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Economics of Climate Change in Azerbaijan, Kazakhstan, and Uzbekistan: The Economics of Reducing Greenhouse Gas Emissions in the Energy and Transport Sectors

TA8119-REG Economics of Climate Change in Central and West Asia – Mitigation Component (Financed by the Asian Clean Energy Fund under the Clean Energy Financing Partnership Facility)

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For the State Agency on Alternative and Renewable Energy Sources of the Republic of Azerbaijan, the Ministry of Energy of the Republic of Kazakhstan, and the Ministry of Finance of the Republic of Uzbekistan

Asian Development Bank

ABBREVIATIONS

ADB	Asian Development Bank
AZN	Azerbaijan manat
BAU	Business as usual
CCNG	Combined cycle natural gas
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
CFL	Compact fluorescent light
CHP	Combined heat and power
CNG	Compressed natural gas
CSP	Concentrated solar power
CO_2e	Carbon dioxide equivalent
ETS	Emission trading scheme
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoules
GWP	Global warming potential
HFCs	Hydrofluorocarbons
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KZT	Kazakhstan tenge
LEAP	Long-range Energy Alternatives Planning system
LPG	Liquefied petroleum gas
MACC	Marginal abatement cost curve
MJ	Megajoules
NAMA	Nationally Appropriate Mitigation Action
NE	Non-energy
OECD	Organization for Economic Co-operation and Development
O&M	Operating and maintenance
PM	Particulate matter
PPP	Purchasing power parity
PV	Photovoltaic
RETA	Regional Technical Assistance
SAARES	Azerbaijan State Agency for Alternative and Renewable Energy Sources
SCNG	Single cycle natural gas
SEI	Stockholm Environment Institute
SOCAR	State Oil Company of the Azerbaijan Republic
TA	Technical assistance
T&D	Transmission and distribution
TOE	Tonne of oil equivalent
TPES	Total primary energy supply
TPP	Thermal power plant
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USC	Ultrasupercritical
UZS	Uzbekistan som
WtE	Waste to energy

NOTE In this report, "$" refers to US dollars

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I. INTRODUCTION AND BACKGROUND

1. The Asian Development Bank (ADB) Central and West Asia developing member countries of Azerbaijan, Kazakhstan, and Uzbekistan have growing populations and abundant natural resources which have helped them liberalize their economies and stimulate development since gaining independence from the Soviet Union in the early 1990s. Between 2000 and 2010, real Gross Domestic Product (GDP) grew 95% in Uzbekistan, 220% in Kazakhstan, and 400% in Azerbaijan. The countries' rich hydrocarbon reserves have been a key contributor to this growth, both as a source of export revenue and for meeting domestic energy requirements. However, reliance on fossil fuels has also led to notably carbon-intensive economies. Fossil-intensive industries are an important source of greenhouse gas (GHG) emissions in Kazakhstan and Uzbekistan, and fossil fuel production for export and domestic use contributes significant fugitive GHG emissions in all three countries. In addition, Azerbaijan, Kazakhstan, and Uzbekistan are still dealing with a legacy of carbon-intensive Soviet infrastructure and capital equipment (in spite of substantial improvements in energy efficiency over the last 15 years), such as power sectors dominated by fossil technologies.

2. Anticipated future population and economic growth promises to put further pressure on energy resources, including greater demand for motorized transport and electricity. If the energy and transport systems of Azerbaijan, Kazakhstan, and Uzbekistan remain as carbon-intensive as today, significant increases in GHG emissions will follow. But this situation also presents an opportunity to re-examine resources and energy options and pursue green-growth strategies that enable increased development with lower climate impacts. The utilization of cost-effective clean energy technologies and the promotion of energy efficiency, fuel switching, and low-carbon transport can play a crucial role in achieving these goals. Understanding the potential of such approaches will also support the region in leveraging public and private sector finance for prioritized mitigation options that contribute to national development goals.

3. This report is a product of a regional technical assistance (RETA) 8119 on the *Economics of Climate Change in Central and West Asia* (the TA) (Box 1) which was conducted over a two-year period to increase the availability of information on the options and costs for reducing GHG

Box 1: Asian Development Bank Regional Technical Assistance 8119: Economics of Climate Change in Central and West Asia

Regional Technical Assistance 8119 (the TA) was approved by the ADB board in July 2012 and is co-financed by the Asian Clean Energy Fund under the Clean Energy Financing Partnership Facility and the Climate Change Fund. The Mitigation Component of the TA started in May 2013 and will be completed in September 2015.Two main project outputs are expected under the TA:

Output 1: The cost of climate change mitigation in energy and transport is estimated in Azerbaijan, Kazakhstan, and Uzbekistan.
Output 2: Climate change mitigation investment opportunities are identified in Azerbaijan, Kazakhstan, and Uzbekistan.

The TA will result in the publication of regional reports on the economics of climate change, nationally appropriate mitigation actions (NAMAs), and climate change investment concept notes. The development of these reports has been complemented by a two-year capacity development program that has trained decision-makers in economic analysis of mitigation measures and systems for greenhouse gas (GHG) emission monitoring, verification, and reporting. A consultant team of Abt Associates, Stockholm Environment Institute, and Nazar Business and Technology, LLC, implements the TA.

emissions (Mitigation Component) and reduce the negative effects of climate change (Adaptation Component) in Central and West Asia. This TA covers the Mitigation Component of the TA, which estimates the cost of reducing GHG emissions and identifies climate change mitigation investment opportunities in the energy and transport sectors of Azerbaijan, Kazakhstan, and Uzbekistan.

4. This report focuses on the first of the Mitigation Component's objectives—analyzing the costs and benefits of mitigation—and is based on a study of potential energy and transport-related abatement options that are aligned with national development priorities. The options' effectiveness in terms of GHG abatement, social costs, and co-benefits was evaluated; and their potential interactions were assessed in a range of scenarios. The study was complemented by a capacity development program for energy and transport experts in Azerbaijan, Kazakhstan, and Uzbekistan focused on analyzing mitigation scenarios using the national models developed during the study.

5. The report is structured as follows:

- Section II summarizes the existing regional context for the energy and transport sectors of Azerbaijan, Kazakhstan, and Uzbekistan in terms of economic activity, energy production and use, structure of electricity generation, GHG emissions, and energy resource potentials.

- Section III describes the study's methodology, including techniques used to project energy supply and demand,[1] estimate GHG emissions[2], and analyze the costs, benefits, and co-benefits of mitigation.

- Section IV summarizes the results of the GHG emissions baseline analysis for the study period of 2010-2050. The baseline analysis is built around a scenario where no significant action is taken to reduce emissions beyond existing efforts to improve energy intensity and where countries continue to rely primarily on fossil fuels for energy and transport. This is called the No Action Scenario.

- Section V presents the results of the cost-benefit and co-benefit analyses of the selected mitigation options and emissions scenarios, including the marginal abatement cost curves (MACCs) developed for each country. This section concludes with a discussion of the policy implications of the mitigation analysis.

- Several appendices provide additional documentation on study data and methods as well as references.

[1] Emissions from transport are included under the definition of energy supply and demand here since GHG emissions from transport are all fuel-related.

[2] Although the focus of this study is the energy and transport sectors, the consultant team included GHG emissions from non-energy sectors in the study models to enable linkages between all sectors during the analysis of mitigation scenarios.

II. EXISTING REGIONAL CONTEXT IN AZERBAIJAN, KAZAKHSTAN, AND UZBEKISTAN

6. This study focuses on three countries in Central and West Asia: Azerbaijan, Kazakhstan, and Uzbekistan. The region has highly diverse and rich ecological zones, with mountains, flatlands, and deserts in each country. All three countries have posted strong economic growth over the last decade. Between 2000 and 2010, real GDP grew 95% in Uzbekistan, 220% in Kazakhstan, and 400% in Azerbaijan. Per capita real GDP in purchasing power parity (PPP, at constant 2011 international $) improved as well, particularly in Kazakhstan and Azerbaijan. Industry and services together account for over 80% of GDP in the three countries, with services playing the biggest role in Kazakhstan and Uzbekistan and industry in Azerbaijan. The contribution of agriculture generally declined across the region, with Uzbekistan remaining the most dependent on this sector. Table 1 presents the performance of each country according to selected indicators.

Table 1: Selected Social and Economic Indicators of Azerbaijan, Kazakhstan, and Uzbekistan

Indicators	Azerbaijan			Kazakhstan			Uzbekistan		
	2000	2005	2013	2000	2005	2013	2000	2005	2013
Population (million) [a]	8.07	8.50	9.42	14.9	15.1	17.0	24.7	26.2	30.2
Population growth rate (%) [a]	1.1	1.2	1.3	-0.3	0.9	1.4	1.4	1.2	1.6
% Urban population [a]	51.1	52.5	53.2	56.3	57.1	54.9	37.2	36.1	51.2 [a]
GDP per capita, PPP (constant 2011 $) [b]	4,459	8,052	16,593	9,706	15,619	22,470	2,481	3,041	5,002
Growth rate of real GDP [a]	11.1	26.4	5.8	9.8	9.7	6.0	3.8	7.0	8.0
Sector Contribution to GDP (%) [a]									
Agriculture	17	10	6	9	7	5	34	30	19
Industry	45	63	62	40	39	38	23	29	33
Services	38	27	32	51	54	57	43	41	48

GDP = gross domestic product, PPP = purchasing power parity.
Sources: [a] Asian Development Bank (2011b); [b] World Bank (2015b).

1. Energy Production and Use

7. Azerbaijan, Kazakhstan, and Uzbekistan's hydrocarbon reserves have served as the engine for their recent economic growth, both as a source of export revenue and for meeting domestic energy demand (Abt Associates 2014b). Table 2 presents the overall structure of the total primary energy supply (TPES) in the region in 2000, 2005, and 2010, which covers energy supply for both energy and transport. Overall total TPES increased by 45%, due to growth in Kazakhstan. TPES in Azerbaijan declined by 3% and in Uzbekistan by 14%, due to significant energy efficiency improvements in both countries. As shown in Table 2, fossil fuels (coal, natural gas, and petroleum products) provide 99% of combined TPES for the study countries. Coal is the single largest energy source in Kazakhstan, while natural gas dominates in Azerbaijan and Uzbekistan. During the period from 2000 to 2010, Uzbekistan showed a growing dependence on natural gas, and the two other countries on petroleum products. Meanwhile, the share of hydropower decreased in Azerbaijan and Kazakhstan and increased in Uzbekistan.

Table 2: Structure of Total Primary Energy Supply in Azerbaijan, Kazakhstan, and Uzbekistan, 2000–2010

Indicators	Azerbaijan			Kazakhstan			Uzbekistan		
	2000	2005	2010	2000	2005	2010	2000	2005	2010
TPES (thousand toe)	12,059	12,858	11,684	53,689	60,983	77,997	50,219	46,346	43,223
Energy resource share in TPES (%)									
Coal				47.9	53.0	46.7	1.7	1.5	1.9
Natural gas	68.4	66.0	67.8	13.6	9.2	11.1	82.7	85.1	84.6
Petroleum products	29.7	31.7	31.1	39.2	39.9	44.6	12.6	10.0	9.1
Hydropower	1.4	1.9	0.6	1.2	1.1	0.9	1.0	1.1	2.0
Wind									
Solar									
Biomass	0.7	0.6	0.8	0.1	0.1	0.1			

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

8. The energy intensity of GDP is defined as energy use (i.e., TPES) per unit of GDP, which provides a picture of an economy's energy use efficiency, i.e., the amount of energy required per dollar of GDP. To compare across countries, GDP in constant 2010 $ was used in this study. All three countries' energy intensity declined from 2000 to 2010, with Uzbekistan showing the most dramatic decline of 55.6% during that time period (Table 3). TPES per capita increased in Kazakhstan but declined in Azerbaijan and Uzbekistan. The GHG intensity of TPES increased in Azerbaijan, declined in Kazakhstan, and remained flat in Uzbekistan.

Table 3: Energy Indicators for Azerbaijan, Kazakhstan, and Uzbekistan, 2000–2010

Indicators	Azerbaijan			Kazakhstan			Uzbekistan		
	2000	2005	2010	2000	2005	2010	2000	2005	2010
TPES per capita (toe)	1.5	1.5	1.3	3.6	4.0	4.8	2.0	1.8	1.5
TPES/GDP (MJ 2010 $)	38	22	9	34	23	22	108	77	48
Greenhouse gas intensity of TPES (Kg CO_2e/GJ)	66	73	84	97	100	94	56	58	58

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

2. Structure of Electricity Generation

9. Table 4: presents the structure of installed electricity generation in Azerbaijan, Kazakhstan, and Uzbekistan. As of 2010, the total installed electricity generation capacity in the region was estimated at 38,468 MW. The composition was approximately 40% natural gas, 38% coal, 8% oil, and 12% hydropower. In Kazakhstan, coal dominates power generation. In Azerbaijan and Uzbekistan natural gas powers most of the electricity generation. During the period from 2000 to 2010, there was a minor shift to renewables for power generation in Uzbekistan and a slight decrease in Azerbaijan and Kazakhstan.

Table 4: Structure of Installed Electricity Generation Capacity in Azerbaijan, Kazakhstan, and Uzbekistan, 2000 - 2010 (MW)

Capacity (MW)	Azerbaijan			Kazakhstan			Uzbekistan		
	2000	2005	2010	2000	2005	2010	2000	2005	2010
Coal				12,220	12,442	12,605	2,283	2,283	2,283
Natural gas	3,157	3,632	4,780	2,291	2,465	2,936	7,230	8,052	7,835
Petroleum products	970	968	1,037	1,931	1,946	1,949	271	271	271
Hydropower	820	970	785	2,227	2,247	2,255	1,690	1,710	1,730
Wind			1.7						0.8
Solar									
Total	**4,947**	**5,570**	**6,604**	**18,669**	**19,100**	**19,744**	**11,474**	**12,317**	**12,120**

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

3. Greenhouse Gas Emissions

10. As a result of this heavy fossil fuel–based energy mix, the economies of Azerbaijan, Kazakhstan and Uzbekistan are carbon-intensive. As presented in Table 5, total GHG emissions have grown in Azerbaijan and Kazakhstan, while they declined in Uzbekistan, where energy efficiency has improved significantly. In all three countries, more than 75% of total 2010 GHG emissions are a result of activities in the energy and transport sectors.

Table 5: Greenhouse Gas Emissions in Azerbaijan, Kazakhstan, and Uzbekistan, 2000–2010 (million metric tons CO_2e)

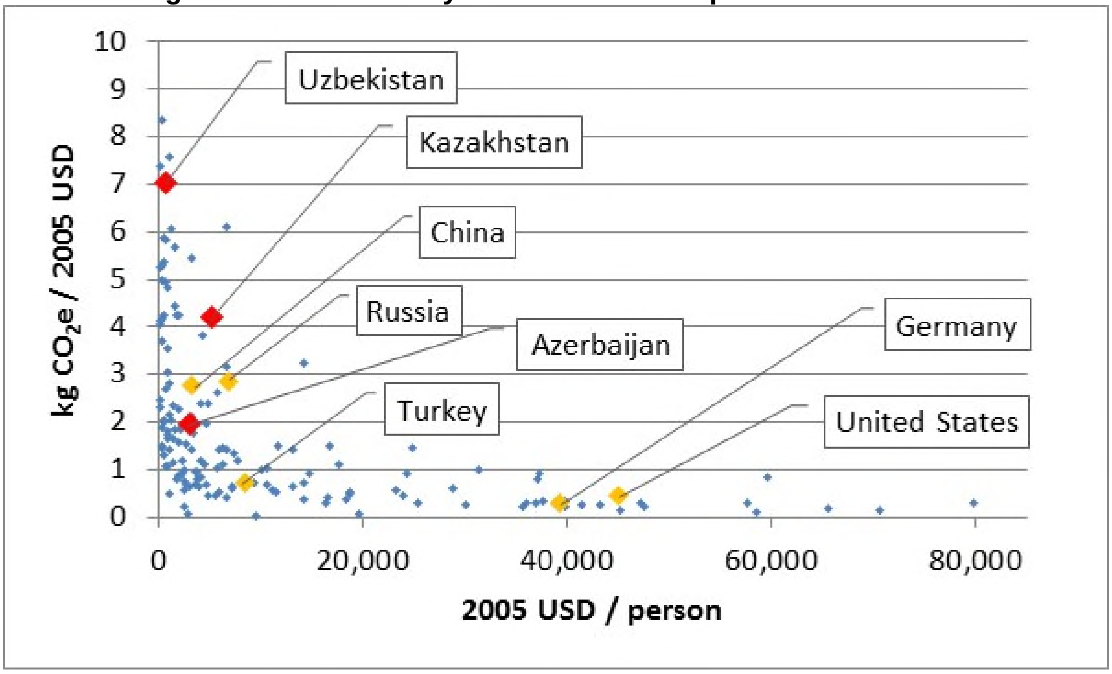
	Greenhouse Gas Emissions (Million metric tons CO_2e)		
Country	2000	2005	2010
Azerbaijan	36	44	47
Kazakhstan	223	275	329
Uzbekistan	148	148	137

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)s

11. Even though the three countries account for a small fraction of global GHG emissions—about 1% of global carbon dioxide (CO_2) emissions in 2013 (European Commission JRC Joint Research Centre, 2015)—when compared to countries with similar per capita income, all three show relatively high GHG intensity of GDP (Figure 1). Uzbekistan's and Kazakhstan's intensities are notably higher than Azerbaijan's (and China's and Russia's, for example), while Azerbaijan's is somewhat lower but still greater than in nearby countries such as Turkey and Georgia. This is due to the continued reliance on fossil fuels in buildings and for industry, transport, and power – oil and natural gas in Azerbaijan, oil and coal in Kazakhstan, and natural gas in Uzbekistan.

12. Energy-intensive industries are an important source of the GHG emissions in Kazakhstan and Uzbekistan, and fossil fuel production for export and domestic use contributes significant fugitive emissions in all three countries. In addition, Azerbaijan, Kazakhstan, and Uzbekistan are still dealing with the legacy of an energy-intensive Soviet infrastructure, in spite of significant improvements in energy efficiency over the last 15 years, and their power sectors remain dominated by fossil fuel technologies.

Figure 1: GHG Intensity of GDP vs. Per Capita Income in 2012



Sources: World Bank (2015) and European Commission JRC Joint Research Centre (2015).

4. Energy Resource Potentials

13. The endowment of energy resources favors fossil fuels in all three countries (Table 6). Kazakhstan has abundant coal resources, Azerbaijan has significant oil and natural gas resources, and Uzbekistan has large natural gas resources and modest coal and coal reserves. Given these large reserves, all three countries are expected to continue to rely heavily on fossil fuels in the next few decades.

14. Significant potential for renewables exists, although these are less well understood and will need to be assessed in more detail (Table 7). Uzbekistan has strong potential for solar energy, Kazakhstan has significant wind potential and moderate potential for hydropower, and Azerbaijan has moderate potential for wind and solar energy. Thus, all three countries have significant room to increase the share of renewables in the primary energy mix.

Table 6: Fossil Fuel Reserves

Country	Reserves as of 2011		
	Crude Oil (billion barrels)	Natural Gas (trillion m^3)	Coal (billion tonnes)
Azerbaijan	7	0.9	NA
Kazakhstan	28.6	1.3	35
Uzbekistan	0.6	1.1	1.9

Sources: BP (2014); Ministry of Industry and New Technologies of Kazakhstan (2014); U.S. Energy Information Administration (2014).

Table 7: Potential for Generating Energy from Renewable Resources

Country	Annual Yield (billion kWh)				
	Large hydro	Small Hydro	Solar	Wind	Biomass
Azerbaijan	11	5	39.6	86.4	0.77
Kazakhstan	51	11	4	930	NA
Uzbekistan	20.9		2,055	4.6	3.5

Sources: Asian Development Bank (2014); Centre of Hydrometeorological Service (2008); Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012); Ministry of Environment and Water Protection of the Republic of Kazakhstan (2013); Mitsubishi Heavy Industries et al. (2014); Suleymenov (2014b); UNFCCC CDM Executive Board (2012b).

III. STUDY APPROACH AND METHODOLOGY

A. Modeling Tools

15. The core modeling for this study—of energy and transport systems, air pollutant emissions, and direct costs and benefits of mitigation—was carried out using the Long-range Energy Alternatives Planning (LEAP) system, a modeling tool developed by the Stockholm Environment Institute (SEI) (Stockholm Environment Institute 2015b). LEAP is a platform for building integrated models of energy and transport systems and GHG emissions and is widely used for mitigation policy analysis. Over 30 countries have employed LEAP models in preparing National Communications to the United Nations Framework Convention on Climate Change (UNFCCC), and a variety of national energy, economics, and environment agencies rely on LEAP as a planning tool of choice. Further information about the features and algorithms of the LEAP platform is documented in SEI (2015a).

16. Key features of the LEAP tool include support for constructing different scenarios within a model, an annual time step for input data and results (with smaller time slices optionally considered for particular sources of energy demand and supply), and support for multiple modeling methodologies within an energy and transport accounting framework (Bhattacharyya 2011). In Asia, some recent publications based on LEAP studies include “Long-Term Energy and Development Pathways for India” (Indo-German Centre for Sustainability 2014), “Strategies for Development of Green Energy Systems in Mongolia” (von Hippel et al. 2014), and “Reinventing Fire: China” (Rocky Mountain Institute et al. forthcoming). At the TA’s inception, the European Commission was working with LEAP in Kazakhstan and Azerbaijan to support the development of climate mitigation scenarios and policy portfolios for mitigation and adaptation planning (European Union 2015), and Uzhydromet in Uzbekistan had independently started using LEAP for preparation of the country’s national communications to the UNFCCC.

17. LEAP was selected for this study because of its flexibility, transparency, and user friendliness. The methodological options inherent in the platform allow useful models to be constructed even when data are scarce—as is sometimes the case in Azerbaijan, Kazakhstan, and Uzbekistan. Top-down approaches can be taken for sectors with limited data, while more detailed analyses of technologies and energy end uses can be conducted for sectors with more available information. LEAP’s inline documentation capabilities and straightforward syntax for coding formulas within a model (which closely resembles the syntax in Microsoft Excel) promote clarity about assumptions, facilitating broader use and review of modeling outputs (Stockholm Environment Institute 2015a). The tool also has a number of features that increase user productivity and accelerate adoption, including a Microsoft Windows graphical user interface, integration with Microsoft Office tools, built-in unit conversions, and a library of GHGs and global warming potentials (GWPs) from Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. In addition, SEI provides LEAP (with user support) free of charge to government, academic, and non-profit institutions in Azerbaijan, Kazakhstan, and Uzbekistan, making it easier for stakeholders to continue to use the national models after the TA’s completion. Stakeholders in all three countries indicated strong interest in extensive training on the use of LEAP to build up internal government capacity for its use (Abt Associates 2014).

18. At the completion of the TA, the three models, including the data and assumptions used, will be turned over to the national counterparts in Azerbaijan, Kazakhstan, and Uzbekistan. They will also be posted on ADB’s website, thereby making it easier for relevant stakeholders to update the models in the future.

19. The analysis of co-benefits was done separately from the national LEAP models, using quantitative outputs from the models, such as changes in air pollutants, renewable energy generation, and energy consumption by fuel type. To analyze the human health co-benefits of reduced air pollution concentrations, the consultants developed a spreadsheet model for linking air pollution concentrations to human mortality and for monetizing the value of avoiding these mortalities. The approach is documented in the *Interim Report* for the TA (Abt Associates 2014c).

B. Model Scope and Boundaries

20. Three national-scale LEAP models were constructed for this study—one for each of Azerbaijan, Kazakhstan, and Uzbekistan. National stakeholders requested this approach due to pronounced differences in the availability and quality of input data, structure of the energy and transport systems, and mitigation strategies in the countries. These factors implied that the modeling for the countries should be at different levels of detail and have varying sectoral emphases. Using this approach, the individual country models can also be turned over to national stakeholders for further use and elaboration at the end of the study project.

21. The analysis of the three countries' energy and transport systems was carried out in two stages. The first stage, related to projecting emissions to 2050 and analyzing the direct costs and benefits of mitigation, was done in LEAP. The second stage, related to analyzing the co-benefits of mitigation, was prepared as follows:

(i) The reduction in air pollutants was estimated using LEAP outputs;
(ii) The assessment of human health benefits of mitigation was developed in a separate spreadsheet model using quantitative outputs from LEAP; and
(iii) The energy security benefits were estimated based on quantitative outputs from LEAP.

22. The scope of the analysis is summarized in Table 8.

Table 8: Scope and Analytical Approach

Subsector	Direct Costs and Benefits Modeled in LEAP	Co-benefits					
		Air Pollution Reduction	Human Health (i.e., reduced mortality)	Energy Security			
				Fuel Saving	Energy intensity	Carbon intensity	Percent share of renewables in energy supply
Electricity generation	✓	✓	✓	✓	✓	✓	✓
Heat Generation	✓	✓		✓	✓	✓	✓
Transport	✓	✓	✓	✓	✓	✓	

Source: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

23. The national LEAP models simulate the energy and transport systems for the corresponding country, including all sources of energy demand and supply that cause GHG emissions. Energy demand is categorized by economic sector, subsector, fuel, and (where possible) end use. On the supply side, all energy producing industries—from primary resource extraction through conversion and delivery to end customers—are represented. Physical constraints on primary (naturally occurring) energy sources are also represented, such as reserves of fossil fuels and annual yields of renewable resources. Energy imports and exports across the national border are allowed, although the origin of imports and the destinations for exports are not modeled

explicitly. Thus, for example, purchases from particular trading partners are not distinguished within total imports.

24. The models estimate all GHG emissions from energy, transport, and non-energy sources as well as emissions of other significant air pollutants from energy use. Table 9 lists the GHGs and air pollutants covered.

Table 9: GHGs and Air Pollutants Covered in the National Cost-Benefit Models

Greenhouse Gases	Air Pollutants
- Carbon dioxide - Methane - Nitrous oxide - Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and other high global warming potential (GWP) gases	- Carbon monoxide - Nitrogen oxides - Non-methane volatile organic compounds - Particulate matter - Sulfur dioxide

Source: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

25. LEAP can report estimates of GHG emissions in terms of the mass of each individual pollutant (e.g., tonnes of methane) or as carbon dioxide equivalent (CO_2e). Conversions to CO_2e can be carried out using 20, 100, or 500-year GWPs. In this report, all quantities of CO_2e are calculated using the 100-year GWPs in IPCC's Second Assessment Report (Houghton and Intergovernmental Panel on Climate Change 1996).

26. The models also incorporate an accounting of direct costs and benefits of the energy and transport systems and mitigation measures. These costs and benefits are *social* costs and benefits, meaning that they are figured from the perspective of society as a whole without explicit consideration of distributional impacts (i.e., who pays or benefits). Four primary types are represented:

(i) Capital (equipment) costs
(ii) Operating and maintenance (O&M) costs
(iii) Fuel costs
(iv) Other implementation costs for mitigation measures (e.g., governmental program administration costs)

27. Reductions in any of these costs as a result of mitigation are considered a benefit—for instance, decreased fuel costs due to an efficiency measure would be a benefit. All direct costs and benefits are expressed in real (constant monetary year) terms in the models.[3] When discounted costs are reported, a 7% real discount rate is used.

28. It should be emphasized that the costs and benefits included in the LEAP accounting do not represent all possible costs and benefits of mitigation. For example, they exclude potential damages due to climate change (e.g., to agriculture, infrastructure, or ecosystems), which by themselves can justify mitigation action in some cases (Oppenheimer et al. 2014). However, evaluating mitigation options on the basis of their direct social costs and benefits provides a simple and generally conservative estimate of their usefulness for GHG abatement. The study's co-benefits assessment then deepens the analysis by considering key indirect costs and benefits of mitigation (see Sections III.C and V.B).

[3] Economic variables including GDP, value added, and fuel prices are also expressed in real terms in the models.

29. The national models comprise both historical data and projections of energy use, emissions, and costs. The extent of the historical period in each model was determined by available historical data, notably national energy balances and fuel price data. The projections in all models run through 2050. Table 10 defines the historical and projection periods in the three models.

Table 10: Model Years

Country	Historical Period	Projections
Azerbaijan	2000–2010	2011–2050
Kazakhstan	2000–2012	2013–2050
Uzbekistan	1995–2011	2012–2050

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

C. Indirect Co-Benefits

30. The analysis of the indirect co-benefits of mitigation focuses on air pollution, human health, and energy security benefits, as these are the metrics for which data are readily available to quantify impacts.

31. The human health assessment focuses on the benefits of reduced air pollutant concentrations from mitigation options that reduce emissions from electricity generation and transport. It does not cover emissions from mitigation options that reduce emissions from heating. Electricity and transport are the two subsectors for which sufficient data and methods are available for establishing a quantifiable relationship between air pollutants and health co-benefits, such as reduced mortality.

32. The human health benefits analysis is based on emissions of fine particulate matter ($PM_{2.5}$), since this pollutant has dominated cost-benefit analyses of reduced air pollution in the United States and elsewhere (U.S. EPA, 2011). As documented in the *Interim Report* for this TA, inhaling $PM_{2.5}$ can lead to adverse health outcomes in humans, including premature mortality (Abt Associates 2014c). This TA estimates the avoided mortalities from reducing primary $PM_{2.5}$, and the associated sulfur dioxide and nitrogen oxides, and then monetizes the value of these avoided mortalities.

33. The consultants also quantified the energy security benefits of the proposed mitigation actions. Increased energy security means that a country is more resilient and better able to withstand shocks and minimize disruptions in economic functioning, human health and environmental quality. Several metrics are applied in this report to analyze whether Azerbaijan, Kazakhstan, or Uzbekistan are becoming more or less energy secure. These metrics include the following:

(i) Fuel savings (million gigajoules);
(ii) Energy intensity (energy consumption per unit of GDP);
(iii) Carbon intensity (CO_2 emissions per unit of GDP); and
(iv) Percentage share of renewable energy in energy supply.

D. Scenarios

34. Evaluation of scenarios is a central feature of the analysis conducted for this study. A scenario is an internally consistent, physically plausible storyline that describes how the economy, energy system, pollutant emissions, and costs might evolve over time. It includes

exogenous inputs or assumptions and modeling outputs calculated on the basis of the assumptions.

35. In LEAP, scenarios are developed in a hierarchy allowing each scenario to inherit inputs or assumptions from other scenarios as desired. In this way, a scenario can mirror a pre-existing scenario except for a few key parameters, isolating the effects of these changes. The foundational scenario in this study is a no action or business-as-usual scenario. Designed in collaboration with national stakeholders, it envisions a future in which no significant new mitigation policies are enacted and historical trends in key drivers of energy use and emissions continue. In other words, it assumes the past is an essentially reliable guide to the future. In several cases, policies and targets that governments have recently introduced to reduce GHG emissions are excluded from the No Action Scenario. Instead, these are analyzed as mitigation options to properly determine their abatement potential and cost-effectiveness. Table 11 lists key targets and policies in each country that are excluded from the *no action* scenario and instead are analyzed as mitigation options.

Table 11: Existing Policies and Targets Not Reflected in the No Action Scenario

Azerbaijan	Kazakhstan	Uzbekistan
- Renewable power target - State Program of Poverty Reduction - Introduction of Euro-4 vehicle standards	- Early vehicle retirement - Emissions Trading System - Alternative power target - Natural gas power target - Green growth strategy - Introduction of Euro-5 vehicle standards	- Residential building efficiency standards - State program on development of hydropower - Solar road map

Sources: Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

36. The No Action Scenario comprises both historical data and a projection to 2050 and serves as the baseline for the mitigation analysis. All mitigation scenarios inherit from the No Action Scenario and are measured in comparison to it.

37. Three types of mitigation scenarios are explored:

1) **Pricing mitigation mini-scenarios**, which add one discrete price-based mitigation option to the No Action Scenario, such as a change in fuel or carbon prices.

2) **Technical mitigation mini-scenarios**, which add one discrete physical or behavioral mitigation option to the No Action Scenario, such as a change in technology deployment, differential resource management practices, or the attainment of a non-price target.

3) **Combined mitigation scenarios**, which combine multiple technical mini-scenarios into a portfolio of mitigation options.[4]

38. This classification scheme facilitates the analysis of particular mitigation options and the potential interactions of mitigation technologies and practices. To maximize the relevance of the mitigation analysis, the mini-scenarios for each country were developed following a fundamental rule: that each scenario be based on *nationally appropriate* mitigation options that have been considered in the particular country and for which there is national input data on the impacts and costs of the corresponding mitigation option. These requirements ensure that the mitigation

[4] The combined scenarios focus on combinations of technical options only because the pricing mini-scenarios by default engage (implicitly or explicitly) all technical options that are cost-effective under the new prices. Thus the pricing mini-scenarios already represent self-consistent combinations of technical measures.

options are appropriate and feasible in each country. For the purposes of this study, nationally appropriate data are data produced in the modeled country or, in a few cases, data produced in a neighboring country or region that are clearly applicable to the modeled country.[5] The mini-scenarios were defined and their input data were collected through reviews of national literature and consultations with national stakeholders. Mini-scenarios were not created for potential mitigation options for which no nationally appropriate modeling inputs could be determined. This approach was intentional and designed to produce an analysis that is as reflective of national circumstances, feasibility, and plans as possible.

39. Table 12 lists the technical mitigation mini-scenarios considered for Azerbaijan, Kazakhstan, and Uzbekistan. Table 13 lists the pricing mini-scenarios considered. No pricing scenarios were developed for Uzbekistan given the limited availability of historical fuel price data to inform the development of a price-responsive model for that country. Table 14 lists the combined mitigation scenarios considered for each country.

Table 12: Technical Mitigation Mini-Scenarios

Name	Sector	Description
		Azerbaijan
Residential CFL Lighting	Residential	By 2030, all lightbulbs in both urban and rural households are high-efficiency compact fluorescent (CFL) bulbs, using 75% less energy than incandescent bulbs. Based on Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012).
Improved Insulation	Residential	Insulation upgrades in 20% of urban residential buildings by 2050. Heat losses in upgraded buildings are about half of those in existing urban residential buildings. Based on Aliyev (2013).
Biogas	Residential	Installation of biogas digesters in rural areas not supplied with natural gas. Assumes that 10% of rural households have biogas by 2030, and that the energy supplied is used for heating and cooking. Based on The Republic of Azerbaijan (2013).
Solar Hot Water	Residential	Installation of solar hot water systems in rural households to reduce demand for conventional fuels. Assumes that 25% of rural households have such systems by 2050. Based on The Republic of Azerbaijan (2013).
Efficient Stoves	Residential	Efficient liquefied petroleum gas and wood cook stoves are installed in rural households not supplied with natural gas. Assumes that 10% of rural households have such stoves by 2030. Based on The Republic of Azerbaijan (2013).
Samukh Agro-Energy Complex	Agriculture/Residential	Construction of the Samukh Agro-Energy Complex according to Findsen (2015a), including 6 MW of solar photovoltaic and 0.75 MW of biogas power, as well as 0.75 MW of biogas, 0.6 MW of geothermal, and 6 MW of solar thermal heat capacity by 2016. Following the initial deployment, an additional 14 MW of solar photovoltaic and 7.25 MW of biogas power, as well as 7.25 MW of biogas, 2.4 MW geothermal and 32 MW of solar thermal heat capacity come online by 2020. All heat and power is consumed locally by the agricultural and residential sectors.
Commercial CFL Lighting	Commercial/Services	By 2030, all lightbulbs in commercial establishments are high-efficiency compact fluorescent bulbs. Based on Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012).
Euro 4 Vehicle Standards	Transport	Implementation of Euro-4 standards for all new light and medium duty passenger vehicles, beginning in 2014. Based on Posada Sanchez et al. (2012) and other sources.
Rail Electrification	Transport	Alternating current (AC) electrification of railways that are not electrified in the No Action Scenario. Full implementation is expected by 2050. Based on World Bank (2013a) and other sources.
AC Rail Conversion	Transport	Conversion to AC of all electrified rail existing in the No Action Scenario, which is assumed to be entirely direct current (DC). Full implementation is anticipated by 2050. Based on World Bank (2013b) and other sources.

[5] Mini-scenarios that explore the effects of harmonization with international prices are an exception. Target prices in this case are necessarily based on international data.

