An Overview of Policies Influencing Air Pollution from the Electricity Sector in Central Asia

J. Erik Ness, Garvin Heath, and Vikram Ravi

National Renewable Energy Laboratory

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List of Acronyms

AAQS	ambient air quality standards
ADB	Asian Development Bank
CASA-1000	Central Asia-South Asia (transmission project)
CBET	cross-border electricity trade
CEMS	continuous emissions monitoring system
CHP	combined heat and power
CO	carbon monoxide
COPD	chronic obstructive pulmonary disease
DG	distributed generation
DHC	district heating and cooling
ESP	electrostatic precipitator
EPA	U.S. Environmental Protection Agency
ESCO	energy service company
FGD	flue gas desulfurization
FIT	feed-in tariff
GDP	gross domestic product
GHG	greenhouse gas
GW	gigawatt(s)—1 gigawatt equals 1000 megawatts or 1 million kilowatts
INDC	intended nationally determined contribution
kW	kilowatt(s)—1 kilowatt equals 1000 watts
kWh	kilowatt-hour(s)
LPG	liquified petroleum gas
MW	megawatt(s)—1 megawatt equals 1000 kilowatts
NDC	nationally determined contribution
NAAQS	national ambient air quality standards
NOx	oxides of nitrogen
PM	particulate matter—e.g., $PM_{2.5}$, which has an aerodynamic diameter of 2.5 µm
PPA	power purchase agreement
ppm	parts per million
PV(s)	photovoltaic(s)
REC	renewable energy credit
RES	renewable electricity standard
RPS	renewable portfolio standard
SCR	selective catalytic reduction
SNCR	selective noncatalytic reduction
SOx	oxides of sulfur
T&D	transmission and distribution
TAP	Turkmenistan-Afghanistan-Pakistan
TUTAP	Turkmenistan, Uzbekistan, Tajikistan, Afghanistan, and Pakistan
TW	terawatt(s)—1 terawatt equals 1000 gigawatts or 1 billion kilowatts
U.S.	United States
USAID	U.S. Agency for International Development
VOC	volatile organic compound
W	watt(s)

Abstract

The electricity sector is a substantial source of air pollution and associated health problems in Central Asia and elsewhere. Fossil-fueled power plants emit a wide variety of harmful pollutants and their chemical precursors. The pollutants with the greatest health impacts are particulate matter and ozone. Once released into the atmosphere, there is no practical way to remove air pollutants, which means that policies designed to improve air quality have to limit the pollutants before release. However, tackling such pollution is challenging, particularly in developing economies, due to the need to provide electricity as a basic necessity for citizens and as an engine of economic growth.

This report provides examples of policies impacting air pollution from the electricity sector in the Central Asian countries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. It is a partner publication to an earlier report that addressed policies in South Asia.[1] As with the South Asia report, information on policies in some countries was difficult to locate; therefore, this is not a comprehensive study, but rather an overview or "scan" of the sector that includes examples of: (1) policies that directly regulate air quality by limiting emissions from specific point sources (by restricting operating hours, for instance); and (2) indirect policies that incentivize or disincentivize polluting activities, such as policies to encourage fuel switching to or from cleaner renewable resources. Note that this report was prepared before the Russia-Ukraine conflict and therefore doesn't address consequences of that war for Central Asia.

The report finds:

1. That Central Asian countries typically have relatively few policy instruments available for regulating national air emissions
2. That many countries, especially those that have a mismatch between seasonal demand and resource availability, could improve energy security and reduce air pollution through increased cross-border electricity trade
3. That some countries have seemingly contradictory policies (promoting both coal and renewables, for instance).

[1] https://www.nrel.gov/docs/fy21osti/80156.pdf

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1. Introduction and Report Objectives

Central Asia has abundant coal, natural gas and hydropower, but with a very uneven distribution of these resources among the individual countries [15].[2] The power generation and transmission infrastructure in the region was largely constructed at least 30 years ago during the Soviet era and much of it is in need of repair. Roughly three-fourths of the power generation in Central Asia comes from fossil fuel power plants (see Table 1 in Section 1.2, below) [50]. Until the inefficient plants are either upgraded or replaced with cleaner electricity options, they are a source of harmful air pollution that adversely affects human health.

The U.S. Department of State commissioned this report as part of a broader effort to examine the connection between electricity production and air quality in the region, with the goal of highlighting areas where technical assistance and capacity building can support future policy development and implementation. For the purposes of this report, the Central Asia region consists of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

The scope of this initial investigation is to examine existing Central Asian energy sector policies and regulations that could affect air pollution, focusing on the laws of central governments. It is not an exhaustive review. Rather, this report describes standards and policy instruments that are used in the region and gives some examples of Central Asian countries that have those instruments available. It is intended as a useful starting point for developing a more comprehensive record of all air quality policies in the countries and an analysis of their effectiveness, which are more substantial tasks beyond the scope of this initial scan. This report focuses on air pollution stemming from fossil fuel combustion in the electricity (power generation) sector. It does not address transportation (except for electric vehicles), although that sector is also an important source of air pollution and may be the subject of a future study. It also does not address greenhouse gas (GHG) emissions and other climate-related impacts from emissions to the air from the power sector. GHG and non-GHG air pollutant emissions are related yet distinct; analysis of GHG emission policies would be greatly aided by the policy scan provided herein, but requires additional research.

Reducing harmful emissions (see Section 1.1) from the power sector is a substantial challenge in many Central Asian countries because economic development is also a priority and can compete with clean air goals.

In this report, a policy is defined as "a high-level overall plan embracing the general goals and acceptable procedures especially of a governmental body."[3] The purpose of a policy is to guide decision-making on a particular topic, and this definition gave the authors the flexibility to address both formal policies that are codified in published laws or official decrees as well as informal, unwritten policies that represent customary practice. A policy is a statement of intent and typically refers to a particular standard or target, such as an air pollution reduction goal. Successful implementation of a policy typically requires regulations and procedures addressing enforcement, as well as the governmental institutional capacity to ensure implementation.

[2] Throughout this report, references are provided in square brackets at the end of a sentence or clause.

[3] https://www.merriam-webster.com/dictionary/policy

Challenges encountered in the preparation of this report:

- In many Central Asian countries, the authors found no comprehensive, central record of policies, which made it difficult to establish if a policy addressing a particular issue exists. In other Central Asian countries, the accessible records were incomplete or required payment of a fee. In Kazakhstan, for example, some laws are behind a paywall[4], including important legislation such as the country's rules and register for tracking polluting sites[5] [99].
- Many policies are informal, set by government ministers on an ad hoc basis, and do not necessarily refer to, or comply with, existing national standards or prior formalized governmental guidance (see Sections 4.3.1 and 4.3.3).
- Policies and regulations may exist on paper but there is no straightforward way to find out if they are actually implemented or enforced.
- The report focuses on national-level policies. Yet, in some countries most air quality policies or mandated actions are subnational (e.g., see Kyrgyzstan in Section 3.1).

1.1 Types of Pollutants and Their Potential Impacts

A wide variety of pollutants are emitted from fossil-fueled power plants. The pollutants addressed in this report are a subset of those that constitute particulate matter (PM)[6] or ozone (O_3, the primary constituent of photochemical smog) and their precursors: $PM_{2.5}$, PM_{10}, oxides of sulfur (SOx), oxides of nitrogen (NOx), carbon monoxide (CO), ammonia (NH_3), and volatile organic compounds (VOCs). Photochemical smog is sometimes visible as a "brown cloud" (see Figure 1).

Figure 1. Smog over Almaty, Kazakhstan. Photo: Igors Jefimovs/Wikimedia Commons [104]

[4] https://prg.kz/
[5] https://online.zakon.kz/Document/?doc_id=31655444
[6] Called $PM_{2.5}$ and PM_{10} because they have aerodynamic diameters of 2.5 µm and 10 µm, respectively.

In the atmosphere, NOx and SOx are noxious alone and can also undergo physical and chemical transformation and convert to $PM_{2.5}$. $PM_{2.5}$ can penetrate deep into the lungs and bloodstream causing respiratory issues, lung cancer, cardiovascular problems, and strokes—and can also degrade physical infrastructure, mainly through corrosion of building exteriors. Ozone exacerbates respiratory problems in the short term; long-term exposure can cause chronic obstructive pulmonary disease (COPD), an inflammatory lung disease that obstructs airflow from the lungs.

Globally, more than two-thirds of SO_2 emissions are anthropogenic in origin [20]. Three of the top 20 global emitters in 2019 were in Central Asia: Kazakhstan (no. 10), Uzbekistan (no. 14), and Turkmenistan (no. 17) [20].

Once released into the atmosphere, there is no practical way to remove air pollutants or slow the atmospheric reactions forming the two pollutants of greatest concern from a health standpoint: $PM_{2.5}$ and ground-level ozone. Consequently, policies intended to positively impact air quality must be designed to mitigate air pollutants before release. This can be especially challenging with $PM_{2.5}$ because it is a "regional" pollutant that can be carried great distances, including across national borders [51].

