficiency in Kazakhstan's energy system. In: Lecture notes in energy, vol 30, pp 141–150. https://doi.org/10.1007/978-3-319-16540-0_8

Kerimray A, Baigarin K, De Miglio R, Tosato GC (2016) Climate change mitigation scenarios and policies and measures: the case of Kazakhstan. Clim Pol 16:1–21

Kerimray A, De Miglio R, Rojas-Solórzano L, Ó Gallachóir BP (2017a) Causes of energy poverty in a cold and resource rich country. Evidence from Kazakhstan. Local Environ. https://doi.org/10.1080/13549839.2017.1397613

Kerimray A, Rojas-Solórzano L, Amouei Torkmahalleh M, Hopke PH, Ó Gallachóir BP (2017b) Coal use for residential heating: patterns, health implications and lessons learned. Energy Sustain Dev 40C:19–30

Kerimray A, Kolyagin I, Suleimenov B (2017c) Analysis of the energy intensity of Kazakhstan: from data compilation to decomposition analysis. Energ Effi. https://doi.org/10.1007/s12053-017-9565-9

Law "On gas and gas supply" (2012). https://online.zakon.kz/Document/?doc_id=31107618. Accessed 28 Nov 2017

Ministry of Energy of the Republic of Kazakhstan (2017) Kazakhstan was represented by the Minister of Energy at the climate summit in Paris. http://energo.gov.kz/index.php?id=16460

PMR (2016) Assessment of economic, social and environmental effects of different mitigation policies using combined top-down (CGE-KZ) and bottom-up (TIMES-KZ) models. World Bank project: development of policy options for mid- and long-term emissions pathways and role of carbon pricing. Final report

Sarbassov Y, Kerimray A, Tokmurzin D, Tosato G, De Miglio R (2013) Electricity and heating system in Kazakhstan: exploring energy efficiency improvement paths. Energy Policy 60:431–444

Suleimenov B, De Miglio R, Kerimray A (2016) Emissions reduction potential assessment in regions of Kazakhstan using TIMES-16RKZ model. IEA-ETSAP Workshop, Madrid. https://www.slideshare.net/IEA-ETSAP/emissions-reduction-potential-in-regions-of-kazakhstan-using-times16rkz-model. Accessed 20 Sept 2017

Tengrinews (2017) Cheap coal is available for 300 years, said Deputy. https://tengrinews.kz/kazakhstan_news/deshevogo-uglya-nam-hvatit-na-300-let-deputat-331922/

The Climate Action Tracker (2017) Kazakhstan. http://climateactiontracker.org/countries/kazakhstan.html. Accessed 5 Oct 2017

UNFCCC (2016a) Intended Nationally Determined Contribution—Submission of the Republic of Kazakhstan. http://www4.unfccc.int/submissions/INDC/PublishedDocuments/Kazakhstan/1/INDCKz_eng.pdf. Accessed 25 Jun 2017

UNFCCC (2016b) National Inventory Submissions 2016. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/9492.php. Accessed 25 Aug 2017

World Bank (2017) Kazakhstan. Available from http://www.worldbank.org/en/country/kazakhstan. Accessed 17 Aug 2017