Name	Sector	Description
SOCAR Eco-driving	Transport	Implementation of an eco-driving program for SOCAR's vehicle fleet, beginning in 2015. Based on UNDP (2014a).
Electricity Network Upgrade	Electricity Production	Electricity transmission and distribution (T&D) losses are reduced to 10% by 2050. The improvement affects both existing and newly constructed T&D lines. Based on Energy Charter Secretariat (2013) and ADB (2008).
Small Hydro	Electricity Production	164 new small hydroelectricity plants averaging 2 MW apiece are constructed by 2030. Based on Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012).
Onshore Wind	Electricity Production	Build-out of onshore wind power capacity to 800 MW by 2050. Based on Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012).
3 MW Small Solar	Electricity Production	Construction of an additional 3 MW of distributed solar electricity capacity by 2030. Based on Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012).
Municipal Solid Waste to Energy	Electricity Production	New waste-to-energy (WtE) capacity is deployed to maintain the diversion of 25% of municipal solid waste to WtE plants through 2050 (currently, about 25% of municipal solid waste is diverted to the Baku WtE plant). Based on UNFCCC CDM Executive Board (2012a).
SAARES Short-term Plans	Electricity Production	New capacity targets for large and small hydro, onshore wind and utility-scale photovoltaic plants from 2015 – 2018. Targets are provided by the State Agency for Alternative and Renewable Energy Sources (SAARES) of the Republic of Azerbaijan
Forests 12.5% of Total Land Area	Non-Energy	An increase in forested area during 2008-2015 to 12.5% of total land area. Based on President of the Republic of Azerbaijan (2008).
Forests 20% of Total Land Area	Non-Energy	Forested area increases to 20% of total land area by 2050. Based on Ministry of Ecology and Natural Resources of Azerbaijan Republic (2013).
Sustainable Land Management	Non-Energy	Pilot projects to improve management of and rehabilitate forests and pasture land, affecting approximately 47,000 hectares. Based on UNDP (2011).
Kazakhstan		
Advanced Windows	Residential	Replacement of inefficient windows in urban households using windows with a higher insulation value, beginning with 1200 urban apartment buildings by 2020, and reaching all currently existing urban households by 2040. Costs and energy savings from Ergonomika (2011).
Improved Insulation	Residential	Improvement of insulation in urban residential walls and ceilings, beginning with 1200 urban apartment buildings by 2020, and reaching all currently existing urban households by 2040. Costs and energy savings from Ergonomika (2011).
Improved Heat Pipe Insulation	Residential	Improvement of internal (in-building) heat pipe insulation in urban households, beginning with 1200 urban apartment buildings by 2020, and reaching all currently existing urban households by 2040. Costs and energy savings from Ergonomika (2011).
Internal Heating Network Improvements	Residential	Improvement of internal heating distribution network in urban households, beginning with 1200 urban apartment buildings by 2020, and reaching all currently existing urban households by 2040. Specific measures include introducing thermostatic and pressure balancing values, heat meters and hot water heat exchangers. Costs and energy savings from Ergonomika (2011).
Efficient New Homes	Residential	Six million square meters of newly-constructed residential space that meet heating efficiency standards are added each year through 2020, from Ministry of Environment and Water Protection of the Republic of Kazakhstan (2013). Following this period, all additional new urban households are assumed to meet the same standard. Costs and energy savings from UNDP (2014c).
Urban LED Lighting	Commercial/Services	Upgrading of inefficient sodium lighting to new LED technology, in outdoor public spaces. The measure initially covers only Almaty through 2021 according to UNDP (2014b), before expansion to all urban areas by 2030.
Coalbed Methane Capture	Industrial	Expansion of small-scale heat and power generation projects from coal mine methane (CMM) capture, for consumption by local mining operations. Based on a project described by US EPA (2013b).
CNG Passenger	Transport	Integration of an additional 3000 Euro M1 category compressed natural gas (CNG) passenger vehicles by 2015, rising to 50,000 vehicles beyond the No

Name	Sector	Description
Cars		Action Scenario by 2018. Based on information from NGV Global (2010).
CNG Fleet	Transport	Sales of 325,000 cars, 45,000 buses and 60,000 trucks by 2025, to meet CNG conversion targets laid out by Findsen (2015b), displacing sales of gasoline and diesel vehicles which would otherwise occur.
Early Vehicle Retirement	Transport	The President of the Republic of Kazakhstan (2014) sets a target to retire 80% of all vehicles on the road in 2014, by the year 2030. This measure assumes the gradual scrappage across all vehicle categories of Euro 0, 1, 2 and 3-compliant vehicles that were in operation in the year 2014, and their replacement with new vehicles.
Euro 5 Vehicles	Transport	Beginning in 2016, only vehicles adhering to Euro 5 standards may be sold. Based on Dzhaylaubekov (2014).
Rehabilitation of National Grid	Electricity Production	This measure aims to reduce electrical transmission losses to 6% by 2040, implemented in two phases. The first phase rehabilitates 2,604 km of existing transmission line by 2020, followed by the second phase which rehabilitates the remainder of currently existing transmission line stock by 2040. Based on energy efficiency plans described by ADB (2011), and input from national partners.
Expanded Nuclear Power	Electricity Production	Total installed nuclear generation capacity reaches 1.5 GW by 2030 and 2.0 GW by 2050, as described by the President of the Republic of Kazakhstan (2013).
Optimistic Nuclear Power	Electricity Production	In addition to nuclear capacity that is introduced in the No Action scenario (900 MW by 2030), an additional 1800 MW of capacity is brought online in 2023 in Kurchatov, based on input from national partners.
Waste to Energy	Electricity Production	Transformation of municipal solid waste (MSW) to electricity in waste-to-energy plants, consuming 5% of MSW generated in Almaty by 2020, and 30% of MSW in Almaty by 2050. Based on plans described by Mitsubishi Heavy Industries et al. (2014).
Alternative Power Target [a]	Electricity Production	Total alternative power generation (includes both renewables and nuclear) reaches 3% by 2020, 30% by 2030, and 50% by 2050, as described by the President of the Republic of Kazakhstan (2013).
Natural Gas Power Target [b] (Green Growth target)	Electricity Production	Total natural gas power generation reaches 20% by 2020, 25% by 2030 and 30% by 2050, as described by the President of the Republic of Kazakhstan (2013).
CO_2 Cap on Power Generation [c] (Green Growth target)	Electricity Production	Implementation of an emissions cap on carbon dioxide from electricity generation: -3% by 2015, -7% by 2020, -15% by 2030, and -40% by 2050, relative to 2012 emissions. Based on Abt Associates et al. (2014a).
Heat Distribution Upgrades	Heat Production	Renovation of highly worn sections of the district heating distribution network, reducing losses from 36% to 6% (or 17.1%, when viewed in aggregate for the entire national heating network), as described by Ministry of Regional Development (2014).
		Uzbekistan
Residential Building Efficiency	Residential	Reductions in residential building specific energy consumption (total energy demand/m^2 floor space) due to enhanced efficiency standards for new buildings and retrofits of existing buildings. Average specific energy consumption falls to 250 kWh/m^2/year by 2030 and 70 kWh/m^2/year by 2050. Based on UNDP (2015).
Residential Renewable Energy	Residential	Deployment of solar PV, solar hot water, and biogas for residential buildings, collectively accounting for 1% of residential energy demand by 2030 and 5% by 2050. Based on UNDP (2015).
Alternative Vehicles	Transport	A scenario in which 29% of 1.634 million vehicles currently on the road switch from gasoline or diesel to compressed natural gas, by the year 2016. Described in Azernews (2013).
Rail Electrification	Transport	45% of railways are electrified by 2030, and the percentage remains constant through 2050. Based on Center for Economic Research and UNDP (2014).
Electricity Grid Improvements	Electricity Production	Reductions in in electricity transmission and distribution losses due to grid improvements. Total losses reach 15% by 2030 and 10% by 2050. Based on UNDP (2015).
Small Hydro	Electricity Production	Small hydropower component of the State Program on Development of Hydropower: 688.5 MW capacity expansion of small hydro by 2030 (Khalmirzaeva 2015a). New capacity is in addition to that constructed in No

Name	Sector	Description
		Action Scenario.
Large Hydro	Electricity Production	Large hydropower component of the State Program on Development of Hydropower: 1,824 MW capacity expansion of large hydro by 2030 (Khalmirzaeva 2015a). New capacity is in addition to that constructed in No Action Scenario.
Solar Electricity	Electricity Production	Construction of approximately 1,650 MW solar PV capacity and 330 MW concentrated solar power (CSP) capacity by 2030. Based on the "Optimistic" development trajectory described in STA et al. (2014b; 2015a).
Heat Plant Efficiency	Heat Production	An accelerated increase (compared to the No Action Scenario) in the efficiency of natural gas-powered heat plants. Average efficiency reaches 80% by 2030 and 90% by 2050. Based on UNDP (2015).
Heat Network Improvements	Heat Production	Reductions in heat transmission and distribution losses due to heating network improvements. Total losses reach 20% by 2030 and 10% by 2050. Based on UNDP (2015).

[a] In addition to the Alternative Power Target described here, targets of a) 3% by 2020, 20% by 2030 and 40% by 2050, and b) 3% by 2020, 10% by 2030 and 30% by 2050 were implemented.
[b] In addition to the Natural Gas Power Target described here, targets of a) 15% by 2020, 20% by 2030 and 25% by 2050, and b) 20% by 2020, 30% by 2030 and 50% by 2050 were implemented.
[c] In addition to the CO_2 cap described here, targets of (a) -1.5% by 2015, -5% by 202 and -10% by 2030, and (b) -5% by 2015, -10% by 2020, -20% by 2030 and -50% by 2050 were implemented.
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

Table 13: Pricing Mini-Scenarios for Azerbaijan and Kazakhstan

Name	Sector	Description
		Azerbaijan
Fossil Subsidy Removal	All sectors	Price subsidies for fossil fuels and derived secondary fuels are phased out by 2030. Based on subsidy rates reported in IEA (2014b).
OECD Fuel Prices	All sectors	Prices for major fuels equalize with current (2013) OECD averages by 2030. Based on IEA (2014a).
Carbon Tax [a] (EU Harmonization)	All sectors	Implementation of the following gradual carbon tax schedule (all taxes in 2010 $): $5 by 2015, $15 by 2020, $25 by 2030 and $50 by 2050. Based on Abt Associates et al. (2014a).
		Kazakhstan
OECD Fuel Prices	All sectors	Prices for major fuels equalize with current (2013) OECD averages by 2030. Based on IEA (2014a).
Emissions Trading Scheme (ETS)	Industry / Electricity Production	An emissions cap is imposed on all industry (including mining) and electricity production, in three phases (from ICAP (2015)): • By 2013, emissions are capped at their 2010 levels; • In 2014, emissions across are capped at 2012 levels. In 2015, emissions are capped at 1.5% below those observed in 2013; and • By 2020, the industrial and energy sector's CO_2 emissions are reduced by 15% relative to their 1992 levels.
Extended Emissions Trading Scheme	All sectors	Continuing where the ETS scenario leaves off, the market-clearing price for carbon is assumed to grow at 3% each year through 2050. In addition, beginning in 2020 a carbon tax is applied across the remainder of the economy not covered by the original ETS, reaching parity with the ETS price by 2030.

[a] In addition to the carbon tax schedule described here, targets of a) $5 by 2015, $12 by 2020, $20 by 2030 and $50 by 2050, and b) $5 by 2015, $8 by 2020 and $16 by 2030 and $35 by 2050 were implemented.

Table 14: Combined Mitigation Scenarios for Azerbaijan, Kazakhstan, and Uzbekistan

Name	Sector	Description
		Azerbaijan
State Program of Poverty Reduction	All Sectors	Models a selection of measures and targets given in President of the Republic of Azerbaijan (2008). Includes: • Double GDP per capita during 2008-2015; • During 2008-2015, increase forested area to 12.5% of total land area; and • During 2006-2015, decrease fuel combustion (conditional fuel spent/kWh) in electricity production by 20%.
Renewable Power Target	Electricity Production	Models renewable generation and capacity targets for 2020 described in IEA and IRENA (2014), including short term plans from the State Agency for Alternative and Renewable Energy Sources of the Republic of Azerbaijan (2014). • Renewable sources must provide at least 20% of generated electricity; and • At least 2,000 MW of renewable electricity capacity must be installed.
All Low-Cost Technical Measures	All sectors	A combined scenario including all technical mini-scenarios whose cumulative discounted direct cost per tonne of GHG reductions <= 10 2010 $.
All Moderate-Cost Technical Measures [a]	All Sectors	A scenario quantifying potential moderate-cost technical mitigation options for Azerbaijan. Includes all individual mitigation options whose cumulative discounted direct cost per tonne of GHG reductions <= 50 2007 AZN.
All Technical Measures	All sectors	A combined scenario including all technical mini-scenarios showing abatement potential.
		Kazakhstan
All Low-Cost Technical Measures	All sectors	A combined scenario including all technical mini-scenarios whose cumulative discounted direct cost per tonne of GHG reductions <= 10 2010 $.
All Technical Mini-Scenarios	All Sectors	All technical mini-scenarios with positive abatement potential are combined into a full mitigation scenario. Overlaps between specific measures are addressed individually, as needed.
		Uzbekistan
All Low-Cost Technical Measures	All sectors	A combined scenario including all technical mini-scenarios whose cumulative discounted direct cost per tonne of GHG reductions <= 10 2010 $.
All Technical Mini-Scenarios	All Sectors	All technical mini-scenarios with positive abatement potential are combined into a full mitigation scenario. Overlaps between specific measures are addressed individually, as needed.

[a] This scenario responds to a request from Azerbaijan's UNFCCC focal point to analyze a potential emission reduction scenario for consideration for Azerbaijan's Intended Nationally Determined Contribution (INDC).
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

E. Projection Methods

40. In each model's historical period, energy use and emissions of GHGs and other air pollutants are a matter of historical data. Energy supply and demand are determined from historical energy balances, and energy and transport-related emissions are calculated by multiplying quantities of fuels by emission factors. Non-energy GHG emissions are taken from national GHG emission inventories.[6] In the projection period, divergent techniques are used to estimate emissions from energy and non-energy sources. The modeling and treatment of non-energy emissions are quite basic since the focus of this study is mitigation in the energy and

[6] Importantly, historical energy and transport-related GHG emissions in the models do not always align exactly with the corresponding national GHG inventories. This is because the models' emissions are based on national energy balances, and for institutional and other reasons the balances may differ from the energy assumptions in the national inventories. The consultant team chose to base the models on the energy balances because they offer a more thorough and detailed record of the energy and transport systems—the main subject of this study—than any inventories do.

transport sectors. Nonetheless, non-energy sources are still projected alongside energy-related emissions to provide a picture of total GHG emissions.

41. Direct costs and benefits are projected by defining unit costs for equipment, activities, and fuels and multiplying them by equipment requirements, activity levels, and fuel consumption calculated in the energy and transport system model. In mitigation scenarios, mitigation program implementation costs may also be entered and added to the social cost accounting.

42. The following sections provide additional detail on the projection methods for energy use and energy and transport emissions; non-energy emissions; cross-cutting assumptions affecting energy, transport, and non-energy emissions; and social costs. Each section focuses initially on the No Action projection since it forms the critical baseline for the study, and the various mitigation scenarios inherit many values directly from it. Additional methods used in mitigation scenarios are then briefly reviewed as needed.

1. Energy Use and Related Emissions

43. Projections for the energy and transport systems begin with projections of energy supply and demand. Energy-related emissions are then calculated in the same way as in the historical period: by multiplying quantities of fuels by emission factors. The national models enforce a few basic accounting rules as a framework for supply and demand projections:

(i) Final demand (by fuel) is determined first, then supply is matched to demand. Requirements for intermediate fuels (inputs to energy production processes) are determined by final demand and production technologies and efficiencies. Ultimately, the identity:

Equation 1

$$demand = domestic\ demand + exports = domestic\ production + imports = supply$$

is true in every year and for every fuel.

(ii) Unless official national projections of fuel imports or exports were available, the most recently observed historical imports and exports are assumed to continue in the future.[7]

(iii) After accounting for domestic demand and the exogenous imports and exports in rule 2, domestic energy production is utilized to meet remaining supply requirements. However, domestic production is limited by natural resource and production capacity constraints.

(iv) Any remaining requirements that cannot be met by domestic production are satisfied by additional imports.

44. Appendix 2 provides a more detailed description of the methods used for projecting energy supply and demand.

[7] Official projections of exports of coal, natural gas, and crude oil from Kazakhstan were available in Ministry of Industry and New Technologies of Kazakhstan (2014). These were used in place of the most recently observed exports for these fuels. Exports of non-renewable primary resources (e.g., crude oil) cease once reserves of the resources are exhausted.

2. Non-Energy GHG Emissions

45. Historical non-energy GHG emissions are taken from the most recent national GHG inventories available to the study team[8] (Aliyev 2015; Ministry of Environment and Water Resources of the Republic of Kazakhstan and JSC 'Zhasyl Damu' 2014; European Commission JRC Joint Research Centre and Netherlands Environmental Assessment Agency 2010).[9] Emissions are categorized by source and subsource following the inventories' structure and IPCC practice (see Section V.A). In the projection period, No Action emissions are assumed to change in proportion to changes in key independent or driving variables relevant to the various sources and subsources (or, if this approach produces implausible results, emissions are assumed to continue changing as they have historically). Table 63 in Appendix 3 provides a more detailed overview of the techniques used.

3. Cross-Cutting Assumptions

46. As the previous sections indicate, the energy, transport, and non-energy projections in the national models are influenced by a few significant cross-cutting variables: population, GDP, and value added. All three are exogenous inputs to the models. Historical data for these variables are from the sources listed in Section III.E.5, while projections were developed using the methods described in Table 15.[10]

Table 15: Projection Techniques for Population, GDP, and Value Added

Country	Variable	Projection Technique
Azerbaijan	Population	Growth at average annual 1.14% rate observed in historical data during 2000 to 2010.
	GDP	Short-term projections of 4.3% per year (2013 through 2019) from International Monetary Fund (2014); after 2019, growth at average annual 3.6% rate observed for 2010-2019.
	Value added	Calculated as GDP multiplied by shares for sectoral value added; shares grow at average annual % rates observed in historical data.† Shares normalized so sum of shares = 100%.
Kazakhstan	Population	Projected population growth at average annual 1.13% through 2050 from Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014a).
	GDP	Short-term projections (through 2017) based on growth rates reported in news@mail.ru (2015); after 2017, 4% annual growth assumed per President of the Republic of Kazakhstan (2014).
	Value added	Growth at same % rate as GDP.
Uzbekistan	Population	Projected population growth of 0.64% per year through 2050 from United Nations Department of Economic and Social Affairs (2015).
	GDP	Projection through 2050 based on growth rates specified by the Ministry of Economy of the Republic of Uzbekistan and consistent with UNDP (2015) analysis of targets for the energy sector (8.2% through 2030, then decreasing linearly to 5% by 2050).
	Value added	Calculated as GDP multiplied by shares for sectoral value added; shares grow at average annual % rates observed in historical data.† Shares normalized so sum of shares = 100%. Exception: short-term projections for industrial value added (through 2019) from President of the Republic of Uzbekistan (2015).

Notes: † Changes limited to a few percent per year to avoid unreasonable developments over the long term.
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c).

[8] Uzbekistan is an exception: as a recent national GHG inventory was not available, estimates of non-energy emissions are taken from the European Commission's Emissions Database for Global Atmospheric Research (EDGAR).

[9] The inventory for Azerbaijan (Aliyev 2015) is a draft version of an inventory that was officially published after this study was completed (see Ministry of Ecology and Natural Resources of Azerbaijan Republic (2015) for the final published version). The published data do not substantially differ from the draft data.

[10] As shown in Table 15, some of the projections were taken directly from outside sources (e.g., population in Kazakhstan). These sources are also noted in Appendix 4.

47. These methods were confirmed with stakeholders during the project's interim workshops. Figure 2-Figure 6 illustrate the projection results for each variable and country.

Figure 2: Population in Azerbaijan, Kazakhstan, and Uzbekistan (No Action Scenario)

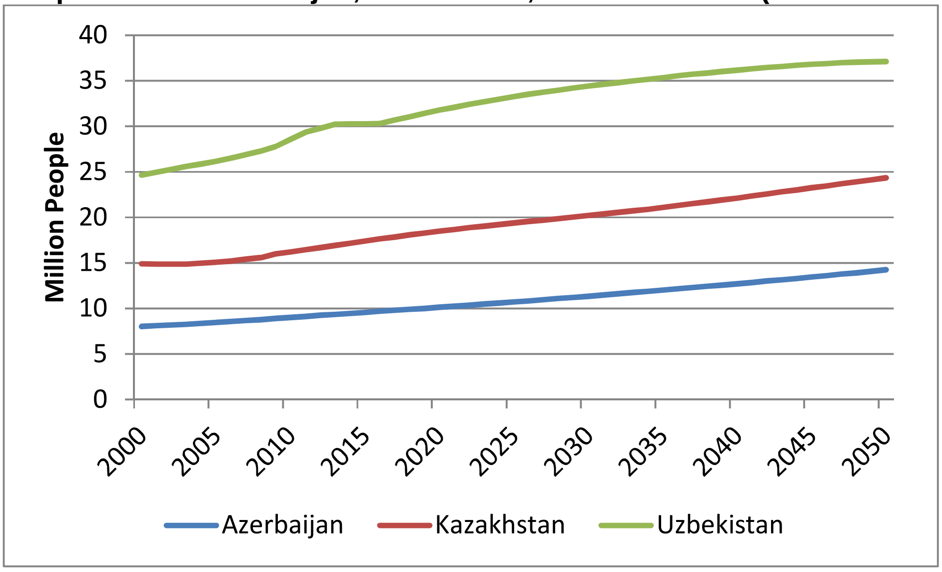


Table 16: Population in Azerbaijan, Kazakhstan, and Uzbekistan (No Action Scenario, Million People)

Country	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Azerbaijan	8.0	8.4	9.0	9.6	10.1	10.7	11.3	12.0	12.7	13.5	14.2
Kazakhstan	14.9	15.1	16.2	17.4	18.5	19.4	20.2	21.1	22.1	23.2	24.3
Uzbekistan	24.7	26.2	28.6	30.3	31.8	33.3	34.4	35.3	36.2	36.8	37.1

Sources: See Table 15 and Table 64.

Figure 3: GDP in Azerbaijan, Kazakhstan, and Uzbekistan (No Action Scenario)

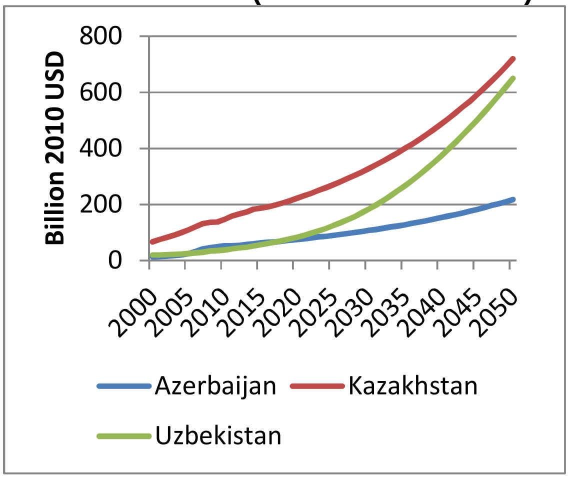


Figure 4: Value Added in Azerbaijan (No Action Scenario)

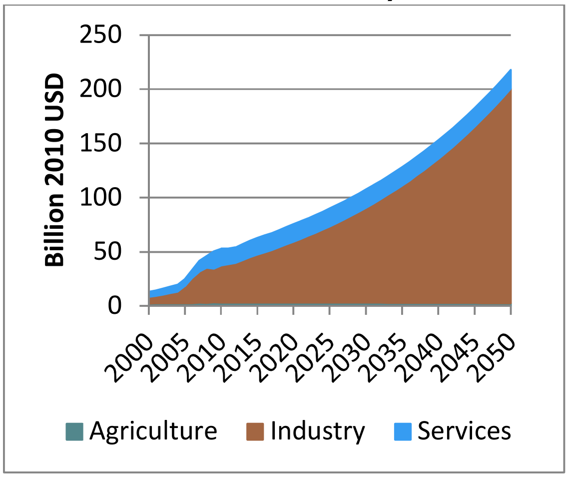


Figure 5: Value Added in Kazakhstan (No Action Scenario)

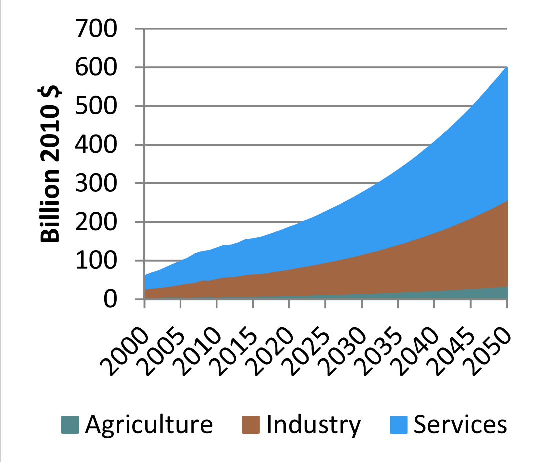


Figure 6: Value Added in Uzbekistan (No Action Scenario)

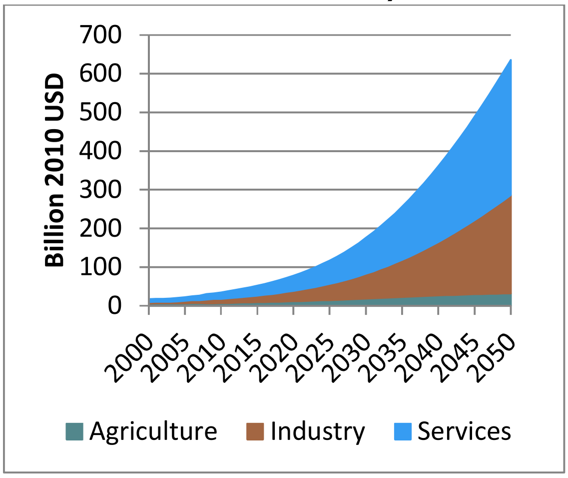


Table 17: GDP and Value Added in Azerbaijan, Kazakhstan, and Uzbekistan (No Action Scenario, Billion 2010 $)

Country	Variable	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Azerbaijan	GDP	13.2	24.8	52.9	62.9	75.4	90.0	107.4	128.2	153.0	182.6	218.0
	Agriculture Value Added	2.3	2.5	3.0	3.1	3.1	3.0	2.9	2.8	2.7	2.6	2.5
	Industry Value Added	6.0	15.8	34.3	44.3	56.2	70.4	87.6	108.2	133.0	162.7	198.2
	Services Value Added	4.9	6.6	15.6	15.5	16.2	16.6	16.9	17.2	17.3	17.4	17.4
Kazakhstan	GDP	66.9	109.5	148.1	186.5	221.9	270.0	328.5	399.7	486.2	591.6	719.8
	Agriculture Value Added	5.4	7.0	6.7	9.1	10.8	13.2	16.0	19.5	23.7	28.8	35.1
	Industry Value Added	21.8	32.6	48.7	57.4	68.3	83.1	101.1	123.1	149.7	182.2	221.6
	Services Value Added	32.4	57.0	76.5	89.0	106.0	128.9	156.8	190.8	232.2	282.5	343.7
Uzbekistan	GDP	19.5	25.3	38.0	54.8	69.9	79.1	89.5	101.3	114.6	129.7	146.7
	Agriculture Value Added	19.5	25.3	38.0	56.4	83.6	124.0	183.8	266.6	372.5	501.4	649.7
	Industry Value Added	5.8	6.7	6.8	9.4	11.9	15.0	18.8	22.9	26.8	30.0	32.2
	Services Value Added	3.9	6.6	11.5	17.1	26.9	41.6	64.1	96.1	138.4	191.4	254.3

Sources: See Table 15 and Table 64.

4. Social Costs

48. As explained in Section III.E.1, social costs are projected in the national models by defining unit costs that are multiplied by projected equipment requirements, activity levels, and fuel consumption. Critically, because the goal of social cost accounting in this study is to estimate costs and benefits of mitigation relative to No Action conditions, it is not necessary to model every direct social cost in the No Action Scenario. Instead, *differences* in costs between the No Action and mitigation scenarios must be captured. The cost inputs in mitigation scenarios are specified with this qualification in mind.

49. In general, when capital or equipment costs are entered in the models, they are annualized at a 7% real interest rate and spread over the lifetime of the corresponding equipment. O&M costs are entered as annual amounts that apply while related equipment or processes are active. Costs incurred for mitigation measures, including any incremental program implementation costs, are assumed to continue for the duration of the measures. Any equipment that is necessary for a measure is replaced at the end of its service life while the corresponding measure is in effect.

50. Real unit costs are allowed to change in the projection period if there is justification in the literature for doing so. This is the case for some power and vehicle technology costs, for example.[11] It is also the case for fuels. Fuels require special discussion because their value affects both the social cost accounting and the energy supply and demand calculations in LEAP (e.g., through the econometric models of demand discussed above). With the exception of electricity, each national model uses one unit value per fuel—an exogenously specified fuel price, which can change from year to year—for both these purposes. Historical price data were derived from the sources noted in Section III.E.5, and future prices are projected by extrapolating historical trends. Historical prices of each fuel in each country, as well as their projections, are included in Appendix 1. The consultant team settled on this projection approach after unsuccessfully seeking official national price projections and ruling out indexing prices to an international market forecast (such as those in IEA (2014c) and World Bank (2015a)) due to the highly regulated price regimes in Azerbaijan, Kazakhstan, and Uzbekistan.

51. Extrapolated national prices are admittedly an imperfect proxy for the true social cost of fuels as they do not reflect potential costs of subsidies or price controls. The consultant team did look for nationally sourced data on such additional costs but was unable to find any. International sources (such as IEA (2014c)) suggest that accounting for subsidies would raise the social cost of fossil fuels in all three study countries, particularly for oil and oil products. Such a change would improve the cost-effectiveness (lower the cost per tonne of CO_2e abated) of mitigation options that save fossil energy—the majority of options in this study. However, as stakeholders in the project's interim workshops expressed skepticism about international estimates of subsidies, these data are not incorporated in this analysis.[12] The net result is a more conservative cost assessment of mitigation than would otherwise be the case.

52. For electricity, the bottom-up power sector submodels permit separate estimation of the fuel's social cost. In this case, an exogenously projected price is used in demand-side calculations—reflecting the regulated price consumers face in purchasing decisions—while the social cost of electricity is determined as the modeled costs of electricity production (capital, O&M, fuel inputs). This approach takes advantage of the electricity submodels to improve social costing for this fuel.

5. Baseline Data Sources

53. Appendix 4 lists the principal data sources used in the No Action Scenario. Supplemental sources for particular mitigation scenarios are discussed in Section III.C.

[11] See Appendix 1.H for sources.
[12] Except for the Fossil Subsidy Removal scenario in the Azerbaijan model.

IV. GHG EMISSION PROJECTIONS TO 2050 FOR AZERBAIJAN, KAZAKHSTAN, AND UZBEKISTAN – THE NO ACTION SCENARIO

54. The economies of Azerbaijan, Kazakhstan, and Uzbekistan are carbon-intensive when compared to countries with similar per capita income (Figure 1). Uzbekistan and Kazakhstan's intensities are notably higher than Azerbaijan's. A variety of reasons underlie this phenomenon. A legacy of energy-intensive Soviet infrastructure, abundant domestic supplies of fossil fuels, and climatic conditions (particularly the cold climate in Kazakhstan) all play a role in driving energy use and emissions. Energy-intensive industries are an important emitter in Kazakhstan and Uzbekistan, and fossil fuel production for export and domestic use contributes significant fugitive emissions in all three countries. Although the countries have plans to expand renewable power, their power sectors are currently dominated by fossil technologies.

55. Meanwhile, growing population and economic activity are increasing demands for energy and other resources. The economic contraction following the dissolution of the Soviet Union is over; since the late 1990s, real GDP has rebounded. Between 2000 and 2010, for instance, real GDP grew 95% in Uzbekistan, 220% in Kazakhstan, and 400% in Azerbaijan (The State Statistical Committee of the Republic of Azerbaijan 2014d; Agency on Statistics of the Republic of Kazakhstan 2013c; Khalmirzaeva 2015c). Population grew at least 9% in the same period (16% in Uzbekistan) (The State Statistical Committee of the Republic of Azerbaijan 2014a; Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics 2014e; Khalmirzaeva 2015c). Coupled with carbon-intensive energy and transport systems, continued growth along these lines will have important consequences for GHG emissions.

56. The baseline scenario for this study (the No Action Scenario) explores these consequences through 2050. As explained in Sections III.C and III.E, modeling of the No Action Scenario provides projections of energy, transport, and non-energy GHG emissions with detail on sources, fuels, technologies, and other factors. This section presents a selection of the most significant No Action results, starting with outcomes in the energy and transport systems and proceeding to overall emission projections.

A. Energy and Transport System Results

57. An initial focus on the energy and transport systems is warranted because the preponderance of the three countries' GHG emissions is from energy use and production. Estimates from the LEAP models using historical energy balances and inventories of non-energy GHG emissions show that the share of total 2010 GHG emissions due to energy and transport exceeded 75% in all three countries. A useful way of considering broad trends in the drivers of energy and transport-related emissions is the Kaya identity, which describes emissions from energy use as the product of population, GDP per capita, the energy intensity of GDP, and the carbon intensity of energy (Kaya and Yokobori 1997). In the No Action Scenario, as noted above, population and GDP projections are exogenous (Figure 2-Figure 3). Dividing GDP by population, these projections yield the GDP per capita trajectories in Figure 7.

58. In each country real personal income is projected to climb even as population increases. The growth is steepest in Uzbekistan but substantial in all countries: projected income in Azerbaijan and Kazakhstan both nearly triple between 2010 and 2050.

Figure 7: GDP Per Capita (No Action Scenario)

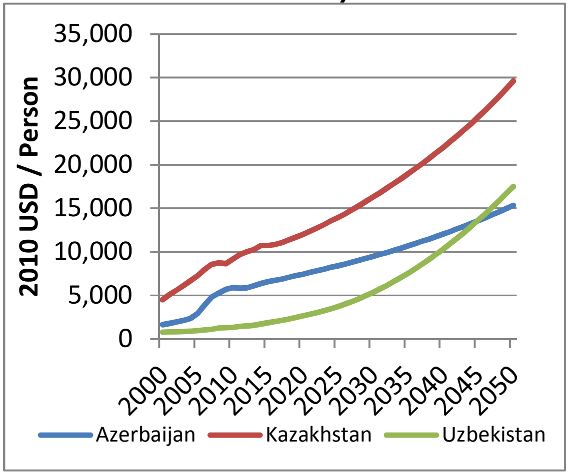


Figure 8: Energy Intensity of GDP (No Action Scenario)

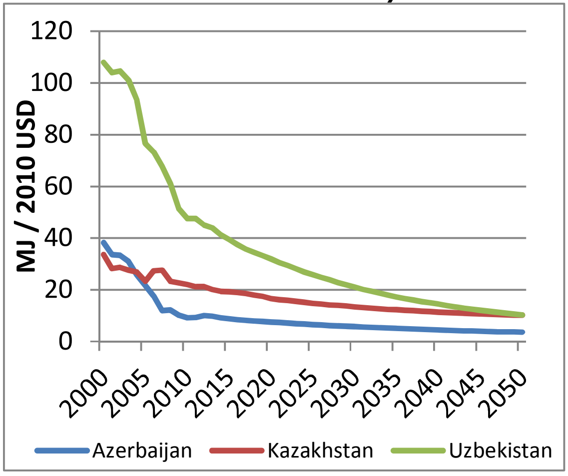


Table 18: GDP Per Capita (No Action Scenario, Thousand 2010 $ / Person)

Country	2000	2010	2020	2030	2040	2050
Azerbaijan	1.6	5.9	7.4	9.5	12.0	15.3
Kazakhstan	4.5	9.1	12.0	16.3	22.0	29.6
Uzbekistan	0.8	1.3	2.6	5.3	10.3	17.5

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Table 19: Energy Intensity of GDP (No Action Scenario, MJ / 2010 $)

Country	2000	2010	2020	2030	2040	2050
Azerbaijan	38.4	9.2	7.5	5.8	4.5	3.7
Kazakhstan	33.6	22.1	16.7	13.4	11.4	10.3
Uzbekistan	108.0	47.6	32.0	21.1	14.4	10.3

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

59. Figure 8 shows the energy intensity of GDP emerging from the No Action Scenario.[13] As evidenced in the figure, all three countries have experienced significant improvement in this indicator over the last decade, and the No Action projection anticipates continued progress. The projected rates of change are consistent with recent historical data in Azerbaijan and changes since 2000 in Kazakhstan. In Uzbekistan, the rate decreases somewhat compared to historical data but continues to be significant throughout the modeling period.

60. Several factors contribute to the projected intensity changes. In all three countries, energy efficiency improvements are realized in the bottom-up power sector submodels. These include rehabilitation of existing plants (particularly in Uzbekistan and Azerbaijan), gradual retirement of existing plants and replacement with more efficient contemporary technology, and some deployment of renewables. In Azerbaijan and Kazakhstan, efficiency improvements are also realized in the stock turnover submodels for road transport. Old, inefficient vehicles are eventually taken off the road and replaced by newer, more efficient units. For the demand-side sectors and subsectors that are analyzed from the top down in Azerbaijan and Kazakhstan, the econometric projections of energy demand—which account for GDP and other factors—lead to lower energy intensity in some cases. In the Uzbekistan model, the energy intensity of residential space decreases over time in keeping with Center for Energy Efficiency and UNDP (2013); while intensities in other demand-side sectors follow historical trends, which are often downward-sloping. The Uzbekistan model also incorporates projected baseline reductions in electricity transmission and distribution losses and improvements in heat plant efficiency from

[13] "Energy" here and in the context of the carbon intensity of energy means the total primary energy supply: indigenous production of primary energy + energy imports - energy exports. This definition avoids double counting domestically produced secondary fuels (International Energy Agency 2015). Transport is part of "energy" since all GHG emissions from this sector are fuel-related.

UNDP (2015). It is worth comparing these energy intensity projections with other countries at different stages in their development. Figure 9, Figure 10, and Figure 11 plot economy-wide, industrial, and residential energy intensities of GDP versus per capita income. Data since 1960 are shown for six reference countries (China, Japan, South Korea, Russia, Turkey, and Germany). For the study countries, three data points are shown: the most recent historical value (2011 or 2012, depending on the country) and projected values in the No Action Scenario for 2030 and 2050. Since per capita income rises in the study countries during the projection and the graphs show per capita income on the x-axis, these points are arranged in chronological order from left to right.

Figure 9: Energy Intensity of GDP vs. Per Capita Income

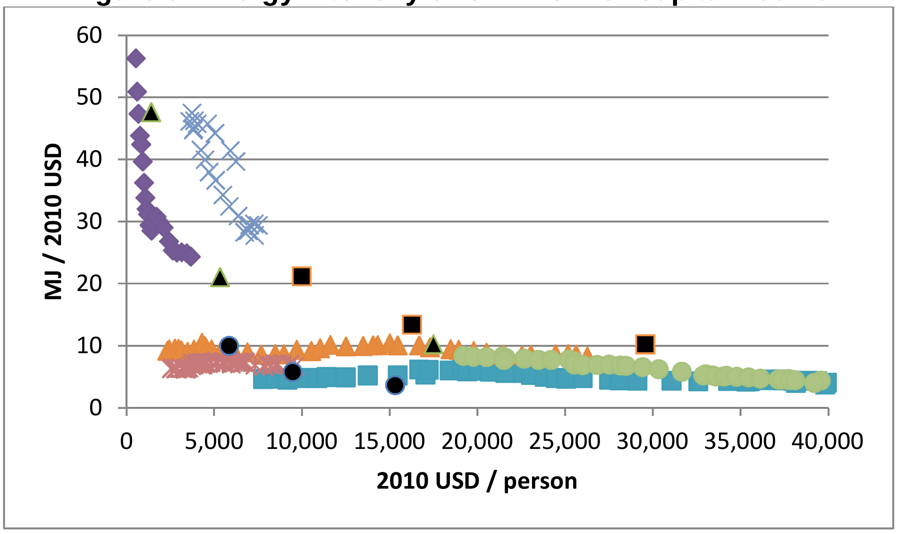


Figure 10: Industrial Final Energy Intensity of GDP vs. Per Capita Income

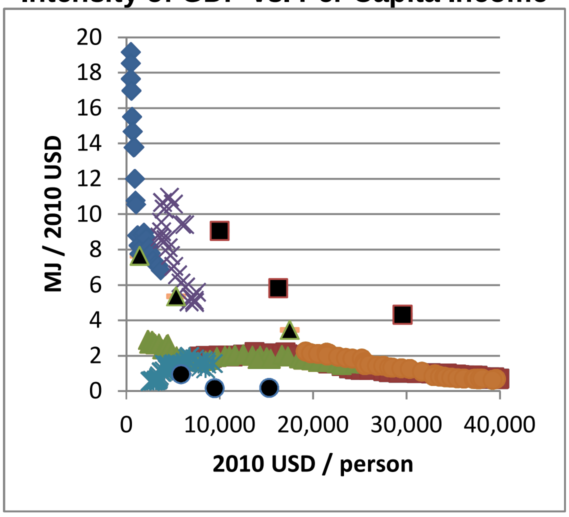
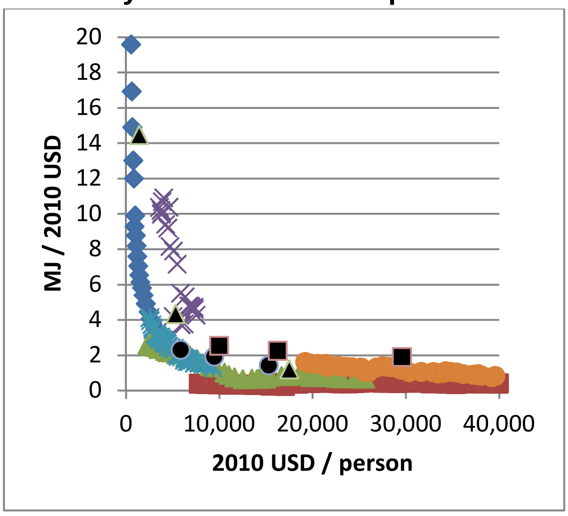


Figure 11: Residential Final Energy Intensity of GDP vs. Per Capita Income



China Japan Korea Russia Turkey
Germany Azerbaijan Kazakhstan Uzbekistan

Sources: IEA (2014b), World Bank (2015b), SEI and Abt Associates (2015a; 2015b; 2015c)

62. As these figures illustrate, the projected energy intensities in Azerbaijan, Kazakhstan, and Uzbekistan are quite consistent with historical evidence from the reference countries. Both the trend with rising income and the magnitude of the projected intensities generally agree with other countries' experiences. The most significant difference is that the economy-wide and industrial intensities in Kazakhstan are somewhat higher than in other countries at comparable income levels. This result is likely due to the structure of the industrial and power sectors in Kazakhstan as well as climatic influences.

63. Putting the first three terms of the Kaya identity together yields the total primary energy supply projections in Figure 12. In each country declining energy intensity is outweighed by rising population and income, and supply requirements increase.