There is a dual concern in many countries with limiting GHG emissions and controlling emissions of other air pollutants that have been traditionally regulated for protecting public health. While some national strategies can reduce both GHG and non-GHG air pollutants, other strategies achieve only one outcome (e.g., controlling fluorocarbons reduces the emission of these highly potent GHGs, but these chemicals do not have direct health effects). Kazakhstan, for example, has an emissions trading scheme that governs the electricity sector, but it only addresses CO_2 emissions [81].

According to the *State of Global Air 2020* report published by the Health Effects Institute, air pollution is the fourth leading cause of premature death worldwide (Figure 2).

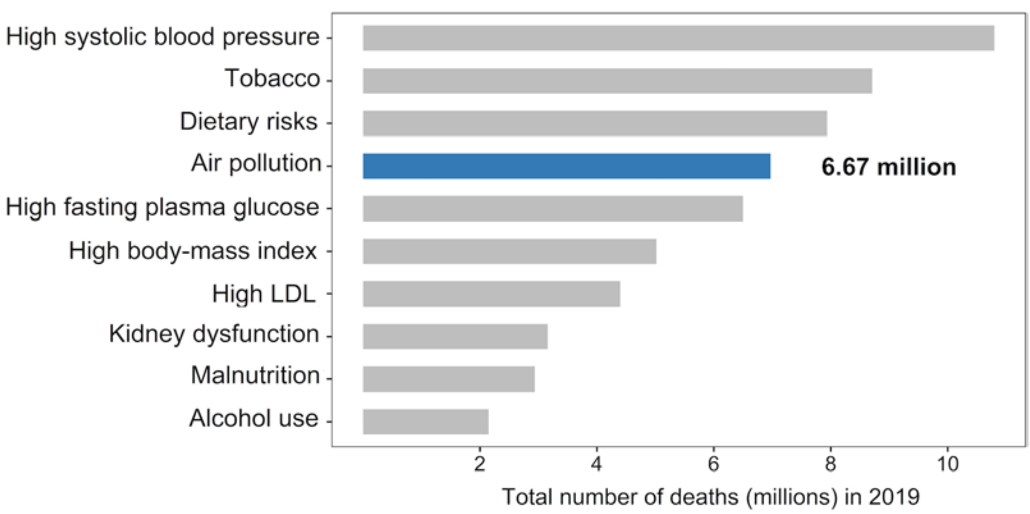

Figure 2. Global ranking of risk factors for early death (from all causes) in 2019 [51]

Fine particulate matter is by far the largest cause of death from air pollution: of roughly 6.67 million total worldwide deaths in 2019, an estimated 4 million people died from $PM_{2.5}$ pollution, and 365,000 from exposure to ground-level ozone [51]. In 2016, 7% of all deaths in Kyrgyzstan were due to ambient particulate matter [4].

According to the Organisation for Economic Cooperation and Development (OECD), Central Asian countries all had $PM_{2.5}$ pollution levels higher than the OECD average in 2018 (Figure 3). This figure reflects $PM_{2.5}$ pollution from all sources, not just the electricity sector.

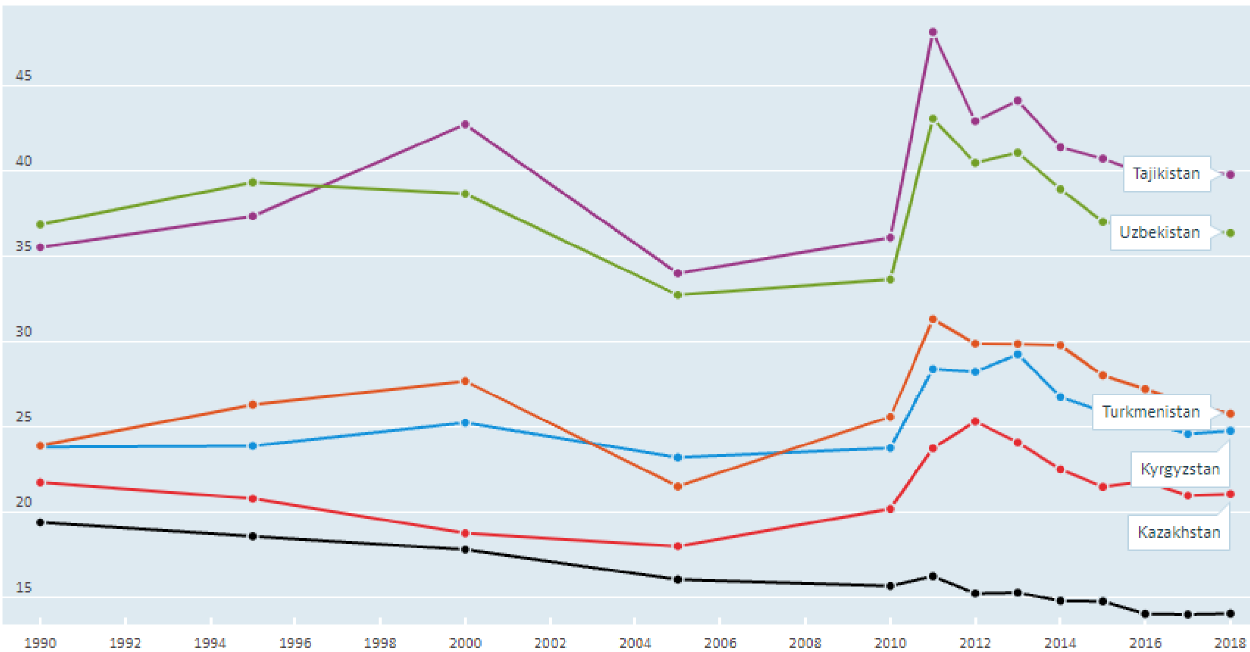

Figure 3. $PM_{2.5}$ mean annual exposure concentration by country compared to OECD average (black line) in micrograms per cubic meter [52]

From 1990–2010, data is available at 5-year intervals. From 2010 onward, annual data is available.

From 2005 until recently, the World Health Organization (WHO) recommendation was that a person's exposure to $PM_{2.5}$ air pollution not exceed 10 micrograms per cubic meter on average annually. In September 2021, this limit was revised down to 5 micrograms per cubic meter in response to growing evidence that the health impacts of particulate air pollution are much more serious than previously realized [11, 12]. Air pollution in all Central Asian countries considerably exceeds both the old and the new $PM_{2.5}$ limits. This is especially true in some of the larger cities, sometimes aggravated by the local geography.

Almaty in Kazakhstan (Figure 1) and Bishkek in Kyrgyzstan are both surrounded by mountains, and this bowl-shaped topography tends to trap polluted air, especially in cold conditions. For several days in January 2021, Bishkek was recorded as being the most polluted city in the world based on $PM_{2.5}$ concentrations [3]. In December 2020, Bishkek's $PM_{2.5}$ levels were equivalent to every resident smoking a total of 200 cigarettes during the month [5]. In 2017, the city exceeded Kyrgyzstan's standard for maximum daily NO_2 concentrations on 294 days [4].

1.2 Energy Insecurity and Pollution in the Post-Soviet Power System

The Central Asian region has vast energy resources—both conventional and renewable—yet with substantial disparity in the distribution of these resources across the region. Turkmenistan, Uzbekistan, and Kazakhstan all have extensive supplies of natural gas; Kazakhstan also has large coal reserves. Tajikistan and Kyrgyzstan, on the other hand, have extensive hydropower resources—controlling roughly 60% of the region's water storage capacity—but with very little in the way of accessible fossil fuel resources [15]. The emphasis here is on *accessible* resources. Kyrgyzstan, for example, ranks 15th globally for coal resources but they are difficult to extract, so its exploitable coal reserves are much lower [68].

Table 1 shows how the regional imbalance in accessible resources is reflected in the electricity generation profiles of each country. While Kazakhstan, Turkmenistan, and Uzbekistan are producing around 90% or more of their electricity from fossil resources, the situation is reversed in Kyrgyzstan and Tajikistan, which generate 90% or more of their electricity from renewables.

Table 1. Electricity Production in Central Asian Countries, by Source, 2018 [50]

(in gigawatt-hours [GWh] and by percentage[a])

Country / Source	Kazakhstan		Kyrgyzstan		Tajikistan		Turkmenistan		Uzbekistan	
	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)
Coal	74,833	69.5	1,093	7.0	1,348	6.8	0	0.0	2,109	3.4
Natural Gas	21,467	19.9	80	0.5	0	0.0	22,534	100.0	54,432	86.5
Oil	63	0.1	33	0.2	0	0.0	0	0.0	459	0.7
Fossil Subtotal	96,363	89.5	1,206	7.7	1,348	6.8	22,534	100.0	57,000	90.6
Hydro	10,395	9.7	14,318	92.2	18,394	93.2	0	0.0	5,897	9.4
Solar / Wind	845	0.8	0	0.0	0	0.0	0	0.0	0	0.0
Other Renewables	1	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Renewables Subtotal	11,241	10.5	14,318	92.2	18,394	93.2	0	0.0	5,897	9.4
Total	107,604		15,524		19,742		22,534		62,897	

[a] May not add up to 100% due to independent rounding.