Figure 12: Total Primary Energy Supply (No Action Scenario)

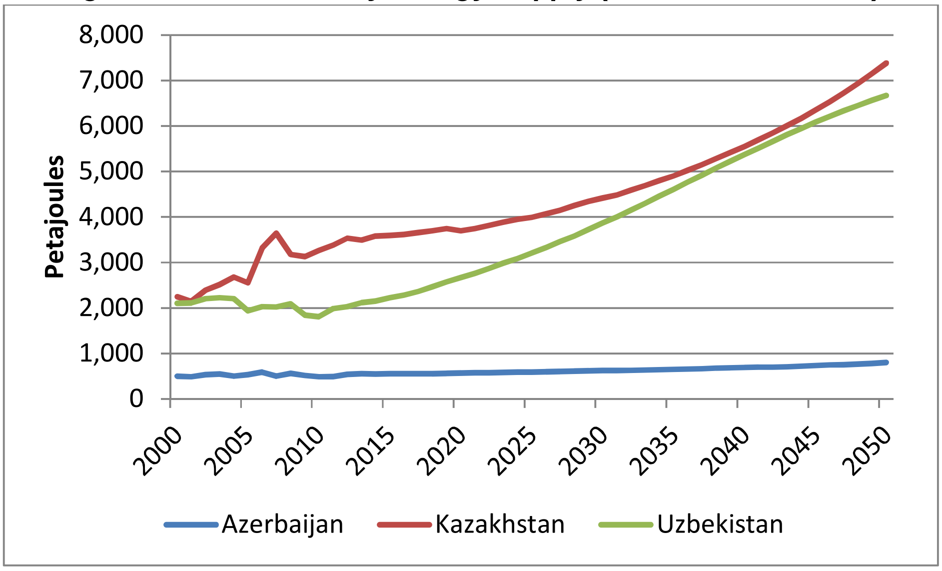


Table 20: Total Primary Energy Supply (No Action Scenario, Petajoules)

Country	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Azerbaijan	505	538	489	553	569	593	623	652	695	733	801
Kazakhstan	2248	2553	3266	3596	3700	3990	4416	4905	5549	6346	7382
Uzbekistan	2103	1940	1810	2227	2673	3207	3871	4609	5379	6079	6669

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

64. With energy requirements on the rise, the carbon intensity of energy assumes crucial importance. In the No Action Scenario, as Figure 13 illustrates, the overall carbon intensity of the energy supply is not projected to change significantly. Fundamentally, this is due to continued reliance on fossil fuels in buildings and for industry, transport, and power—oil and natural gas in Azerbaijan, oil and coal in Kazakhstan, and natural gas in Uzbekistan. Figure 14-Figure 16 depict these basic dependencies by showing projected shares of primary energy in the three countries.

Figure 13: Carbon Intensity of Energy (No Action Scenario)

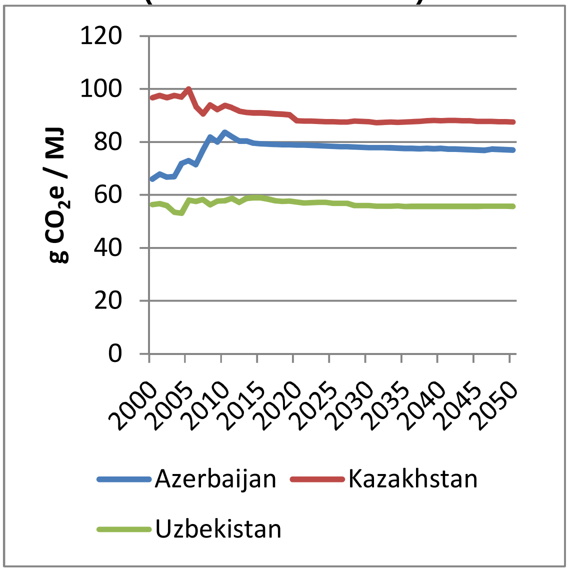


Figure 14: Shares of Primary Energy in Azerbaijan (No Action Scenario)

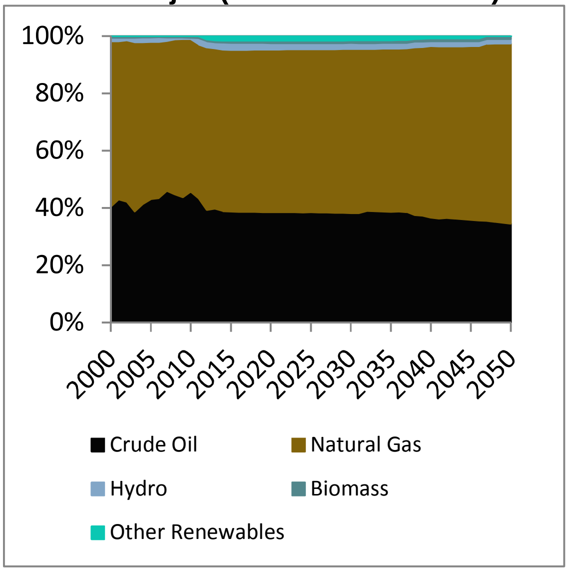


Figure 15: Shares of Primary Energy in Kazakhstan (No Action Scenario)

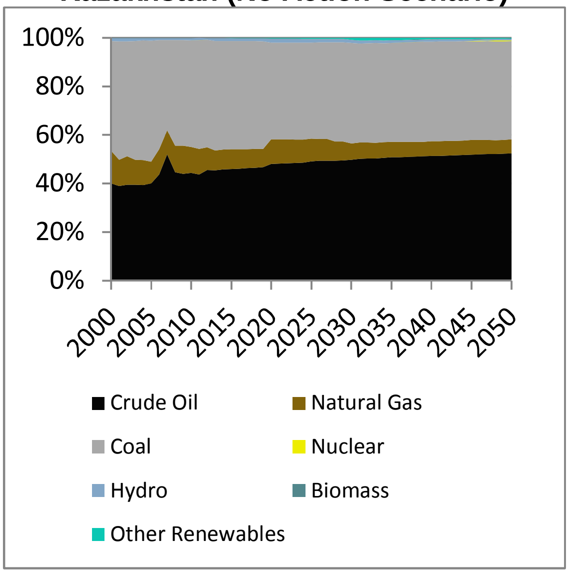


Figure 16: Shares of Primary Energy in Uzbekistan (No Action Scenario)

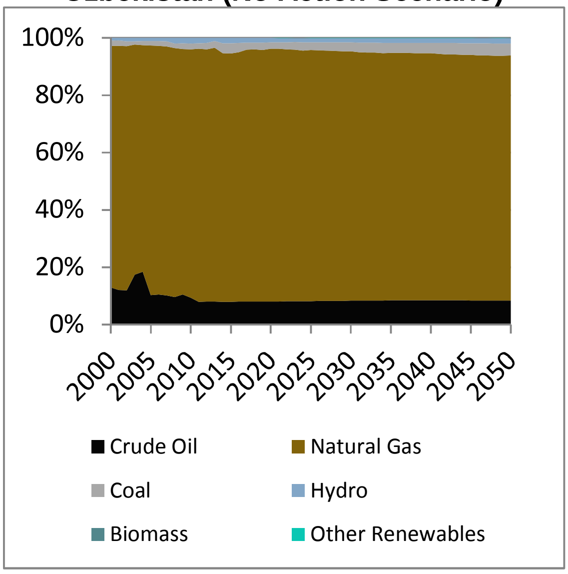


Table 21: Carbon Intensity of Energy (No Action Scenario, gCO_2e / MJ)

Country	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Azerbaijan	66.0	72.9	83.6	79.3	78.8	78.4	77.9	77.5	77.5	76.9	76.9
Kazakhstan	96.7	99.9	93.7	90.9	88.0	87.6	87.7	87.5	88.0	87.7	87.5
Uzbekistan	56.3	58.0	57.7	58.9	57.2	56.8	55.9	55.7	55.7	55.7	55.7

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Table 22: Shares of Primary Energy in Azerbaijan, Kazakhstan, and Uzbekistan (No Action Scenario, %)

Country	Resource	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Azerbaijan	Crude Oil	40.5	43.0	45.7	38.7	38.5	38.5	38.2	38.6	36.6	35.8	34.5
	Natural Gas	57.7	54.9	53.2	56.5	56.7	56.8	57.3	56.9	59.8	60.6	62.9
	Hydro	1.2	1.6	0.5	2.4	2.3	2.2	2.1	2.0	1.7	1.7	1.5
	Biomass	0.6	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0	1.0	1.1
	Other Renewables	0.0	0.0	0.0	1.7	1.7	1.6	1.6	1.5	0.9	0.8	0.0
Kazakhstan	Crude Oil	40.1	40.0	44.4	45.9	48.1	49.2	49.8	50.8	51.4	51.9	52.4
	Natural Gas	13.4	9.0	10.7	8.2	10.1	9.3	6.7	6.4	6.1	6.0	5.8
	Coal	45.2	49.8	43.9	44.6	39.8	39.6	41.3	40.7	40.9	40.6	40.4
	Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4
	Hydro	1.2	1.1	0.9	1.2	1.6	1.4	1.2	1.0	0.8	0.7	0.5
	Biomass	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
	Other Renewables	0.0	0.0	0.0	0.1	0.3	0.4	0.8	0.9	0.6	0.5	0.3
Uzbekistan	Crude Oil	12.9	10.3	9.4	7.9	8.0	8.2	8.3	8.4	8.4	8.4	8.3
	Natural Gas	84.4	87.0	86.6	86.6	88.1	87.6	87.0	86.4	86.2	85.7	85.5
	Coal	1.7	1.5	2.0	3.6	2.3	2.7	3.1	3.4	3.6	4.1	4.2
	Hydro	1.0	1.2	2.0	1.9	1.5	1.5	1.5	1.7	1.7	1.8	1.9
	Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Other Renewables	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1

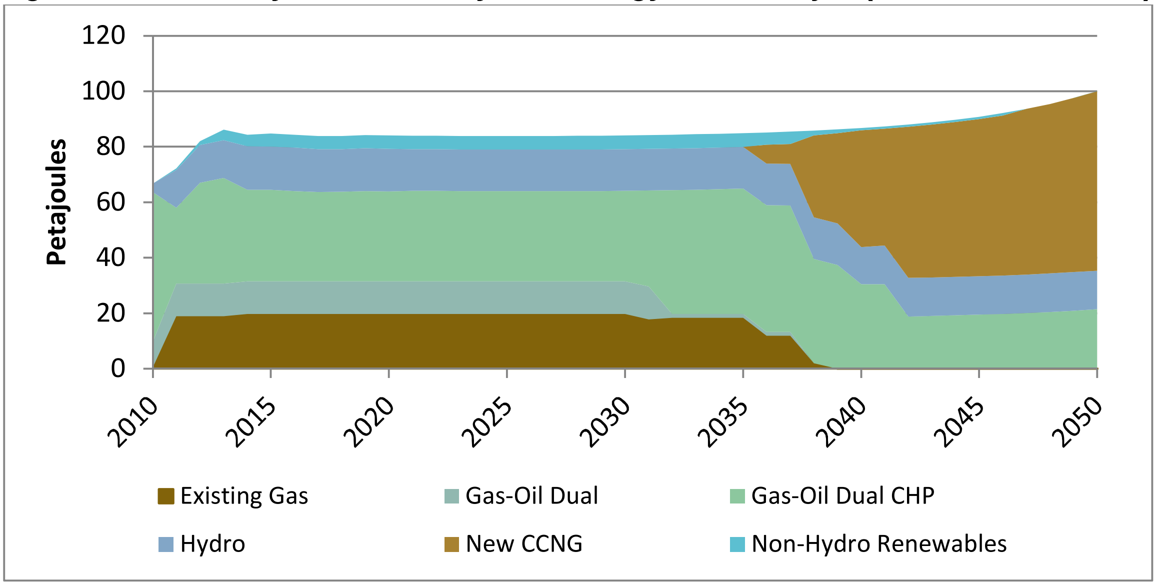
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

65. The relative stability of the carbon intensity of energy is not surprising given the make-up of the No Action Scenario (see Section III.C). A central assumption in the scenario is that no significant new mitigation policies are introduced, so radical shifts from fossil fuels are not anticipated. This outcome is clearly displayed in the bottom-up power submodels, where technologies are explicitly modeled and mediate fuel switching opportunities. As shown in Figure 17-Figure 19, electricity production in each country continues to depend on fossil energy even after accounting for definitive short and medium-term capacity expansion plans. Modern fossil technologies (e.g., ultrasupercritical (USC) coal and contemporary combined cycle natural gas (CCNG)) gradually replace legacy technologies, but the overall reliance on fossil sources is not reduced. In the Azerbaijan and Kazakhstan models, which use least-cost optimization to determine capacity additions, this result is due to the cost advantages of fossil technologies.[14] In the Uzbekistan model, the result issues from simulation rules that determine capacity additions based on the current mix of power technologies (see Section III.E.1).

66. In each of the charts below, the terms *new* and *existing* are used to describe some power plants. These qualifiers are used where necessary to differentiate between technologies for which an improved variant is added to the supply mix, while previous-generation power plants continue to produce power.

[14] It is worth re-emphasizing, however, that only *direct* costs are modeled in the power sector simulation (see Section III.B). Co-benefits such as public health impacts are covered elsewhere in this study.

Figure 17: Electricity Production by Technology in Azerbaijan (No Action Scenario)



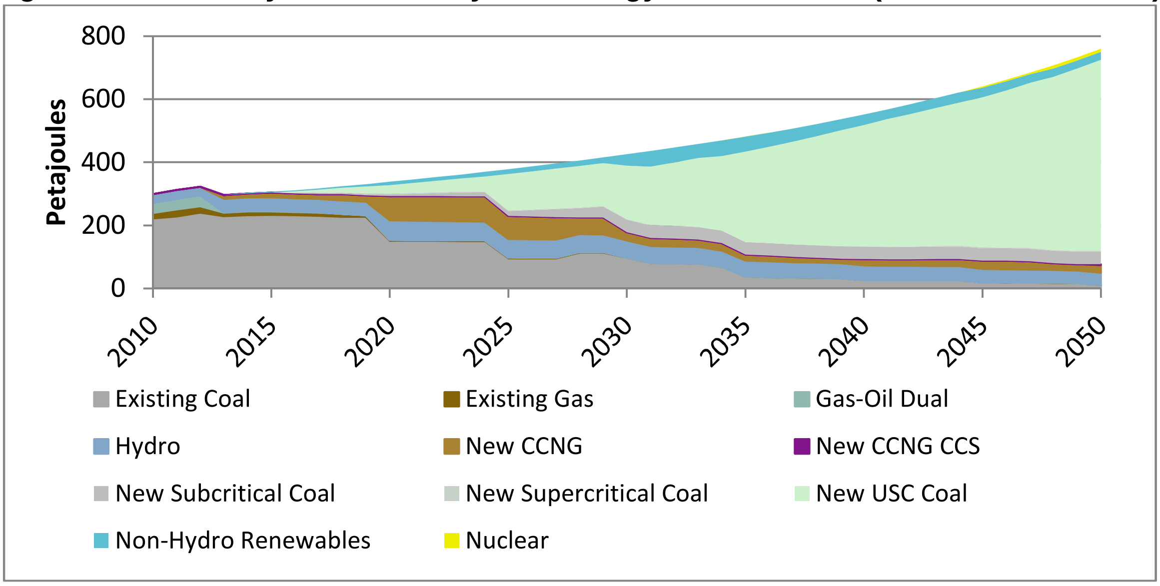
Notes: CHP = combined heat and power, CCNG = combined cycle natural gas

Table 23: Electricity Production in Azerbaijan (No Action Scenario, Petajoules)

Technology	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Gas	1.1	3.5	0.3	19.7	19.7	19.7	19.7	18.4	0.0	0.0	0.0
Gas-Oil Dual	5.6	17.7	9.2	11.8	11.8	11.8	11.8	1.4	0.0	0.0	0.0
Gas-Oil Dual CHP	51.8	55.1	54.1	32.9	32.4	32.4	32.6	45.2	30.4	19.5	21.4
Hydro	7.1	10.1	3.0	15.7	15.4	15.0	15.0	15.0	13.4	13.9	13.9
New CCNG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.1	56.6	64.7
Non-Hydro Renewables	0.0	0.0	0.0	4.7	4.8	4.9	4.9	5.0	0.8	0.8	0.0

Notes: CHP = combined heat and power, CCNG = combined cycle natural gas
Source: Stockholm Environment Institute and Abt Associates (2015a)

Figure 18: Electricity Production by Technology in Kazakhstan (No Action Scenario)



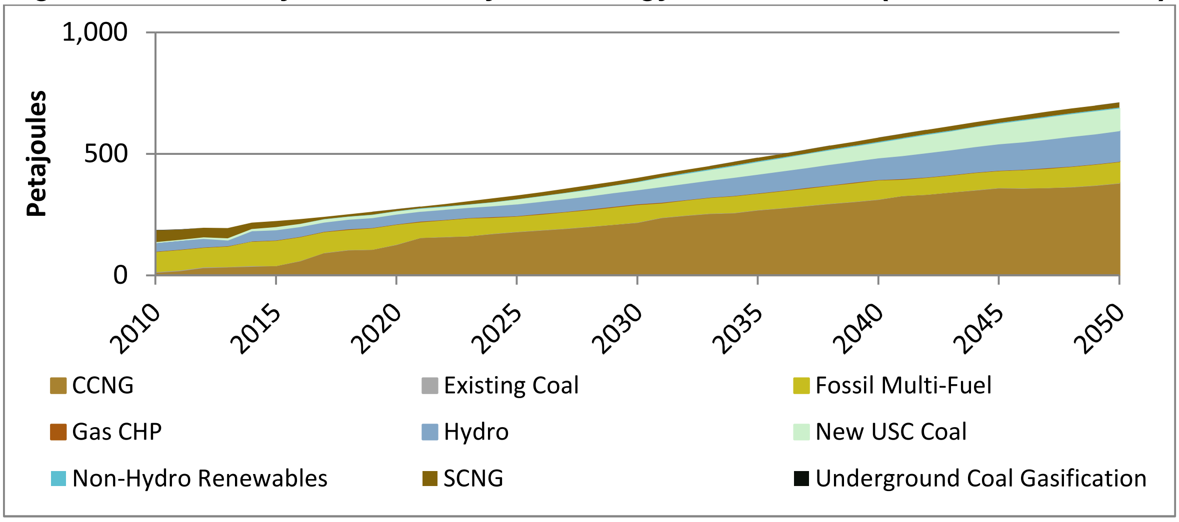
Notes: CCS = carbon capture and storage, CCNG = combined cycle natural gas, USC = ultrasupercritical coal

Table 24: Electricity Production in Kazakhstan (No Action Scenario, Petajoules)

Technology	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal	135.1	178.5	221.6	232.5	150.7	95.2	97.0	37.3	26.3	18.3	10.0
Existing Gas	4.2	11.9	17.9	11.6	2.8	2.7	0.0	0.0	0.0	0.1	0.4
Gas-Oil Dual	16.9	24.2	30.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	27.1	28.2	29.2	42.6	62.1	58.7	54.7	50.8	46.9	43.0	39.1
New CCNG	0.0	0.0	0.0	14.7	77.2	72.9	26.4	19.0	20.3	27.0	24.3
New CCNG CCS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
New Subcritical Coal	0.0	0.0	0.0	0.0	4.8	15.5	39.6	39.6	39.6	39.6	39.6
New Supercritical Coal	0.0	0.0	0.0	0.0	3.5	2.0	2.1	0.0	0.1	2.4	2.7
New USC Coal	0.0	0.0	0.0	0.0	26.6	115.9	169.0	287.3	384.8	475.7	605.8
Non-Hydro Renewables	0.0	0.0	0.0	2.8	10.3	15.0	36.6	47.4	33.4	30.1	24.7
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	10.0

Notes: CCS = carbon capture and storage, CCNG = combined cycle natural gas, USC = ultrasupercritical coal
Source: Stockholm Environment Institute and Abt Associates (2015c)

Figure 19: Electricity Production by Technology in Uzbekistan (No Action Scenario)



Notes: CHP = combined heat and power, CCNG = combined cycle natural gas, USC = ultrasupercritical coal

Table 25: Electricity Production in Uzbekistan (No Action Scenario, Petajoules)

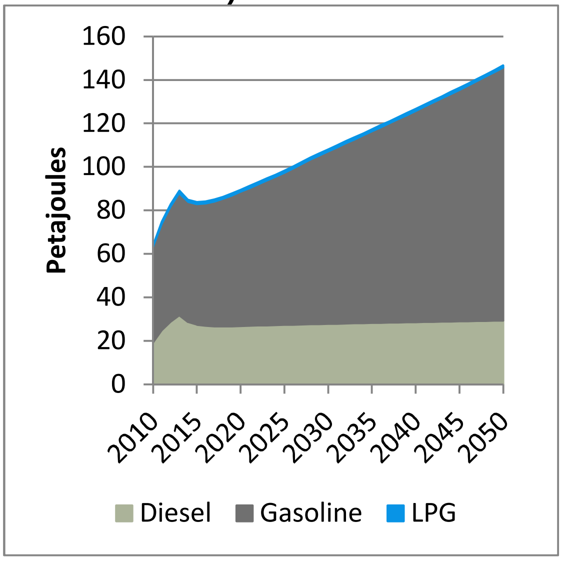
Technology	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
CCNG	0.0	14.5	14.9	41.4	129.1	182.0	219.4	270.8	314.7	361.8	381.8
Existing Coal	1.7	1.7	1.7	1.1	0.4	1.1	1.0	0.8	0.8	0.8	0.8
Fossil Multi-Fuel	88.2	80.9	83.1	103.5	82.2	62.1	73.1	67.2	78.8	70.2	86.9
Gas CHP	1.4	1.3	1.3	1.1	1.7	2.2	2.0	1.7	1.8	1.7	1.7
Hydro	21.2	22.0	36.0	41.8	40.8	48.2	58.7	77.2	89.4	108.5	126.3
New USC Coal	0.0	0.0	0.0	9.9	8.8	16.0	28.5	48.2	60.5	80.4	89.6
Non-Hydro Renewables	0.0	0.0	0.0	0.0	1.2	1.9	2.4	3.4	4.0	3.8	3.8
SCNG	55.7	51.0	48.7	25.0	7.9	15.7	16.4	14.1	16.4	17.4	20.1
Underground Coal Gasification	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: CHP = combined heat and power, CCNG = combined cycle natural gas, USC = ultrasupercritical coal
Sources: Stockholm Environment Institute and Abt Associates (2015c)

67. The road transport submodels for Azerbaijan and Kazakhstan show similar patterns to those in the power sector. Road transport in both countries remains dependent on fossil fuels (Figure 20 and Figure 21), although alternative fuels make inroads in Kazakhstan due to operating cost advantages of alternative vehicles and the rising affluence of consumers.[15]

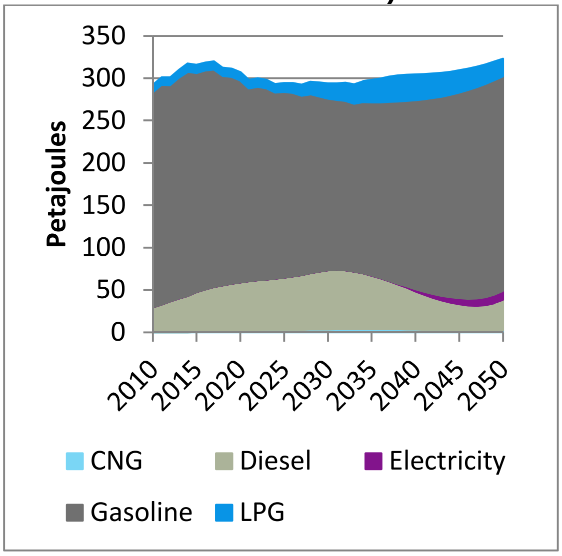
[15] The study team notes again that stakeholders in Kazakhstan recommended that alternative-fueled vehicles be included in the stock turnover projections, while stakeholders in Azerbaijan did not. Thus, liquefied petroleum gas (LPG), CNG, and electric light-duty passenger vehicles are not available as future options in the Azerbaijan stock turnover model though more efficient gasoline and diesel vehicles are.

Figure 20: Final Energy Demand for Road Transport in Azerbaijan (No Action Scenario)



Note: LPG = liquefied petroleum gas

Figure 21: Final Energy Demand for Road Transport in Kazakhstan (No Action Scenario)



Notes: CNG = compressed natural gas, LPG = liquefied petroleum gas

Table 26: Final Energy Demand for Road Transport in Azerbaijan (No Action Scenario, Petajoules)

Fuel	2010	2020	2030	2040	2050
Diesel	19.1	26.8	27.7	28.6	29.2
Gasoline	44.0	61.7	79.3	97.1	116.4
LPG	0.9	1.0	1.0	1.1	1.1

Note: LPG = liquefied petroleum gas
Source: Stockholm Environment Institute and Abt Associates (2015a)

Table 27: Final Energy Demand for Road Transport in Kazakhstan (No Action Scenario, Petajoules)

Fuel	2010	2020	2030	2040	2050
CNG	0.0	2.1	3.4	3.1	2.2
Diesel	29.4	56.7	69.8	45.1	36.1
Electricity	0.0	0.0	0.0	2.6	10.5
Gasoline	253.8	238.4	202.6	223.1	253.4
LPG	9.2	10.1	18.1	30.5	21.0

Notes: CNG = compressed natural gas, LPG = liquefied petroleum gas
Source: Stockholm Environment Institute and Abt Associates (2015b)

68. The relatively flat long-run trajectory for road transport demand in Kazakhstan derives from substantially improved end-use efficiencies for many classes of liquefied petroleum gas (LPG), compressed natural gas (CNG), and electric vehicles as compared to conventional gasoline and diesel varieties. According to Dzhaylaubekov (2010) and other sources noted in Table 64, these improvements, together with some technology switching, are enough to keep final energy demand in check even as the number of vehicles on the road increases. As shown in the following section, this development helps contain projected long-term GHG emissions from transport (although the reduced final demand by itself does not reflect changing upstream emissions associated with the production of LPG, CNG, electricity, and petroleum).

B. GHG Emissions

69. The Kaya analysis just sketched ends at a similar conclusion in each study country: increasing demand for carbon-intensive energy, driven by population and income growth, leads to rising GHG emissions overall. Combining the energy and transport system results with simple projections of non-energy emissions (see Appendix 2 and Appendix 3) produces the baseline projections in Figure 22. Figure 23-Figure 25 disaggregate these projections by source category.

Figure 22: Total GHG Emissions (No Action Scenario, 100-Year GWPs)

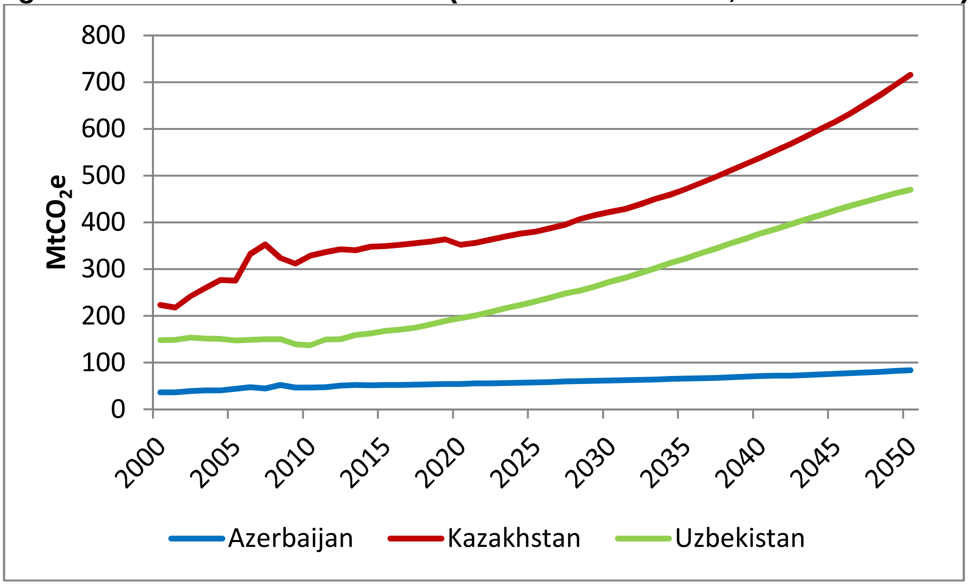
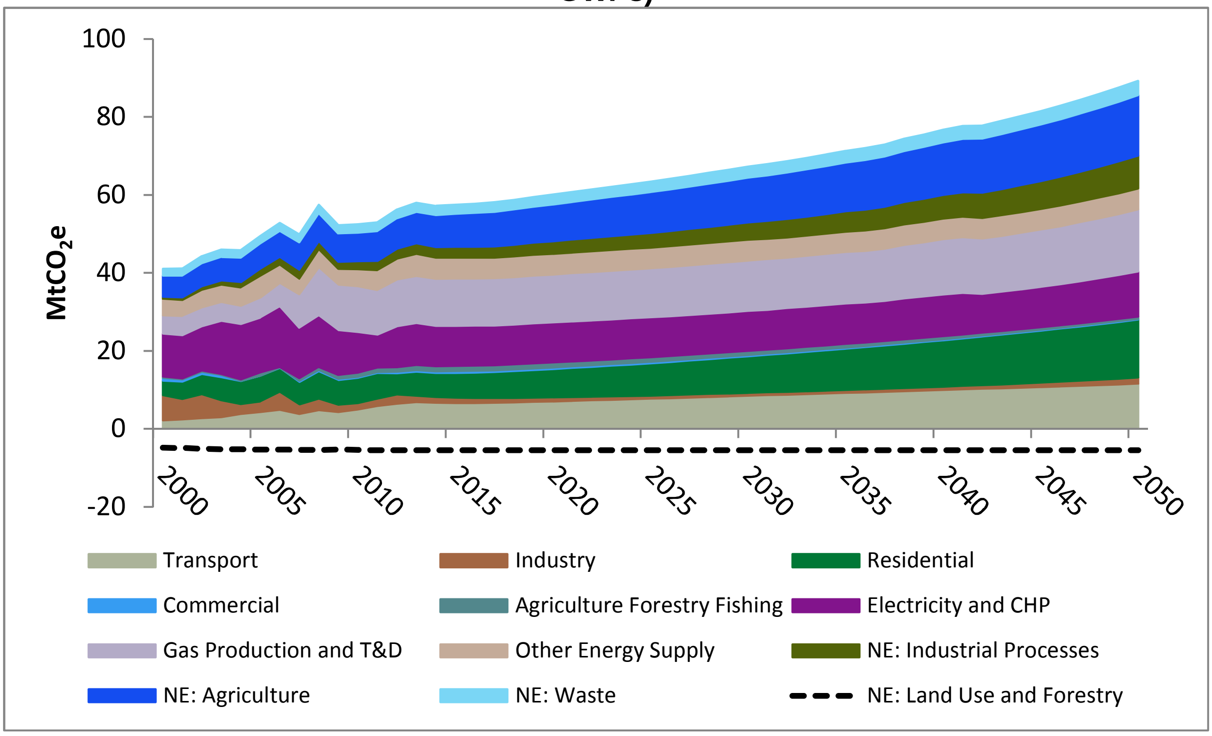


Table 28: Total GHG Emissions (No Action Scenario, $MtCO_2e$)

Country	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Azerbaijan	36.2	44.2	47.1	52.1	54.6	57.9	61.8	65.9	71.3	76.1	83.8
Kazakhstan	223.1	275.3	328.6	349.6	352.0	380.2	422.9	471.4	538.0	615.4	715.7
Uzbekistan	148.0	147.6	137.0	167.6	195.1	230.9	273.2	322.7	375.9	425.7	469.9

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Figure 23: GHG Emissions by Source in Azerbaijan (No Action Scenario, 100-Year GWPs)



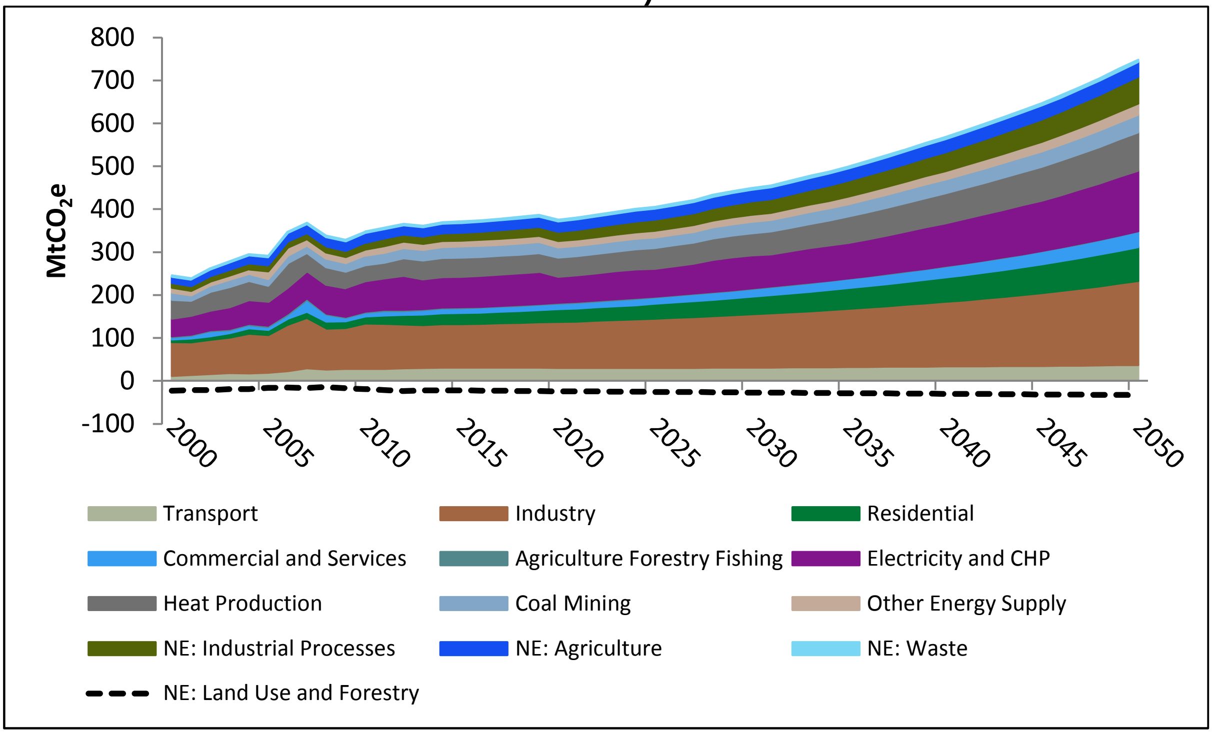
Notes: NE = Non-energy, CHP = combined heat and power, T&D = transmission and distribution.

Table 29: GHG Emissions by Source in Azerbaijan (No Action Scenario, 100-Year GWPs)

Sector	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Transport	2.2	4.2	5.0	6.6	7.0	7.7	8.4	9.2	9.9	10.7	11.6
Industry	6.4	2.8	1.6	1.4	1.0	0.8	0.7	0.8	0.9	1.1	1.6
Residential	3.7	6.6	6.5	6.4	7.3	8.3	9.4	10.6	11.9	13.3	14.9
Commercial	0.8	0.0	0.2	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.2
Agriculture Forestry Fishing	0.3	0.8	1.1	1.3	1.3	1.2	1.0	0.9	0.8	0.6	0.5
Electricity and CHP	11.0	14.1	10.5	10.3	10.3	10.2	10.2	10.4	10.7	10.3	11.6
Gas Production and T&D	4.7	5.1	11.7	12.1	12.3	12.6	13.0	13.2	14.2	14.7	15.9
Other Energy Supply	4.2	5.6	4.3	5.4	5.3	5.3	5.3	5.2	5.3	5.3	5.4
NE: Industrial Processes	0.6	1.8	2.1	2.8	3.2	3.8	4.4	5.2	6.1	7.2	8.4
NE: Agriculture	5.4	6.5	7.2	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5
NE: Land Use and Forestry	-4.9	-5.3	-5.4	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5
NE: Waste	1.8	2.0	2.3	2.4	2.6	2.7	2.9	3.1	3.3	3.5	3.7

Notes: NE = Non-energy, CHP = combined heat and power, T&D = transmission and distribution.
Source: Stockholm Environment Institute and Abt Associates (2015a)

Figure 24: GHG Emissions by Source in Kazakhstan (No Action Scenario, 100-Year GWPs)



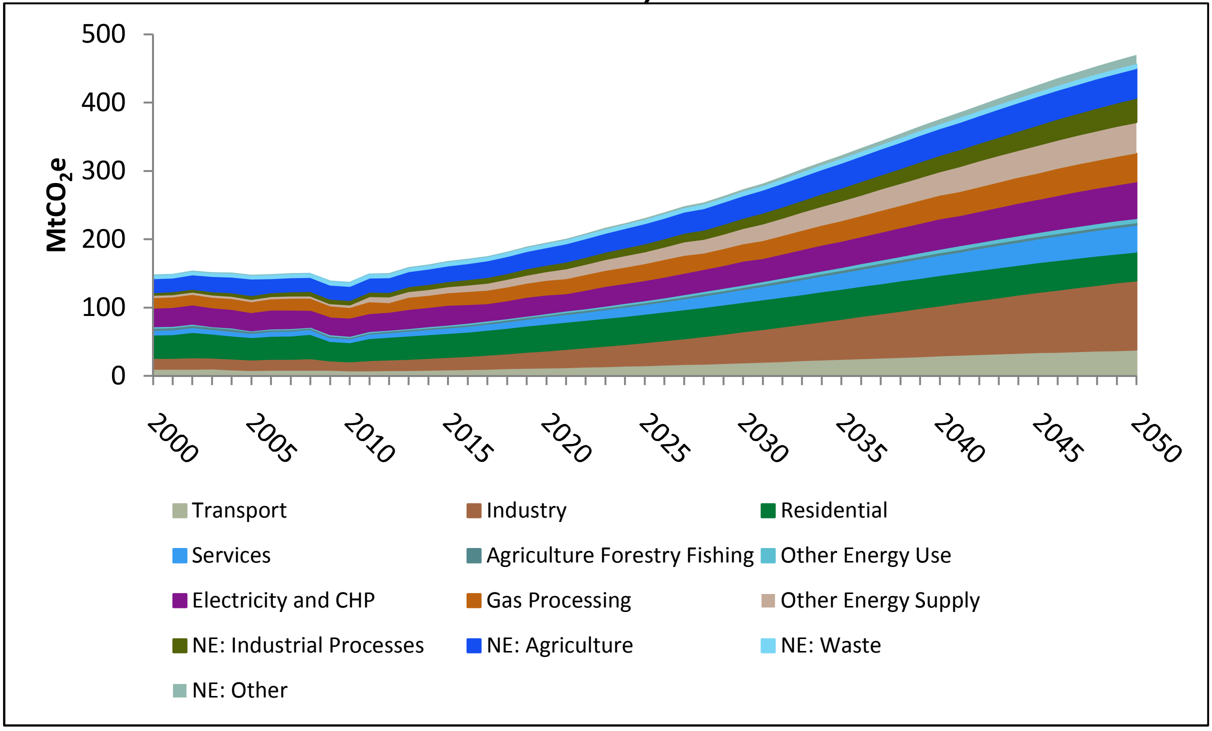
Notes: NE = Non-energy, CHP = combined heat and power

Table 30: GHG Emissions by Source in Kazakhstan (No Action Scenario, $MtCO_2e$)

Sector	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Transport	11.5	18.8	27.9	30.5	30.4	30.2	30.9	32.2	33.5	34.8	37.1
Industry	78.6	88.0	105.4	101.7	107.1	114.7	124.1	135.7	150.5	169.7	195.7
Residential	6.3	11.8	16.5	25.7	29.4	34.6	40.9	48.3	56.9	67.0	79.2
Commercial and Services	5.2	7.2	9.1	11.2	13.0	15.3	18.1	21.4	25.4	30.1	35.8
Agriculture Forestry Fishing	2.3	2.9	2.0	2.1	1.9	1.7	1.5	1.3	1.1	1.0	0.9
Electricity and CHP	40.8	55.5	70.9	70.9	60.5	64.9	76.6	82.2	99.2	117.0	141.3
Heat Production	44.1	37.1	37.4	44.9	45.1	48.4	52.0	61.8	70.1	78.9	89.4
Coal Mining	17.1	15.9	22.6	25.8	23.6	24.4	26.7	28.8	32.0	35.6	40.3
Other Energy Supply	11.3	17.9	14.0	14.0	14.6	15.4	16.3	17.8	19.8	22.4	26.1
NE: Industrial Processes	10.9	14.0	15.8	18.6	21.9	26.0	31.0	36.9	44.0	52.5	62.8
NE: Agriculture	14.6	19.2	22.4	22.3	24.0	25.5	26.9	28.5	30.3	32.2	34.3
NE: Land Use and Forestry	-22.8	-16.4	-19.4	-22.4	-23.9	-25.5	-27.0	-28.5	-30.0	-31.5	-33.0
NE: Waste	3.2	3.5	3.9	4.2	4.5	4.7	4.9	5.1	5.3	5.6	5.8

Notes: NE = Non-energy, CHP = combined heat and power
Source: Stockholm Environment Institute and Abt Associates (2015b)

Figure 25: GHG Emissions by Source in Uzbekistan (No Action Scenario, 100-Year GWPs)



Notes: NE = Non-energy, CHP = combined heat and power

Table 31: GHG Emissions by Source in Uzbekistan (No Action Scenario, $MtCO_2e$)

Sector	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Transport	10.4	8.7	8.0	9.6	12.2	15.6	19.9	24.8	29.8	34.5	38.4
Industry	16.0	15.2	13.0	18.0	24.9	33.6	45.1	58.8	73.5	88.1	101.4
Residential	34.1	32.6	28.4	35.2	39.3	41.7	43.2	44.1	44.2	43.6	42.2
Services	6.7	6.4	5.5	7.9	10.6	14.1	18.6	23.9	29.4	34.6	39.1
Agriculture Forestry Fishing	3.3	2.5	2.0	2.3	2.6	2.9	3.3	3.6	3.8	3.8	3.6
Other Energy Use	2.0	1.1	1.5	1.9	2.3	2.9	3.6	4.4	5.1	5.9	6.5
Electricity and CHP	27.4	26.7	26.8	28.9	26.9	29.2	34.9	38.2	44.5	48.4	53.6
Gas Processing	13.8	14.7	14.4	17.1	20.2	23.4	24.1	28.5	33.2	37.3	40.9
Other Energy Supply	4.8	4.5	4.9	10.1	14.0	18.8	23.9	30.4	36.0	42.1	45.6
NE: Industrial Processes	3.9	5.4	6.5	7.6	9.4	11.8	14.9	18.9	23.7	29.3	35.6
NE: Agriculture	20.7	24.3	20.7	23.2	26.1	29.3	32.9	36.4	39.5	42.0	43.6
NE: Waste	4.2	4.6	4.6	4.8	5.0	5.3	5.4	5.6	5.7	5.8	5.9
NE: Other	0.7	0.7	0.7	1.0	1.5	2.3	3.5	5.2	7.4	10.2	13.6

Notes: NE = Non-energy, CHP = combined heat and power
Source: Stockholm Environment Institute and Abt Associates (2015c)

70. Between 2010 and 2050, total projected emissions rise 78% in Azerbaijan, 118% in Kazakhstan, and 243% in Uzbekistan. These increases have important implications for mitigation, simultaneously highlighting the need for mitigation effort and a growing potential to reduce fossil fuel emissions through efficiency, fuel switching, and other measures.

71. The very high emission growth in Uzbekistan results in part from the high GDP growth rates assumed in the No Action scenario (8.2% through 2030, decreasing linearly to 5% by 2050). As mentioned in Section III.E.3, these GDP growth rates were specified by Uzbekistan's Ministry of Economy. The Ministry also provided alternate, lower rates to be examined in an alternative baseline: 7% in 2015 and 7.2% in 2016, decreasing linearly to 4% by 2050. Using these rates and all other No Action inputs, projected GHG emissions increase 115% by 2050, a result comparable to the increase in Kazakhstan. However, these lower rates are not part of this study's formal baseline.

72. Within energy and transport, certain source categories stand out in the emission projections due to their contribution to the 2050 total and emission growth over time (Table 32). Many of these categories or sectors are the target of mitigation options explored in this study, but some—such as fossil fuel production in Azerbaijan and Uzbekistan—are not. Focusing future national planning on mitigation opportunities in these sectors could be helpful.

Table 32: Significant GHG Emission Source Categories in Energy and Transport (No Action Scenario)

Country	Source	Share of 2050 Emissions, %	Growth, 2010-2050, %
Azerbaijan	Gas Production and T&D	19	35
	Residential	18	128
	Transport	14	133
	Electricity and CHP	11	14
Kazakhstan	Industry	27	86
	Electricity and CHP	20	99
	Heat Production	12	139
	Residential	11	379
	Coal Mining	6	79
Uzbekistan	Industry	22	678
	Electricity and CHP	11	100
	Gas Processing	9	184
	Residential	9	49
	Heat Production	8	881
	Services	8	616
	Transport	8	378

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

V. COSTS AND BENEFITS OF MITIGATION IN AZERBAIJAN, KAZAKHSTAN, AND UZBEKISTAN

73. This Section presents findings from the mitigation analysis for Azerbaijan, Kazakhstan, and Uzbekistan. The first two parts provide quantified costs and benefits for the mitigation options that were studied (mitigation mini-scenarios, pricing scenarios, and combined scenarios), including measures of direct cost-effectiveness and co-benefits. The third part discusses policy implications of the mitigation analysis with an emphasis on connecting short and long-run planning.

A. Direct Costs and Benefits of Mitigation

74. The analysis of direct costs and benefits of mitigation considers two primary questions: the mitigation potential (tonnes CO_2e reduced) and the cost-effectiveness (direct cost per tonne CO_2e reduced) of each mitigation option. The cost-effectiveness calculus comprises the social costs described in Section III.B, including capital, O&M, fuel, and program implementation costs. Focusing on these costs (and benefits, in the case of net cost reductions) in the first level of the mitigation analysis helps identify options that provide the greatest abatement return for society's direct investment.

75. A key issue in the estimation of mitigation potential and costs per tonne is how to account for interactions between mitigation options. Implementing certain options together can lower (or raise) their total effectiveness—for example, an electric efficiency measure will result in greater abatement when the power system is carbon intensive, but less if a renewable power measure is deployed concurrently. This study addresses this issue following the retrospective systems approach in Sathaye and Meyers (1995). In brief, this method involves four steps:

(i) Each mitigation option is first evaluated individually (compared to the No Action case), and an initial cost per tonne for each is recorded.
(ii) The options are sorted according to their initial costs per tonne in ascending order.
(iii) The options are added one at a time and in order to a new combined mitigation scenario, and emissions and costs for the combined scenario are recorded after each addition.
(iv) The final abatement potential and cost per tonne for each option are calculated using the marginal emission reductions and costs incurred after the option was added to the combined scenario. Thus, the first option is evaluated in comparison to the No Action Scenario only, the second option in comparison to the No Action Scenario plus the first option, and so forth.

76. The consultant team used the retrospective systems approach to calculate mitigation potential and costs for all technical mitigation options (technical mitigation mini-scenarios) as well as combined mitigation scenarios that are amenable to joint evaluation with other options. Table 33 summarizes the results of this analysis. Abatement potential and costs for other mitigation scenarios, including the pricing mini-scenarios, was estimated by comparing each scenario directly (and individually) with the No Action Scenario. Table 34 lists the pricing mini-scenarios considered for Azerbaijan and Kazakhstan. No pricing scenarios were developed for Uzbekistan given the limited availability of historical fuel price data to inform the development of a price-responsive model for that country. Table 35 lists the combined mitigation scenarios considered for each country.

Table 33: Direct Costs and Abatement Potential for Technical Mitigation Mini-Scenarios (Cumulative through 2050 Using Retrospective Systems Analysis)

Azerbaijan			
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Discounted Reduction Cost per Tonne [2007 AZN / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
Euro 4 Vehicle Standards	12,301,298	-47.7	-70.2
SOCAR Eco-driving	1,926,241	-43.2	-63.6
Commercial CFL Lighting	44,199,773	-6.3	-9.3
Residential CFL Lighting	76,763,797	-5.8	-8.5
Forests 20% of Total Land Area	45,706,558	0.5	0.8
Forests 12.5% of Total Land Area	8,466,758	0.9	1.3
Improved Insulation	72,144,742	1.0	1.5
Small Hydro	33,939,169	1.3	1.9
Sustainable Land Management	12,052,454	2.2	3.3
Onshore Wind	15,534,982	5.8	8.5
Samukh Agro-Energy Complex	4,074,171	6.8	10.0
Renewable Power Target[16]	32,550,700	24.2	35.6
3 MW Small Solar	93,009	28.6	42.0
Municipal Solid Waste to Energy	4,751,891	56.5	83.1
Biogas	1,963,020	124.2	182.7
Electricity Network Upgrade	20,107,941	236.2	347.3
AC Rail Conversion	529,352	325.0	477.8
Solar Hot Water	1,416,631	379.5	558.0
Efficient Stoves	196,768	773.9	1,137.8
Rail Electrification	91,026	909.4	1,337.1
SAARES Short-Term Plans	0	NA*	NA*
Kazakhstan			
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 KZT / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
CNG Fleet	27,295,626	-12,170.7	-82.6
CNG Passenger Cars	1,453,274	-2,786.3	-18.9
Improved Heat Pipe Insulation	166,006,789	-292.3	-2.0
Coalbed Methane Capture	94,167,987	-139.5	-0.9
Efficient New Homes	238,762,921	-43.4	-0.3
Natural Gas Power Target (Green Growth)	399,039,208	337.0	2.3
Internal Heating Network Improvements	404,198,552	507.4	3.4
CO_2 Cap on Power (Green Growth)	673,820,538	558.4	3.8
Improved Insulation	395,591,779	1,007.6	6.8
Advanced Windows	77,757,249	1,808.7	12.3

[16] The Renewable Power Target Scenario is actually a combined mitigation scenario (it combines SAARES's short-term plans with renewable power targets for 2020), but it is included with the technical scenarios because it was evaluated using the retrospective systems method.

Heat Distribution Upgrades	159,352,071	2,877.4	19.5
Alternative Power Target	217,505,879	4,457.0	30.2
Expanded + Optimistic Nuclear Power[17]	38,826,060	4,771.7	32.4
Rehabilitation of National Grid	21,979,657	13,991.4	95.0
Urban LED Lighting	459,737	19,499.8	132.3
Waste to Energy	-142,956	NA*	NA*
Euro 5 Vehicles	-10,237,033	NA*	NA*
Early Vehicle Retirement	-31,179,955	NA*	NA*
Uzbekistan			
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Discounted Reduction Cost per Tonne [2013 UZS / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
Residential Building Efficiency	569,147,765	-111,064.7	-44.9
Large Hydro	110,835,506	-100,493.5	-40.7
Small Hydro	22,924,927	-51,184.7	-20.7
Residential Renewable Energy	26,166,554	-24,043.9	-9.7
Alternative Vehicles	128,471,751	1,546.2	0.6
Heat Network Improvements	48,112,419	19,898.4	8.1
Heat Plant Efficiency	71,424,254	45,803.2	18.5
Solar Electricity	31,200,307	60,451.5	24.5
Electricity Grid Improvements	57,640,715	223,258.6	90.3
Rail Electrification	3,737,049	3,107,406.1	1,257.3

Notes: * Mini-scenarios marked "NA" have undefined abatement costs since they result in increased or unchanged emissions. In many cases (e.g., the Renewable Power Target scenario in Azerbaijan), this result is due to interactions with mini-scenarios ranked higher in the retrospective systems order.
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Table 34: Direct Costs and Abatement Potential for Pricing Scenarios (Cumulative Through 2050 Relative to the No Action Scenario)

Azerbaijan				
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Percent Change by 2050 Relative to No Action Scenario (%)**	**Discounted Reduction Cost per Tonne [2007 AZN / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
Carbon Tax (Low)	449,401,278	-14.9	3.0	4.4
Carbon Tax (Moderate)	517,191,771	-17.1	3.3	4.8
Carbon Tax (EU Harmonization)	549,828,236	-18.2	3.5	5.2
Fossil Subsidy Removal	575,454,155	-19.1	5.0	7.4
OECD Fuel Prices	1,103,806,342	-36.6	5.2	7.7
Kazakhstan				
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Percent Change by 2050 Relative to No Action Scenario (%)**	**Discounted Reduction Cost per Tonne [2010 KZT / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**

[17] For the purposes of this mitigation analysis, the Expanded Nuclear Power and Optimistic Nuclear Power mini-scenarios are combined so that the total abatement cost is reflective of all proposed nuclear expansions.

Emissions Trading Scheme	1,544,370,058	-7.1	638.7	4.3
Extended ETS	1,558,672,146	-7.2	11,904.8	80.8
OECD Fuel Prices	1,124,925,667	-5.2	3,090.1	21.0

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b)

Table 35: Direct Costs and Abatement Potential for Combined Mitigation Scenarios (Cumulative Through 2050 Relative to the No Action Scenario)

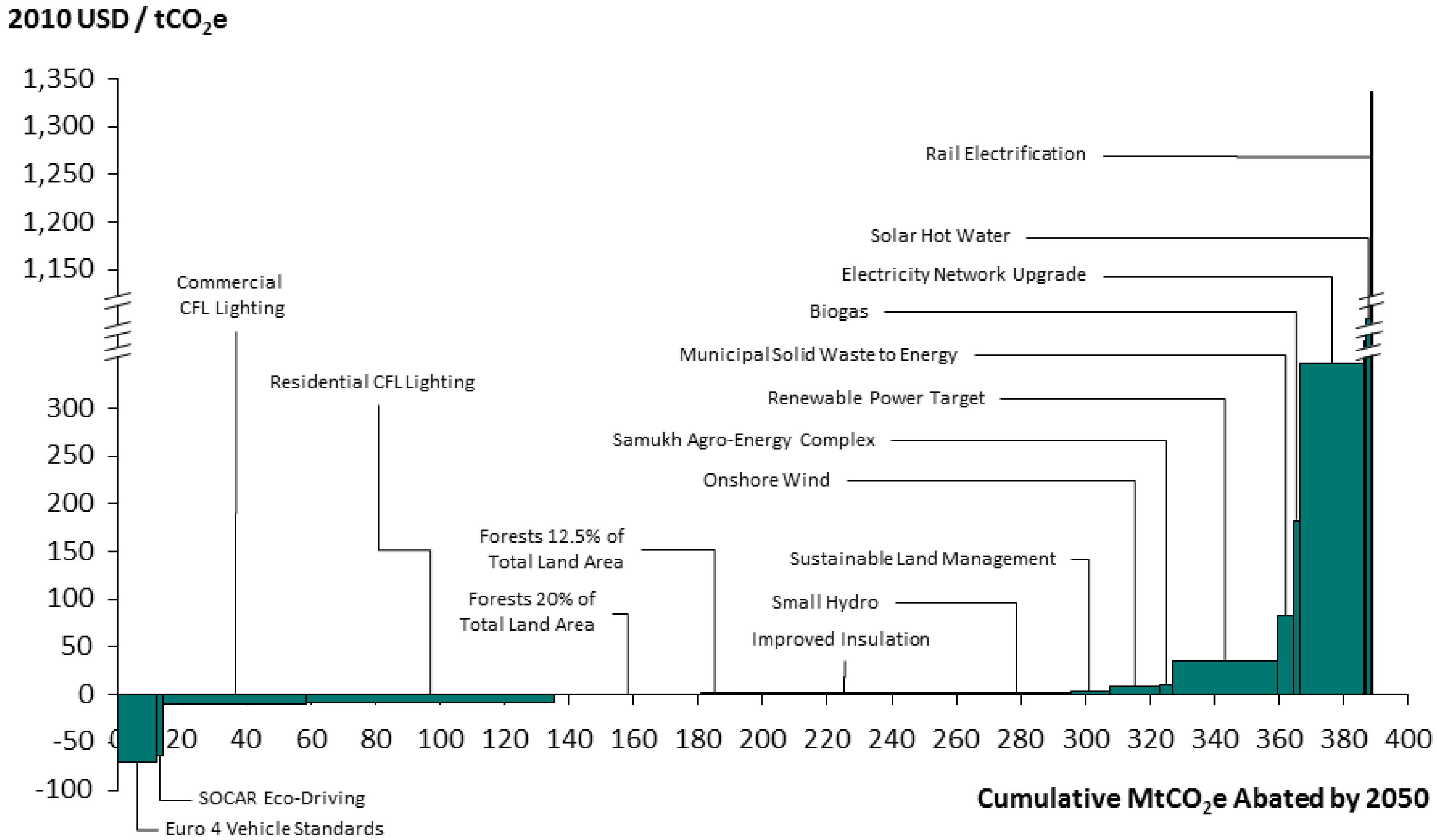
Azerbaijan				
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Percent Change by 2050 Relative to No Action Scenario (%)**	**Discounted Reduction Cost per Tonne [2007 AZN / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
State Program of Poverty Reduction	-479,774,029	15.9	NA*	NA*
All Low-Cost Technical Measures	327,109,943	-10.8	-3.4	-4.9
All Moderate-Cost Technical Measures	359,753,652	-11.9	-0.9	-1.3
All Technical Measures	388,810,279	-12.9	15.2	22.3
Kazakhstan				
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Percent Change by 2050 Relative to No Action Scenario (%)**	**Discounted Reduction Cost per Tonne [2010 KZT / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
All Low-Cost Technical Measures	2,777,194,623	-12.9	768.4	5.2
All Technical Measures	2,916,074,370	-13.5	956.0	6.5
Uzbekistan				
Scenario	**Cumulative Potential GHG Emission Reductions [tCO_2e]**	**Percent Change by 2050 Relative to No Action Scenario (%)**	**Discounted Reduction Cost per Tonne [2013 UZS / tCO_2e]**	**Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]**
All Low-Cost Technical Measures	905,658,923	-6.5	-82,809.3	-33.5
All Mini-Scenarios	1,069,661,249	-7.7	-42,404.2	-17.2

Notes: * Scenarios marked "NA" have undefined abatement costs since they result in increased or unchanged emissions.
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

77. The abatement potential and costs of options evaluated via the retrospective systems method can be represented visually in a *marginal abatement cost curve*, or MACC. Such a curve is composed of a series of segments for the mitigation options that are explored—the width represents the total abatement potential of an option, while the height describes the option's cost-effectiveness. The segments (usually rectangles, for a set of discrete mitigation measures) are then aligned in order of increasing cost per tonne. The widths of segments can be added to determine the total mitigation potential at a given cost.

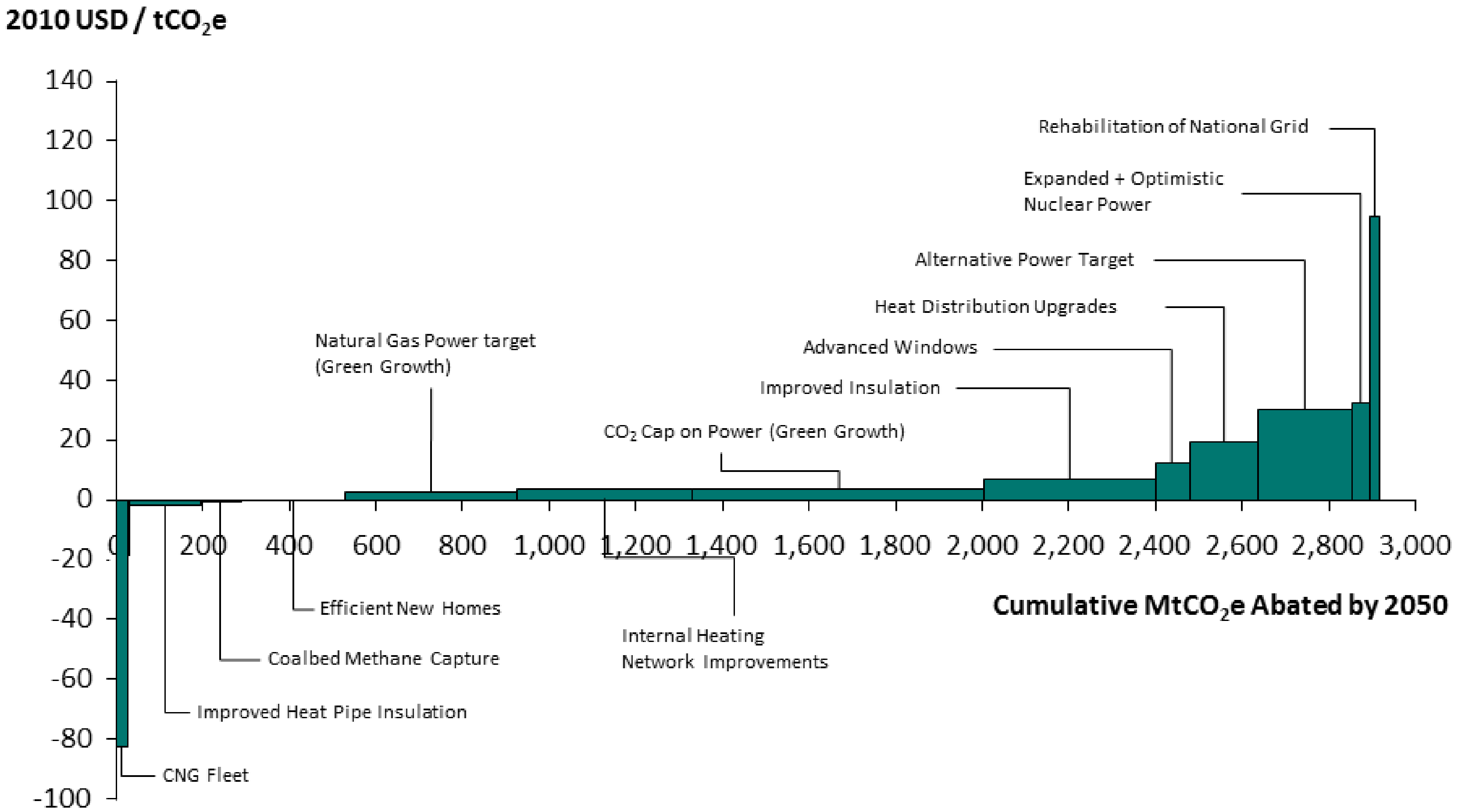
78. MACCs for all three study countries follow. For the sake of readability, some options with very small mitigation potential are not labeled in the MACCs (however, their values can be retrieved from Table 33 above).

Figure 26: MACC of Technical Mitigation Mini-Scenarios in Azerbaijan



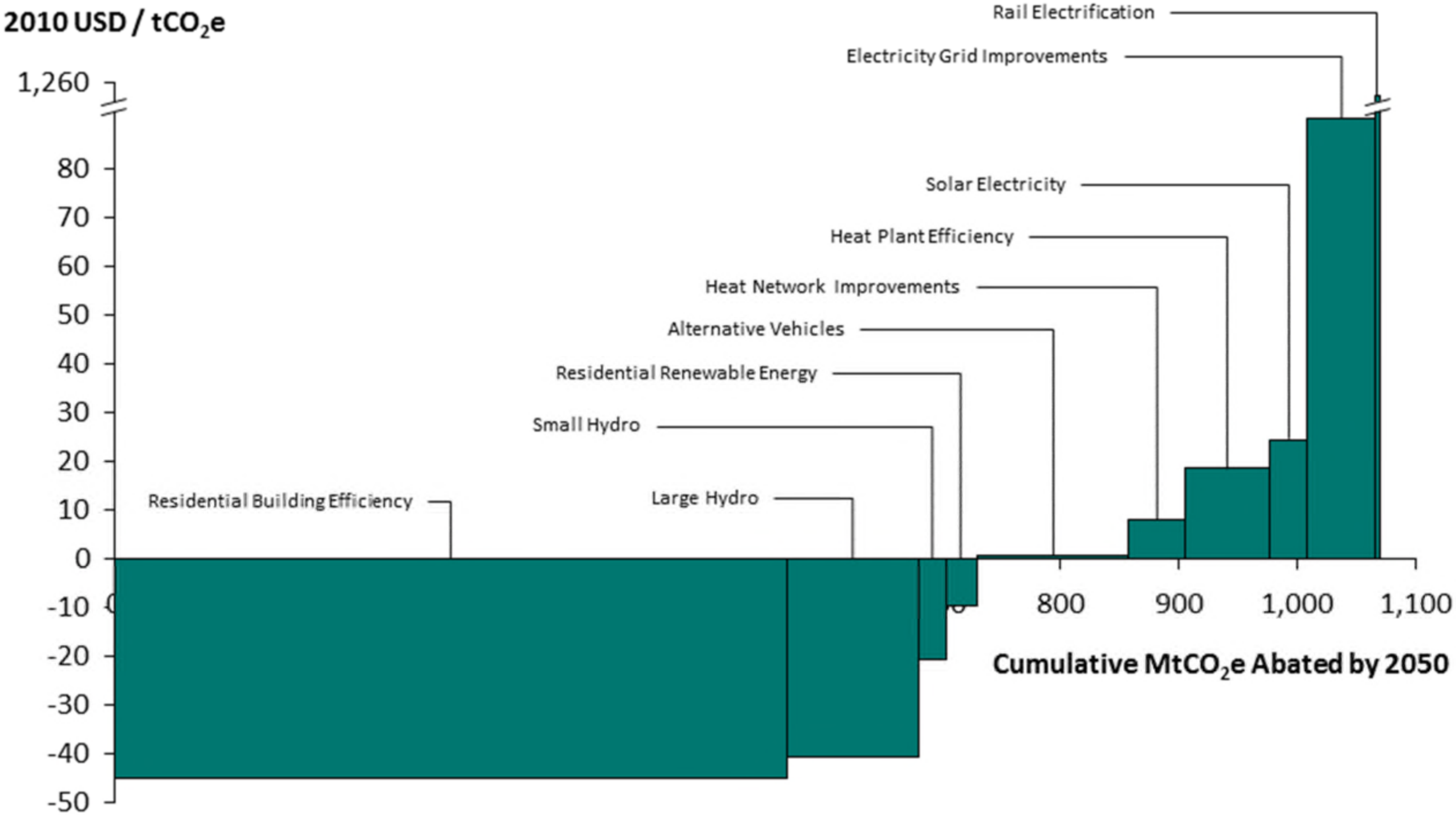
Source: Stockholm Environment Institute and Abt Associates (2015a)

Figure 27: MACC of Technical Mitigation Mini-Scenarios in Kazakhstan



Source: Stockholm Environment Institute and Abt Associates (2015b)

Figure 28: MACC of Technical Mitigation Mini-Scenarios in Uzbekistan



Source: Stockholm Environment Institute and Abt Associates (2015c)

79. The MACCs indicate that in each country there is a selection of technical mitigation measures with high mitigation potential that can be accessed at either a direct cost savings or a very low cost per tonne of abatement. These are particularly attractive options. Efficiency improvements in buildings and vehicles fall into this category across the three countries, and in some cases renewable energy options are also quite cost-effective (e.g., small hydropower in Azerbaijan). Many of the highest-cost measures contribute relatively little to the overall level of abatement that is achievable by the ensemble of mitigation options. This finding suggests that mitigation planning in the countries is indeed focused on cost-effective approaches, although high-cost options may still be worth considering if they advance other social goals, such as economic development.

80. Pricing-based mitigation policies can also contribute to significant GHG abatement at a relatively low cost, as illustrated by the results provided in Table 34. In Azerbaijan, several of the price-based carbon tax scenarios result in a higher amount of cumulative GHG abatement than if all low-cost technical measures were implemented, albeit at a slightly higher cost. Similarly, if Azerbaijan were to equalize fossil fuel prices with those of countries in the Organization for Economic Co-operation and Development (OECD) by 2030 the country can achieve a 36% reduction in GHG emissions by 2050 as compared to the No Action Scenario. This can be done at a fairly low cost to society of about $ 7 tCO_2e. This indicates that there are several additional low cost mitigation options available to Azerbaijan, beyond those analyzed in this TA which the government can incorporate into its development plans. For example, due to lack of data, this study does not analyze mitigation measures targeting fugitive emissions from oil and gas production although there is significant potential for reducing emissions from this sector.

81. The price-based mitigation measures analyzed for Kazakhstan, such as emissions trading and removal of fossil fuel subsidies, result in a 5-7% reduction in cumulative emissions by 2050 compared to the No Action Scenario which is about half as much as if all the low-cost technical mitigation measures are implemented (12.9%). This indicates that Kazakhstan is already planning to implement measures that will result in considerable emission reductions, such as switching away from coal for power generation and improving the efficiency of energy use for buildings.

82. Many of the mitigation scenarios evaluated in the direct cost-benefit analysis have noteworthy features beyond their abatement potential and costs. A brief discussion of the most salient such scenarios and features follows, organized by country.

Azerbaijan

Residential and Commercial CFL Lighting

83. Together, large scale programs for compact fluorescent lighting in the residential and commercial sectors provide one of the largest mitigation potentials among the options that were analyzed. The cost-effectiveness of the measures is remarkable, especially when compared to a similar measure to improve lighting efficiency using LEDs in Kazakhstan. Differences between these measures point to the relatively small capital costs of CFL technology compared to LED, but also to the high efficiencies of contemporary CFL bulbs.

Improved Insulation

84. Despite the seasonal climate in Azerbaijan, which includes both warm and cold periods, many residential buildings remain poorly insulated. In the winter, district heating with natural gas

as well as distributed gas and electric heating systems require significant energy inputs to condition residential space. Upgrading residential insulation has been shown to have a substantial impact on these requirements (Aliyev 2013). This mini-scenario demonstrates the effect of scaling up a program of insulation upgrades to reach an important fraction of residences by 2050. The fuel cost savings nearly equal the implementation costs, leading to low cost per tonne of abatement.

Small Hydro

85. Expansion of small hydropower stations in Azerbaijan yields intermediate GHG reductions at a low cost per tonne. Attention is drawn to it here because of the cost differences for small hydro deployment between Azerbaijan and Uzbekistan, where small hydropower stations provide a cost *savings* while reducing emissions. The key to understanding the difference between the two countries is in the price of fuels that are displaced by the introduction of hydro. In Uzbekistan, fuel savings alone are sufficient to drive the cost per tonne of abatement to negative values, whereas in Azerbaijan fuel cost savings are outweighed by the capital and operating expenses of the new hydro plants.

Samukh Agro-Energy Complex

86. The pilot agro-energy complex in the Samukh district, the subject of a proposed nationally appropriate mitigation action for Azerbaijan, presents a modest reduction potential at a low cost per tonne. However, the prototype could be scaled to other districts, which means that the true abatement potential of community projects like those planned in Samukh may not yet be realized.

Renewable Power Target and SAARES Short-Term Plans

87. Since the Renewable Power Target Scenario includes SAARES' short-term plans, the Short-Term Plans Scenario does not provide any incremental abatement once Renewable Power Target is implemented under retrospective systems. The Power Target Scenario relies on SAARES' plans to attain its generation and capacity goals through 2020; after 2020, it deploys additional renewable capacity as needed to ensure that 20% of generation continues to come from renewables. It is interesting to compare SAARES' program with the capacity additions after 2020. SAARES' plans are weighted heavily toward solar PV (48% of planned capacity) and wind (26%) with some hydro and bioenergy. After 2020, the least-cost optimization solution is predominantly wind (82% of capacity additions) and small hydro (17%). The differences suggest that SAARES' decision-making may account for social and political factors not represented in this study's direct cost analysis. Additionally, continued government support may be necessary to ensure solar development in the longer term.

Rail Electrification

88. Rail Electrification is the least cost-effective option considered for Azerbaijan and also has minimal abatement potential. These results reflect the high capital costs of rail, including the purchase of new electric locomotives, and the indirect GHG emissions impact of switching to electricity. Substituting electricity for diesel reduces direct GHG emissions from trains but increases emissions from power generation. In the Rail Electrification Scenario, these two factors nearly offset each other. However, as the net change in emissions depends on the carbon intensity of generation, rail electrification would become more cost-effective if deeper decarbonization of the power sector were pursued.

State Program of Poverty Reduction

89. Despite including measures to improve the efficiency of the power system, as well as a plan to increase carbon uptake in forested areas, the State Program of Poverty Reduction Scenario does not generate any emissions abatement. The personal income targets laid out in the program mean that energy demand increases (via income elasticities shown in Table 49) as incomes rise, and with the rise in energy demand comes increased emissions.

Kazakhstan

CNG Fleet

90. Like the CNG Passenger Cars Scenario, this measure describes a fixed increase in the number of CNG (or dual-fueled CNG with gasoline or diesel) vehicles on the road. However, the two scenarios are distinct in that the CNG Fleet Scenario assumes that *all* vehicle categories, with the exception of motorcycles, are eligible for conversion to natural gas. The savings per tonne of GHGs reduced, which is achievable by integrating compressed natural gas across the entire vehicle fleet, is significantly greater than the savings if only M1 category vehicles (light-duty passenger vehicles) are targeted for fuel switching. In fact, the CNG Fleet Scenario shows the lowest abatement cost of all measures explored in Kazakhstan. Though some initial investment would be required by users, these costs are amply compensated by reduced fuel expenses due to the high efficiency of CNG engines.

91. Not only is CNG for heavier-duty vehicles a highly cost-effective means of reducing emissions, but the total national reduction potential is likely much greater than this limited scenario suggests. Under the CNG Fleet Scenario, only 17% of M2, M3, and N vehicles use CNG by 2025 (the target year for attaining the scenario's CNG vehicle sales goals), and significant numbers of conventional (gasoline and diesel) heavy-duty vehicles are still sold (Stockholm Environment Institute and Abt Associates 2015b). Gasoline and diesel vehicles produce 89% of heavy-duty GHG emissions by 2025, or nearly 50% of total on-road emissions. These figures indicate the potential to decrease on-road emissions further with a more aggressive deployment of CNG trucks and buses.

Improved Heat Pipe Insulation

92. The existing building stock in Kazakhstan suffers large losses of heat energy due to poorly insulated internal (in-building) heating pipes. Many of these losses arise from the delivery of heat to spaces that are uninhabited—hallways and elevator shafts, or through ceilings into the attic (Ergonomika 2011). Reducing the loss of energy inside these networks results in very similar abatement potential to the improvement of the (external) district heating network described by the Heating Distribution Upgrades Scenario, but at a cost savings.

Efficient New Homes

93. The construction of new homes that satisfy more stringent heating efficiency standards is an important abatement tool, likely with even higher abatement potential than indicated in this scenario (which assumes that efficient new residences will be constructed only to address growth in urban population, but not to replace demolished homes). This scenario also suggests that it is more cost-effective to implement improved heating standards for new homes than it is

to retrofit existing homes, since the majority of individual residential retrofit measures studied were found to have a higher abatement cost.

Urban LED Lighting

94. Deploying efficient LED outdoor lighting in municipalities across Kazakhstan is the least cost-effective mitigation option studied (and also has a relatively low emissions impact). In part, this is due to high device costs used to estimate project costs in UNDP (2014b). Though a middle estimate was selected among the range of costs presented in this report, the cost is still well beyond ordinary consumer prices for similar technology.

Euro 5 Vehicles

95. The Euro 5 Vehicles Scenario does not show any abatement potential, raising cumulative GHG emissions by 2050 by about 10 $MtCO_2e$. The underlying reason is in the consumer choice model of new vehicle sales described in Section III.E.1. Considering a range of attributes, including vehicle purchase and fuel costs, consumers opt for more gasoline and diesel vehicles when sales are restricted to Euro 5 only than when both Euro 4 and Euro 5 vehicles are available. In other words, the relative attractiveness of gasoline and diesel increases when all new vehicles are held to the Euro 5 standard. The shift in purchasing leads to more gasoline and diesel vehicles and fewer alternative-fuel vehicles on the road than would otherwise be the case. Although Euro 5 gasoline and diesel engines are more efficient than older gasoline and diesel variants, their greater deployment causes higher emissions.

Early Vehicle Retirement

96. As described in Dzhaylaubekov (2010), vehicles in Kazakhstan tend to be driven fewer kilometers each year that they age. In a scenario that replaces old vehicles with new, it is therefore likely that total kilometers traveled will increase. This effect is observed in this mini-scenario, with the result that fuel demand and emissions rise as the average age of the fleet declines, despite modest efficiency improvements provided by the newer vehicles.

Natural Gas Power Target

97. Among the higher-potential measures explored, generating power from natural gas is also quite cost-effective. The No Action Scenario foresees a short term switch away from natural gas generation (which has historically represented 10-12% of electricity produced in Kazakhstan), followed by a period of increased natural gas use, before reverting back to a primarily coal-based power system in the long term. Therefore meeting a larger share of power generation with gas, especially in the short and long term time horizons, provides considerable mitigation benefits. The additional natural gas generation mostly displaces coal-fired power, but also small quantities of wind and small hydropower (and eventually a small amount of nuclear) when compared to the No Action Scenario.

Alternative Power Target

98. Implemented with no other measures, the Alternative Power Target replaces mostly coal-fired generation with a mixture of wind, solar, and nuclear power. This leads to steep emission reductions despite high absolute costs. However, in the retrospective systems analysis, the power system has already undergone significant changes from the business-as-usual trajectory by the time Alternative Power Target is added (most notably arising from the Natural Gas Power

Target and CO_2 Cap on Power mini-scenarios), so the alternative sources of power instead tend to displace natural gas. This means that similarly high upfront costs are spread over a much smaller gain in abatement, resulting in substantially higher abatement costs than would otherwise be expected.

Rehabilitation of the National Grid

99. This measure clearly demonstrates the importance of understanding interactions between different mitigation options. Added by itself to the No Action Scenario, reducing electricity losses offers significant GHG reductions— nearly 43 $MtCO_2e$ cumulatively through 2050—because the power system is primarily coal-based. However, once electricity generation has shifted to renewables, natural gas, and nuclear, the impact of grid improvements is diminished. Lower losses still provide somewhat lower GHG emissions, but a rather high cost per tonne is implied.

Waste to Energy

100. When compared individually to the No Action Scenario, Waste to Energy (WtE) provides modest GHG emission reductions due to fuel switching away from coal. However, due to the high cost of this mitigation option, in the retrospective systems approach it is not evaluated until a number of lower-cost power sector measures have already been deployed. At this point, WtE emissions are higher than those of the new, lower carbon power mix, so the option does not have an abatement potential. Nevertheless, WtE may still be worth pursuing for reasons that do not hinge on GHG mitigation, such as improving solid waste management.

Emissions Trading Scheme

101. Since it can be demonstrated that carbon tax and cap-and-trade systems yield identical emission reductions at identical costs (Goulder and Schein 2013), Kazakhstan's ETS plans are modeled as if they were a carbon tax to which only the industrial and electricity sectors are subjected.[18] Reduction targets in 2013 and 2014 under the ETS are met already in the model's No Action Scenario. However, a carbon price of 550 2010 KZT/tonne CO_2e, increasing linearly to 5,260 2010 KZT/tonne CO_2e, is necessary to achieve the targeted abatement by 2015 and 2020, respectively. No further assumptions are made about the implementation of the ETS, so the carbon price attained in 2020 is held constant. In effect, what this means is that a hypothetical emissions cap is being allowed to increase as the industrial and power generation sectors grow, but emission permits remain sufficiently scarce to keep their price at 2020 levels. Some points emerge that are worth highlighting:

(i) On the transformation and supply side of the energy system, the largest reductions are seen in the electricity and CHP sector, followed by reductions in fugitive emissions from coal mining. However, the production of less carbon-intensive electricity requires that fewer combined heat and power thermal plants are in operation. As a result, dedicated heat plants—which consume primarily coal and natural gas—must make up a larger share of the heating supply, and increased emissions in this area somewhat diminish the effect of cleaner electricity production.

[18] The initial design of Kazakhstan's emissions trading scheme covers only the largest polluting firms in the industrial, mining, oil and gas, and electricity generation sectors. However, some simplifying assumptions are made to capture the impact of the ETS: namely, the entire industrial sector is assumed to participate in the market, including mining, extraction, and quarrying activities.