The five Central Asian countries historically operated on a single, integrated power grid. Although that is no longer the case today, it is worth providing some historical background about how that cross-border power grid functioned and what happened when the individual countries had to adjust to the realities of power generation in the post-Soviet era—partly because all of the countries have expressed interest in reestablishing some version of that grid, and partly because much of the power system inefficiencies and air pollution that some Central Asian countries face today are the result of their departure from that integrated grid, as explained in the following pages.

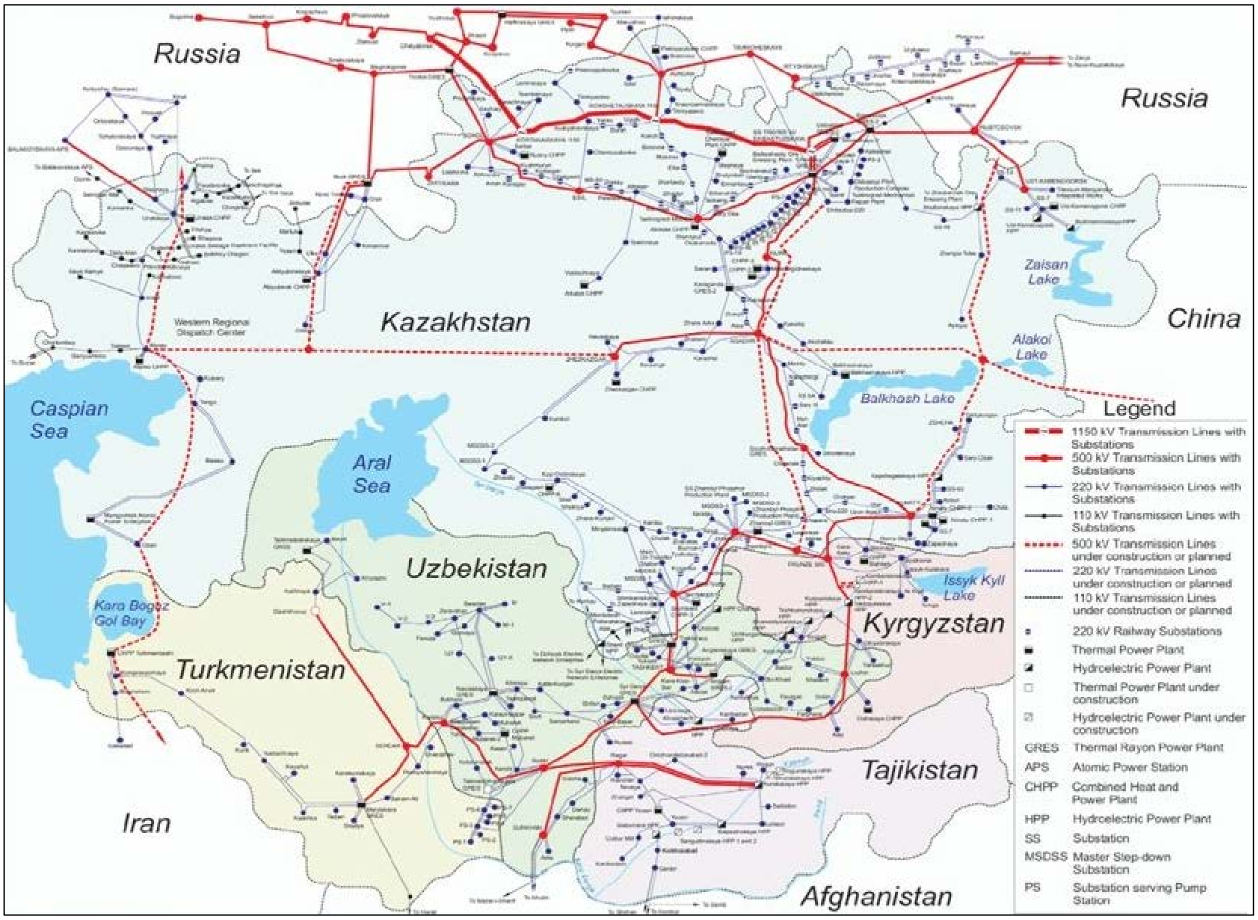

Figure 4. Unified Central Asian Power System: Existing and Planned Transmission, 2012 [16]

(Solid red lines are 500 kV or above. Dashed lines are under construction or planned.)

From the 1960s to the 1980s, the Soviet Union built a regional power grid to take advantage of this distribution of energy resources. The resulting "Central Asian Power System" (CAPS) included a ring of 500 kV transmission lines connecting southern Kazakhstan with its four neighbors to the south, while northern Kazakhstan stayed connected to the Russian grid [15]. Until the 1990s, CAPS was virtually isolated from the rest of the Soviet power grid [15]. Roughly 30% of total electricity generation came from hydropower plants in Tajikistan and Kyrgyzstan, and 70% from thermal power plants in the other three countries [57]. The thermal plants covered base loads and the hydropower plants covered peak loads and frequency regulation services [15]. As it was roughly at the center of the 80+ power plants in the original CAPS grid, power flows were coordinated through a dispatch center in Tashkent, the capital of Uzbekistan [57]. Uzbekistan also contributed half of the total power generation for the entire system [57]. Power lines crossed administrative borders but that didn't matter at the time.

As originally designed, the system worked relatively well, although there was little excess generation or redundant transmission in CAPS, which meant that, while smaller power imbalances were not a problem, a major outage in one republic could lead to blackouts in the others [42]. Additional generation had been planned for CAPS but was never completed [18].

Power flows were managed using a centralized barter system based on needs, not market value: Kyrgyzstan and Tajikistan provided hydropower and irrigation water to the other three countries during the summer, in exchange for their thermal electricity during the winter [57, 15]. Incorporating such a large amount of hydropower presumably kept CAPS' air emissions substantially lower than if the system had used only fossil-fueled thermal power plants.

Most countries in Central Asia suffered major economic declines following the collapse of the Soviet Union in 1991. Kyrgyzstan, for example, experienced a 49% drop in GDP from 1990 to 1995 [86]. Such a dramatic decline would have led to a contraction in the region's electricity sector, which could be expected to reduce all air emissions from power plants in the short term.

Without technical support from the Soviet Union, the five newly independent republics attempted to replace Soviet central coordination of electricity and water resources with various bilateral bartering arrangements but without much enduring success [68]. According to Tetra Tech, USAID’s implementing partner that is currently working with Central Asian governments to try to reestablish CAPS, "In 1991-1992, international boundaries and markets for fuel changed the terms of this barter and became a significant source of today's energy-water conflicts in the region" [15, p. 3]. As a result of increasing tensions between them, each participant started to seek energy independence, and CAPS gradually declined with varying impacts on electricity availability, power grid stability, energy security, and economic activity in each country [68, 57]. Fully independent operation wasn't feasible for any one country at the time; as an example, the power lines connecting north and south Kyrgyzstan passed through Uzbekistan [57]. The same thing was true for Tajikistan. Energy insecurity consequently grew; this and the resulting power system inefficiencies have been the source of most of the electricity supply challenges and associated air pollution concerns in the region over the past 30 years [15].

Tajikistan was, and still is, in a particularly vulnerable position as more than 70% of its electricity comes from a single source, the Nurek hydropower plant outside Dushanbe [55]. The plant's aging switchyards, more than 30 years old at the time, were replaced with assistance from the Asian Development Bank (ADB) in 2016 because they were no longer able to deliver stable power to the grid [55, 56]. Because the Nurek plant can provide crucial frequency regulation services to the electricity grids of the other Central Asian countries, ADB anticipates that this system upgrade will improve energy security for all the countries, provided they agree to share electrical power [55].

Although well-endowed with energy resources, Kazakhstan has an energy supply imbalance with roughly three-quarters of the country's electricity produced in the north yet with major load centers in the south [57]. A new north-south 500 kV line was built in 1998 to help cover peak demand in the south and those times when Uzbekistan would choose to cut the flow of electricity to Kazakhstan [57]. That transmission capacity was expanded again in 2018 [42].

Kyrgyzstan relies on oil and gas imports to generate electricity during winter, when hydropower production is low [68]. According to IEA, more than half of the country's energy infrastructure needs to be replaced; additionally, losses from electricity transmission and distribution (T&D) are above 20% [68, 86]. Following the disintegration of CAPS, the country constructed a transmission line connecting the northern and southern regions, which improved internal distribution of electricity, but the country still faces supply shortages in winter [57].