(ii) It is important to distinguish between the imposed carbon tax and the net present value of social costs found in the model (as reported in Table 33, 639 2010 KZT/tonne CO_2e). A key reason for the difference between the two is that the latter includes only the direct social costs specified in section III.B. In addition, the carbon tax applies only to the industrial and power sectors, whereas the social cost per tonne includes reductions in other sectors influenced by energy consumption in industry and power.

Extended Emissions Trading Scheme

102. Despite covering four additional energy demand sectors (residential; commercial and services; agriculture, forestry, and fishing; and transport), the extended ETS Scenario achieves only modest improvements in abatement potential. This is primarily due to slightly positive average fuel price elasticities (see Table 49) observed from historical energy consumption in some residential and commercial/services sectors. The effect of the ETS carbon price is to raise fuel prices (in proportion to their carbon content), but this increase does not reduce demand in sectors with such small positive price elasticities.

Uzbekistan

Residential Building Efficiency

103. Following UNDP (2015), the Residential Building Efficiency scenario contemplates a substantial decrease in specific energy consumption in residences—about 80% between now and 2050. Coupled with projected growth in residential building space (from around 450 million m^2 in 2012 to 965 million m^2 in 2050 in all scenarios), this change produces significant energy and emissions savings (Stockholm Environment Institute and Abt Associates 2015c). The total cumulative abatement potential by 2050, 569 $MtCO_2e$, is the largest provided by any of the individual mitigation measures studied in Uzbekistan. About 80% of the potential is due to reductions in direct GHG emissions from buildings with the remainder caused by lower energy supply requirements (electricity and natural gas in particular). It is noteworthy that even after additional labor, materials, and other costs for efficient buildings (which average around 300 million 2010 $ per year from now till 2050), the cumulative cost per tonne of abatement is negative. Lower fuel expenditures as well as reduced capital and O&M costs in the power sector more than offset the required investments in buildings, providing a net cost savings from society's perspective.

Large and Small Hydro

104. Analysis of Uzbekistan's State Program on Development of Hydropower indicates that it is a cost-effective approach to GHG mitigation. In particular, large hydro installations detailed in the mid-term development plan (Khalmirzaeva 2015a) have the greatest potential, and it can be accessed at a lower direct cost than with small or distributed hydro stations. It should be reiterated, however, that the direct cost-benefit analysis reported here does not include some potential indirect costs of hydropower, such as ecosystem damages or impacts on rural livelihoods. These costs can be considerable and must be weighed against the GHG benefits of hydropower (Koch 2002).

Residential Renewable Energy

105. The Residential Renewable Energy Scenario shows the effects of meeting 5% of residential energy demand with distributed renewables by 2050 (as compared to 0.1% in the No

Action Scenario). As described in UNDP (2015), the renewable technologies utilized include solar PV, solar hot water, and biogas heating equipment. The scenario assumes that 50% of the displaced demand is for grid-generated electricity, and 50% is for natural gas used directly for heat in buildings. Total investment costs for the renewables are sizable, reaching 1.5 billion 2010 $ by 2050 (cumulative and discounted), but are offset by natural gas and electricity savings. It is conceivable that the target of 5% of demand by 2050 could be exceeded—UNDP (2015) suggests an "optimistic" value of 10% could be achievable—in which case a higher abatement potential than the 26 $MtCO_2e$ shown for this scenario might be realized. The study team was unable to analyze this possibility due to a lack of nationally appropriate data on the costs of greater renewables penetration; however, more aggressive implementation of renewables probably implies higher costs per tonne (e.g., as sites with lower solar potential are exploited).

Alternative Vehicles

106. There is a stark difference in the cost-effectiveness of CNG vehicles deployed in Kazakhstan and in Uzbekistan. The cost assumptions used for the purchase of conventional and alternative-fueled vehicles are the most important factor contributing to this difference. In Kazakhstan, local data were available for the purchase price of each vehicle technology, whereas no such data were available in Uzbekistan. International proxy data from Windecker and Ruder (2013) were therefore used to estimate the cost difference between conventional and CNG vehicles in Uzbekistan; but these data suggest larger incremental costs for CNG technology than do the Kazakhstan sources.

Heat Network Improvements and Heat Plant Efficiency

107. Although district heating is not as important a part of the energy system in Uzbekistan as in Kazakhstan, it nonetheless offers substantial mitigation potential. Increasing boiler efficiency and reducing network losses could save 120 $MtCO_2e$ of emissions by 2050 at an average discounted cost of 14 2010 $ per tonne. Cumulative natural gas savings after Heat Network Improvements and Heat Plant Efficiency are implemented total 1.9 exajoules (EJ) by 2050, about 1.6% of projected national natural gas use between 2015 and 2050. The estimated costs of the Heat Network Improvements Scenario are reasonably close to those found for the similar Heat Distribution Upgrades Scenario in Kazakhstan (8.1 versus 19.5 2010 $ per tonne).

Solar Electricity

108. The Government of Uzbekistan has a strategic interest in solar power as a means of diversifying the national energy supply and promoting energy independence (STA et al. 2014b). Developed in coordination with government stakeholders, the Solar Electricity Scenario explores an ambitious deployment of solar generation, with over 1,650 MW of solar PV capacity (15% of the currently installed capacity of the power system) and a fifth as much CSP capacity added to the grid by 2030. Capital costs for the scenario are derived from the mean investment costs for potential solar plants in Surkandaria, Kashkadarya, Namangan, and Tashkent (STA et al. 2014a). They amount to about 1,700 $ per kW for solar PV and 5,600 $ per kW for CSP and, to be conservative, are held constant throughout the scenario. Given the comparatively low O&M costs for solar, the capital costs are the main driver of the estimated mitigation cost per tonne, 25 2010 $. This value could come down if technological advances and implementation

experience reduce the local costs of constructing solar facilities in Uzbekistan.[19] At 31 $MtCO_2e$, the cumulative abatement potential of the Solar Electricity Scenario is considerable, surpassing that of two other renewable energy scenarios, Small Hydro and Residential Renewable Energy.

Electricity Grid Improvements

109. The Electricity Grid Improvements Scenario has the second-highest cost per tonne of the technical mitigation options analyzed for Uzbekistan (90 2010 $) but offers nearly 60 $MtCO_2e$ of cumulative emission reductions. The high capital and labor intensity of updating T&D infrastructure is the principal factor behind the cost per tonne. While reducing electricity losses does induce fuel, capital, and O&M savings in electricity generation, expenditures on the T&D infrastructure itself substantially outweigh these benefits. The net cost per tonne found for this scenario is quite close to that of the analogous scenario in Kazakhstan (Rehabilitation of National Grid), pointing to similar dynamics in the countries although each scenario was modeled using costs from independent, national sources.

B. Indirect Co-Benefits of Mitigation

110. This subsection summarizes the indirect co-benefits that can be achieved by implementing the mitigation options analyzed in this TA. The analysis focuses on those co-benefits for which data is readily available for quantifying impacts. These include reduced air pollutant emissions, human health benefits of reduced air pollution, and improved energy security. Focusing on these indirect results of GHG mitigation helps improve the overall benefits that may be derived from the mitigation options examined. There are other potential indirect benefits of mitigation such as income and employment generation. However, these are not quantified in this TA.

111. The analysis of human health co-benefits examines the benefits of mitigation measures that reduce both GHG and conventional air pollutant emissions from the electricity and transport sectors. These benefits are expressed in terms of the potential health benefits of reduced air pollution. The relevant metrics analyzed are:

(i) Cumulative avoided mortalities of each mitigation option as compared to the No Action Scenario. As described in Section III.C these are the cumulative deaths avoided due to reduced exposure to emissions of $PM_{2.5}$ which in turn reduces the risk of premature mortality.
(ii) Monetized value of avoided mortality expressed in 2010 $. This metric presents the net presented value of the avoided mortalities of mitigation and is based on the estimated amount people are willing to pay for small reductions in risk of early death. Many of the avoided mortalities would have occurred in the future. Their value is discounted using a 7% real discount rate.

112. Increased energy security means that the energy system is more resilient and better able to withstand shocks and minimize disruptions in economic functioning, human health and environmental quality. Improvements to energy security can include changes based on fuel diversity, transport diversity, import diversity, price volatility, energy efficiency, and infrastructure reliability. Furthermore, an increase in domestically produced fuels with low fossil fuel content, such as renewable energy, reduces security risks and is more environmentally benign, thus

[19] Such cost decreases are a recognized possibility in the international literature (National Renewable Energy Laboratory 2015; International Energy Agency 2012) but, as previously indicated, are not assumed here in order to provide a conservative assessment of solar.

contributing to co-benefits. Impacts on energy security from the mitigation options are expressed in comparison to the *no action* case. These metrics include:

(i) Fuel savings. This metric describes cumulative fuel savings from 2010 – 2050, expressed in million gigajoules of primary energy supply in LEAP;
(ii) Energy intensity. This metric describes the percentage change compared to the *no action* scenario in 2020 and 2050, and is expressed in terms of energy consumption per unit of GDP;
(iii) Carbon intensity. This metric describes the percentage change compared to the *no action* scenario in 2020 and 2050, and is expressed in terms of CO_2 emissions per unit of GDP; and
(iv) Percentage share of imports in total energy supply. This metric describes the percentage change in the renewable energy share compared to the *no action* scenario in 2020 and 2050.

113. Unlike the analysis of the direct costs and benefits of the technical mitigation measures, the co-benefits analysis does not account for interactions and potential overlap between mitigation options (i.e., the retrospective cost analysis is not applied in this case). The impact of each mitigation option is analyzed individually relative to the No Action Scenario to isolate the effect of each particular option on human health and energy security. Table 36 to Table 41 summarize the results of the co-benefits analyses for Azerbaijan, Kazakhstan, and Uzbekistan, respectively.

Table 36: Energy Security Co-Benefits of Mitigation in Azerbaijan (Cumulative Impacts by 2050 Relative to the No Action Scenario)

Azerbaijan							
Mitigation Option	**Cumulative Fuel Savings (million gigajoules)**	**Energy Intensity of GDP (percent change, %)**		**Carbon Intensity of GDP (percent change, %)**		**Renewable Energy Percentage in Primary Energy Supply (percent change, %)**	
	2010 – 2050	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
Technical Mitigation Mini-Scenarios							
Euro-4 Vehicle Standards	160.5	-0.30	-0.90	-0.30	-0.90	0.30	0.90
SOCAR Eco-driving	18.2	-0.10	-0.10	-0.10	-0.10	0.10	0.10
Commercial CFL Lighting	621.9	-1.10	-3.20	-1.00	-3.00	1.10	3.30
Residential CFL Lighting	1,032.4	-1.90	-5.20	-1.70	-4.90	1.90	5.50
Forests 20% of Total Land Area	-0.2	0.00	0.00	0.00	0.00	0.00	0.00
Forests 12.5% of Total Land Area	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Improved Insulation	985.6	-1.80	-6.90	-1.60	-6.30	1.80	7.40
Small Hydro	243.3	-1.00	-0.30	-1.40	-0.50	10.70	8.30
Sustainable Land Management	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Onshore Wind	125.1	0.00	-1.40	0.00	-2.20	0.00	35.20
Samukh Agro-Energy Complex	17.6	-0.10	-0.10	-0.30	-0.20	3.40	4.50
2020 Renewable Power Targets	338.4	-2.30	-1.10	-3.40	-1.70	28.10	27.50
3 MW Small Solar	0.7	0.00	0.00	0.00	0.00	0.00	0.00
Municipal Solid Waste to Energy	-218.7	0.60	1.70	-0.20	-0.40	14.00	76.40

Azerbaijan							
Mitigation Option	Cumulative Fuel Savings (million gigajoules)	Energy Intensity of GDP (percent change, %)		Carbon Intensity of GDP (percent change, %)		Renewable Energy Percentage in Primary Energy Supply (percent change, %)	
	2010 – 2050	2020	2050	2020	2050	2020	2050
Biogas	25.4	-0.10	-0.10	-0.10	-0.10	0.00	-0.20
Electricity Network Upgrade	382.6	-0.80	-2.60	-0.70	-2.40	0.80	2.70
AC Rail Conversion	7.6	0.00	-0.10	0.00	-0.10	0.00	0.10
Solar Hot Water	19.9	0.00	-0.10	0.00	-0.10	0.00	0.00
Efficient Stoves	5.1	0.00	0.00	0.00	0.00	-0.10	-0.60
Rail Electrification	-0.2	0.00	0.00	0.00	0.00	0.00	0.00
SAARES Short-Term Plan	299.8	-2.30	-0.20	-3.40	-0.30	28.10	4.50
Pricing and Combined Mitigation Scenarios							
Carbon Tax (Low)	5,380.6	-11.10	-36.90	-12.20	-38.30	51.50	260.80
Carbon Tax (Moderate)	6,263.0	-14.00	-42.10	-14.90	-43.20	55.70	286.70
Carbon Tax (EU Harmonization)	6,671.1	-16.10	-42.20	-16.90	-43.30	59.10	287.60
Fossil Subsidy Removal	6,849.2	-13.70	-37.90	-14.30	-40.70	34.50	267.50
OECD Fuel Prices	14,369.6	-55	-65	-52.80	-64.30	153.30	346.10
State Program of Poverty Reduction	-4,987.7	-9.40	-25.70	-5.40	-23.90	-5.80	8.60
All Low-Cost Technical Measures	3,353.1	-7.00	-18.05	-7.26	-18.01	24.90	77.93
All Moderate-Cost Technical Measures	3,644.6	-9.50	-18.20	-10.70	-18.30	54.10	83.60
All Technical Measures	3,783.2	-9.85	-18.64	-11.63	-20.56	69.38	180.80

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Table 37: Human Health Co-Benefits of Mitigation in Azerbaijan (Cumulative Impacts by 2050 Relative to the No Action Scenario)

Azerbaijan		
Mitigation Option	**Cumulative Avoided Mortalities**	**Monetized Value of Avoided Mortalities (2010 $)**
	2010 – 2050	**2010 – 2050**
Technical Mitigation Mini-Scenarios		
Euro-4 Vehicle Standards	22	$3,055,547
SOCAR Eco-driving	1	$103,649
Commercial CFL Lighting	22	$3,546,868
Residential CFL Lighting	36	$5,877,731
Forests 20% of Total Land Area	0	$0
Forests 12.5% of Total Land Area	0	$0
Improved Insulation	11	$1,883,886
Small Hydro	14	$3,248,360
Sustainable Land Management	0	$0
Onshore Wind	6	$465,213
Samukh Agro-Energy Complex	1	$250,040
2020 Renewable Power Targets	18	$4,114,261
3 MW Small Solar	0	$7,666
Municipal Solid Waste to Energy	-14	-$1,899,378
Biogas	1	$159,690
Electricity Network Upgrade	13	$2,059,867
AC Rail Conversion	0.3	$30,210
Solar Hot Water	0.2	$42,139
Efficient Stoves	0	$0
Rail Electrification	0.1	$4,810
SAARES Short-Term Plan	16	$3,997,387
Pricing and Combined Mitigation Scenarios		
Carbon Tax (Low)	130	$21,424,289
Carbon Tax (Moderate)	147	$23,931,503
Carbon Tax (EU Harmonization)	155	$25,652,998
Fossil Subsidy Removal	165	$25,836,142
OECD Fuel Prices	242	$44,814,480
State Program of Poverty Reduction	-44	-$17,835,647
All Low-Cost Technical Measures	110	$18,662,070
All Moderate-Cost Technical Measures	128	$22,042,095
All Technical Measures	120	$21,627,499

Notes: Costs are discounted using a 7% real discount rate.
Source: Abt Associates analysis

Table 38: Energy Security Co-Benefits of Mitigation in Kazakhstan (Cumulative Impacts by 2050 Relative to the No Action Scenario)

Kazakhstan							
Mitigation Option	Cumulative Fuel Savings (million gigajoules)	Energy Intensity of GDP (percent change, %)		Carbon Intensity of GDP (percent change, %)		Renewable Energy Percentage in Primary Energy Supply (percent change, %)	
	2010 – 2050	2020	2050	2020	2050	2020	2050
Technical Mitigation Mini-Scenarios							
CNG Fleet	470	-0.60	0.00	0.00	0.20	0.80	0.00
CNG Passenger Cars	25	0.00	0.00	0.40	0.20	0.00	0.00
Improved Heat Pipe Insulation	1,604	0.00	-1.00	0.40	-1.00	0.00	1.00
Coalbed Methane Capture	122	0.00	0.00	0.40	0.20	-1.20	0.00
Efficient New Homes	2,307	-1.20	-1.30	-1.00	-1.30	1.20	1.30
Natural Gas Power Target (Green Growth)	1,508	0.10	-1.40	0.40	-4.50	-0.10	10.20
Internal Heating Network Improvements	3,906	0.00	-2.50	0.40	-2.80	0.00	2.60
CO_2 Cap on Power (Green Growth)	1,907	-0.20	-1.30	-4.00	-14.80	31.80	29.40
Improved Insulation	3,992	0.00	-2.60	0.40	-2.90	0.00	2.70
Advanced Windows	838	0.00	-0.50	0.40	-0.40	0.00	0.50
Heating Distribution Upgrades	3,261	-0.70	-2.00	-0.50	-2.10	0.70	2.00
Alternative Power Target	2,204	0.10	-3.50	0.40	-10.90	-0.10	397.80
Expanded Nuclear Power	136	0.10	0.10	0.40	-0.20	0.20	-0.10
Optimistic Nuclear Power	302	0.00	0.20	0.40	-0.40	0.50	0.20
Rehabilitation of National Grid	366	0.10	-0.30	0.40	-0.20	-0.80	0.30
Urban LED Lighting	14	0.10	0.00	0.40	0.20	-0.10	0.00
Waste to Energy	-35	0.10	0.10	0.40	0.20	0.30	4.60
Euro 5 Vehicles	-149	0.00	0.10	0.40	0.30	0.00	-0.10
Early Vehicle Retirement	-148	0.20	0.10	0.60	0.30	-0.20	-0.10
Pricing and Combined Mitigation Scenarios							
Emissions Trading Scheme	3,675	-6.10	0.00	-13.40	-2.60	37.40	5.90
Extended ETS	2,320	-5.70	0.90	-14.90	-1.50	36.90	17.00
OECD Fuel Prices	15,584	-3.90	-12.40	-1.20	-11.10	9.20	-1.10
All Low-Cost Technical Measures	14,289	-3.09	-6.81	-4.96	-24.77	49.20	55.59
All Technical Measures	16,945	-2.59	-7.72	-4.86	-25.49	40.65	68.60

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Table 39: Human Health Co-Benefits of Mitigation in Kazakhstan (Cumulative Impacts by 2050 Relative to the No Action Scenario)

Kazakhstan		
Mitigation Option	Cumulative Avoided Mortalities	Monetized Value of Avoided Mortalities (2010 $)
	2010 – 2050	2010 – 2050
Technical Mitigation Mini-Scenarios		
CNG Fleet	3	$1,193,106
CNG Passenger Cars	0.1	$22,090
Improved Heat Pipe Insulation	0	$0
Coalbed Methane Capture	-2	-$342,419
Efficient New Homes	0	$0
Natural Gas Power Target (Green Growth)	634	$163,597,636
Internal Heating Network Improvements	0	$0
CO_2 Cap on Power (Green Growth)	1,152	$626,721,937
Improved Insulation	0	$0
Advanced Windows	0	$0
Heating Distribution Upgrades	0	$0
Alternative Power Target	278	$59,461,986
Expanded Nuclear Power	362	$61,617,376
Optimistic Nuclear Power	884	$174,150,546
Rehabilitation of National Grid	-4	-$1,261,905
Urban LED Lighting	-0.3	-$71,473
Waste to Energy	-6	-$927,279
Euro 5 Vehicles	-2	-$245,411
Early Vehicle Retirement	9	$1,959,940
Pricing and Combined Mitigation Scenarios		
Emissions Trading Scheme	5,582	$1,647,191,287
Extended ETS	5,826	$1,692,388,280
OECD Fuel Prices	283	$3,094,576
All Low-Cost Technical Measures	2,070	$550,556,144
All Technical Measures	3,109	$880,484,954

Notes: Costs are discounted using a 7% real discount rate.
Source: Abt Associates analysis

Table 40: Energy Security Co-Benefits of Mitigation in Uzbekistan (Cumulative Impacts by 2050 Relative to the No Action Scenario)

Uzbekistan							
Mitigation Option	Cumulative Fuel Savings (million gigajoules)	Energy Intensity of GDP (percent change, %)		Carbon Intensity of GDP (percent change, %)		Renewable Energy Percentage in Primary Energy Supply (percent change, %)	
	2010 – 2050	2020	2050	2020	2050	2020	2050
Technical Mitigation Mini-Scenarios							
Residential Building Efficiency	9,686	-3.69	-8.90	-3.87	-9.37	3.07	7.19
Large Hydro	898	-0.47	-0.47	-1.04	-1.02	24.38	24.49
Small Hydro	181	-0.11	-0.08	-0.24	-0.20	5.46	5.81
Residential Renewable Energy	846	-0.18	-0.85	-0.21	-0.83	-0.07	-1.80
Alternative Vehicles	1,882	-0.60	-1.87	-0.71	-2.29	0.62	1.97
Heat Network Improvements	776	-0.05	-1.05	-0.06	-1.17	0.05	1.06
Heat Plant Efficiency	1,206	-0.21	-1.17	-0.23	-1.30	0.21	1.19
Solar Photovoltaic	270	-0.13	-0.16	-0.28	-0.34	6.71	8.41
Electricity Grid Improvements	1,085	-0.31	-0.97	-0.37	-0.94	-0.28	-3.53
Rail Electrification	22	0.00	-0.01	0.00	-0.03	0.04	0.19
Pricing and Combined Mitigation Scenarios							
All Low-Cost Measures	13,875	-5.03	-12.66	-5.98	-14.34	34.52	44.54
All Technical Measures	16,350	-5.64	-14.85	-6.77	-16.83	40.83	53.00

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

Table 41: Human Health Co-Benefits of Mitigation in Uzbekistan (Cumulative Impacts by 2050 Relative to the No Action Scenario)

Uzbekistan		
Mitigation Option	Cumulative Avoided Mortalities	Monetized Value of Avoided Mortalities (2010 $)
	2010 – 2050	2010 – 2050
Technical Mitigation Mini-Scenarios		
Residential Building Efficiency	39	$2,993,208
Large Hydro	155	$10,879,816
Small Hydro	25	$1,781,548
Residential Renewable Energy	26	$1,475,678
Alternative Vehicles	146	$6,370,534
Heat Network Improvements	0	$0
Heat Plant Efficiency	0	$0
Solar Photovoltaic	43	$2,829,712
Electricity Grid Improvements	52	$3,239,945
Rail Electrification	22	$862,994
Pricing and Combined Mitigation Scenarios		
All Low-Cost Measures	379	$22,768,063
All Technical Measures	489	$29,319,380

Notes: Costs are discounted using a 7% real discount rate.
Source: Abt Associates analysis

114. The above analysis shows that there are several important indirect benefits to mitigation beyond the GHG emission reductions quantified in Table 33 through Table 35 . Most noticeably, almost all of the analyzed mitigation scenarios result in fuel savings and improvement in the energy intensity of GDP, particularly those that are based on energy efficiency improvements, introduce renewables, or use price-based signals to encourage less energy consumption. This means that introducing mitigation measures in the energy and transport sectors tends to also improve energy security.

115. In Azerbaijan, the most attractive technical mitigation options, in terms of fuel savings, are residential and commercial CFL lighting, improved insulation, the 2020 renewable power targets, the SAARES short-term plan, and upgrades to the electricity network. In Kazakhstan, the mitigation measures based on improved heat pipe insulation, efficient new homes, the natural gas power target, the CO_2 cap on power, internal heating network improvements, improved insulation, heating distribution upgrades, and the alternative power target result in significant fuel savings. In Uzbekistan, all the measures analyzed result in measurable fuel savings, with residential building efficiency potentially contributing two thirds of the potential savings. Overall, the price-based mitigation scenarios are the most effective at reducing fuel consumption. In Azerbaijan, the scenario based on aligning domestic fuel prices with OECD prices results in cumulative savings of 14,370 gigajoules by 2050, which is far more than if all the technical mitigation measures are implemented. Similarly, the three carbon tax scenarios result in greater fuel savings than the combined technical mitigation measures. This result is driven by differences in the prices for key fuels in Azerbaijan, which increase a lot more in the OECD price scenario than in the carbon tax scenarios. For example, depending on the year, the price of natural gas is 70-80% higher in the OECD scenario than in the Carbon Tax (EU Harmonization) scenario; the prices of gasoline and diesel are 40-50% higher; the price of LPG is 70-80% higher. Higher prices depress demand relative to the carbon tax scenarios and lead to greater fuel savings. Similarly, the three carbon tax scenarios result in greater fuel savings than the combined technical mitigation measures. This occurs because the carbon price in the tax scenarios is economy- or energy system-wide, whereas the all technical measure scenarios only affect certain parts of the energy system. The broad applicability of the carbon price means that it touches a number of sectors and subsectors that aren't changed in the all technical measure scenarios, particularly on the demand side of the energy system.

In Kazakhstan, the OECD fuel price scenario results in savings of 15,584 gigajoules, which is almost as much as all of the technical mitigation measures combined. This indicates that the mitigation measures proposed by the government of Kazakhstan are already designed to have a significant impact on energy consumption.

116. Table 38, Table 40, and Table 42 also shows the percent change in renewables in primary energy supply resulting from each mitigation scenario. As expected, all of the mitigation scenarios based on increasing the share of renewables show a positive impact on this metric. However, several other technical mitigation measures also improve this metric, in some cases significantly. In Azerbaijan, commercial and residential CFL and improved insulation result in a 3-7% improvement in the share of renewables in primary energy supply. In Kazakhstan, the natural gas power target and the CO_2 cap on power increase the renewable share by 10% and 29%, respectively, while the residential building efficiency measure in Uzbekistan increases the share of renewables by 7%. The effectiveness of price based scenarios in encouraging renewables depends on the country and the type of scenario. In Azerbaijan, both the carbon tax and OECD fuel price scenarios result in large improvements in renewable energy generation, ranging from 260% for the low carbon tax scenario to 346% for the OECD fuel price scenario. In Kazakhstan, both emission trading scenarios lead to an increase in the share of renewables

while the OECD fuel price scenario increases the share of renewables by 9% by 2020 but reduces it by 1% by 2050.

117. In addition to improving energy security, many of the mitigation scenarios result in cumulative avoided mortalities through 2050. The relevant mitigation measures are those that result in reductions in air pollutants such fine particulate matter and measures implemented in countries with the most air pollutant concentrations will show the greatest benefits. In all three countries, the impact on human health and mortality are moderate for most mitigation options, except for several measures in Kazakhstan that result in a switch away from coal-fired power. This includes the natural gas power target, the CO_2 cap on power, the nuclear power scenario, and the two emissions trading scenarios. In these cases, the discounted monetized value of the avoided mortalities is significant, ranging from $163 million for the natural gas power target to $1,692 million for the extended emissions trading system. The human health benefits of introducing these mitigation measures make an additionally strong case for their implementation.

C. Sensitivity Analysis

118. The modeling of costs and benefits conducted for this study depends on a number of exogenously determined parameters (model inputs). These help define both the No Action Scenario and the mitigation scenarios. The values adopted for the parameters in each scenario are best estimates of the most likely values, based on national and other sources, or values that were explicitly requested by stakeholders. Section II and the appendices document values used for these parameters.

119. Two parameters merit particular sensitivity analysis due to their widespread use in the national models, their importance for the social costing of mitigation options, and the inherent uncertainty in their future trajectories: GDP and fuel prices. Appendix 5 presents a brief assessment of the impact of these variables on the study's results. As described in the appendix, twelve new scenarios are considered in each model, based on higher and lower growth in GDP and higher and lower oil and gas prices compared with those used for the No Action Scenario in Section IV and the mitigation scenarios described in Section V.A. Oil and gas are the focus of the fuel price analysis because their prices are strongly influenced by international markets and evidence suggests the majority of energy subsidies in the study countries are for these fuels (International Energy Agency 2014c). Both of these factors may contribute to future price volatility.

120. The results presented in Appendix 5 show that varying GDP, oil prices, or gas prices by 25% generally induces less than a 25% change in emissions. Emission results tend to be more sensitive to GDP than to oil or gas prices across the three models, with higher GDP raising emissions and lower GDP decreasing them. The exact effects of varying GDP or fuel prices in a given model depend on the model's structure and the composition of modeled mitigation options. Nonetheless, from the standpoint of mitigation policy, the long-run cost-effectiveness of to proposed mitigation options is relatively stable through a wide range of GDP, oil price, and gas price assumptions. By 2050, the direct costs of the portfolio of mitigation options in Azerbaijan average between 20 and 30 2010 $ per tonne, depending on assumptions; direct costs in Kazakhstan average around 7 2010 $ per tonne; and direct costs in Uzbekistan are less than -10 2010 $ per tonne. These findings may strengthen the case for proceeding with national mitigation plans in the face of key uncertainties.

D. Policy Implications of Mitigation Scenarios

121. A clear finding of this study is that the economies of Azerbaijan, Kazakhstan, and Uzbekistan provide ample opportunities for climate mitigation at a low cost and with significant co-benefits. In a business-as-usual future, as the study's No Action projections illustrate, carbon-intensive growth in each country leads to markedly higher GHG emissions. Total emissions increase 78% in Azerbaijan between 2010 and 2050, 118% in Kazakhstan, and 243% in Uzbekistan (Figure 23-Figure 25). Rising demand for fossil fuels is the dominant factor behind these emission trends. Core dependencies on fossil fuels remain in place in all three economies (Figure 14-Figure 16), and requirements for many fossil sources double or more by 2050 (Table 42). Emissions from fossil use for energy and transport constitute over 70% of national GHG emissions in each country through 2050.

Table 42: Total Primary Energy Supply of Fossil Fuels (No Action Scenario)

Country	Fuel	Petajoules					Percent Growth (2010-2050, %)
		2010	2020	2030	2040	2050	
Azerbaijan	Oil and Oil Products	152	163	181	196	216	42
	Natural Gas	332	376	411	473	564	70
Kazakhstan	Oil and Oil Products	1455	1768	2197	2866	3908	169
	Natural Gas	360	380	303	345	433	20
	Coal	1,481	1,511	1,869	2,325	3,044	106
Uzbekistan	Oil and Oil Products	166	214	321	452	556	236
	Natural Gas	1,532	2,357	3,368	4,638	5,702	272
	Coal	35	60	121	196	281	697

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

122. By themselves, these emission and energy projections suggest numerous possibilities for mitigation. If Azerbaijan, Kazakhstan, and Uzbekistan follow such carbon-dependent development pathways, the potential scope for energy-related mitigation measures, including efficiency and fuel switching, should be significant. This intuition is substantiated by this study's analysis of nationally determined mitigation options. The MACCs in Figure 26-Figure 28 show multiple mitigation opportunities in the energy and transport sectors, and the co-benefits analysis in the preceding section demonstrates that many of these options become even more attractive when human health and energy security impacts are considered. The negative cost options quantified for each country represent especially attractive investments, promising net savings to society for varying levels of upfront expenditure. These options could be compelling even if mitigation is not a strategic national policy objective.

123. A range of other reasons imply strategic importance for mitigation, however. Each of the three countries is vulnerable to impacts from climate change. Azerbaijan expects to see rising temperatures throughout the country. This is expected to result in a reduction in surface water resources which could adversely affect agriculture, hydropower, and water supply in already vulnerable areas. In addition, increased flooding due to sea level rise is expected in coastal areas around the Caspian Sea, where recent increases in flood events have already caused significant economic damage (Ministry of Ecology and Natural Resources of the Azerbaijan Republic 2014). In Kazakhstan, expected temperature increases by 2050, particularly in summer and winter months, may lead to a decrease in precipitation in summer months and an increase in precipitation in winter months. This in turn is expected to lead to an increase in extreme events such as strong winds and heavy snow and sleet; heavy showers, storm winds,

and blizzards in mountains and foothills; and strong blizzards in northern parts of the country. Some agricultural products, such as spring wheat will be adversely affected by these climatic changes, and the surface water flow of Kazakhstan's rivers is expected to continue to decline exacerbating existing regional water constraints (Ministry of Environment and Water Protection of the Republic of Kazakhstan 2013). In Uzbekistan, expected warming will lead to increased glacier melt, reduced water flow in several key river basins, and water loss in irrigation zones, the impact of which will be especially acute during low-flow years. The most serious consequences are expected in the Aral Sea area. These adverse factors threaten food security throughout Uzbekistan and could lead to an agricultural deficit of 10-15% by 2050 compared to 2008 (Centre of Hydrometeorological Service 2008).

124. Avoiding these expected climate change impacts will require cooperative effort with the international community due to the transboundary nature of GHG emissions and atmospheric warming (United Nations 1992). For example, recent projections from IPCC's Fifth Assessment Report indicate that worldwide GHG emissions must decrease 50-60% between now and 2050 in order to have a significant chance of limiting to 2˚ C the increase in average global temperature since pre-industrial times (Clarke et al. 2014).[20] This target, commonly taken as a prerequisite for avoiding dangerous impacts from climate change, obviously necessitates multilateral action, and programs of national mitigation are a first step in that direction. While real questions remain about how the burden of emission reductions should be divided among countries, a national commitment to mitigation encourages reciprocity and can strengthen a country's position in climate negotiations, especially if other parties are undertaking mitigation themselves (Weiler 2012).

125. On the domestic front, mitigation also has energy security benefits. Mitigation can improve the self-sufficiency of a country's economy, reduce its vulnerability to carbon pricing, and increase its attractiveness to foreign investors. Efficiency measures and shifting to renewable energy can reduce domestic consumption of strategically important non-renewable energy resources, preserving them for export or non-energy uses. In Uzbekistan, for example, the relatively small set of technical mitigation options analyzed in this study save almost 14 EJ of natural gas between now and 2050—about seven times the country's current annual requirements for gas. In Azerbaijan over the same time period, the technical mitigation options in the study save .5 EJ of crude oil and 4 EJ of gas (approximately twice and 11 times current annual consumption, respectively). Similarly, as discussed in V.B the mitigation scenarios analyzed for Kazakhstan result in significant fuel savings while also reducing the incidence of mortality caused by air pollution. Improvements in air quality can reduce the adverse human health effects resulting from exposure to air pollution and reduce the costs of associated health risks.

126. Recognizing the strategic value of mitigation, the governments of Azerbaijan, Kazakhstan, and Uzbekistan have already taken steps to reduce GHG emissions. With the support of civil society, academia, and international donors, they have developed a number of policies and programs enabling mitigation activity, a sample of which is summarized in Table 43.

[20] 430-480 parts per million CO_2e scenarios.

Table 43: Selected Policies and Measures Enabling Climate Change Mitigation in the Energy and Transport Sectors of Azerbaijan, Kazakhstan, and Uzbekistan

Country	Policies and Programs	Notes on Specific Targets and Measures
Azerbaijan	Azerbaijan-2020: Vision to the Future	Bring the amount of energy used and CO2 emissions per GDP in line with that of OECD countries.
	State Programme on Utilization of Renewable and Alternative Sources of Energy, 2008-2015	Set an alternative and renewable energy target of 20% of electricity consumption by 2020.
	State Program of Poverty Reduction and Sustainable Development, 2008-2015	Decrease fuel combustion for power generation by 20% by the end of 2015 to reduce GHG emissions.
	Action Plan on the Improvement of the Environmental Situation in Azerbaijan, 2014-2020	Under development.
	State Programme on Energy Efficiency, 2015-2020	Under development.
Kazakhstan	Voluntary GHG commitment under UNFCCC and the Kyoto Protocol	(i) By 2020, reduce GHG emissions by 15% compared to 1990 (ii) By 2050, reduce GHG emission by 25% compared to 1990
	2013 Concept of Transition of the Republic of Kazakhstan to a Green Economy	(i) Reduce the energy intensity of GDP by 10% by 2015, 25% by 2020, 30% by 2040, and 50% by 2050 (compared to 2008) (ii) Increase the share of alternative energy in electricity generation to: wind and solar not less than 3% by 2020, 30% by 2030 and 50% by 2050 (iii) Increase the share of gas power plants in electricity generation to: 20% by 2020, 25% by 2030 and 30% by 2050 (iv) Bring natural gas infrastructure to regions such as Akmola and Karaganda Oblasts by 2020, and to North and East Kazakhstan by 2030 (v) Reduce GHG emissions from the power sector to 2012 levels by 2020, and reduce them by 15% by 2030 and 40% by 2050.
	General Scheme of Gasification of the Republic of Kazakhstan to 2030	By 2020 the use of natural gas by public transport and public vehicles must be >30% in Astana and Almaty and >10% in other cities. By 2030 the share of natural gas must be >50% in Almaty and Astana and >30% in other regional cities.
	National Emissions Trading System	Companies representing 55% of Kazakhstan's GHG emissions must reduce CO_2 emissions by 3% compared to 2011-2012 during 2014-2015.
	Law on Energy Saving and Energy Efficiency	Decrease energy intensity of GDP by no less than 10% by 2015, 25% by 2020, and 50% by 2050, including through increased energy efficiency.
Uzbekistan	Decree of the President of the Republic of Uzbekistan (2013, No. UP-4512) on Measures to Develop Alternative Energy Sources	
	Resolution of the President of the Republic of Uzbekistan (2013, No. PP-1929) on Creation of the International Solar Energy Institute	
	Resolution of the President of the Republic of Uzbekistan (2014, No. PP-2183) on Measures to Implement Investment O=Projects	Construction of the 100 MW solar power station in the Samarkand region
	Resolution of the President of Uzbekistan (2015, no. PP-2343) on the Program of Measures to Lower Energy Intensity and Implement Energy	Introduces a Road Map of 33 activities to increase renewable energy and energy efficiency

Country	Policies and Programs	Notes on Specific Targets and Measures
	Efficient Technologies and Systems in the Economy and Social Sphere from 2015 to 2019	
	Program for Development of Small Hydropower during 2015–2030	Under development

127. The mitigation options evaluated in this study are closely linked to these policies and programs. Developed in coordination with national stakeholders, in some cases the options are explicitly defined by national policy (e.g., short-term renewable power deployment plans of the Azerbaijan State Agency for Alternative and Renewable Energy Sources); in others they are based on national data produced by government programs and ministries. Analyzing their projected GHG benefits and costs offers insights into the impact of mitigation measures that are being actively considered in the three countries.

Co-benefits also play an important role in weighing the costs and benefits of mitigation options. Even if not explicitly included in the monetized cost-to-benefit ratio, considering the multiple co-benefits of mitigation options improves understanding of the full range of effects of these potential actions. A more comprehensive assessment that accounts for co-benefits can help identify options that can achieve multiple objectives beyond the primary objective of GHG emissions mitigation (e.g., improved energy security and improved air quality as described above), thus maximizing net social benefits. In addition, co-benefits can be important differentiators when evaluating mitigation options that are otherwise similar on a cost-per-ton basis. In Kazakhstan, for example, the Internal Heating Network Improvements and the CO_2 Cap on Power options offer significant mitigation at a similar cost: $3.4 and $3.8 2010 per tCO_2e, respectively (Table 33). Based solely on direct costs and benefits, the Internal Heating Network Improvements option is less expensive and therefore may be preferred over the slightly more expensive CO_2 Cap on Power option. However, when co-benefits are also considered one might judge the CO_2 Cap on Power as the preferred option between these two. This option provides significantly greater energy security co-benefits for two indicators (carbon intensity and renewable energy percentage). In addition, this option results in more than $600 million in reduced human health effects (i.e., monetized value of avoided mortalities), whereas the heating network improvements option results in no such human health benefits (Table 38 and 39).