Turkmenistan was in the strongest position of all Central Asian countries after the fall of the Soviet Union: It had the most complete power grid and sufficient energy resources to meet its own needs [57]. The country has the fourth-largest reserves of natural gas in the world, the source of 100% of its power generation today (Table 1) [23]. By 2003, Turkmenistan was in a position to withdraw from CAPS and develop its electricity sector independently; it continued building power plants and started exporting electricity to Iran and Afghanistan [69, 18]. It is also strengthening its energy independence by constructing a high-voltage "ring transmission grid" within its own borders [71]. However, the country did not increase extraction of gas reserves to match the pace of power plant construction and is now facing electricity shortages [57].

In 2009, Uzbekistan withdrew from CAPS after spending $1 billion to upgrade its transmission T&D system so that it could transmit electricity without having to use power lines in neighboring countries [13]. This meant that Tajikistan could no longer participate in CAPS, as the country did not have other T&D connections to its neighbors.

Figure 4 depicts CAPS as it was circa 2012, after new transmission lines were built connecting south Kazakhstan to Russia; in the 1980s, the 500 kV line connecting north and south Kazakhstan did not exist [15]. CAPS maps from 2008 and 2019 (in Russian) can be viewed on the *bne IntelliNews* website.[7]

The decline of CAPS, and subsequent efforts by individual countries to attain energy independence, is the single most defining issue impacting electricity generation and associated air pollution in Central Asia today.

Although there is currently some bilateral cross-border electricity trade, lack of cooperation means that the electricity supply in each country is almost entirely dependent on its own generating capacity and available domestic resources. Today, the countries rich in fossil fuels are self-sufficient in terms of electricity supply; Tajikistan and Kyrgyzstan are not [94]. The more fossil fuel in the energy mix used for power generation, the more air pollutants are likely to be emitted by power plants, and the greater the incentive countries have to put in place policies to curb emissions, if they are also concerned with the associated health effects. Whether such incentives are actually implemented or have any impact may depend on factors such as competing incentives, business interests, the existing energy infrastructure, and potential cost hurdles.

[7] https://www.intellinews.com/central-asia-s-electricity-network-underpowered-and-fragmented-169985/

1.3 Emissions Standards and Policy Options for Limiting Air Pollutants

There are three broad categories of responses to emissions of atmospheric pollutants, each of which is described in much greater depth in the following sections:

- **Section 2—Air quality standards** that set limits on the atmospheric concentration of specific pollutants or set limits on pollutant emissions from a specific source.
- **Section 3—Direct policies** that require actions to directly regulate air quality (targeting emissions or emissions factor, as explained below).
- **Section 4—Indirect policies** that incentivize/disincentivize polluting activities, such as policies to encourage fuel switching or granting some generators preferential access to transmission.

Air quality standards for ambient air and point-source pollutants reflect a country's desired goals but don't accomplish air quality improvements without effective mechanisms to meet the standards. Direct and indirect policy instruments and regulations are necessary to move toward those goals.

A generic equation to estimate emissions is:

$$E = EF \times A$$

where:

E is emissions in units of mass.

EF is emissions factor (accounting for any emission control equipment), measured in units of mass emitted per unit activity.

A is the activity, e.g., producing 1 MWh or consuming one unit of fuel.

The direct air quality regulations discussed in this report regulate EF or E (i.e., cap E or limit EF) or constrain the operation of an emission source (e.g., limiting operating hours, which limits A).

Indirect policies modulate the use of different fuels or emission sources (the "activity"). Indirect policies incentivize/disincentivize an activity such as fuel switching (e.g., generating electricity with renewables vs. fossil sources). There are many more varieties of indirect policies than direct policies.

This policy scan identifies whether air quality policies and regulations exist, such as incentives for clean energy production and installation of pollution prevention technologies. It is much harder to ascertain whether a country implements actions to ensure compliance with regulations (e.g., monitoring, enforcement, fines) and thus this scan does not attempt such an assessment. The scan focuses on indirect policies because their impact can be more challenging to grasp and, consequently, they have not previously been investigated in much detail.

While this report focuses on policies that could influence emissions, there are many other policies, regulations, economic practices, and infrastructure elements that need to be in place before air quality policies can be implemented. Dramatic expansion of electricity generation in a country requires a reliable grid regardless of the type of energy it carries, and countries with competitive electricity markets need a system for ensuring fair and transparent pricing in energy transactions and access to project financing.

Similarly, developing an interconnection standard for small generators on the distribution grid is a necessary prerequisite for adopting a net metering policy for renewable power. Net metering is addressed in this report because it can influence air pollution. While interconnection standards are generally considered "emissions neutral," this report addresses interconnection policies that support integration of renewables because renewables generally reduce air pollutant emissions from the power sector (see Section 4.2.3.3).

2. Air Quality Standards that Set Pollutant Limits

The first step in regulating harmful emissions is setting environmental standards—ideally for both ambient-air pollutant concentrations and point-source emissions.

Limits on ambient (atmospheric) concentrations of pollutants of concern have been established in many countries and by the World Health Organization to protect public health. Standards are typically set in the form of pollutant concentration limits averaged over a specified time period. Ambient air quality standards (AAQS) typically apply broadly to a country or portion of a country and are more commonly referred to as national ambient air quality standards (NAAQS). Many countries have provisions for revising the limits as new evidence emerges on the health effects of different pollutants.

Some countries do not promulgate NAAQS, instead preferring to set specific emissions limits on potentially polluting point sources, such as fossil fuel power plants. Many countries use a combination of both, as point-source regulation can help meet the ambient standards [25]. Globally, roughly two-thirds of countries have some type of formal NAAQS [25].

In September 2021, the UN Environment Programme (UNEP) released a landmark publication titled *Regulating Air Quality: The First Global Assessment of Air Pollution Legislation* ("GAAPL" for short) [25]. According to that report, which examined air quality legislation in 194 countries, including all of Central Asia, 34% of countries do not have any legally mandated ambient air quality standards [24]. Of those that do, only 33% impose penalties for not meeting the standards [24]. Additionally, the report found that 37% of countries do not require monitoring of emissions, 43% do not even have a legal definition of air pollution, and 69% have no legislation addressing cross-border air pollution [24].

According to the GAAPL, of the roughly two-thirds of countries that do not codify their NAAQS in legislation, many only have standards in the form of general policy/guidance from the national government [25]. However, this has limited value as "AAQS in policy/guidance may provide practical guidance for national air quality policy and sectoral regulation, but are of limited help with regard to ensuring citizen rights relating to air quality or in establishing legal certainty for operators" [25, p. 50].

The air quality policy situation in Central Asia is complicated and was quite challenging to untangle; both for NREL and for the UNEP authors of the GAAPL. According to the GAAPL, except for Uzbekistan, all of the Central Asian countries have legal instruments containing NAAQS for one or more target pollutants [25]. But in Tajikistan and Turkmenistan, the standards are in the form of "general policy/guidance" (a term used in the GAAPL) that is either not publicly accessible or not published [25]. As an example, according to the United Nations Economic and Social Commission for Asia and the Pacific, Turkmenistan's "State Programme on Energy Saving for 2018-2024 ... is not publicly available" [106, p. 69]. Only in Kazakhstan and Kyrgyzstan have the NAAQS been codified in legislation that is readily available [25]. The information in the GAAPL on NAAQS in individual Central Asian countries is incomplete. There was a prior study specifically focused on NAAQS that was sponsored by WHO for its 194 member countries [27]. Taken together, the GAAPL and the WHO reports provide a more comprehensive picture of the prevailing NAAQS in Central Asia [26].

Current NAAQS for Central Asian countries are provided in Table 2. However, there are caveats to the data presented in the table.

Some NAAQS in Central Asia are defined in terms of a maximum permissible concentration (MPC), also referred to as a maximum allowable concentration (MAC), terminology carried over from the Soviet era [19, 96]. MACs are broadly comparable to, but do not always map directly onto, WHO standards due to differences in averaging time and sometimes also the definition of the pollutants [26]. As an example, in Central Asia, only Kazakhstan and Kyrgyzstan distinguish between $PM_{2.5}$ and PM_{10}; the other countries have a single standard for PM or total suspended particles (TSP) [26, 27, 4]. Kyrgyzstan has issued MACs for PM but has also retained its old TSP standard [4].

MACs were historically expressed in terms of (1) a one-time, acute, non-recurring maximum exposure level (typically measured over 20 minutes, although this can vary by pollutant and promulgating agency), and (2) a longer averaging time designed to prevent chronic health effects when inhaled over the long term (e.g., daily MACs defined as 8 hours of exposure per 24-hour period, not to exceed 41 hours per week; and/or an annual maximum exposure level similar to that used in the United States) [19, 89, 109]. In those cases where MAC averaging durations are not defined in NAAQS, these values cannot be directly compared to the WHO standards. However, WHO has noted that the *acute* (short-period) MACs are broadly comparable to its 1-hour or shorter exposure standards [27]. The authors have determined that the *daily* MACs are broadly comparable to WHO's 24-hour exposure standards. Variations from WHO's approach are enclosed in square brackets in Table 2 and explained in the notes below the table. Averaging time periods in quotes ("short, "long," "MAC") are a little different in each country; time periods that are not in quotes are equivalent. Where the term "1-time MAC" is used in the notes below Table 2 without further qualification, it means that the authors were unable to ascertain the precise exposure duration.