128. Figure 29-Figure 31 show the overall effect of the study's mitigation options on GHG emissions. Three scenarios are depicted for each country: No Action, All Low-Cost Technical Measures (cumulative, discounted direct abatement cost ≤ 10 2010 $), and All Technical Measures.[21]

[21] See Table 12 for further description of these scenarios.

Figure 29: Impact of Mitigation Options on GHG Emissions in Azerbaijan

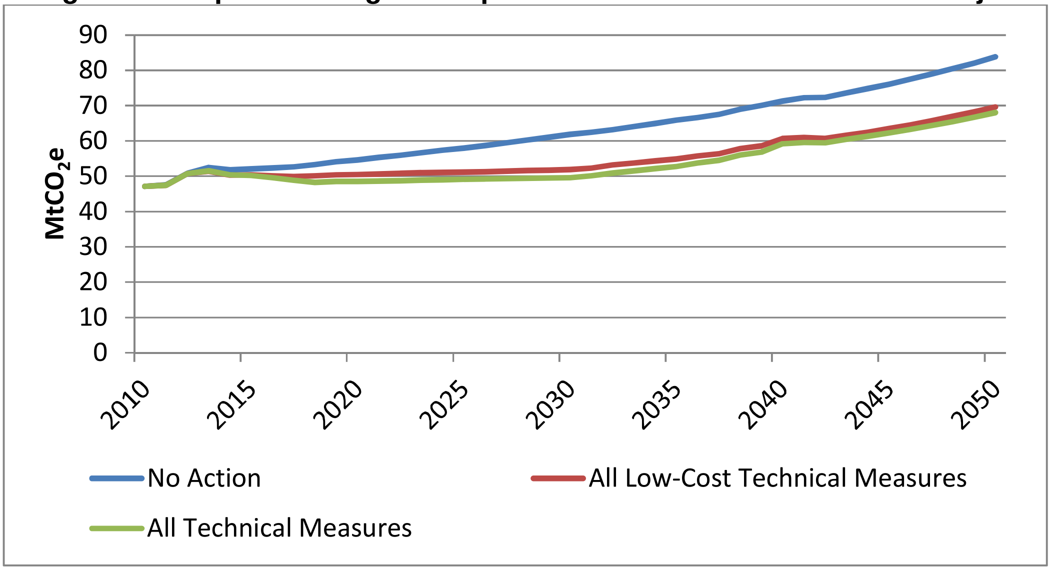


Table 44: Impact of Mitigation Options on GHG Emissions in Azerbaijan ($MtCO_2e$)

Scenario/Year	2010	2020	2030	2040	2050
No Action	47.1	54.6	61.8	71.3	83.8
Low-Cost Technical Measures	47.1	50.4	51.9	60.7	69.6
All Technical Measures	47.1	48.5	49.6	59.1	68.0

Source: Stockholm Environment Institute and Abt Associates (2015a)

Figure 30: Impact of Mitigation Options on GHG Emissions in Kazakhstan

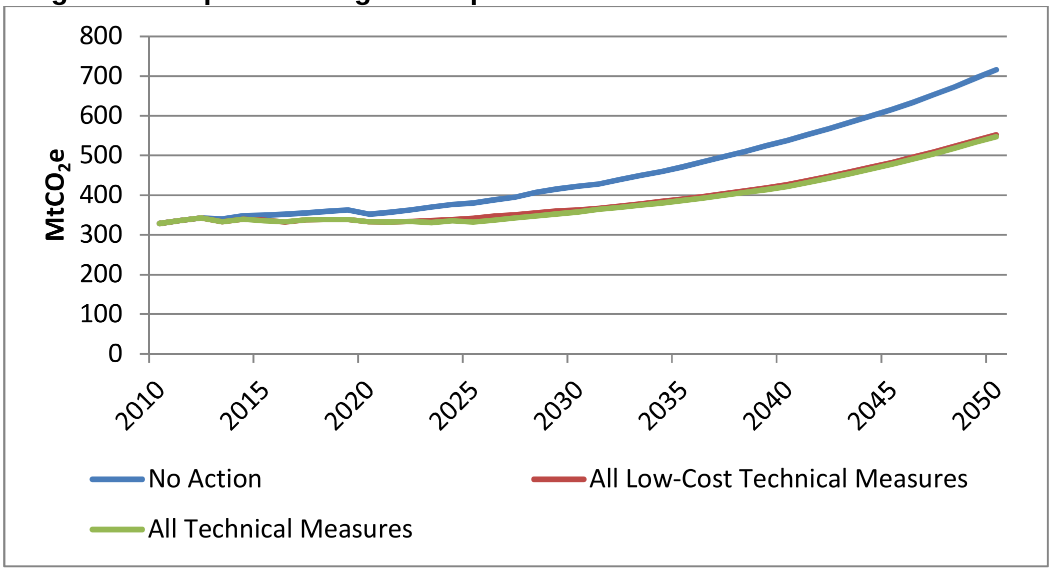


Table 45: Impact of Mitigation Options on GHG Emissions in Kazakhstan ($MtCO_2e$)

Scenario/Year	2010	2020	2030	2040	2050
No Action	328.6	352.0	422.9	538.0	715.7
Low-Cost Technical Measures	328.6	333.0	362.8	426.3	552.2
All Technical Measures	328.6	333.3	357.2	421.7	547.6

Source: Stockholm Environment Institute and Abt Associates (2015b)

Figure 31: Impact of Mitigation Options on GHG Emissions in Uzbekistan

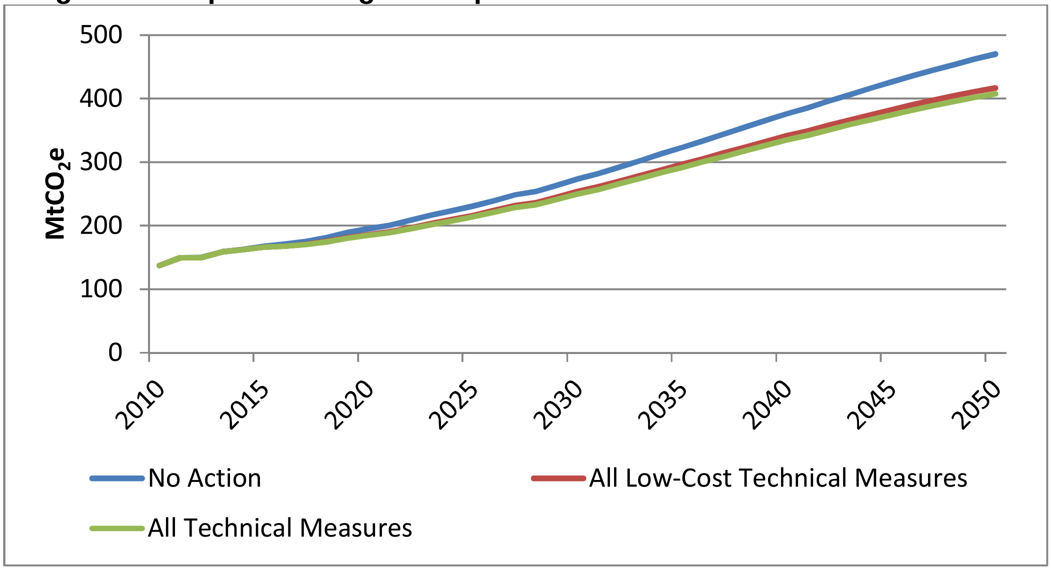


Table 46: Impact of Mitigation Options on GHG Emissions in Uzbekistan ($MtCO_2e$)

Scenario/Year	2010	2020	2030	2040	2050
No Action	137.0	195.1	273.2	375.9	469.9
Low-Cost Technical Measures	137.0	185.9	253.7	341.3	416.6
All Technical Measures	137.0	184.7	249.8	334.9	407.4

Source: Stockholm Environment Institute and Abt Associates (2015c)

129. A few key observations emerge from these graphs. The overall magnitude of emission reductions achieved by all technical measures is similar in each country, ranging from 13% of 2010-2050 emissions in Uzbekistan to 16% of 2010-2050 emissions in Kazakhstan. Most of the mitigation potential is low-cost: adding the higher-cost options that were analyzed provides only modest abatement gains. As noted in Section V.A, this result indicates that national plans and sources in the study countries are prioritizing cost-effective measures. It may also signify that mitigation is a subordinate objective for higher-cost measures that do appear in national sources, their primary goal being economic development, energy security, public health, or another purpose.

130. In Azerbaijan and Kazakhstan, the nationally determined options are able to keep emissions in check in the short to medium-term—through about 2025 or 2030. Beyond that point, however, growing population, economic activity, and affluence take over, and emissions begin to rise. In Uzbekistan, very high assumed economic growth (coupled with a somewhat smaller set of mitigation options) prevents a similar flattening of the short-term emission trajectory. In each country total emissions are greater in 2050 than in 2015 even when all of the technical mitigation options are deployed.

131. Table 47 describes the direct (undiscounted) costs of the study's mitigation options as a percentage of GDP.[22] The options are grouped as in the preceding figures (low-cost options and all options), and "net savings" is shown for years in which mitigation produces direct cost savings.

[22] Direct costs include capital, operating and maintenance, fuel, and mitigation option implementation costs. See Section II for a discussion.

Table 47: Annual Direct Costs of Mitigation as % of GDP

Country	Scenario	Year, Percent of GDP (%)			
		2020	2030	2040	2050
Azerbaijan	Low-Cost Technical Measures	*Net savings*	*Net savings*	*Net savings*	*Net savings*
	All Technical Measures	0.69	0.71	0.63	0.69
Kazakhstan	Low-Cost Technical Measures	0.34	0.21	0.55	0.66
	All Technical Measures	0.36	0.43	0.63	0.69
Uzbekistan	Low-Cost Technical Measures	*Net savings*	*Net savings*	*Net savings*	*Net savings*
	All Technical Measures	0.34%	*Net savings*	*Net savings*	*Net savings*

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

132. It should be noted that the modeling conducted for this study did not evaluate the potential impact of mitigation on GDP itself. Thus, the data in Table 47 can also be interpreted as direct mitigation costs as a percentage of baseline (No Action Scenario) GDP. As the table shows, relatively modest costs are incurred for the nationally determined options under analysis. Implementing all technical measures in Azerbaijan and Kazakhstan entails costs that rise as high as 0.7% of GDP in some years; these result especially from capital investments in the residential and power sectors.

133. From a climate change standpoint, a natural question prompted by Figure 29-Figure 31 is what steps Azerbaijan, Kazakhstan, and Uzbekistan could take to achieve further mitigation beyond the levels explored in this study. After accounting for nationally determined options, where is the mitigation frontier? The question is particularly salient since even the All Technical Measures Scenarios are unlikely to be compatible with a global 2˚ C pathway. Clearly they do not provide the 50-60% reductions from current emissions that are likely necessary at the global level; and they are also inconsistent with long-term abatement requirements in most studies of equitable mitigation effort sharing. For example, Clarke et al. (2014) survey the effort-sharing literature and report that under most arrangements, holding warming to 2˚ C implies that developing countries in Asia must cut GHG emissions 30-50% between 2010 and 2050. This target surpasses what is achieved by the All Technical Options scenarios by a considerable margin.

134. Deeper mitigation in Azerbaijan, Kazakhstan, and Uzbekistan will probably require more ambitious measures across the economy, touching energy, transport, and non-energy sectors. Nonetheless, a few sectors stand out due to their share of projected GHG emissions in the All Technical Measures Scenarios: residential buildings and industry on the demand side of the energy system, and the power sector and fossil fuel production on the supply side. Each of these sectors is a significant contributor to emissions in at least two of the three countries after the study’s technical measures are implemented.

135. In the No Action Scenario, residential buildings are responsible for 52% of demand-side GHG emissions in Azerbaijan by 2050, 23% in Kazakhstan, and 18% in Uzbekistan. Absolute residential emissions grow by nearly 50% in Uzbekistan between 2010 and 2050 and more than double in Azerbaijan and Kazakhstan over the same period. In the All Technical Measures Scenario, a combination of mitigation options reverses the trend in Uzbekistan, actually leading to a decline in absolute emissions by 2050 (from 28 $MtCO_2e$ in 2010 to 13 $MtCO_2e$ in 2050). The Residential Building Efficiency mini-scenario is the primary reason for the drop, involving a nearly 80% decrease in residential building specific energy consumption between now and the final projection year. This change is brought about by enhanced building energy codes, a program of residential retrofits, and deployment of better insulating, heating, and control technologies (United Nations Development Programme 2015).

136. Some residential building measures were also analyzed for Azerbaijan and Kazakhstan, but they do not go as far as in Uzbekistan. For example, the Improved Insulation scenario in Kazakhstan targets urban residences for energy retrofits, rather than all residences as in Uzbekistan, and the energy savings per residence are considerably lower than in the Uzbekistan Residential Building Efficiency Scenario. Applying all of the study's technical measures saves about 23% of final residential energy demand in Kazakhstan in 2050 compared to the No Action Scenario, and about 17% in Azerbaijan. Notwithstanding, demand still rises by more than 200% in Kazakhstan and 80% in Azerbaijan over the 2010 level. GHG emissions also rise as fossil fuels continue to dominate the residential energy mix. In the final year of the All Technical Measures Scenario, natural gas accounts for 87% of residential demand in Azerbaijan, while coal and oil products make up 90% of residential demand in Kazakhstan.

137. Further reducing emissions from the residential sector requires directly addressing fossil fuel consumption. Key options include more expansive energy efficiency retrofit programs, strong energy codes for all new residential construction, and shifting to low carbon heating technologies such as solar thermal, efficient electric heat pumps, and additional distributed combined heat and power installations (International Energy Agency 2011). Switching heating and cooking end uses from fossil fuels is especially critical to realizing deep mitigation in the residential sector. In part, such a change can be effected using building-generated renewable energy (e.g., electricity from solar PV and small-scale wind), which can also contribute to achieving net zero energy buildings (Li et al. 2013).

138. Emissions from industry are a sizable part of the GHG projections for both Kazakhstan and Uzbekistan. In the Kazakhstan No Action Scenario, industry's share of national GHG emissions hovers around 30% through 2050, while in Uzbekistan it rises from approximately 10% today to 22% in 2050. These percentages increase in the All Technical Measures Scenarios since there are few technical mitigation options targeting industry. Both before and after deploying the technical measures, industry is the largest demand-side contributor to GHG emissions over the long term.

139. Energy balance data from the Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014b) show that mining, quarrying, and metal manufacturing are especially large energy users and GHG emitters within Kazakhstan's industrial sector. These subsectors include inherently energy-intensive activities such as fuel production and production of iron, steel, aluminum, and copper. In Uzbekistan, the constituents of industrial demand cannot readily be identified from the available energy balances—most industrial energy use is classified under a subsector called "other industry" in the balances (International Energy Agency 2013)—but State Committee of the Republic of Uzbkistan on Statistics (2015) suggests that leading subsectors in terms of output are fuel production, machinery and metalworking, and food manufacturing.

140. The Emissions Trading Scheme System in Kazakhstan does reduce cumulative industrial GHG emissions by almost 250 $MtCO_2e$ through 2050 (about 5% of industrial emissions during 2015-2050), demonstrating potential despite the structural challenges for mitigation in the sector. However, deeper mitigation at the national level clearly necessitates greater ambition for industry. With benefits for competitiveness, productivity, and energy security, energy efficiency should be a cornerstone of additional industrial mitigation efforts (International Energy Agency and Institute for Industrial Productivity 2012). While specific actions to improve efficiency vary widely by subsector and even facility, lack of information about efficient technologies and practices and financing for upgrades are common barriers that can be addressed through cross-cutting initiatives (United Nations Industrial Development Organization 2011). Looking at

industry globally, Fischedick et al. (2014) report that deploying most-efficient available technologies could reduce the energy intensity of production by up to 25% from today's level. Further decreasing energy use and emissions may require measures beyond efficiency, including industrial CCS, fuel switching (notably to clean electricity), product design changes and longevity improvements, and reduced consumer demand. These changes will likely be more costly than efficiency alone.[23]

141. The power sector is the target of several mitigation options in each study country yet remains a large source of GHG emissions in the All Technical Measures Scenario. Electricity and CHP plants contribute 7% of 2050 emissions in All Technical Measures in Azerbaijan, 6% in Kazakhstan, and 11% in Uzbekistan. This result is substantially lower emissions compared with the No Action Scenario (Table 48), but more aggressive mitigation pathways probably necessitate even greater reductions. This is particularly true if electrification is pursued as a mitigation strategy in buildings, industry, and transport.

Table 48: GHG Intensity of Electricity Generation

Country	Scenario	Year, gCO_2e / kWh				
		2010	2020	2030	2040	2050
Azerbaijan	No Action	542	429	428	435	408
	All Technical Measures	542	322	211	349	289
Kazakhstan	No Action	632	546	543	595	632
	All Technical Measures	632	491	394	316	207
Uzbekistan	No Action	417	306	280	260	251
	All Technical Measures	417	280	234	228	225

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

142. Further decarbonization of power generation will require additional investments in renewables, nuclear, CCS, or a combination of these (Bruckner et al. 2014). Each of these approaches presents challenges, however. The costs of integrating an increasing share of renewable power on the grid are non-linear due to system balancing, siting, regulatory, and other factors (Hart et al. 2012); thus, the abatement costs for renewable electricity found in this study would not be expected to hold in very high renewables scenarios. Nuclear power involves significant up-front costs, requires specialized technical expertise, and raises safety and waste disposal concerns (International Atomic Energy Agency 2014). CCS for large power plants is still in its infancy, with only one plant operating to date (Massachusetts Institute of Technology 2015), and questions remain about the potential for CO_2 leakage from CCS reservoirs and the regional availability of reservoir capacity (Keppo and van der Zwaan 2012). National policy makers must weigh these issues as well as national resource potential, human capacity, security, and political goals when charting a low-carbon course for power.

143. Fugitive emissions from fossil fuel production are particularly salient given the limited attention they receive in the national plans and sources reviewed for this study. The Coalbed Methane Capture Scenario for Kazakhstan is the only mitigation option addressing fugitive emissions, yet these emissions constitute approximately 23% of 2010-2050 emissions in the All Technical Measures Scenario in Azerbaijan, 7% in Kazakhstan, and 10% in Uzbekistan. Most of the emissions in Kazakhstan are from coal mining, while natural gas production is the dominant factor in Azerbaijan and Uzbekistan. Fugitive emissions are calculated in the study models

[23] Fischedick et al. (2014) note that reducing industrial emissions near to zero probably necessitates measures costing 50-150 2010 $ per tonne.

using emission factors from national GHG inventories (Azerbaijan and Kazakhstan) or IPCC (Uzbekistan) (Ministry of Ecology and Natural Resources of Azerbaijan Republic 2014; Ministry of Environment and Water Resources of the Republic of Kazakhstan and JSC ‘Zhasyl Damu’ 2014; Intergovernmental Panel on Climate Change 2015). The projections in the models might actually be too low since evidence is emerging that official inventories tend to underestimate emissions from gas and oil production (Brandt et al. 2014). Additionally, the IPCC factors used for Uzbekistan are regional averages that may not reflect actual circumstances in the country.

144. A variety of technical options exist to mitigate fugitive emissions from fossil fuel production, including new or upgraded equipment in oil and gas operations (e.g., wells, compressors, engines), directed inspection and maintenance programs, methane recovery for power or other uses, flaring, and catalytic or thermal oxidation of ventilation air from coal mines (U.S. Environmental Protection Agency 2013c). The applicability of any given option depends on local conditions and practices, but globally options with negative or zero direct costs per tonne CO_2e could reduce fugitive emissions from underground coal mining by 10% and from oil and gas systems by 35% by 2030 (U.S. Environmental Protection Agency 2013c). In many cases these measures would promote energy security or increase revenue from fossil production by reducing wasted resources.

145. Taking the next steps on mitigation will require concerted effort by multiple stakeholders in Azerbaijan, Kazakhstan, and Uzbekistan—government, industry, and ordinary citizens—across a range of technical, financial, and political activities. No single policy can ensure success, but several policy emphases can help create an enabling environment for mitigation actions. Implementation of such policies may be costly, however, and may only be feasible if supporting international finance and technical cooperation is available.

146. Building up and strengthening the institutions and expertise for accessing climate finance is therefore crucial for Azerbaijan, Kazakhstan, and Uzbekistan. The three countries will need to establish clear frameworks and procedures for tracking climate finance and developing indicators for measuring and monitoring impacts on GHG emissions and associated co-benefits metrics. Additionally, there is a need for developing the requisite domestic financial institutions that can attract climate funds to Azerbaijan, Kazakhstan, and Uzbekistan. The respective governments will likely need to engage national financial institutions to help with accessing international climate funds by leveraging domestic resources for clean energy and transport measures. One example is Bank Respublika in Azerbaijan, which is partnering with the IFC to provide eco-loans for energy-efficient equipment, building retrofits, and repair of existing energy appliances. The Bank also manages a program to retrofit appliances that are switched to using renewable energy.

147. Azerbaijan, Kazakhstan, and Uzbekistan will also need to establish capable national bodies which can facilitate climate finance projects and coordinate the work of implementing entities. This includes establishing Nationally Designated Authorities in order to obtain funds from the Green Climate Fund, such as those already announced by the governments of Kazakhstan and Uzbekistan. It will also be necessary to develop capacity within relevant ministries to prepare, process, and appropriately screen projects for climate change mitigation opportunities. Paired with a solid understanding of opportunities to cost-effectively reduce emissions, such institutions will be well-situated to leverage the full range of available resources for the implementation of mitigation options that contribute to national development goals.

APPENDIX 1: DOCUMENTATION

A. Structure of the National Models

1. Azerbaijan

	Sector	Subsectors or Technologies, as appropriate			
Demand	Transport	Road	Passenger	Light and Medium Duty	Pre-1991 Soviet
					Consumer Autos less than $17,000
					Post-2000 American and Japanese Imports
					Luxury Imports
					Euro 4 Consumer Autos less than $17k
					Euro 4 Post-2000 American and Japanese Imports
					Euro 4 Luxury Imports
				Heavy Duty	Gasoline Buses
					Diesel Buses
					Other
			Freight		
		Civil Aviation			
		Rail			
		Water			
		Pipelines			
	Industrial				
	Residential				
	Commercial				
	Agriculture, Forestry and Fishing				
	Non-Energy Use				

	Energy Industry or Sector	Feedstock Fuel[1] and Technology	
Supply	Electricity and Heat Transmission and Distribution		
	Electricity and CHP	Natural Gas and Residual Fuel Oil	Shimal I and II
		Natural Gas	Astara
		Natural Gas	Sheki
		Natural Gas	Khachmaz
		Natural Gas	Sumgait I and II
		Natural Gas and Diesel	Sengechal
		Natural Gas	Shahdagh
		Natural Gas	Baku PS
		Natural Gas and Residual Fuel Oil	Shirvan CHP
		Natural Gas and Residual Fuel Oil	Ali Bairamli
		Natural Gas	Babek
		Hydro	Mingechevir
		Hydro	Shamkir
		Hydro	Yenikend
		Hydro	Araz
		Hydro	Varvara
		Hydro	Vaykhur
		Small Hydro	Takhtakozpu
		Natural Gas and Residual Fuel Oil	Azerbaijan CHP
		Natural Gas and Residual Fuel Oil	Baku CHP
		Natural Gas	New Gas
		Natural Gas and Residual Fuel Oil	New Gas Oil
		Natural Gas and Residual Fuel Oil	New Gas Oil CHP
		Large Hydro	New Large Hydro

[1] Fuel listed in this column are feedstock fuels only, which have their energy content converted into an output fuel. Auxiliary fuels, such as own-use which is not represented under another sector, are not listed.

		Small Hydro	Small Hydro
		Wind	Onshore Wind
		Solar	Utility Scale Solar PV
		Solar	Distributed Solar PV
		Solar	CSP
		Biomass	Biomass
		Geothermal	Geothermal
		Municipal Solid Waste	Waste to Energy
		Landfill Gas	Landfill Gas
		Biogas	Biogas CHP
	Heat Production		
	Gas Transmission and Distribution		
	Gas Production and Processing		
	Oil Refining		
	Oil Production		

	Sector	Subsector	
Non-Energy GHG Emissions	Industrial Processes	HFCs	Split Residential Air Conditioners
			Car Air Conditioning
			Large Vehicle Air Conditioning
			Domestic Refrigeration
			Centralized Systems for Supermarkets
		Other	
	Agriculture	Enteric Fermentation	
		Manure Management	
		Rice Cultivation	
		Agriculture Soils	
		Field Burning of Agricultural Residues	
		Other	
	Land Use and Forestry	Change in Forest and Other Woody Biomass	
		Forest and Grassland Conversion	
		CO_2 Emissions and Removals from Soil	
	Waste	Solid Waste Disposal	
		Wastewater Handling	

2. Kazakhstan

	Sector	Subsectors or Technologies, as appropriate			
Demand	Transport	Road	M1	Euro 0	Gasoline
					LPG
					Diesel
					Gasoline LPG Dual
				Euro 1 2 3	Gasoline
					LPG
					Diesel
					Gasoline LPG Dual
				Euro 4	Gasoline
					LPG
					CNG
					Diesel
					Electricity
					Gasoline Electric hybrid
					Diesel Electric Hybrid
					Gasoline LPG Dual
					Gasoline CNG Dual
					Diesel CNG Dual
				Euro 5	Gasoline

					LPG
					CNG
					Diesel
					Electricity
					Gasoline Electric hybrid
					Diesel Electric Hybrid
					Gasoline LPG Dual
					Gasoline CNG Dual
					Diesel CNG Dual
			M2 and M3	Euro 0	Gasoline
					LPG
					Diesel
				Euro 1 2 3	Gasoline
					LPG
					Diesel
				Euro 4	Gasoline
					LPG
					Diesel
					CNG
				Euro 5	Gasoline
					LPG
					Diesel
					CNG
			Motorcycles	Euro 0	Gasoline
				Euro 1 2 3	Gasoline
				Euro 4	Gasoline
				Euro 5	Gasoline
			M2 and M3	Euro 0	Gasoline
					LPG
					Diesel
				Euro 1 2 3	Gasoline
					LPG
					Diesel
				Euro 4	Gasoline
					LPG
					Diesel
					CNG
				Euro 5	Gasoline
					LPG
					Diesel
					CNG
			N	Euro 0	Gasoline
					LPG
					Diesel
				Euro 1 2 3	Gasoline
					LPG
					Diesel
				Euro 4	Gasoline
					LPG
					Diesel
					CNG
				Euro 5	Gasoline
					LPG
					Diesel
					CNG
		Domestic Aviation			
		Domestic Navigation			
		Telecom and Post			
		Warehousing			

		Rail
		Pipelines
	Industrial	Non-Metallic Minerals
		Rubber and Plastic
		Pulp and Paper
		Metal Manufacture
		Chemical and Pharmaceutical
		Wood and Wood Products
		Food and Tobacco
		Transport and Other Equipment
		Electronics Manufacturing
		Textile and Leather
		Mining and Quarrying
		Construction
	Residential	
	Commercial and Services	Trade and Repair
		Real Estate
		Hotels and Restaurants
		Recreation and Other
		Financial Services
		Public Services
		Education
		Healthcare
	Agriculture, Forestry and Fishing	Agriculture
		Forestry
		Fishing

	Energy Industry or Sector	Feedstock Fuel and Technology	
Supply	CNG Compression		
	Electricity, Heat and Gas Transmission and Distribution		
	Electricity and CHP	Coal Kazakhstan	Coal Steam
		Coal Kazakhstan	Regional Coal Steam
		Natural Gas and Residual Fuel Oil	Dual Fuel Steam
		Natural Gas and Residual Fuel Oil	Regional Dual Fuel Steam
		Natural Gas	Gas Turbines
		Large Hydro	Large Hydropower
		Small Hydro	Small Hydropower
		Solar	Solar Photovoltaic
		Wind	Wind
		Coal Kazakhstan	New Coal Steam CHP
		Coal Lignite	Supercritical Circulating Fluidized Bed Coal Steam
		Coal Lignite	Supercritical Circulating Fluidized Bed with CCS
		Coal Kazakhstan	Ultrasupercritical Coal Steam
		Coal Kazakhstan	Ultrasupercritical OxyFuel with CCS
		Coal Kazakhstan	Integrated Gasification Combined Cycle Coal
		Coal Kazakhstan	Integrated Gasification Combined Cycle Coal CCS
		Natural Gas	Natural Gas Combined Cycle
		Natural Gas	Natural Gas Combined Cycle CHP
		Natural Gas	Natural Gas Combined Cycle CCS
		Nuclear	New Nuclear
		Municipal Solid Waste	Municipal WtE
	Heat Production		
	Petroleum Refining		
	Gas Processing		
	Condensate Production		
	Crude Extraction		
	Lignite Mining		
	Other Coal Mining		

	Sector	Subsector		
Non-Energy GHG Emissions	Industrial Processes	Mineral Products	Cement Production	
			Lime Production	
			Limestone and Dolomite Use	
			Soda Ash Production and Use	
		Chemical Industry	Ammonia Production	
			Carbide Production	
			Coke Production	
		Metal Production	Iron and Steel Production	Steel
				Pig Iron
			Ferroalloys Production	
			Aluminum Production	
		Consumption of Halocarbons and SF_6	Refrigeration and Air Conditioning	
			Electrical Equipment	
	Agriculture	Enteric Fermentation	Cattle	Dairy Cattle
				Non-Dairy Cattle
			Buffalo	
			Sheep	
			Goats	
			Camels and Llamas	
			Horses	
			Mules and Asses	
			Swine	
		Manure Management	Cattle	Dairy Cattle
				Non-Dairy Cattle
			Buffalo	
			Sheep	
			Goats	
			Camels and Llamas	
			Horses	
			Mules and Asses	
			Swine	
			Poultry	
			Solid Storage and Dry Lot	
		Rice Cultivation	Irrigated	
		Agricultural Soils	Direct Soil Emissions	Synthetic Fertilizers
				Animal Manure Applied to Soils
				N-Fixing Crops
				Crop Residue
			Pasture Range and Paddock Manure	
			Indirect Emissions	Atmospheric Deposition
				Nitrogen Leaching and Runoff
	Land Use Change and Forestry	Forest Land	Forest Land Remaining Forest Land	Wildfires
		Cropland	Cropland Remaining Cropland	
		Grassland	Grassland Remaining Grassland	Wildfires
			Land Converted to Grassland	
		Wetlands	Wetlands Remaining Wetlands	
			Land Converted to Wetlands	
	Waste	Solid Waste Disposal on Land	Managed	
			Unmanaged	
		Wastewater Handling	Domestic and Commercial	
		Waste Incineration		

3. Uzbekistan

<table>
<tr><th></th><th>Sector</th><th>Subsectors or Technologies, as appropriate</th></tr>
<tr><td rowspan="15">Demand</td><td rowspan="5">Transport</td><td>Road</td></tr>
<tr><td>Domestic Aviation</td></tr>
<tr><td>Rail</td></tr>
<tr><td>Pipelines</td></tr>
<tr><td>Other Transport</td></tr>
<tr><td rowspan="5">Industry</td><td>Construction</td></tr>
<tr><td>Machinery</td></tr>
<tr><td>Non-Metallic Minerals</td></tr>
<tr><td>Textile and Leather</td></tr>
<tr><td>Other Industry</td></tr>
<tr><td colspan="2">Residential</td></tr>
<tr><td colspan="2">Services</td></tr>
<tr><td colspan="2">Agriculture, Forestry and Fishing</td></tr>
<tr><td colspan="2">Other Energy Use</td></tr>
<tr><td colspan="2">Non-Energy Use</td></tr>
</table>

<table>
<tr><th></th><th>Energy Industry or Sector</th><th colspan="2">Feedstock Fuel and Technology</th></tr>
<tr><td rowspan="36">Supply</td><td colspan="3">CNG Compression</td></tr>
<tr><td colspan="3">Transmission and Distribution</td></tr>
<tr><td rowspan="28">Electricity and CHP</td><td>Brown Coal</td><td>Angren TPP</td></tr>
<tr><td>Brown Coal, Natural Gas and Residual Fuel Oil</td><td>Novo Angren TPP</td></tr>
<tr><td>Brown Coal</td><td>New USC Coal Steam</td></tr>
<tr><td>Brown Coal</td><td>Underground Coal Gasification</td></tr>
<tr><td>Hydro</td><td>Large Hydro</td></tr>
<tr><td>Hydro</td><td>Small Hydro</td></tr>
<tr><td>Hydro</td><td>Ministry of Agriculture and Water Resources (MAWR) Hydropower</td></tr>
<tr><td>Solar</td><td>Solar PV</td></tr>
<tr><td>Solar</td><td>Solar CSP</td></tr>
<tr><td>Wind</td><td>Wind</td></tr>
<tr><td>Natural Gas</td><td>Tashkent CHP</td></tr>
<tr><td>Natural Gas</td><td>Tashkent CCNG</td></tr>
<tr><td>Natural Gas and Residual Fuel Oil</td><td>Takhiatash TPP Dual Fuel</td></tr>
<tr><td>Natural Gas</td><td>Takhiatash CCNG</td></tr>
<tr><td>Natural Gas and Residual Fuel Oil</td><td>Fergana CHP Dual Fuel</td></tr>
<tr><td>Natural Gas</td><td>Fergana CCNG</td></tr>
<tr><td>Natural Gas and Residual Fuel Oil</td><td>Syrdarya CHP Dual Fuel</td></tr>
<tr><td>Natural Gas</td><td>Syrdarya CCNG</td></tr>
<tr><td>Natural Gas</td><td>Mubarek CHP</td></tr>
<tr><td>Natural Gas</td><td>Navoi SCNG</td></tr>
<tr><td>Natural Gas</td><td>Navoi CCNG</td></tr>
<tr><td>Natural Gas</td><td>Tolimarjon CCNG</td></tr>
<tr><td>Natural Gas</td><td>Turakurgan CCNG</td></tr>
<tr><td>Natural Gas</td><td>Unspecified SCNG</td></tr>
<tr><td>Natural Gas</td><td>New CCNG</td></tr>
<tr><td>Natural Gas and Residual Fuel Oil</td><td>New CHP Dual Fuel</td></tr>
<tr><td>Natural Gas</td><td>New CHP</td></tr>
<tr><td colspan="3">Main Producer Heat Plants</td></tr>
<tr><td colspan="3">Oil Refining</td></tr>
<tr><td colspan="3">Gas Processing</td></tr>
<tr><td colspan="3">Brown Coal Mining</td></tr>
<tr><td colspan="3">Stone Coal Mining</td></tr>
<tr><td colspan="3">Oil Extraction</td></tr>
</table>

	Sector	Subsector
Non-Energy GHG Emissions	Industrial Processes	Cement Production
		Lime Production
		Production of Chemicals
		Production of Metals
		Refrigeration and Air Conditioning
		Foam Blowing
		Aerosols
		Other F-Gas Use
		Non-Energy Use of Lubricants and Waxes
	Solvent and Other Product Use	Solvent and Other Product Use for Paint
		Solvent and Other Product Use for
		Solvent and Other Product Use for
		Other Solvent and Other Product Use
	Agriculture	Enteric Fermentation
		Manure Management
		Rice Cultivation
		Direct Soil Emissions
		Manure in Pasture Range and Paddock
		Indirect N_2O From Agriculture
		Other Direct Soil Emissions
	Land Use Change and Forestry	Forest Fires
		Grassland Fires
	Waste	Solid Waste Disposal on Land
		Wastewater Handling
		Other Waste Handling
	Other	Indirect N_2O From Non-Agricultural NOX
		Indirect N_2O From Non-Agricultural NH_3

B. Key Variables in the Econometric Submodels of Final Energy Demand

Table 49: Fuel Price and Income/Economic Activity Elasticities

Country	Sector	Subsector	Fuel Price Elasticity	Income/Economic Activity	
				Variable	Elasticity
Azerbaijan	Transport	Light and Medium Duty Passenger Vehicles†	*Not used*	Per capita GDP	0.61
	Transport	Road Freight	-0.77	GDP	0.33
	Transport	Civil Aviation	0.48	Per capita GDP	1.03
	Transport	Rail	-1.46, 0.17*	GDP	1.62, 4.92e-3*
	Transport	Water	0.17	GDP	4.92e-3
	Transport	Pipelines	1.70	GDP	-0.13
	Industry		-0.50, -0.34*	Value added	0.20, -0.42*
	Residential		-1.12	GDP	0.51
	Commercial		-1.54	Value added	1.32
	Agriculture, Forestry, and Fishing		-0.29	Value added	3.74
Kazakhstan	Transport	Rail	-0.51	GDP	6.75e-2
	Transport	Domestic Navigation	-0.23	GDP	1.87
	Transport	Domestic Aviation	-0.34	GDP	0.94
	Transport	Telecom and Post	-0.59	Value added	0.53
	Transport	Pipeline and Transport	-0.55	GDP	9.03e-2
	Transport	Road /M1†	-1.70	Per capita GDP	1.43
	Transport	Road/M2 and M3†	-0.74	Per capita GDP	2.03
	Transport	Road/Motorcycles†	-8.53e-2	Per capita GDP	-2.15
	Transport	Road/N†	-1.14	Per capita GDP	-1.46
	Industry	Nonmetallic Minerals	-0.53	Value added	0.44
	Industry	Rubber and Plastic	-0.81	Value added	0.85
	Industry	Pulp and Paper	-0.76	Value added	0.22

Country	Sector	Subsector	Fuel Price Elasticity	Income/Economic Activity Variable	Income/Economic Activity Elasticity
	Industry	Metal Manufacture	-0.07	Value added	0.22
	Industry	Chemical and Pharmaceutical	1.932, 1.909*	Value added	-0.45, -0.19*
	Industry	Food and Tobacco	-1.22, -0.53*	Value added	-1.61, -1.14*
	Industry	Transport and Other Equipment	1.29, 0.27*	Value added	1.50, 1.16*
	Industry	Electronics Manufacturing	1.96	Value added	0.71
	Industry	Textile and Leather	-0.11	Value added	0.40
	Industry	Mining and Quarrying	-0.30	Value added	0.51
	Industry	Construction	-0.46	Value added	2.26
	Residential		0.28	Per capita GDP	0.76
	Commercial and Services	Trade and Repair	-1.63	Value added	2.07
	Commercial and Services	Hotels and Restaurants	1.36e-2	GDP	0.78
	Commercial and Services	Recreation and Other	0.74	GDP	0.51
	Commercial and Services	Financial Services	0.94	Value added	0.92
	Commercial and Services	Public Services	0.92	GDP	0.19
	Commercial and Services	Healthcare	0.35	Value added	6.05E-02
	Commercial and Services	Education	-0.65	Value added	0.85
	Agriculture, Forestry, and Fishing	Agriculture	-0.22	Value added	-0.28
	Agriculture, Forestry, and Fishing	Forestry	-0.28	Value added	0.87
	Agriculture, Forestry, and Fishing	Fishing	-0.11, -0.44*	Value added	0.46, -0.51*

Notes: † Elasticities are used to project vehicle sales. * Two elasticities are shown—one calculated with an exogenous annual trend term in the geometric distributed lag equation (δt in Equation 3, Appendix 2) and one without. The elasticity used in the model is interpolated from the first value to the second as the trend term reduces to 0 in the projection.
Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b; 2015c)

C. Historical Fuel Price Data

148. Figure 32 to Figure 34 and Table 50 to Table 52 illustrate the projected fuel prices for Azerbaijan, Kazakhstan and Uzbekistan. These are used in the No Action Scenario and the mitigation scenarios, unless otherwise specified.