For a detailed description of how MAC air quality standards are derived, see "1.4.1. Environmental quality standards" in OECD's 2006 report titled *Environmental Policy and Regulation in Russia*[8] [89] and chapter 1 in WHO's 1964 report on air pollution control in the USSR[9] [19].

[8] https://www.oecd.org/env/outreach/38118149.pdf
[9] https://apps.who.int/iris/bitstream/handle/10665/279983/EP-68.2-eng.pdf

Table 2. National Ambient Air Quality Standards (NAAQS) for Central Asian Countries and the United States (for reference) [27]*

Pollutant	Averaging Time Period	NAAQS by Country					
		Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan [109]	USA [c] [22]
CO (mg/m^3) [d]	"short" [a]	5	--	--	--	5	40
	"long" [b]	[3]	--	--	--	[3]	10
NO_2 ($\mu g/m^3$) [e]	"short" [f]	200	85	--	[85]	85	188
	24 hours	40	40	40	40	40	--
	1 year	--	--	--	--	40	100
O_3 ($\mu g/m^3$)	"short" [g]	--	160	--	--	160	137
	24 hours	--	30	--	--	30	--
$PM_{2.5}$ [h] ($\mu g/m^3$)	"MAC"	[160]	[160]	--	[500]	--	--
	24 hours	35	[35]	[150]	[150]	--	35
	1 year	--	[25]	--	--	--	12
PM_{10} [h] ($\mu g/m^3$)	"MAC"	[300]	[300]	--	[500]	[500]	--
	24 hours	60	[60]	[150]	[150]	[150]	150
	1 year	--	[40]	--	--	[150]	--
SO_2 ($\mu g/m^3$)	"short" [i]	--	500	--	500	500	196
	24 hours	125	50	50	50	50	366[c]
	1 year	--	--	--	--	50	78[c]

* The WHO NAAQS study is used as the data source unless otherwise indicated.

[a] Kazakhstan and Uzbekistan: 1-time MAC (not further defined) [44, 109]; USA: 1 hour.

[b] Kazakhstan: average 24-hour MAC [44]; Uzbekistan: average daily MAC [109]; USA: 8 hours.

[c] The U.S. Environmental Protection Agency (EPA) has revoked some standards, which are still included in the table for comparison and marked with a superscript "c" in the USA column. Several EPA NAAQS concentrations are reported in parts per billion or parts per million; these were converted using standard conditions to $\mu g/m^3$ (1 atmosphere pressure and 298 K temperature) by Vikram Ravi, NREL.

[d] Milligrams per cubic meter.

[e] Micrograms per cubic meter.

[f] Kyrgyzstan, Kazakhstan, and Uzbekistan: 1-time MAC [34, 109]; Turkmenistan: unspecified MAC; USA: 1 hour.

[g] Kyrgyzstan: 8-hour MAC; Uzbekistan: 1-time MAC [109]; USA: 8 hours.

[h] Kazakhstan: 1-time MAC [34]. Tajikistan, Turkmenistan, and Uzbekistan measure TSP, not PM. Kyrgyzstan MAC is "maximum single concentration" [4]. Turkmenistan has an additional unspecified MAC in addition to its 24-hour MAC.

[i] "Short" duration is one-time MAC in Central Asia [4]; 1 hour in USA.

The table shows that Tajikistan and Turkmenistan have very similar standards, with Kazakhstan and Kyrgyzstan being generally more restrictive. Uzbekistan has been updating its NAAQS to bring it more in line with its neighbors [109]. As an example, Uzbekistan's 24-hour PM_{10} (TSP) limit used to be 300 $\mu g/m^3$, twice what it is today, to allow for naturally high background levels resulting from desertification [26]. Roughly 80% of the country is desert [86]. Of the five countries, only Kyrgyzstan and Uzbekistan have set a limit on ozone [26, 109]. They also promulgate ammonia standards, with a one-time MAC of 200 $\mu g/m^3$ and an average daily MAC of 40 $\mu g/m^3$ in both countries [4, 109].

There are actually more similarities between the standards in different countries than it appears. As an example, the U.S. EPA standards for CO (both exposure durations), PM_{10}, and 1-hour SO_2 exposure all say "not to be exceeded more than once per year," so they are effectively one-time MACs, just measured over specific durations [22].

Regardless of whether countries have set NAAQS, the regulation of emissions from stationary (point) sources, such as power plants, is another policy option for improving air quality. Officially, this is the approach used in Tajikistan, Turkmenistan, and Uzbekistan [24].

Electricity generation plants may be required to meet emissions standards for a variety of criteria pollutants using various emissions control methodologies. Typically, the emissions standards are given in the form of mass of pollutant emitted per unit volume of flue gas, although the authors could not find information on such standards in Central Asian countries. Methods to reduce emissions from power plants often follow some or all of the approaches listed below:

1. Removal of pollutant species (e.g., sulfur, nitrogen) from raw fuel stream—includes precombustion steps, such as cleaning the fuel.
2. Process modifications to provide efficient combustion conditions.
3. Removal of pollutant after combustion—includes capturing the pollutant before it is released in the atmosphere. This can be further divided into three subcategories:
    - Installing and maintaining control technology for capturing the pollutant released from fuel combustion.
    - Limiting pollutant mass emitted from a polluting unit over a given time period.
    - Enforcing pollutant-specific emission factors (emission rate per unit of production or fuel consumed).

These emissions reduction regulations can be considered direct emission control policies because they directly control the mass of pollutants released into the atmosphere. There are also semidirect policies focused on improving power plant efficiencies, which reduce emissions because less fuel is required to produce the same amount of electricity. In the following section, we identify and discuss the policies based on the three methods (1–3), above, as well as policies to improve power plant efficiency.

3. Direct Policies Intended to Reduce Air Pollution

Environmental regulations can directly affect emissions of air pollutants from power plants. Direct policies addressing air quality are those that limit air emissions from specific point sources—in this case, fossil fuel power plants. Such policies put a limit on total mass emissions of a pollutant or on the emission factor (mass emitted per unit activity) and can be implemented by imposing a variety of constraints, such as limiting operating hours. This section describes national policies and regulations that are intended to directly reduce air pollution from a country's power sector.

There are very few examples from the region as the authors found that Central Asian countries are typically more focused on improving problematic air pollution in specific locations. For example, Kyrgyzstan's only nationally determined law on coal quality doesn't pertain to coal power plants around the entire country, only to a single power plant in the country's capital [102]. As another example, in 2019, Uzbekistan's national government passed a law "On improving the environmental monitoring system in the Republic of Uzbekistan," which established a system for monitoring ambient air pollution but only "in 25 cities at 63 stationary observation points" [109]. This focus on cities is understandable as larger populations are impacted by poor air quality in urban areas.

In order to provide a more complete picture of the types of policy options available to national governments, six direct policy interventions common in other countries are included below, even where there are few or no illustrative examples from Central Asia.

3.1 Removal of Fuel Contaminants Before Combustion

Policies that improve coal quality reduce the emissions associated with fuel combustion and, indirectly, also from transportation (because there is less mass shipped if there are fewer contaminants). Similar measures are also adopted to remove pollutants from other fossil fuels, such as removal of sulfur from natural gas or fuel oil to reduce related SO_2 emissions.

For coal, a process called coal beneficiation is employed to remove impurities—such as sulfur, ash, or other rocky material—extracted during mining. Coal containing high levels of ash and other inert material can cause a myriad of problems: difficulty in pulverization, reduction in flame temperature, and excessive fly-ash generation containing unburned coal. Further, if the coal-burning power plants are far from pit heads, the transport of this coal (containing a large fraction of inert material) causes higher transportation-related emissions.

The authors found little information on coal beneficiation policies in Central Asia, mostly just anecdotes. As an example, at the Angrensky open-pit lignite coal mine, which supplies 85% of the coal extracted in Uzbekistan, the mine's operator, Uzbekugol JSC, has employees who manually separate coal from rock on a conveyor belt, "reducing the ash content from 60% to 35%" [100].

The one policy exception relates to the coal-fired district CHP plant in Bishkek, Kyrgyzstan, where the high ash content of the fuel and the age of the plant are the two main factors influencing its problematic air emissions, according to one of the plant's operators [6]. In 2019, the Kyrgyz government passed a law governing the selection of solid fuel for the plant, "the purpose of which is to ensure the stability and reliability of the boiler and auxiliary equipment of the CHPP" [102]. The law set a limit on the permissible ash content, moisture, sulfur and other parameters, and mandated that new suppliers should have their product tested at the plant before signing long-term tenders [102], The plant started experimenting with better grades of coal in 2020 in an effort to ascertain the effect of higher-calorie and hotter-burning coal on the plant's aging equipment, built in the 1960s [9]. This raises an interesting challenge for Central Asian countries in addressing air quality issues: improving the quality of the coal may be an effective way to reduce harmful emissions but it may not be feasible for very old power plants.