Figure 32: Prices for Major Fuels in Azerbaijan (No Action Scenario)

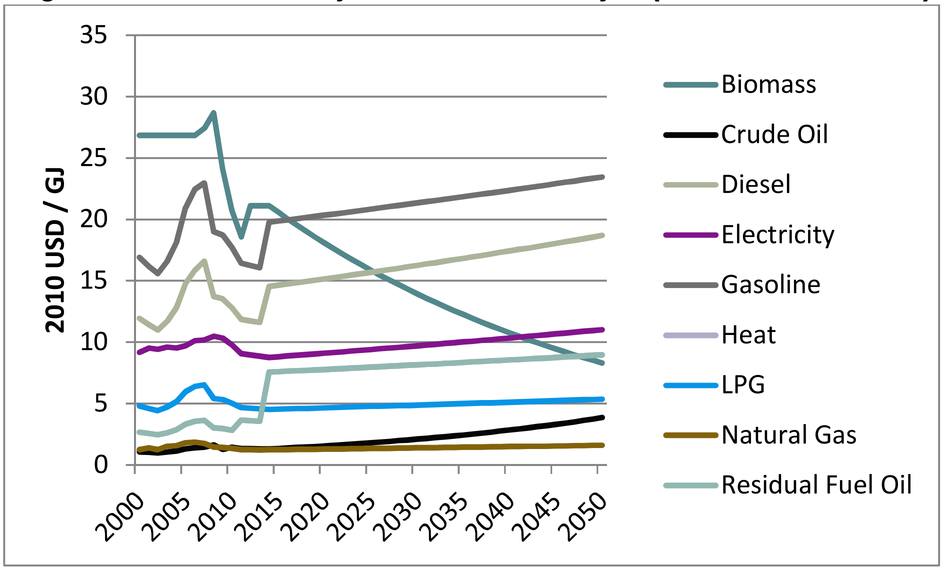


Table 50: Prices for Major Fuels in Azerbaijan (No Action Scenario, 2010 $ / GJ)

Fuel	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	26.9	26.9	20.7	20.6	18.1	15.9	13.9	12.2	10.8	9.4	8.3
Crude Oil	1.1	1.3	1.4	1.3	1.5	1.8	2.1	2.4	2.8	3.3	3.8
Diesel	11.9	14.8	12.8	14.6	15.2	15.7	16.2	16.8	17.4	18.0	18.7
Electricity	9.2	9.7	9.8	8.8	9.1	9.4	9.7	10.0	10.3	10.7	11.0
Gasoline	16.9	21.0	17.7	19.9	20.3	20.8	21.3	21.8	22.4	22.9	23.5
Heat	2.7	3.3	2.8	7.6	7.8	8.0	8.2	8.3	8.5	8.8	9.0
LPG	4.8	6.0	5.0	4.5	4.6	4.8	4.9	5.0	5.1	5.2	5.4
Natural Gas	1.3	1.8	1.4	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6
Residual Fuel Oil	2.7	3.3	2.8	7.6	7.8	8.0	8.2	8.3	8.5	8.8	9.0

Sources: Gurbanov (2014a; 2014c), IEA (2014a), Tariff (price) Council of Azerbaijan Republic (2014), The State Statistical Committee of the Republic of Azerbaijan (2014b), SEI and Abt Associates (2015a)

Figure 33: Prices for Major Fuels in Kazakhstan (No Action Scenario)

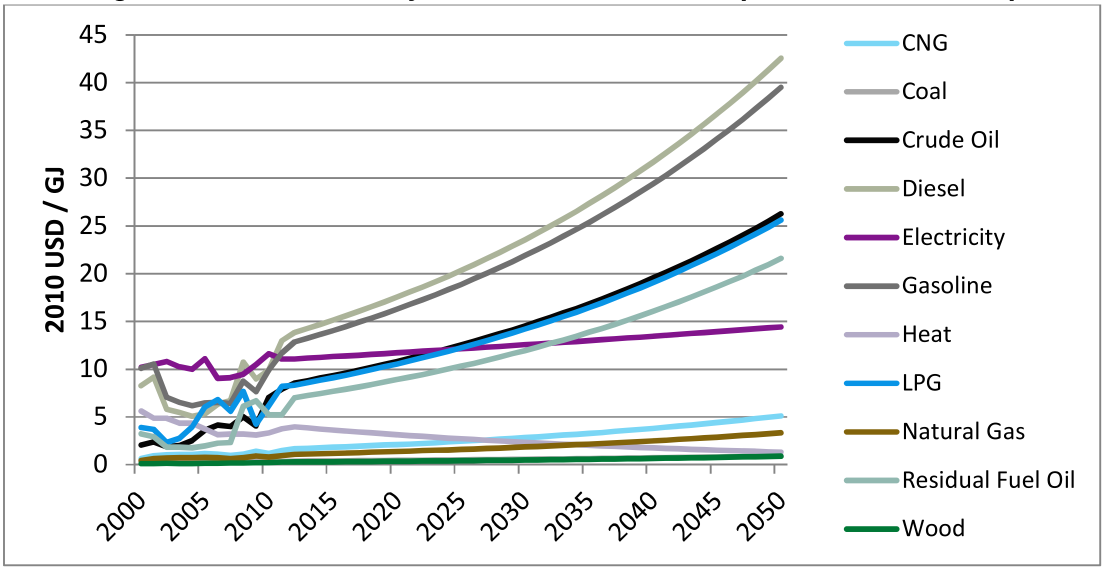


Table 51: Prices for Major Fuels in Kazakhstan (No Action Scenario, 2010 $ / GJ)

Fuel	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
CNG	0.6	1.2	1.2	1.8	2.1	2.4	2.8	3.3	3.8	4.4	5.1
Coal	0.3	0.2	0.4	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9
Crude Oil	2.1	3.6	7.1	9.3	10.8	12.5	14.5	16.8	19.5	22.6	26.2
Diesel	8.3	5.3	9.9	15.1	17.5	20.3	23.6	27.3	31.7	36.7	42.6
Electricity	10.2	11.1	11.6	11.3	11.7	12.1	12.6	13.0	13.5	13.9	14.4
Gasoline	10.1	6.5	9.9	14.0	16.3	18.9	21.9	25.4	29.4	34.1	39.5
Heat	5.6	3.8	3.3	3.6	3.1	2.7	2.3	2.0	1.8	1.5	1.3
LPG	3.9	6.0	6.2	9.1	10.6	12.2	14.2	16.4	19.1	22.1	25.6
Natural Gas	0.4	0.8	0.8	1.2	1.4	1.6	1.8	2.1	2.5	2.9	3.3
Residual Fuel Oil	3.2	2.0	5.2	7.7	8.9	10.3	12.0	13.9	16.1	18.6	21.6
Wood	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9

Note: LPG = liquefied petroleum gas, CNG = compressed natural gas
Sources: Agency on Statistics of the Republic of Kazakhstan (2001; 2013d; 2013e), IEA (2014a), Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014b), news@mail.ru (2015), U.S. Department of Energy (2012), SEI and Abt Associates (2015b)

Figure 34: Prices for Major Fuels in Uzbekistan (No Action Scenario)

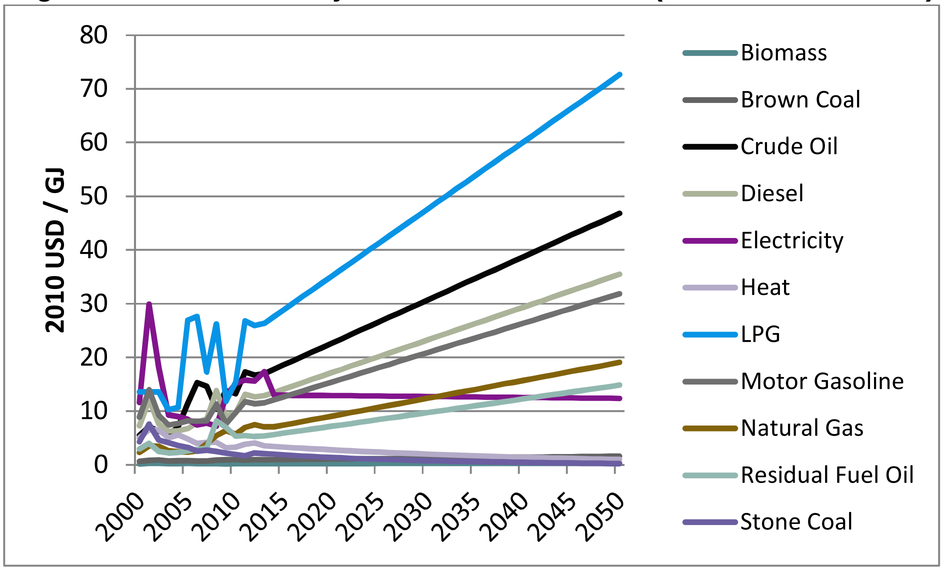


Table 52: Prices for Major Fuels in Uzbekistan (No Action Scenario, 2010 $ / GJ)

Fuel	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Biomass	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Brown Coal	0.6	0.8	1.0	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.6
Crude Oil	5.5	11.4	13.3	18.6	22.6	26.7	30.7	34.7	38.8	42.8	46.8
Diesel	7.3	6.7	9.7	14.1	17.1	20.2	23.3	26.3	29.4	32.4	35.5
Electricity	11.6	8.5	15.1	13.0	12.9	12.8	12.7	12.6	12.5	12.5	12.4
Heat	5.0	4.8	3.3	3.3	2.8	2.4	2.0	1.7	1.4	1.2	1.0
LPG	13.6	26.9	15.5	28.9	35.1	41.4	47.6	53.9	60.1	66.4	72.6
Motor Gasoline	8.9	8.2	9.7	12.7	15.4	18.1	20.9	23.6	26.4	29.1	31.9
Natural Gas	2.3	2.4	5.7	7.4	9.1	10.7	12.4	14.1	15.7	17.4	19.1
Residual Fuel Oil	3.0	2.6	5.3	5.9	7.2	8.4	9.7	11.0	12.3	13.6	14.8
Stone Coal	4.3	3.3	1.9	1.9	1.4	1.0	0.8	0.6	0.4	0.3	0.3

Source: SEI and Abt Associates (2015b; 2015c), Khalmirzaeva (2015c)

D. Technical and Cost Parameters in the Power Sector Submodels

149. The following subsections summarize the technical and cost parameters used in the power sector submodels developed for the No Action Scenarios for Azerbaijan, Kazakhstan, and Uzbekistan. This includes the sources used for their development.

1. Azerbaijan

Table 53: Technical and Cost Parameters in the Azerbaijan Power Sector Submodel (No Action Scenario)

Plant / Technology	Efficiency [%][2]		Availability Factor [%]		Lifetime [Years]	Capital Cost [2007 AZN/kW]		Fixed OM Cost [2007 AZN/kW]		Variable OM Cost [2007 AZN/MWh][3]	
	2010	2050	2010	2050		2010	2050	2010	2050	2010	2050
Ali Bairamli	28	28	60	60	30	340	340	6.8	6.8	2.2	2.2
Araz	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0
Astara	45	45	60	60	30	681	681	13.6	13.6	2.2	2.2
Azerbaijan CHP	38	40	74	74	30	340	340	6.8	6.8	2.2	2.2
Babek	20	20	60	60	30	681	681	13.6	13.6	2.2	2.2
Baku CHP	30	30	60	60	30	340	340	6.8	6.8	2.2	2.2
Baku PS	30	30	60	60	30	681	681	13.6	13.6	2.2	2.2
Biogas CHP	29	29	62	62	20	2831	2831	98.7	98.7	21.1	21.1
Biomass	31	31	60	60	40	2450	2450	67.4	67.4	2.6	2.6
CSP	40	40	45	45	30	4424	1565	44.2	15.7	0.0	0.0
Distributed Solar PV	100	100	17	20	25	3335	885	33.4	8.9	0.0	0.0
Geothermal	100	100	75	75	30	3403	2836	0.0	0.0	7.5	7.5
Khachmaz	43	43	60	60	30	681	681	13.6	13.6	2.2	2.2
Landfill Gas	31	31	0	0	15	20522	1168	13.6	13.6	2.2	2.2
Mingechevir	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0
Nakhchivan	20	20	60	60	30	681	681	13.6	13.6	2.2	2.2
Nakhchivan EQ	20	20	60	60	30	681	681	13.6	13.6	2.2	2.2
New Gas	45	45	60	60	30	681	681	13.6	13.6	2.2	2.2
New Gas Oil	40	40	60	60	30	340	340	6.8	6.8	2.2	2.2
New Gas Oil CHP	40	40	60	60	30	340	340	6.8	6.8	2.2	2.2
New Large Hydro	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0
Onshore Wind	100	100	26	31	25	1225	1021	24.5	20.4	9.5	9.5
Sengechal	45	45	15	15	30	340	340	6.8	6.8	2.2	2.2
Shahdagh	42	42	60	60	30	681	681	13.6	13.6	2.2	2.2
Shamkir	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0
Sheki	42	42	60	60	30	681	681	13.6	13.6	2.2	2.2
Shimal I and II	37	37	60	60	30	340	340	6.8	6.8	2.2	2.2
Shirvan CHP	28	28	60	60	30	340	340	6.8	6.8	2.2	2.2
Small Hydro	100	100	59	59	50	1361	1361	23.8	23.8	0.0	0.0
Sumgait I and II	49	49	60	60	30	340	340	6.8	6.8	2.2	2.2
Takhtakozpu	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0
Utility Scale Solar PV	100	100	19	21	25	2722	715	27.2	7.5	0.0	0.0
Varvara	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0

[2] All efficiencies reported in this section are efficiencies of electricity generation only (i.e., excluding any heat that may be produced as a co-product).

[3] Variable O&M costs exclude fuel costs. Fuel costs are calculated separately in the models based on fuel consumption and assumed fuel prices.

Plant / Technology	Efficiency [%][2]		Availability Factor [%]		Lifetime [Years]	Capital Cost [2007 AZN/kW]		Fixed OM Cost [2007 AZN/kW]		Variable OM Cost [2007 AZN/MWh][3]	
	2010	2050	2010	2050		2010	2050	2010	2050	2010	2050
Vaykhur	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0
Waste to Energy	12	12	67	67	35	8344	5373	67.4	67.4	2.6	2.6
Yenikend	100	100	55	55	50	1293	1293	23.8	23.8	0.0	0.0

Sources: Edenhofer et al. (2012), Gurbanov (2014b), IEA (2012), Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012), President of the Republic of Azerbaijan (2012), RINA Services S.p.A. (2012), Schlömer et al. (2014), The State Statistical Committee of the Republic of Azerbaijan (2014g), U.S. Energy Information Administration (2013c), U.S. Environmental Protection Agency (2013a), UNFCCC CDM Executive Board (2012a; 2012b; 2013), World Bank (2013b)

2. Kazakhstan

Table 54: Technical and Cost Parameters in the Kazakhstan Power Sector Submodel (No Action Scenario)

Plant / Technology	Efficiency [%]		Availability Factor [%]		Lifetime [Years]	Capital Cost [Million 2010 KZT/MW]		Fixed OM Cost [Million 2010 KZT/MW]		Variable OM Cost [2010 KZT/MWh]	
	2010	2050	2010	2050		2010	2050	2010	2050	2010	2050
Coal Steam	33	34	60	60	40	344	344	4.6	4.6	1099	1263
Dual Fuel Steam	32	32	40	40	30	370	370	3.3	3.5	4770	4176
Gas Turbines	55	55	80	80	30	173	173	12.6	8.4	920	777
Integrated Gasification Combined Cycle Coal	39	50	70	85	35	457	365	6.8	6.8	871	871
Integrated Gasification Combined Cycle Coal CCS	32	43	70	85	35	796	545	8.8	3.4	1020	1020
Large Hydropower	100	100	50	50	50	718	718	5.2	5.2	0	0
Municipal WtE	18	18	67	67	20	1869	1869	14.0	14.0	560	560
Natural Gas Combined Cycle	57	63	60	60	30	147	147	2.9	2.9	472	472
Natural Gas Combined Cycle CCS	52	56	85	85	30	265	221	8.0	6.6	1223	1223
Natural Gas Combined Cycle CHP	57	63	60	60	30	212	212	3.8	3.8	615	615
New Coal Steam CHP	39	39	63	63	40	428	428	3.5	3.5	522	522
New Nuclear	36	37	85	85	50	678	589	16.9	14.9	1916	1916
Regional Coal Steam	38	33	65	65	40	344	344	12.9	14.2	1509	1855
Regional Dual Fuel Steam	29	27	50	50	30	370	370	6.4	7.0	2549	2160
Small Hydropower	100	100	70	70	50	319	319	5.2	5.2	0	0
Solar Photovoltaic	100	100	30	30	25	589	155	5.9	1.6	0	0
Supercritical Circulating Fluidized Bed Coal Steam	41	41	80	80	35	460	460	5.9	5.9	463	463
Supercritical Circulating Fluidized Bed with CCS	34	34	80	80	35	899	573	9.4	6.0	829	829
Ultrasupercritical Coal Steam	47	52	85	85	35	339	339	6.8	6.8	501	501
Ultrasupercritical OxyFuel with CCS	39	44	85	85	35	589	435	17.7	13.1	1474	1474
Wind	100	100	44	44	25	265	221	5.3	4.4	2063	2063

Sources: IEA (2012), IEA and OECD Nuclear Energy Agency (2010), Mitsubishi Heavy Industries et al. (2014), Samruk-Green Energy (2013), Schlömer et al. (2014), Suleymenov (2014a; 2014c), U.S. Energy Information Administration (2013c), UNFCCC CDM Executive Board (2012a)

3. Uzbekistan

Table 55: Technical and Cost Parameters in the Uzbekistan Power Sector Submodel (No Action Scenario)

Plant / Technology	Efficiency [%]		Availability Factor [%]		Lifetime [Years]	Capital Cost [Billion 2013 UZS/MW]		Fixed OM Cost [Million 2013 UZS/MW]		Variable OM Cost [Thousand 2013 UZS/MWh]	
	2010	2050	2010	2050		2010	2050	2010	2050	2010	2050
Angren TPP	44	49	60	19	30	2.20	2.20	56.84	56.84	8.4	8.4
Fergana CCNG	58	58	60	60	30	2.47	2.47	49.43	49.43	7.9	7.9
Fergana CHP Dual Fuel	31	31	66	66	30	1.73	1.73	32.13	32.13	10.3	10.3
Large Hydro	100	100	77	77	50	4.33	4.33	86.50	86.50	0.0	0.0
Ministry of Agriculture and Water Resources Hydro	100	100	46	46	50	6.08	6.08	86.50	86.50	0.0	0.0
Mubarek CHP	31	31	50	60	30	1.73	1.73	32.13	32.13	10.3	10.3
Navoi CCNG	58	58	81	81	30	2.21	2.21	49.43	49.43	7.9	7.9
Navoi SCNG	31	31	60	60	30	1.24	1.24	24.71	24.71	7.9	7.9
New CCNG	57	63	60	60	30	2.47	2.47	49.43	49.43	7.9	7.9
New CHP	40	40	60	60	30	1.73	1.73	32.13	32.13	10.3	10.3
New CHP Dual Fuel	40	40	66	66	30	1.73	1.73	32.13	32.13	10.3	10.3
New USC Coal Steam	47	52	85	85	35	5.68	5.68	113.69	113.69	8.4	8.4
Novo Angren TPP	45	45	60	60	30	2.20	2.20	56.84	56.84	8.4	8.4
Small Hydro	100	100	46	46	50	6.08	6.08	86.50	86.50	0.0	0.0
Solar CSP	100	100	22	36	30	13.77	13.77	160.65	56.84	0.0	0.0
Solar PV	100	100	18	18	25	4.20	4.20	98.86	27.19	0.0	0.0
Syrdarya CCNG	58	58	60	60	30	2.47	2.47	49.43	49.43	7.9	7.9
Syrdarya CHP Dual Fuel	31	31	66	66	30	1.73	1.73	32.13	32.13	10.3	10.3
Takhiatash CCNG	58	58	60	60	30	2.47	2.47	49.43	49.43	7.9	7.9
Takhiatash TPP Dual Fuel	31	31	66	66	30	1.24	1.24	24.71	24.71	7.9	7.9
Tashkent CCNG	58	58	60	60	30	2.47	2.47	49.43	49.43	7.9	7.9
Tashkent CHP	31	31	50	60	30	1.73	1.73	32.13	32.13	10.3	10.3
Tolimarjon CCNG	38	58	66	70	30	3.13	3.13	49.43	49.43	7.9	7.9
Turakurgan CCNG	58	58	89	89	30	2.45	2.45	49.43	49.43	7.9	7.9
Underground Coal Gasification	39	39	70	70	30	8.55	8.55	116.14	116.14	16.3	16.3
Unspecified SCNG	31	31	60	60	30	1.24	1.24	24.71	24.71	7.9	7.9
Wind	100	100	35	35	25	6.10	3.71	88.97	74.14	34.6	34.6

Sources: IEA (2012; 2013), Jafarova (2013), JSC Uzbekenergo (2010), Khalmirzaeva (2015a; 2015b; 2015c), President of the Republic of Uzbekistan (2015), Schlömer et al. (2014), STA et al. (2014a; 2014b), Trend News Agency (2012; 2013), U.S. Energy Information Administration (2013c)

E. Energy Resource Reserves and Yields

150. The national models for Azerbaijan, Kazakhstan and Uzbekistan are based on the following assumptions regarding the availability of fossil fuel and renewable resources.

1. Non-Renewable Resources

Table 56: Fossil Fuel Reserves

Country	Resource	Initial Reserves[4]	Future Additions to Reserves
Azerbaijan	Crude Oil	7 billion barrels	*None identified*
	Natural Gas	0.9 trillion m^3	*None identified*
Kazakhstan	Coal	35 billion tonnes	*None identified*
	Crude Oil	3.9 billion tonnes	*None identified*
	Natural Gas	1.3 trillion m^3	*None identified*
Uzbekistan	Coal	2,095 million short tons	*None identified*
	Crude Oil	0.6 billion barrels	*None identified*
	Natural Gas	1.1 trillion m^3	*None identified*

Sources: BP (2014), Ministry of Industry and New Technologies of Kazakhstan (2014), U.S. Energy Information Administration (2014)

2. Renewable Resources

Table 57: Renewable Resource Yields

Country	Resource	Annual Yield
Azerbaijan	Biomass	66,000 TOE
	Landfill Gas	Rising from 6.1 million m^3 in 2015 to 14.1 million m^3 in 2024[5]
	Large Hydro	11 billion kWh
	Municipal Solid Waste	Rising from 2 million tonnes in 2010 to 4 million tonnes in 2025, then increasing with population thereafter
	Small Hydro	5 billion kWh
	Solar	39,636 GWh
	Wind	86,356 GWh
Kazakhstan	Large Hydro	51 billion kWh
	Municipal Solid Waste	0.67 million tonnes in 2012, then increasing with population thereafter[6]
	Small Hydro	11 billion kWh
	Solar	4 billion kWh
	Wind	930 billion kWh
	Wood	*None identified*
Uzbekistan	Biomass	0.3 million TOE
	Hydro	1.8 million TOE
	Solar	176.8 million TOE
	Wind	0.4 million TOE

Sources: ADB (2014), Centre of Hydrometeorological Service (2008), Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012), Ministry of Environment and Water Protection of the Republic of Kazakhstan (2013), Mitsubishi Heavy Industries et al. (2014), Suleymenov (2014b), UNFCCC CDM Executive Board (2012b)

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[4] Reserves at the start of the projection period.
[5] Reflects the potential exploited by the Balakhani Landfill CDM Project.
[6] Yield for Almaty area only (the proposed site of municipal waste-to-energy projects).

APPENDIX 2: METHOD FOR PROJECTING ENERGY USE

151. Projections for the energy and transport systems in the baseline scenario begin with projections of energy supply and demand. Energy-related emissions are then calculated in the same way as in the historical period: by multiplying quantities of fuels by emission factors. As described in Section III.E.1, the national models enforce a few basic accounting rules as a framework for supply and demand projections:

1) Final demand (by fuel) is determined first, then supply is matched to demand. Requirements for intermediate fuels (inputs to energy production processes) are determined by final demand and production technologies and efficiencies. Ultimately, the identity:

Equation 2

$$demand = domestic\ demand + exports = domestic\ production + imports = supply$$

is true in every year and for every fuel.

2) Unless official national projections of fuel imports or exports were available, the most recently observed historical imports and exports are assumed to continue in the future.[30]

3) After accounting for domestic demand and the exogenous imports and exports in rule 2, domestic energy production is utilized to meet remaining supply requirements. However, domestic production is limited by natural resource and production capacity constraints.

4) Any remaining requirements that cannot be met by domestic production are satisfied by additional imports.

152. In the No Action Scenario, one set of methods is used to project final energy demand in the Azerbaijan and Kazakhstan models and a second, simpler approach is used in the Uzbekistan model. As noted earlier, all three models categorize final demand by economic sector, subsector, and fuel (see Appendix 1 Section A for a schematic of this categorization). Separate demand projections are made in each subsector.

153. The Azerbaijan and Kazakhstan models employ stock turnover submodels of demand for the on-road transport subsector[31] and econometric models of final demand in other subsectors.[32] The econometric models are geometric distributed lag models of this general form:

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[30] Official projections of exports of coal, natural gas, and crude oil from Kazakhstan were available in Ministry of Industry and New Technologies of Kazakhstan (2014). These were used in place of the most recently observed exports for these fuels. Exports of non-renewable primary resources (e.g., crude oil) cease once reserves of the resources are exhausted.

[31] The stock turnover submodel for Azerbaijan comprises light and medium duty passenger vehicles only. On-road freight transport is projected econometrically, and an activity analysis (described below) is used for heavy duty passenger vehicles. The stock turnover submodel for Kazakhstan includes all on-road transport.

[32] The transport/warehousing, industry/wood and wood products, and commercial and services/real estate subsectors in Kazakhstan are exceptions. No realistic parameters for an econometric model for these subsectors could be determined from the available historical data, so subsectoral energy demand is simply extrapolated from historical trends in the No Action Scenario.

Equation 3

$$\ln e_t = \alpha + \beta \ln p_t + \gamma \ln i_t + \lambda \ln e_{t-1} + \delta t$$

where t is the year, e is total final energy demand, p is the weighted average fuel price, i is a measure of economic activity or income (GDP, value added, or per capita GDP, depending on the subsector), β is the price elasticity of demand, γ is the income or economic activity elasticity of demand, and α is a constant. The constant λ controls the effect of lagged energy demand e_{t-1}, and δ permits a linear trend to be added into the demand projection, which is not captured by the other explanatory variables.

154. In certain subsectors, other explanatory variables may be added to the model—for example, population in the civil aviation subsector. Each parameter in the econometric models was estimated through multiple regression over the available historical data in each country. Parameter estimates that were not deemed statistically significant were excluded from Equation 3 with the exception of the fuel price and economic activity terms, which were kept at all significance levels.[33] If the parameter δ was found to be statistically significant, it is assumed to vanish from the projection (i.e., to decrease to 0) by 2050. This approach acknowledges that any exogenous trend observed in historical data is unlikely to continue indefinitely into the future. Otherwise, all regression coefficients are held constant throughout the projection period. Appendix B lists the fuel price elasticities β and income/economic activity elasticities γ that were calculated for each subsector.

155. Given projections of their independent variables (e.g., fuel prices, GDP, value added, population), the econometric models provide an estimate of total final energy demand in each subsector. This total is then divided into demand for various fuels using a projection of fuel shares. Fuel shares are projected by allowing them to grow at the average rate observed in the historical data, subject to the constraint that shares must total 100% (and that the change per year for a fuel cannot exceed a few percent, to avoid unreasonable developments over the long term). This technique allows historical trends in fuel switching to continue in the No Action Scenario.

156. The econometric method described above is inherently a top-down approach—that is, it does not represent specific energy end uses or energy-using technologies. It is applied in subsectors for which insufficient data were available to enable bottom-up modeling. For the road transport subsectors in Azerbaijan and Kazakhstan, however, the consultant team was able to develop data that permit a bottom-up approach. Many of these data were gathered through primary data collection. The principal bottom-up technique employed is stock turnover modeling, while a simpler activity analysis is used for heavy duty passenger vehicles in Azerbaijan.

157. In the stock turnover simulation, the stock of vehicles is represented explicitly in the national models. Vehicle sales add to the stock in each year, and vehicle retirements subtract from it. The stock is divided into vehicle classes (see Appendix 1 Section A for a list), and for each class technical and operating parameters are defined including:

(i) Efficiency (fuel used per kilometer traveled)

[33] Due to high variability and limited years in the available historical record for Azerbaijan and Kazakhstan, a significance level as low as 75% was tolerated before excluding terms from Equation 3. Though a comprehensive sensitivity analysis of the choice of regression coefficients was not conducted, repeated qualitative trials revealed little variation among projection outcomes for different self-consistent parameter sets α, β, γ, λ and δ.

(ii) Annual distance traveled
(iii) Fuel shares for multi-fuel vehicles
(iv) Emission factors

158. Within each class, the stock is divided into vintages, each representing the cohort of vehicles sold in a particular year (and thus having the same age). Vehicle survival is a function of age; and efficiency, annual distance traveled, and emissions performance all degrade as vehicles age.

159. In this framework, a key determinant of projected energy use and emissions is the number of new vehicles sold and put in service. Total vehicle sales are projected using geometric distributed lag models that incorporate income and fuel price elasticities. Sales are projected for the vehicle categories shown in Table 58.

Table 58: Categorization of Vehicle Sales Projections

Country	Category
Azerbaijan	Light and medium duty passenger
Kazakhstan	M1[34]
	M2 and M3
	Motorcycles
	N

Sources: Stockholm Environment Institute and Abt Associates (2015a; 2015b)

160. Within each of these categories, sales are distributed among vehicle classes using a multinomial logit submodel of consumer utility. This submodel estimates the sales share for each class as:

Equation 4

$$\frac{e^{V_j}}{\sum_{i=1}^{J} e^{V_i}}$$

where j is a vehicle class, e is the base of the natural logarithm, and V is a linear function describing consumer utility for a vehicle class. Explanatory variables were chosen for V following the literature and according to data availability (Al-Alawi and Bradley 2013; Ewing and Sarigöllü 1998; Greene et al. 2004; Kavalec 1996; Lee et al. 2013; Lee and Cho 2009; Lin and Greene 2010; Potoglou and Kanaroglou 2007; Potoglou and Kanaroglou 2008; Santini and Vyas 2005; Struben and Sterman 2008; U.S. Energy Information Administration 2013a; U.S. Energy Information Administration 2013b). The specific variables used are listed in Table 59.

[34] The categories M1, M2, M3, and N are defined as in United Nations Economic Commission for Europe (2014).

Table 59: Explanatory Variables in Multinomial Logit Modeling of Vehicle Sales Shares

Country	Variables
Azerbaijan	Vehicle purchase cost
	Annual fuel cost
	Vehicle horsepower
	Per capita income
Kazakhstan	Vehicle purchase cost
	Annual fuel cost
	Annual maintenance cost
	Vehicle range (distance traveled between refuelings)
	Per capita income

Sources: Stockholm Environment Institute Abt Associates (2015a; 2015b)

161. A few other restrictions are put on the sales of certain vehicle classes. In the Azerbaijan model, it is assumed that Euro 4-compliant classes are not sold in the No Action Scenario (they are, however, in the Euro 4 Vehicle Standards scenario). Likewise, in the Kazakhstan model, following Republic of Kazakhstan (2013a) only Euro 4 and Euro 5-compliant classes are sold from 2013 on.

162. Ultimately, final energy demand is determined in the stock submodels by accounting for each vehicle's distance traveled, the type(s) of fuel used by the vehicle, and the vehicle's efficiency. As elsewhere in the energy and transport system models, emissions are calculated by multiplying demand for fuels by the relevant emission factors (adjusted as needed for vehicle age).

163. As mentioned above, a different tack is taken for heavy duty passenger vehicles in Azerbaijan. In this case, there were not sufficient data available to build a stock turnover model. Instead, an activity analysis is performed in which:

(i) Vehicle-kilometers traveled by heavy duty passenger vehicles (the activity level) are projected based on historical trends.
(ii) Total vehicle-kilometers are distributed among gasoline buses, diesel buses, and other heavy duty (diesel) passenger vehicles. The shares of vehicle-kilometers for these technologies are also projected based on historical trends.
(iii) Vehicle-kilometers for each type of vehicle are multiplied by an efficiency for the type to obtain final energy demand.

164. A similar method is used for all projections of final energy demand in the Uzbekistan model. This model is by necessity simpler than those for Azerbaijan and Kazakhstan due to data and schedule limitations. The basic approach in each sector or subsector is to multiply a projection of an activity level by an energy intensity (i.e., total final demand per activity unit), then to allocate the resultant demand to fuels through fuel shares extrapolated from historical trends. The energy intensity for the residential sector is taken from the baseline scenario in Center for Energy Efficiency and UNDP (2013) and reflects business-as-usual improvements in residential building efficiency through 2050. Intensities for other subsectors also change over time and are based on trends in the available historical data. Table 60 presents the activity variables used in each sector or subsector.

Table 60: Demand-Side Activity Variables in Uzbekistan Model

Sector/Subsector	Activity Variable
Residential	m^2 of residential building space, calculated as population x per capita residential space
Agriculture, Forestry, and Fishing	Agricultural value added
Services	Services value added
Industry (all subsectors)	Industrial value added
Transport (all subsectors)	GDP
Other Energy Use	GDP
Non-Energy Use	GDP

Source: Stockholm Environment Institute and Abt Associates (2015c)

165. On the supply side of the models, energy producing industries are represented as shown in Section A. For each industry, energy own use, losses during transformation of energy from one form to another, and GHG emissions are modeled. In the power sector, specific production technologies and production capacities are also modeled to achieve greater realism. The power sector submodels are thus a bottom-up depiction of this critically important industry.[35]

166. All three power submodels—for Azerbaijan, Kazakhstan, and Uzbekistan—represent both existing electricity generation and combined heat and power (CHP) capacity and new power technologies and plants that may be built in the future. Current capacity is modeled at the plant level for Azerbaijan and Uzbekistan; for Kazakhstan, current capacity is modeled at the level of power technologies (i.e., all plants using a technology are aggregated together). A higher level of aggregation was chosen for Kazakhstan to mitigate concerns about disclosing plant-level data. For each plant or technology, a number of technical and cost parameters are modeled including:

(i) Efficiency or heat rate (for both power and heat, as applicable)
(ii) Current and planned capacity
(iii) Availability factor
(iv) Capacity credit (credit toward planning reserve margin[36])
(v) Plant lifetime
(vi) Capital cost
(vii) Fixed O&M cost
(viii) Variable O&M cost
(ix) Emission factors

167. Appendix 1 Section D presents values for key power sector parameters in the No Action Scenario. As it shows, parameters for well-established, mature technologies are generally assumed not to change over the projection period, while parameters for developing technologies may evolve in keeping with assumptions about technological learning and commercialization.

168. Given that the power submodels are based on specific technologies and production capacities, two pivotal questions in determining the power sector's energy and emission impacts are what capacity is used to meet power requirements (capacity dispatch) and how new capacity is added if needed (capacity expansion). Two different approaches to these questions

[35] Due to data limitations, it was not possible to model other energy industries from the bottom up.
[36] The reserve margin refers to extra capacity beyond that necessary to meet generation requirements and expected peak load. When planning new sources of generation, utilities refer to a *planning* reserve margin as a safeguard against system failure in the event of unexpected loads or plant downtime. The margins used in the study models are described in **Error! Reference source not found.**.

are followed in the models. For Azerbaijan and Kazakhstan, capacity dispatch and expansion are simulated using a least-cost optimization algorithm. This algorithm finds the dispatch and capacity expansion solution that minimizes the net present value of social costs incurred in the power sector during the projection period (while satisfying power requirements).[37] In the Uzbekistan model, on the other hand, a simpler method is used. Capacity is dispatched according to rules that approximate historical dispatch patterns; if new capacity is required in the No Action Scenario, it is divided among generating technologies in proportion to each technology's role in the power mix at that time. Table 61 lists the dispatch priorities for power plants and technologies in the Uzbekistan model (lower values indicate higher priorities). Plants and technologies at a given priority level are not dispatched until all higher priority plants and technologies are.

Table 61: Power Sector Capacity Dispatch Priorities in Uzbekistan Model (No Action Scenario)

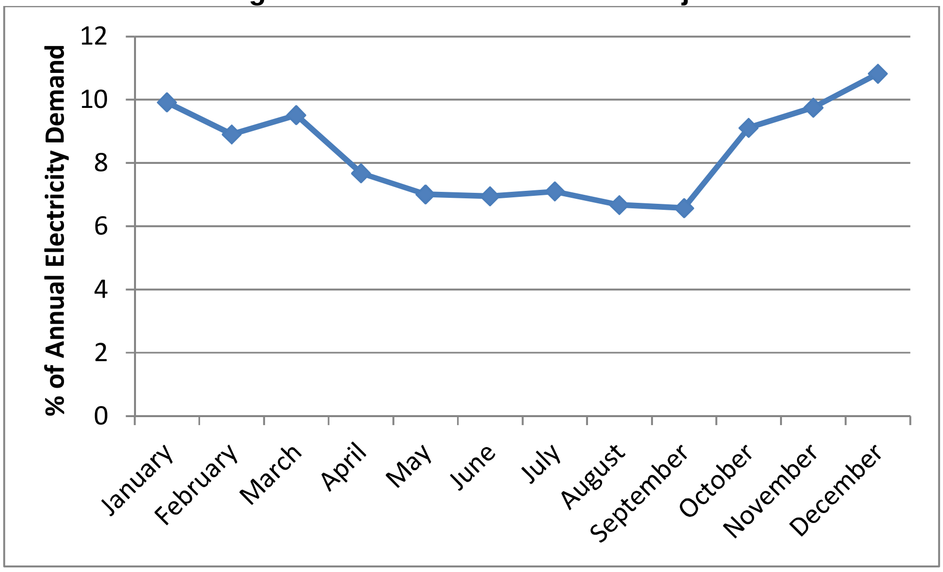
Plant / Technology	Dispatch Priority
Angren Thermal Power Plant (TPP)	2
Fergana Combined Cycle Natural Gas (CCNG)	1
Fergana Combined Heat and Power (CHP) Dual Fuel	3
Hydro	1
Mubarek CHP	3
Navoi CCNG	1
Navoi Single Cycle Natural Gas (SCNG)	2
New CCNG	1
New CHP	3
New CHP Dual Fuel	1
New Utrasupercritical (USC) Coal Steam	1
Novo Angren TPP	2
Concentrated solar power (CSP)	1
Solar photo voltaic (PV)	1
Syrdarya CCNG	1
Syrdarya CHP Dual Fuel	1
Takhiatash CCNG	1
Takhiatash TPP Dual Fuel	1
Tashkent CCNG	1
Tashkent CHP	1
Tolimarjon CCNG	1
Turakurgan CCNG	1
Underground Coal Gasification	3
Unspecified SCNG	2
Wind	1

Source: Stockholm Environment Institute and Abt Associates (2015c)

169. Regardless of the method of dispatch, the LEAP simulation considers not only annual electricity requirements but also requirements in each month of the year. Sufficient capacity must be available and utilized to satisfy monthly power demands. Figure 35, Figure 36, and Figure 37 illustrate how annual electricity requirements are divided among the months of the year in each study country. Although power requirements may grow during the projection period, the distribution of electrical load throughout the year is assumed to be unchanged.

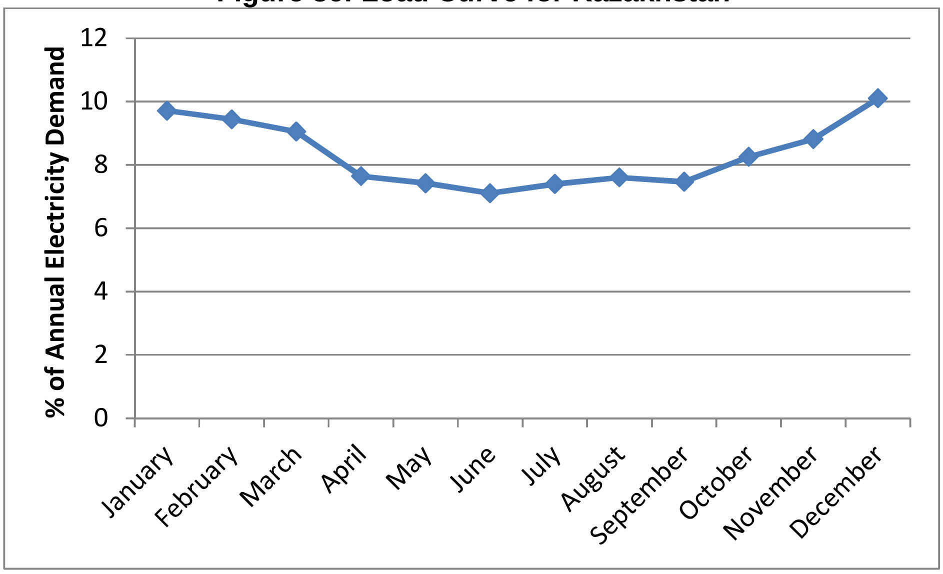
[37] The algorithm is part of the LEAP platform itself—see SEI (2015a) for details.