3.2 Combustion Process Modification to Reduce Emissions

Some pollutant emissions can be reduced by modifying the combustion process to provide optimal conditions for fuel combustion. NOx, which is mostly emitted as NO, is primarily formed through two different mechanisms: thermal NOx (formed when nitrogen and oxygen molecules in air react with each other at high temperature) and fuel NOx (formed when the fuel contains organically bound nitrogen, which is the case with coal and oil) [83]. Combustion modification can control power plant NOx emissions, which limits NOx formation during the combustion phase. Combustion modification techniques include the following three methods for reducing NOx formation [1]:

- Reducing flaming zone peak temperatures—achieved by increasing the rate of flame cooling and decreasing the adiabatic flame temperature using dilution, using a fuel-rich flame zone.
- Reducing the residence time in the flaming zone—achieved by changing the shape of the flaming zone.
- Reducing the oxygen concentration in the flaming zone—achieved by controlling fuel-air mixing and decreasing excess overall air rates.

Some available combustion modification techniques are listed in Table 3 with their corresponding NOx reduction potential. These control techniques could work based on just one of the NOx reduction methods or a combination of them.

The authors could find no examples of combustion process modification in Central Asia.

Table 3. Example Control Techniques Implemented for Combustion Process Modification To Reduce NOx Emissions [2, 10]

Control Technique (see Appendix A1 for description)	**Abatement Principle**	**NOx Reduction Potential for Coal-Fired Boilers**
Overfire air	Reduces peak temperature	20%–30%
Low NOx burners	Reduces peak temperature	35%–55%
Burner out of service	Reduces peak temperature	10%–20%
Air staging	Reduces residence time	50%–70%
Fuel staging	Reduces residence time	50%–70%
Low excess air	Reduces oxygen availability	50%–70%

3.3 Post-Combustion Controls to Reduce Emissions

Post-combustion controls work by reducing the emissions after the pollutant is formed as a combustion by-product but before discharge to the atmosphere. Some pollutant-specific control technologies that are available are listed in Table 4, although the authors found none in use in Central Asia. Once the control technologies are installed, they need to be monitored for performance and periodically inspected and maintained. Control equipment is often monitored and regulatory compliance is demonstrated through the use of automated systems, such as a continuous emissions monitoring system (CEMS), which reports emission rates of SO_2 and NOx. However, many countries do not have any CEMS-based reporting and also lack inspection and maintenance requirements, which can result in degradation in the performance of control equipment going undetected.

Table 4. Available Control Technologies To Reduce Post-Combustion Emissions

Pollutant	Control Technology (see Appendix A1 for description)
$PM_{2.5}$ and PM_{10}	Electrostatic precipitators (ESPs) Cyclones Fabric Filters
Sulfur oxides (SOx)	Flue gas desulfurization (FGD, dry and wet scrubbing methods)
Nitrogen oxides (NOx)	Selective catalytic reduction (SCR) Selective noncatalytic reduction (SNCR) SCR and SNCR are often used in combination with low-NOx burners and over fire air burners

3.4 More-Efficient Combustion Technologies to Reduce Fuel Consumption Per Unit of Energy Generated

Coal power plants vary widely in their thermal efficiency, from an average of 36% (referred to as "subcritical"), to 45% ("supercritical"), and above ("ultrasupercritical"). Despite the maturity of the technology, many existing and recently constructed plants in Central Asia still use subcritical technologies, largely due to their lower capital cost, plus experience with the technology makes it less risky and easier for maintenance. However, in recent years some countries have framed policies or made commitments to implement high-efficiency thermal technologies, the use of which reduces various combustion- and noncombustion-related air pollutants due to decreased coal fuel combustion per unit of energy produced.

In 2017, Uzbekistan passed a resolution affirming investments to convert the country's fossil fuel sector to modern steam turbines and gas turbines [67]. Given that Uzbekistan produces more than 90% of its electricity from fossil sources (Table 1), these upgrades should help to substantially reduce air emissions from the electricity sector.

In 2018, Turkmenistan adopted a similar resolution, Power Sector Development in Turkmenistan 2018, and started renovating the steam turbines in its coal power plants, which average 50-60 years in age [94].

3.5 Higher Stack Height to Improve Pollutant Dispersion

As height from the ground increases, the effect of drag resistance from ground elements (e.g., trees, buildings) decreases and wind speed increases. An increased wind speed causes greater dilution of pollutants. This increased dilution of emissions from point sources can be achieved by increasing stack heights, which often helps to meet the concentration-based emission standards. (Alternatively, emissions control technologies or a combination of control technologies and stack height can be used.) Some countries specifically list the stack height requirement as part of the emission standard. The authors found no examples of such policies being used in Central Asia.

3.6 Control of Pollutants Other Than PM, NOx, and SO_2

Pollutants other than those discussed earlier in this report can also result in the formation of secondary pollutants of concern. Ammonia contributes to the formation of secondary aerosols, whereas VOCs can contribute to the formation of ozone and secondary organic aerosols. While agriculture and animal husbandry remain its largest sources, power plants can also emit ammonia. The power sector is a relatively very small source of ammonia emissions, which are dominated by livestock and fertilizer applications [28]. Most of the power plant-related ammonia can be due to slip from NOx control devices (such as selective catalytic reduction) although the fraction of ammonia slip depends on the fuel type, NOx control equipment type (SCR or SNCR) and equipment installation (based on U.S. data) [38]. Regional agencies in the United States, such as the South Coast Air Quality Management District in California, have regulations that limit ammonia emissions (including slip emissions) [49]. Similarly, newer, efficient power plants are not a big source of emissions for CO and VOCs, but their emissions can still be important as precursors to secondary pollutants such as ozone and $PM_{2.5}$ [62]. However, the authors did not find any policies that control ammonia slip or the release of CO and VOCs in the atmosphere for any of the Central Asian countries.

4. Indirect Policies and their Effect on Air Emissions

Environmental regulations can *directly* affect emissions of air pollutants from power plants; many types of policies and regulations can have an *indirect* effect on air pollution from power generation, sometimes including unintended effects. These policies and regulations may be local or national, may be enacted but unfunded or unimplemented, and may have a net positive or net negative impact on air pollutant emissions and concentrations. This section provides examples of policies and regulations that indirectly result in greater or lesser air pollution from a country's power sector.

4.1 Policies and Regulations that Can Lead to Increased Emissions or Delay Emissions Reductions

4.1.1 Mandates, Financial, and Other Incentives for Combustion-Based Generation and Fuels

Mandates and incentives that support the fossil fuel power industry can increase air pollution. Examples range from subsidies for domestic fossil fuel extraction to tax breaks for coal plants. In other cases, governments may specifically require power producers to use more-polluting fuels for economic or political reasons. This is the case in Central Asia, where sporadic political tensions between the hydro- and fossil-rich countries have driven Kazakhstan, Turkmenistan, and Uzbekistan to rely more heavily on their fossil resources to meet electricity demand.

Regardless of whether such incentives lead to increased or decreased emissions, they obscure market signals that are necessary for the efficient operation of the electricity sector. In Central Asia, both electricity and heat are often priced below cost-recovery levels, which discourages investment in infrastructure [58, 94]. For example, according to the ADB, "Turkmenistan has been known for having the world's lowest energy tariffs" [94, p. 19] and "heavily subsidized electricity tariffs in the low-income Kyrgyz economy make private investment in RE unattractive" [94, p. 17]. In some cases the infrastructure is in need of substantial upgrades but years of undercharging for electricity service means that funds are not available to cover the necessary capital investments [35].

In Kazakhstan, electricity tariffs based on fossil-fuel power generation are kept very low for most customers but they do vary by region, ranging from 12-28 tenge per kilowatt-hour (US 3-7 cents/kWh) in 2020 [59]. This is substantially lower than the electricity tariffs in the EU, for example, which ranged from 10-30 euro cents per kilowatt-hour (US 12-35 cents/kWh) in 2020 [60]. According to Arman Kashkinbekov, Head of UNDP Sustainable Development in Kazakhstan, part of the reason tariffs in Kazakhstan are so low is that most of the country's electricity comes from 40- to 60-year-old coal plants that the country received at no cost from the Soviet Union, so the tariffs don't even reflect construction costs [59]. Replacing these plants with natural gas and cleaner-burning coal facilities would inevitably raise electricity tariffs and have a limited effect on emissions reductions [59]. As Kashkinbekov pointed out when referring to the Soviet coal plants, "45% of them are high time to close and build new modern capacities on gas or clean coal" [59]. However, if Kazakhstan simply replaces them, it will miss the opportunity to reduce overall air emissions from the electricity sector sooner, which would be unfortunate given the fact that electricity from renewables is now competitive with existing tariffs in Kazakhstan (Section 4.2.3.5) [59].

Uzbekistan is planning to increase coal production by a third from 4.5 million tons in 2020 to 6 million tons in 2023 [111, 100]. This coal is intended for domestic consumption in heating and power generation applications and, as it will be replacing mostly natural gas for these purposes, emissions from the power sector are expected to rise [111]. And while its renewable energy law offers several tax breaks for both producers and consumers of renewable electricity, the law also requires producers to bear the cost of upgrading the grid to handle a facility's output, which could potentially be prohibitive to the country's fledgling renewable energy industry, delaying or preventing reductions in air emissions from the electricity sector [66].

Kyrgyzstan's 2020 Clean Air Bill focuses on electric vehicles, hoping to stimulate that sector by providing a variety of tax breaks (see Section 4.2.8) [78]. Shifting transportation fuels from fossil sources to Kyrgyzstan's grid will decrease emissions from the transport sector but increase air emissions from the electricity sector, despite the fact that Kyrgyzstan's electricity generation is only about 8% from fossil sources (Table 1). Total emissions are expected to decrease as a result of this action [95]. However, this situation is changing as Kyrgyzstan is actively developing its coal resources and encouraging households to switch their heating needs from electricity to coal in the near-term [68]. The government plans to phase out subsidies to the coal sector but not to reduce coal consumption; rather, it hopes independent investors will step in and privatize the sector, with the aim of increasing the production of coal [68]. This was one of the few examples encountered of a Central Asian government intentionally using an indirect policy to accomplish its goals. Kyrgyzstan's National Strategy to 2040 includes a plan to switch rural customers from electric to gas-fired heating, which will increase emissions [86].

High government electricity subsidies in the three fossil-rich countries make it hard for cleaner renewable energy technologies to compete with the more-polluting electricity from the grid [94]. As a percentage of GDP in 2017, Uzbekistan's electricity subsidies totaled 26%, Turkmenistan's 23%, and Kazakhstan's 11% [58]. Turkmenistan's government has both growing debt and growing electricity demand, which means that it may have to reduce subsidies in the near future [86].

According to a 2018 report by the Central Asia Regional Economic Cooperation (CAREC) program, another reason governments in the region are not developing policies and regulations to transition away from fossil fuel power and stimulate the adoption of clean energy is simply due to a lack of understanding of the new technologies; CAREC is trying to address this shortcoming by educating its members [85].

4.1.2 Electrification of Transportation

There is a growing trend around the world to electrify transportation. Often driven by climate-related decarbonization targets, such policies reduce the consumption of transportation fuels and increase the consumption of electricity. The intention may well be to decrease total combined emissions from the two sectors—and that can indeed be the result—but such policies also have the indirect effect of increasing total air emissions from the electricity sector. This is especially deleterious for air quality if the electricity comes primarily from fossil sources, as is the case in Kazakhstan, Turkmenistan, and Uzbekistan.

As an example, from 2016 to 2018, Uzbekistan completed the electrification of a 465 km section of railway from Marakand to Termez, replacing diesel locomotives with electric ones. The rationale for the project included reduction of greenhouse gas emissions, which may have been the case for the transportation sector. But Uzbekistan's electricity is more than 90% from fossil resources so emissions of GHGs and other air pollutants from the electricity sector would have risen [53].

Turkmenistan's National Climate Change Strategy includes a target to electrify existing rail networks [86].

Kyrgyzstan's 2020 Clean Air Bill provides customs and tax incentives to EV importers that include zero import duties, with additional incentives to domestic EV producers [78]. As a consequence of the new law, a South Korean manufacturer committed to building an EV plant in the country by the end of 2022, producing up to 300,000 EVs a year [78]. This should cut total emissions of air pollutants, as noted in Section 4.1.1.

4.1.3 Constrained or Unavailable Cleaner Energy Resources

If generation from clean energy supplies such as renewables and nuclear energy—or cleaner fossil fuel options such as natural gas instead of coal—are not available in sufficient quantity to meet demand, power producers will need to switch fuels if that's an option for them, and end users will inevitably have to use other, likely more polluting energy resources from either the grid or self-generation. This can delay emission reductions if people simply continue to use existing polluting sources, or it can actually increase emissions in certain circumstances, such as in rapidly growing economies where utilities have difficulty meeting escalating demand. Government policies regarding which energy resources to develop can influence these emissions. But for the countries that rely primarily on hydropower, weather and climate can play a factor.

During winter months, the city of Bishkek in Kyrgyzstan typically gets roughly half its electricity from a coal-fired CHP plant in town and half from a hydropower plant at the Toktogul reservoir [8]. In October 2021, due to low water levels at the reservoir, the manager of the coal plant announced that the CHP facility would have to generate 2.5 terawatt-hours of electricity during the 2021-2022 winter season, up from 1.2-1.5 terawatt-hours in a typical year [8].

Turkmenistan's government has been leveraging its abundant natural gas resources to produce 100% of the country's electricity since the mid-1990s (Table 1) [86]. It can reduce its air emissions to the extent that it imports cleaner electricity from neighbors (Section 4.2.1) or develops domestic renewable resources. Turkmenistan generated some of its electricity from hydropower in the 1990s, but output dropped from 700 GWh in 1990 to 4 GWh in 1995 and nothing thereafter, which means that natural gas is currently the only option. Given the country's rapid economic growth—GDP in 2018 was 12 times the size it was in 1991—the government's policy to focus exclusively on fossil power production means that emissions have inevitably grown in tandem [86].

As a result of high electricity demand during the harsh winter of 2020-2021, Uzbekistan's gas-dominant electricity generation system experienced multiple failures in both the heating-gas distribution and electricity distribution networks, with the result that people had to switch to space heating with coal and dung cakes, which would have increased total emissions [41]. On one day alone, five thermal power plants failed. There was widespread public protest, unusual for the country. While the crisis was still going on, the energy minister promised to abolish the existing natural gas monopoly and replace it with a market-based system [41].

4.1.4 Electricity Pricing and Tiered Rates

Adjustments to electricity pricing, such as tiered rates or time-of-day rates, are becoming more prevalent. The intended effect is for consumers to react to time of use rates by shifting the timing of their electricity consumption in ways that serve utility objectives, such as decreasing overall costs or improving reliability. However, it is also possible that such pricing could shift individual behaviors to rely on non-electricity energy sources that are cheaper and likely to pollute more, such as portable generators, biomass cooking, and kerosene heaters. Such policies could thus lead to an increase in air pollution from fossil energy sources [63].

As described in Section 4.1.1, electricity prices in Central Asia have traditionally been set below capital cost recovery levels [58, 94]. The resulting lack of funds for system maintenance results in a gradual deterioration of the power generation, transmission, and distribution infrastructure and concomitant increases in air emissions. Kyrgyzstan's tariffs have been criticized for being so low that they discouraged the adoption of technologies, such as geothermal heat pumps, that could reduce overall consumption of electricity [68]. In 2020, Kyrgyzstan adopted a new tariff policy that raised rates to be more cost-reflective yet without increasing the burden on poorer customers [68]. Full cost recovery pricing is planned for 2022. Unfortunately, because Kyrgyzstan does not have enough clean electricity to meet demand—especially in winter when heating needs are high—the government is forced to encourage end users to switch to gas and coal, which will have associated increases in air emissions [68].

According to the Asian Development Bank, in Central Asia, higher electricity prices are directly responsible for fuel switching to more polluting fuels, with associated air pollution: "Regions with higher coal prices prefer cleaner heating, while regions with higher electricity prices prefer solid fuels" [93, p. 12].

Even well-designed electricity tariffs and pricing signals aren't always enough to encourage end users to switch consumption toward lower-emissions fuels. In Kyrgyzstan, 15% of households that cook with electricity cannot use it for heat as the voltage is too low to run a space heater [48]. Even switching from coal to relatively lower-emissions gas would require substantial infrastructure investments in expanding the piping network and switching homes to gas-fired boilers and furnaces [48].

4.2 Policies and Regulations that Can Lead to Decreased Emissions

4.2.1 International Electricity Trade

Cross-border electricity trade (CBET) can enable countries to increase the financial efficiency of their power system operations by importing lower-cost electricity to offset fuel consumption in domestic power plants. Depending on the source of electricity imports, enabling policies for electricity trade can lower total air emissions and/or reduce local emissions impacts. CBET can also lead to economies of scale in investment, greater financing capability within the power sector, greater competition, and improved sector efficiency [29].

4.2.1.1 Key Drivers and Challenges for CBET in Central Asia

As described below, in Central Asia, reliable international electricity trade will require upgrades to both generation and transmission infrastructure, sufficient resource extraction to satisfy generation needs, institutional changes and training to develop familiarity with market-based trading mechanisms, changes to enabling policies and regulations, and trust.

Over the past two decades, economic expansion and population growth in Central Asia have led to growing electricity demand in the region but capacity additions have not kept pace [42]. Today there is insufficient generation for the region as a whole.