Figure 35: Load Curve for Azerbaijan



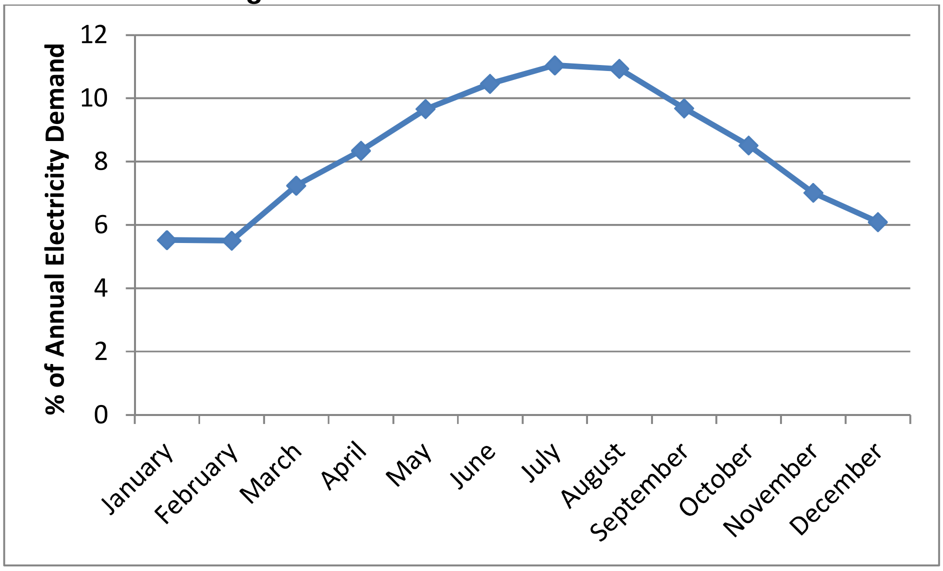
Source: Ramazanov et al. (2007)

Figure 36: Load Curve for Kazakhstan



Source: Suleymenov (2014a)

Figure 37: Load Curve for Uzbekistan



Source: Calculations based on average monthly temperatures (World Weather Online 2015)

170. LEAP differentiates between two types of capacity in the models: *exogenous* and *endogenous*. Exogenous capacity is specified as an input to a model, whereas endogenous capacity is added by the model itself to maintain the required planning reserve margin. All three power submodels represent current or historically existing electricity and CHP plants as exogenous capacity. The submodels for Kazakhstan and Uzbekistan also include exogenous capacity reflecting definitive short and medium-term capacity expansion plans (from Suleymenov (2014a), JSC Uzbekenergo (2010; 2015a; 2015b), President of the Republic of Uzbekistan (2015), and Khalmirzaeva (2015b); no similar plans for Azerbaijan could be identified). If exogenously determined capacity is not sufficient to maintain the reserve margin, endogenous capacity is added according to least-cost principles in the Azerbaijan and Kazakhstan models and the previously described simulation rules in the Uzbekistan model. Depending upon the adequacy of existing or planned capacity for meeting projected generation requirements plus reserve, endogenously added capacity may comprise a significant share of the total electrical capacity during later years in the models. Table 62 lists the planning reserve margins used in the models.

Table 62: Planning Reserve Margins

Country	Reserve Margin [% of Peak Load]	
Azerbaijan*	2015	29.3
	2030	19.2
Kazakhstan*	2014	9.1
	2015	9.8
	2016	9.8
	2017	9.7
	2018	11.4
	2019	11.2
	2020	11.1
	2025	10.8
	2030	9.5
Uzbekistan	8	

Notes: * Values for years not shown explicitly are determined by linear interpolation.
Sources: Japan International Cooperation Agency (2013), Republic of Kazakhstan (2014).

171. For the power sector and other energy industries, natural resource constraints are also an important factor in determining domestic energy production. These constraints are modeled as follows:

(i) Non-renewable energy resources – Current reserves and any projected future additions to reserves are exogenous inputs to the models. Reserves are drawn down during the projection period as fuels are used.
(ii) Renewable energy resources – Annual exploitable yields are inputs to the models. Annual usage of a resource may not exceed its yield.

172. Appendix 1 Section E lists the constraints assumed for key energy resources in the three models.

173. As noted before, the models' mitigation scenarios inherit values and formulas from the No Action Scenario in the first instance. Supplemental or revised inputs are then entered for the scenarios as needed to model mitigation measures' impacts. From a methodological standpoint, then, the modeling of mitigation options occurs within the No Action framework just surveyed. Many mitigation scenarios require only a few parameter changes within that framework to achieve their effect (e.g., an increased deployment of a certain power or vehicle technology). In some cases, though, modeling a mitigation option requires technological or activity detail that is not part of the No Action Scenario—and could not be because there are not sufficient data to model the full scope of the activity or all alternative technologies in the subsector or energy industry. In this situation, the mitigation scenario includes incremental detail that allows the effects of the mitigation technology or activity to be estimated relative to No Action conditions, and incremental energy and emission savings are subtracted from the No Action projection.

174. An example of this approach is the Efficient Stoves scenario in the Azerbaijan model. This scenario is based on a project to upgrade stoves in rural households described in The Republic of Azerbaijan (2013). According to this source, the project achieved an average daily energy savings of 1 kWh per household at a certain cost. The Efficient Stoves scenario explores the implications of deploying similar technology in 10% of rural households by 2030.

175. Because no data on total household energy demand for cooking and use of existing stove technologies were available, a bottom-up model of residential cooking was not feasible in the No Action Scenario. For the Efficient Stoves scenario, then, the anticipated energy savings and costs are scaled by the number of households targeted in the scenario and are subtracted (energy savings) from or added (costs) to the No Action estimate. Emission reductions follow from the energy savings.

APPENDIX 3: METHOD FOR PROJECTING NON-ENERGY GHG EMISSIONS

176. Table 63 describes the techniques used to project emissions for non-energy sources in the No Action Scenario.

Table 63: Projection Techniques for Non-Energy GHG Emissions (No Action Scenario)

Country	Emission Source	Emission Subsource	Projection Technique
Azerbaijan	Industrial processes	Car air conditioning	Driving variable: # of light and medium duty passenger vehicles
	Industrial processes	Large vehicle air conditioning	Driving variable: energy demand for on-road freight transport
	Industrial processes	Other HFCs	Driving variable: population
	Other industrial processes		Driving variable: industrial value added
	Agriculture		Trend extrapolation
	Land use and forestry	Change in forest and other woody biomass	Driving variable: forested area
	Other land use and forestry		Trend extrapolation
	Waste	Solid waste disposal	Driving variable: population
	Waste	Wastewater handling	Driving variable: urban population
Kazakhstan	Industrial processes	Cement production	Driving variable: non-metallic minerals value added
	Industrial processes	Other mineral products	Trend extrapolation
	Industrial processes	Coke production	Trend extrapolation
	Industrial processes	Other chemical industry	Driving variable: chemical and pharmaceutical value added
	Industrial processes	Metal production	Driving variable: metal manufacture value added
	Industrial processes	Refrigeration and air conditioning	Driving variable: population
	Industrial processes	SF_6 from electrical equipment	Trend extrapolation
	Agriculture	Enteric fermentation	Driving variable: population
	Agriculture	Manure management	Driving variable: population
	Agriculture	Rice cultivation	Driving variable: population
	Agriculture	Synthetic fertilizers	Trend extrapolation
	Agriculture	Animal manure applied to soils	Trend extrapolation
	Agriculture	N-fixing crops	Driving variable: agricultural value added
	Agriculture	Crop residue	Driving variable: agricultural value added
	Agriculture	Pasture range and paddock manure	Driving variable: population
	Agriculture	Indirect emissions from agricultural soils	Trend extrapolation
	Land use and forestry		Trend extrapolation
	Waste	Solid waste disposal on land	Driving variable: population
	Waste	Wastewater handling	Driving variable: urban population
	Waste	Waste incineration	Driving variable: population
Uzbekistan	Industrial processes except refrigeration and air conditioning		Driving variable: industrial value added
	Refrigeration and air conditioning		Driving variable: population
	Solvent and other product use		Driving variable: industrial value added
	Agriculture		Driving variable: agricultural value added
	Land use change and forestry		Driving variable: agricultural value added
	Waste		Driving variable: population
	Other		Driving variable: GDP

APPENDIX 4: BASELINE DATA SOURCES

177. Table 64 lists the principal data sources used in the No Action Scenario. Supplemental sources for particular mitigation scenarios are discussed in Section III.D.

Table 64: Data Sources for the No Action Scenario, 2010-2050

Country	Data Type		Sources
Azerbaijan	Population		The State Statistical Committee of the Republic of Azerbaijan (2014a)
	Gross Domestic Product		International Monetary Fund (2014); The State Statistical Committee of the Republic of Azerbaijan (2014d)
	Value Added		International Monetary Fund (2014); The State Statistical Committee of the Republic of Azerbaijan (2014d); World Bank (2013c)
	Fuel Prices		Gurbanov (2014a; 2014c); IEA (2014a); Tariff (price) Council of Azerbaijan Republic (2014); The State Statistical Committee of the Republic of Azerbaijan (2014b)
	Energy Balances		The State Statistical Committee of the Republic of Azerbaijan (2014g)
	On-Road Vehicles	Stock and Sales	Gurbanov (2014d) The State Statistical Committee of the Republic of Azerbaijan (2014e)
	On-Road Vehicles	Efficiency	Bibipedia.info (2014); Mercedes-Benz (2014); Nissan Azerbaijan (2014); U.S. Environmental Protection Agency (2013d)[38]
	On-Road Vehicles	Annual Distance	Gurbanov (2014e); The State Statistical Committee of the Republic of Azerbaijan (2014c; 2014e; 2014f)
	On-Road Vehicles	Costs (Capital, O&M)	Bibipedia.info (2014); Mercedes-Benz (2014); Nissan Azerbaijan (2014); Posada Sanchez et al. (2012); U.S. Environmental Protection Agency (2013d)
	Electricity and CHP Plants	Efficiency / Heat Rate	Edenhofer et al. (2012); Gurbanov (2014b); The State Statistical Committee of the Republic of Azerbaijan (2014g); UNFCCC CDM Executive Board (2012a; 2012b; 2013)
	Electricity and CHP Plants	Existing and Planned Capacity	Abt Associates et al. (2014b); AzerEnerji (2014a; 2014b); Gurbanov (2014b); State Agency for Alternative and Renewable Energy Sources of the Republic of Azerbaijan (2015); UNFCCC CDM Executive Board (2012a; 2012b; 2013)
	Electricity and CHP Plants	Availability	Edenhofer et al. (2012); IEA (2012); Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012); RINA Services S.p.A. (2012); Schlömer et al. (2014); UNFCCC CDM Executive Board (2012a; 2012b; 2013)
	Electricity and CHP Plants	Costs (Capital, O&M)	Edenhofer et al. (2012); IEA (2012); Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012); President of the Republic of Azerbaijan (2012); RINA Services S.p.A. (2012); Schlömer et al. (2014); UNFCCC CDM Executive Board (2012a); U.S. Energy Information Administration (2013a); World Bank (2013b)
	Electricity and CHP Plants	Lifetime	Edenhofer et al. (2012); IEA (2012); RINA Services S.p.A. (2012); Schlömer et al. (2014); UNFCCC CDM Executive Board (2012a; 2012b; 2013)
	Electricity Load Curve		Ramazanov et al. (2007)
	Electricity Reserve Margin		Japan International Cooperation Agency (2013)
	Natural Resource Reserves and Annual Yields		ADB (2014); BP (2014); Ministry of Ecology and Natural Resources of Azerbaijan Republic (2012); UNFCCC CDM

[38] Data gathered for the Kazakhstan vehicle stock turnover model were also used to estimate efficiency improvements associated with Euro 4 vehicles. See On-Road Vehicles – Efficiency for Kazakhstan below.

Country	Data Type		Sources
			Executive Board (2012b)
	Emission Factors		Aliyev (2015); Argonne National Laboratory (2015); Bond et al. (2004); Delphi Automotive (2012); IPCC (2015); Ministry of Ecology and Natural Resources of Azerbaijan Republic (2014); The State Statistical Committee of the Republic of Azerbaijan (2014g); United Nations Framework Convention on Climate Change Clean Development Mechanism Executive Board (2012a); U.S. Environmental Protection Agency (2014); World LP Gas Association (2012)
	Non-Energy GHG Emissions		Aliyev (2015)
Kazakhstan	Population		Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014e)
	Gross Domestic Product		Agency on Statistics of the Republic of Kazakhstan (2013a; 2013c); Ministry of National Economy of the Republic of Kazakhstan (2014); news@mail.ru (2015); President of the Republic of Kazakhstan (2014)
	Value Added		Agency on Statistics of the Republic of Kazakhstan (2003; 2008; 2013b); Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014c; 2014d)
	Fuel Prices		Agency on Statistics of the Republic of Kazakhstan (2001; 2013d; 2013e); IEA (2014a); Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014b); news@mail.ru (2015); U.S. Department of Energy (2012)
	Energy Balances		Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014b)
	On-Road Vehicles	Stock and Sales	Administrative Police Committee of the Ministry of Internal Affairs of the Republic of Kazakhstan (2015); Agency on Statistics of the Republic of Kazakhstan (2012; 2013f); Association of Kazakhstan Auto Business (2014); Kapital.kz (2014); Ministry of National Economy of the Republic of Kazakhstan Committee on Statistics (2014f)
	On-Road Vehicles	Efficiency	Avtopolis Plus (2008); Dzhaylaubekov (2010); European Environment Agency (2007); Ministry of Transport of the Russian Federation (2008); Republic of Kazakhstan (2009)
	On-Road Vehicles	Annual Distance	Avtopolis Plus (2008); Dzhaylaubekov (2010); The Ministry of Justice of the Russian Federation (n.d.); Napolskikh (1993)
	On-Road Vehicles	Costs (Capital, O&M)	Association of Kazakhstan Auto Business (2014); DosHon LLC (2015); Kantemirovskaya (n.d.); Kapital.kz (2014); other primary data collection from vendors.
	Electricity and CHP Plants	Efficiency / Heat Rate	IEA (2012); IEA and OECD Nuclear Energy Agency (2010); Mitsubishi Heavy Industries et al. (2014); Schlömer et al. (2014); Suleymenov (2014c); UNFCCC CDM Executive Board (2012a); U.S. Energy Information Administration (2013c)
	Electricity and CHP Plants	Existing and Planned Capacity	Konyrova (2014); Republic of Kazakhstan (2013b); Suleymenov (2014a)
	Electricity and CHP Plants	Availability	IEA (2012); Samruk-Green Energy (2013); Schlömer et al. (2014); Suleymenov (2014a)
	Electricity and CHP Plants	Costs (Capital, O&M)	IEA (2012); IEA and OECD Nuclear Energy Agency (2010); Mitsubishi Heavy Industries et al. (2014); Schlömer et al. (2014); Suleymenov (2014a; 2014c); U.S. Energy Information Administration (2013c)
	Electricity and CHP Plants	Lifetime	IEA (2012); Mitsubishi Heavy Industries et al. (2014); Schlömer et al. (2014)
	Electricity Load Curve		Suleymenov (2014a)

Country	Data Type		Sources
	Electricity Reserve Margin		Republic of Kazakhstan (2014)
	Natural Resource Reserves and Annual Yields		Ministry of Environment and Water Protection of the Republic of Kazakhstan (2013); Ministry of Industry and New Technologies of Kazakhstan (2014); Mitsubishi Heavy Industries et al. (2014); Suleymenov (2014b)
	Emission Factors		Avtopolis Plus (2008); Bond et al. (2004); Dzhaylaubekov (2010); European Environment Agency (2007); IEA (2012); IPCC (2015); Ministry of Environment and Water Resources of the Republic of Kazakhstan and JSC “Zhasyl Damu” (2014); SEI (2012); U.S. Environmental Protection Agency (2014); World LP Gas Association (2012)
	Non-Energy GHG Emissions		Ministry of Environment and Water Resources of the Republic of Kazakhstan and JSC “Zhasyl Damu” (2014)
Uzbekistan	Population		Khalmirzaeva (2015c); United Nations Department of Economic and Social Affairs (2015)
	Gross Domestic Product		Khalmirzaeva (2015c); Ministry of Economy of the Republic of Uzbekistan
	Value Added		State Committee of the Republic of Uzbkistan on Statistics (2015); President of the Republic of Uzbekistan (2015)
	Fuel Prices		SEI and Abt Associates (2015b); Khalmirzaeva (2015c)
	Energy Balances		IEA (2013)[39]
	Electricity and CHP Plants	Efficiency / Heat Rate	IEA (2012; 2013); JSC Uzbekenergo (2010); Trend News Agency (2013)
	Electricity and CHP Plants	Existing and Planned Capacity	Jafarova (2013); JSC Uzbekenergo (2010; 2015a; 2015b; 2015c); Khalmirzaeva (2015a; 2015b); Otahonov (2015); President of the Republic of Uzbekistan (2015); Trend News Agency (2012; 2013); U.S. Energy Information Administration (2014)
	Electricity and CHP Plants	Availability	IEA (2012); Jafarova (2013); JSC Uzbekenergo (2010); Khalmirzaeva (2015b); President of the Republic of Uzbekistan (2015); STA et al. (2014b); Trend News Agency (2012; 2013)
	Electricity and CHP Plants	Costs (Capital, O&M)	IEA (2012); Jafarova (2013); JSC Uzbekenergo (2010); Khalmirzaeva (2015a); Schlömer et al. (2014); STA et al. (2014a); Trend News Agency (2012; 2013); U.S. Energy Information Administration (2013c)
	Electricity and CHP Plants	Lifetime	IEA (2012); Khalmirzaeva (2015c); Schlömer et al. (2014)
	Electricity Load Curve		SEI calculations based on average monthly temperatures in World Weather Online (2015)
	Electricity Reserve Margin		SEI assumption in absence of other data
	Natural Resource Reserves and Annual Yields		BP (2014); Centre of Hydrometeorological Service (2008); U.S. Energy Information Administration (2014)
	Emission Factors		Argonne National Laboratory (2015); Bond et al. (2004); European Commission JRC Joint Research Centre and Netherlands Environmental Assessment Agency (2010); IEA (2012); IPCC (2015); SEI (2012); U.S. Environmental Protection Agency (2014); World LP Gas Association (2012)
	Non-Energy GHG Emissions		European Commission JRC Joint Research Centre and Netherlands Environmental Assessment Agency (2010)

[39] Official Uzbekistan energy balances were not available.

APPENDIX 5: SENSITIVITY OF NATIONAL MODELS TO KEY PARAMETERS

178. As explained in Section II of this report, the modeling conducted for this study depends on a number of exogenously determined parameters (model inputs). These help define both the No Action Scenario and the mitigation scenarios. The values adopted for the parameters in each scenario are best estimates of the most likely values, based on national and other sources, or values that were explicitly requested by stakeholders. Section II and the preceding appendices document values used for various parameters.

179. Through discussions with stakeholders, the consultant team identified two parameters that merit extra sensitivity analysis due to their widespread use in the national models, their importance for social costing, and the inherent uncertainty in their future trajectories: GDP and fuel prices. This appendix presents a brief assessment of the impact of these variables on the study's results. Twelve new scenarios are considered in each model as outlined in Table 65.

Table 65: Scenarios for Sensitivity Analysis of Key Parameters

	Scenario	Description
Alternate Baseline Scenarios	Higher GDP	Identical to the No Action Scenario except that GDP growth is comparatively higher, culminating in 25% higher GDP in 2050.
	Lower GDP	Identical to the No Action Scenario except that GDP growth is comparatively lower, culminating in 25% lower GDP in 2050.
	Higher Oil Price	Identical to the No Action Scenario except that growth in oil and oil products prices is comparatively higher, culminating in 25% higher prices in 2050.
	Lower Oil Price	Identical to the No Action Scenario except that growth in oil and oil products prices is comparatively lower, culminating in 25% lower prices in 2050.
	Higher Gas Price	Identical to the No Action Scenario except that growth in natural gas prices is comparatively higher, culminating in 25% higher prices in 2050.
	Lower Gas Price	Identical to the No Action Scenario except that growth in natural gas prices is comparatively lower, culminating in 25% lower prices in 2050.
Alternate Mitigation Scenarios	All Technical Measures (Higher GDP)	A scenario applying the portfolio of mitigation options in the All Technical Measures Scenario to the Higher GDP baseline.
	All Technical Measures (Lower GDP)	A scenario applying the portfolio of mitigation options in the All Technical Measures Scenario to the Lower GDP baseline.
	All Technical Measures (Higher Oil Price)	A scenario applying the portfolio of mitigation options in the All Technical Measures Scenario to the Higher Oil Price baseline.
	All Technical Measures (Lower Oil Price)	A scenario applying the portfolio of mitigation options in the All Technical Measures Scenario to the Lower Oil Price baseline.
	All Technical Measures (Higher Gas Price)	A scenario applying the portfolio of mitigation options in the All Technical Measures Scenario to the Higher Gas Price baseline.
	All Technical Measures (Lower Gas Price)	A scenario applying the portfolio of mitigation options in the All Technical Measures Scenario to the Lower Gas Price baseline.

Sources: SEI and Abt Associates (2015a; 2015b; 2015c)

180. Oil and gas are the focus of the fuel price analysis because their prices are strongly influenced by international markets and evidence suggests the majority of energy subsidies in the study countries are for these fuels (International Energy Agency 2014c). Both of these factors may contribute to future price volatility.

181. Figure 38-Figure 40 plot projected national GHG emissions in the No Action Scenario and the alternate baselines in Table 65.

Figure 38: GHG Emissions in Azerbaijan (No Action Scenario and Sensitivity Baselines)

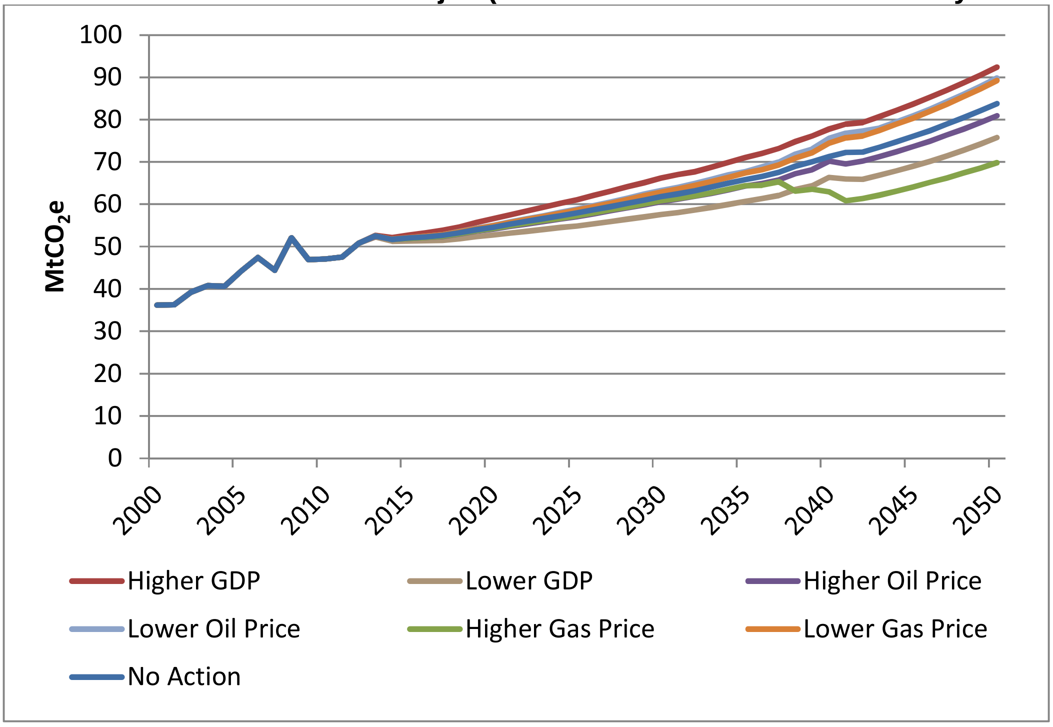


Table 66: GHG Emissions in Azerbaijan (No Action Scenario and Sensitivity Baselines, $MtCO_2e$)

Scenario	2010	2020	2030	2040	2050
No Action	47.1	54.6	61.8	71.3	83.8
Higher GDP	47.1	56.6	66.2	77.8	92.4
Lower GDP	47.1	52.7	57.6	66.3	75.8
Higher Oil Price	47.1	54.2	60.6	70.2	80.9
Lower Oil Price	47.1	55.1	63.3	75.6	89.8
Higher Gas Price	47.1	54.3	60.8	63.0	69.8
Lower Gas Price	47.1	55.0	62.9	74.5	89.2

Source: SEI and Abt Associates (2015a)

Figure 39: GHG Emissions in Kazakhstan (No Action Scenario and Sensitivity Baselines)

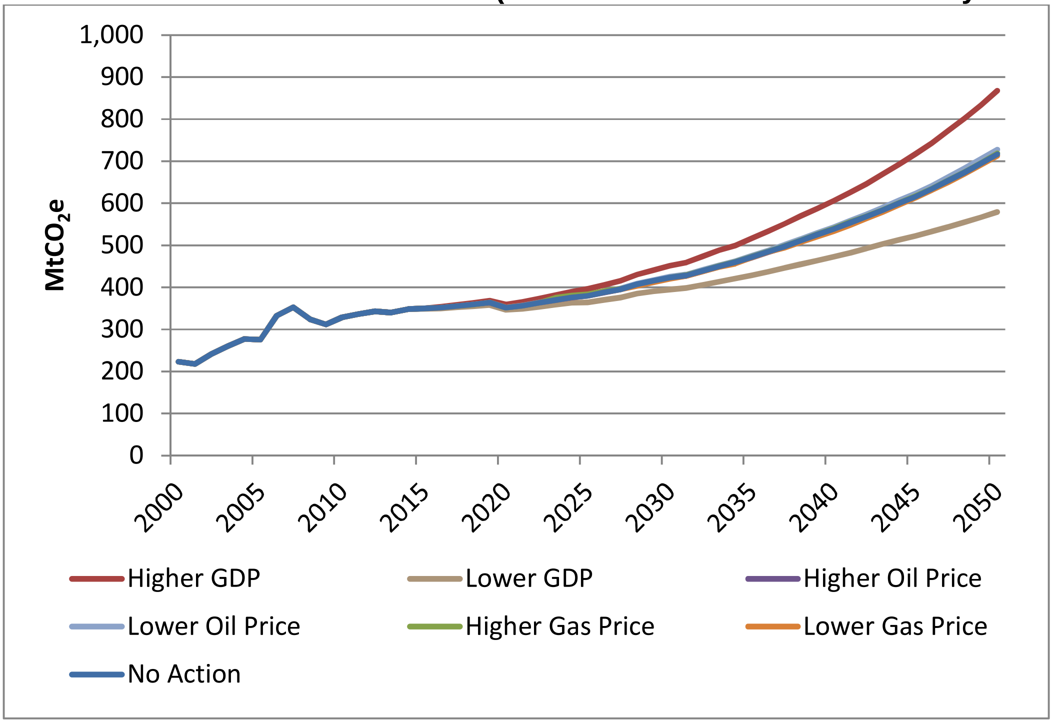


Table 67: GHG Emissions in Kazakhstan (No Action Scenario and Sensitivity Baselines, $MtCO_2e$)

Scenario	2010	2020	2030	2040	2050
No Action	328.6	352.0	422.9	538.0	715.7
Higher GDP	328.6	358.9	451.2	605.5	867.4
Lower GDP	328.6	346.5	395.0	472.6	579.2
Higher Oil Price	328.6	351.8	421.9	536.6	713.8
Lower Oil Price	328.6	352.3	424.8	542.8	727.1
Higher Gas Price	328.6	351.9	422.9	540.2	718.2
Lower Gas Price	328.6	352.6	419.6	533.3	712.6

Source: SEI and Abt Associates (2015b)

Figure 40: GHG Emissions in Uzbekistan (No Action Scenario and Sensitivity Baselines)

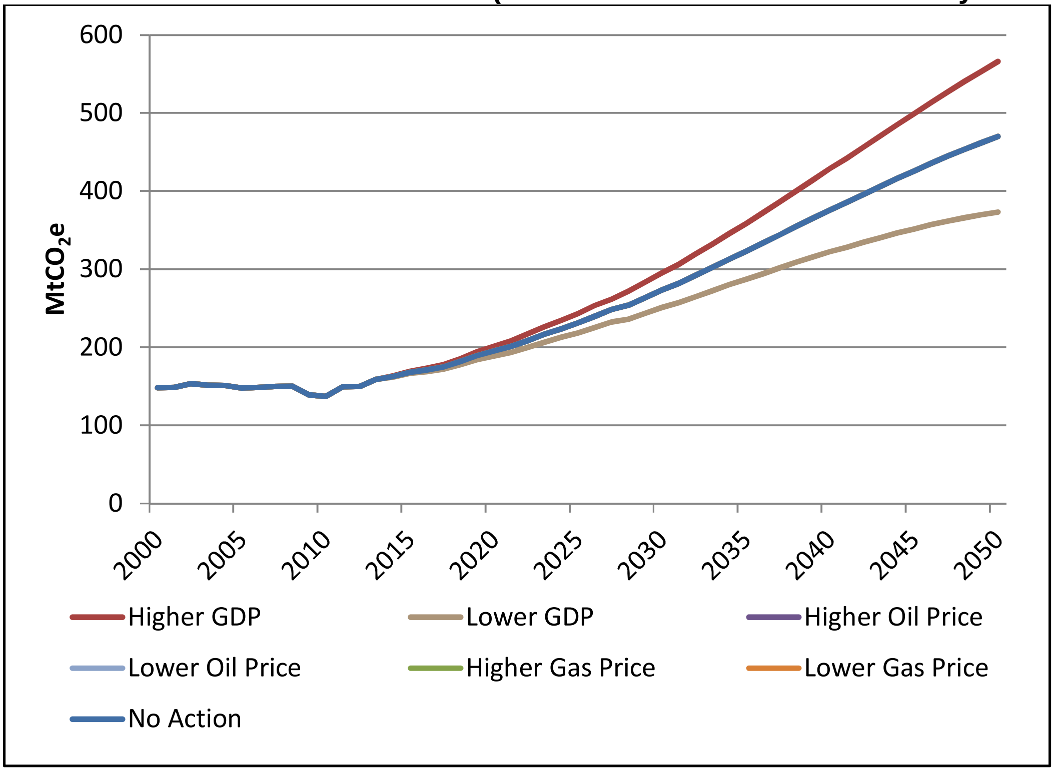


Table 68: GHG Emissions in Uzbekistan (No Action Scenario and Sensitivity Baselines, $MtCO_2e$)

Scenario	2010	2020	2030	2040	2050
No Action	137.0	195.1	273.2	375.9	469.9
Higher GDP	137.0	201.1	295.3	428.7	566.0
Lower GDP	137.0	188.9	251.0	322.5	373.1
Higher Oil Price	137.0	195.1	273.2	375.9	469.9
Lower Oil Price	137.0	195.1	273.2	375.9	469.9
Higher Gas Price	137.0	195.1	273.2	375.9	469.9
Lower Gas Price	137.0	195.1	273.2	375.9	469.9

Source: SEI and Abt Associates (2015c)

182. As the figures show, varying GDP, oil prices, or gas prices by 25% generally induces less than a 25% change in emissions. Emission results tend to be more sensitive to GDP than to oil or gas prices across the three models, with higher GDP raising emissions and lower GDP decreasing them. Due to price-responsive projections of energy demand and supply, changing fuel prices does alter GHG emissions in the Azerbaijan and Kazakhstan models. Higher prices for oil or gas generally suppress emissions by reducing demand for the fuel and its use as an input in electricity production; lower prices produce an opposite effect. In the Uzbekistan model, as noted in Section III.E, energy demand and supply are not a function of fuel prices, so varying prices does not change the emission projection.

183. Table 69 explores the efficacy of the study's technical mitigation options under the alternative GDP and price projections. Cumulative GHG abatement potential and direct, discounted abatement costs per tonne are shown for 2030 and 2050. Results for the All Technical Measures Scenario are provided for reference; results for each alternate mitigation scenario are calculated by comparison to the corresponding alternate baseline.

Table 69: Direct Costs and Abatement Potential for All Technical Mitigation Options (All Technical Measures Scenario and Sensitivity Variants, Cumulative Through 2030 and 2050)

Country	Scenario	2030		2050	
		Potential Cumulative GHG Emission Reductions [tCO_2e]	Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]	Potential Cumulative GHG Emission Reductions [tCO_2e]	Discounted Reduction Cost per Tonne [2010 $ / tCO_2e]
Azerbaijan	All Technical Measures	120.7	42.9	388.8	22.3
	All Technical Measures (Higher GDP)	119.0	45.2	385.5	24.4
	All Technical Measures (Lower GDP)	120.7	41.4	387.5	20.6
	All Technical Measures (Higher Oil Price)	120.9	42.2	389.0	21.7
	All Technical Measures (Lower Oil Price)	120.6	43.6	402.8	22.2
	All Technical Measures (Higher Gas Price)	122.3	41.6	306.3	27.2
	All Technical Measures (Lower Gas Price)	120.0	44.0	393.7	23.1
Kazakhstan	All Technical Measures	601.6	14.6	2,916.1	6.5
	All Technical Measures (Higher GDP)	713.3	14.4	3,363.5	6.4
	All Technical Measures (Lower GDP)	499.6	15.6	2,607.0	6.6
	All Technical Measures (Higher Oil Price)	595.0	14.2	2,912.9	6.3
	All Technical Measures (Lower Oil Price)	611.2	14.6	2,932.3	6.6
	All Technical Measures (Higher Gas Price)	613.8	14.1	2,947.0	6.5
	All Technical Measures (Lower Gas Price)	592.0	14.9	2,847.6	6.6
Uzbekistan	All Technical Measures	216.4	3.2	1,069.7	-17.2
	All Technical Measures (Higher GDP)	217.7	5.8	1,124.0	-15.3
	All Technical Measures (Lower GDP)	210.0	1.4	1,009.2	-19.1
	All Technical Measures (Higher Oil Price)	216.4	1.7	1,069.7	-19.1
	All Technical Measures (Lower Oil Price)	216.4	4.7	1,069.7	-15.2
	All Technical Measures (Higher Gas Price)	216.4	-1.7	1,069.7	-22.5
	All Technical Measures (Lower Gas Price)	216.4	8.1	1,069.7	-11.8

Sources: SEI and Abt Associates (2015a; 2015b; 2015c)

184. Paralleling the baseline results, 25% changes in GDP and fuel prices generally have a smaller percentage effect on cumulative mitigation potential and costs per tonne, at least in the long run. A noteworthy exception is gas prices in Uzbekistan—owing to the overwhelming importance of gas in the national fuel mix, varying gas prices by 25% leads to a 31% change in mitigation cost per tonne by 2050 (compared to All Technical Measures). Higher gas prices make mitigation more cost-effective, and lower prices have an opposite impact.

185. Within each country, certain mitigation results are worth a closer look. In Azerbaijan, varying GDP does not substantially change abatement potential by 2050 (relative to All Technical Measures), but it does have a significant effect on costs. The 2050 cost per tonne increases by 10% under the higher GDP assumption and decreases by 8% under the lower GDP assumption. In part, the minimal changes in abatement potential result from mitigation measures whose implementation targets do not depend on GDP, such as energy upgrades for a fixed number of households or deploying a certain number of MW of renewable electricity capacity. But one dissimilar measure, the Electricity Network Upgrade mini-scenario, also plays a critical role. Costs for this measure scale with electricity demand and the size of the electricity network, both of which vary directly with GDP. The measure saves electricity due to reduced network losses, and these savings also vary directly with demand and GDP. However, in the higher GDP scenario, each kWh of electricity saved is less carbon-intensive than in the No Action Scenario. Greater electricity demand requires greater expansion of the generation fleet; modern gas and dual-fuel CHP plants fill the gap, lowering the overall carbon intensity of generation. The reduction in carbon intensity just about cancels the effect of saving more kWh, so total abatement does not change much even as costs do. An opposite outcome is produced under the lower GDP assumption.

186. The All Technical Measures (Higher Gas Price) Scenario in Azerbaijan also stands out because of its substantially lower long-run abatement potential and higher cost per tonne than in All Technical Measures. By 2050, both of these differ by about 20% from the All Technical Measures values. The main factor behind these results is that in the Higher Gas Price Scenario, more hydropower and less new natural gas power is deployed than in the No Action Scenario. When Higher Gas Price is the baseline, mitigation measures that save electricity therefore have a smaller GHG impact (from reducing more hydro and less gas generation). The reduced abatement potential then leads to a higher cost per tonne as the costs of mitigation are spread over fewer tonnes in total.

187. In Kazakhstan, abatement potential has a strong, positive relationship with GDP, increasing by about 15% by 2050 under the higher GDP assumption (compared to All Technical Measures) and decreasing by 11% under the lower GDP assumption. The costs per tonne do not change much, reflecting the scaling up (or down) of measures such as increased natural gas power whose average costs do not change substantially with deployment levels. Varying oil and gas price assumptions has only a small effect on abatement potential and costs. The most noticeable changes relative to the All Technical Measures Scenario are in average costs in the oil price scenarios: they decrease a bit under higher prices and increase a bit under lower prices as transport mitigation saving gasoline and diesel becomes more or less cost-effective.

188. In the Uzbekistan model, the higher GDP assumption leads to both greater abatement potential and a higher cost per tonne, while the lower GDP assumption does the opposite. The critical dynamic in this case is that the highly cost-effective residential mitigation measures in the model (Residential Building Efficiency and Residential Renewable Energy) do not vary with GDP, whereas some less cost-effective measures do (e.g., Rail Electrification). Abatement and costs from the residential measures are fundamentally driven by demand for housing and the

size of the housing stock, which are modeled to depend primarily on population. This driver does not change in the alternate GDP scenarios. In the higher GDP case, then, very cost-effective residential abatement makes up a relatively smaller share of total abatement than in the All Technical Measures Scenario, and the cost per tonne goes up. The reverse is true when GDP is lower.

189. As noted earlier, energy and emission results in the Uzbekistan model are not a function of fuel prices, so it is not surprising that the abatement potentials in the alternate price scenarios are the same as in All Technical Measures. Abatement costs do vary with prices, however, as the financial benefits of saving oil or gas through mitigation rise or fall. Higher oil or gas prices produce a lower cost per tonne by 2050, while lower prices produce a higher cost per tonne.

190. The preceding discussion shows that the exact effects of varying GDP or fuel prices in a given study model depend on the model's structure and the composition of modeled mitigation options. Nonetheless, from the standpoint of mitigation policy, it is worth noting that in absolute terms, the long-run cost-effectiveness of nationally determined mitigation options is relatively stable through a wide range of GDP, oil price, and gas price assumptions. By 2050, the direct costs of the portfolio of mitigation options in Azerbaijan average between 20 and 30 2010 $ per tonne, depending on assumptions; direct costs in Kazakhstan average around 7 2010 $ per tonne; and direct costs in Uzbekistan are less than -10 2010 $ per tonne. These findings may strengthen the case for proceeding with national mitigation plans in the face of key uncertainties.

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