According to the IEA, a version of the CAPS system is in the process of being revived [17]. If it moves ahead, the new CAPS may possibly consist of only four countries: Uzbekistan, Kazakhstan, Tajikistan, and Kyrgyzstan [68]. Turkmenistan has not expressed interest in rejoining that partnership although it is considering others; the country has already fully disconnected from CAPS and is synchronizing its grid with Iran's. There is a very small amount of CBET between these four countries today: Kyrgyzstan exports electricity to Uzbekistan, imports it from Tajikistan, and engages in two-way electricity trade with Kazakhstan [68].

There are many potential advantages of reviving coordinated CBET in the region. A market-based electricity trading system would benefit all participants compared to existing bilateral agreements, which are mainly fixed-price, long-term contracts with high transaction costs [17].

There is also the prospect of significant emissions reductions in the long term if participants can gain access to the exceptional hydropower resources in the region. The International Energy Agency estimates that Tajikistan has roughly 527 TWh of annual hydropower potential but has only developed about 23 TWh [17]. It would take time, but developing even half of this resource would be enough to satisfy total electricity needs for the entire region (Table 1). Tajikistan's 2030 National Development Strategy has a goal to upgrade its electricity infrastructure and export at least 10 TWh of its hydropower per year [17]. Realistically, due to a lack of government financial resources to build transmission, Tajikistan's prospects for establishing CBET partners by 2030 are limited to the Central Asian countries, Afghanistan, and Pakistan [17]. To the extent that Tajikistan's expanded hydropower output is used in Central Asia, it has the potential to substantially improve air quality in the region [17].

On the other hand, any delay in hydropower development will result in increased emissions. Energy insecurity in several of the countries is high and takes precedence over concerns about air emissions. As an example, Kyrgyzstan is primarily reliant on domestic hydropower but commissioned an overhaul of the capital Bishkek's coal-burning power plant that was completed in 2017 "so that Kyrgyzstan can obtain power independence, in order not to introduce blackouts," according to the prime minister at the time [31, 33].

In addition to infrastructure improvements and increased resource extraction, CBET requires the development of harmonized codes, policies, and regulations governing the power sector in each country [30]. The CAREC[10] organization provides a forum for discussing these changes.

[10] https://www.carecprogram.org/

An October 2021 CAREC progress report identified that the most pressing need, if countries desire to establish a higher volume of CBET, is to modernize the Energia Coordination and Dispatch Center (CDC Energia) that regulates the power flows between the individual national power grids [73]. The first step is to upgrade the central dispatch center with SCADA systems [85, 18].

Political tensions and economic pressures stemming from outside the region are also an important factor in Central Asia's energy development and security. Russia maintains substantial influence and goodwill but has not been willing to further extend its foothold in the region by financing the development of power plants and transmission—in sharp contrast to China, which is financing energy infrastructure in Central Asia and beyond as part of its Belt and Road Initiative (BRI) [32]. In 2016, Russia's failure to provide promised funding for the construction of several dams and hydropower plants in Kyrgyzstan led the Central Asian republic to cancel the agreement and start leaning more heavily on China for project financing [32]. By 2019, Kyrgyzstan had amassed $1.7 billion in external debt to China, which was about 19% of its GDP that year [32, 64]. Most of the energy-project funds from China went to finance coal infrastructure, not the hydropower plants that Russia had planned to finance. Note that Kyrgyzstan has not taken on additional external debt from China since this period.

4.2.1.2 Existing Energy Trading Initiatives in Central Asia

In addition to ongoing discussions about reviving CAPS, some Central Asian countries are members of three other cross-border electricity initiatives and one gas interconnection project, all of which are scheduled to be operational by 2030 [73]. The CBET projects are dependent on foreign financing whereas the gas pipeline is being self-financed by participants [84].

TUTAP, which is the acronym for Turkmenistan, Uzbekistan, Tajikistan, Afghanistan, and Pakistan, is a transmission project that was making good progress and was expected to enable the three Central Asian countries to trade electricity with each other, Afghanistan and Pakistan [73]. However, since the Taliban takeover of Afghanistan, there are now uncertainties about this project's future. Discussions regarding interconnection with Pakistan are ongoing [73]. In 2009, ADB financed the first interconnection, a 220 kV line between Uzbekistan and Afghanistan [85]. This allowed Afghanistan to replace electricity from polluting and expensive diesel generators with cleaner electricity from Uzbekistan, which is primarily from natural gas, thus reducing emissions in Afghanistan [85]. The emissions benefit may not technically accrue to the Central Asian country but given the fact that air pollution knows no borders, reductions in countries surrounding Central Asia have some potential to improve air quality in Central Asian countries. This project is also a good example of effective support from an international donor. The total cost of the line was only $95 million to ADB and it provided many times this value to both countries. In 2016 alone, Uzbekistan exported 1,500 GWh to Afghanistan at 8.5 cents/kWh, much lower than the 35 cents/kWh people in Afghanistan were paying for diesel electricity. Afghanistan saved $119 million and Uzbekistan's revenue was $105 million [85]. A separate interconnection, completed in 2011, allowed Tajikistan to export 1,360 GWh of hydroelectricity to Afghanistan in 2017, reducing annual emissions even further [85]. TUTAP power purchase and sales agreements are negotiated bilaterally on an annual basis [85].

The Turkmenistan-Afghanistan-Pakistan (TAP) electricity transmission project has the goal of Turkmenistan exporting electricity to its southern neighbors year-round [72]. The first part of the project involves connecting the thermal power plant at Mary in Turkmenistan with loads in Herat in Afghanistan via a 220 kV line, at which point Afghanistan plans to synchronize its grid with Turkmenistan [69, 72]. Construction of the Turkmenistan part of the transmission line was completed in 2021, with commissioning expected by the end of the year [69]. Planned expansion involves running a 500 kV line across Afghanistan to Pakistan [72]. However, since early 2020, Pakistan has had excess generating capacity and is currently uninterested [73].

The third CBET project is the Central Asia-South Asia ("CASA-1000") regional high-voltage transmission corridor (Figure 5). With more than $1.2 billion in funding from a half dozen international donors led by the World Bank, the project's goal is to facilitate the transfer of surplus hydropower from Tajikistan and Kyrgyzstan to Pakistan via Afghanistan in the summertime. The project commenced in 2019 with construction under way in all four countries, and with the expectation of the system being fully operational by 2023-2024 [73]. As described below, USAID is working with the CAPS countries to develop a power trading system that could ultimately benefit the CASA-1000 network as well.

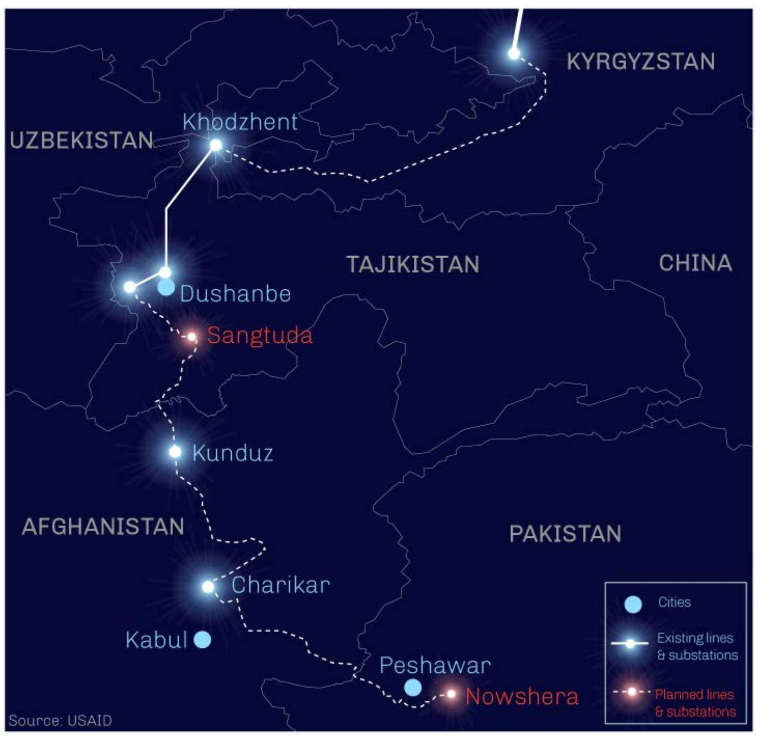

Figure 5. Plans for the CASA-1000 Power Grid, 2018 [21]

The US government, through USAID, is helping Central Asia develop a Central Asia Regional Electricity Market (CAREM) that would be an improved, market-based version of the old CAPS system. USAID is working with the countries to implement the project in stages [75]:

1. Develop coordinated and synchronized operation of their transmission systems
2. Expand the volume of bilateral electricity trade
3. Develop a multilateral power exchange platform
4. Expand the electricity market beyond Central Asia, initially to Afghanistan and Pakistan.

The focus of this project is improving stability of electricity supply in order to stimulate economic growth; to provide greater energy security to each member, including during system emergencies; to create an enabling environment for renewable energy; and to increase the sharing of ancillary services, such as frequency regulation. CAREM participants are advancing not just the infrastructure components but also the market rules for electricity trading—initially to enable higher volumes of bilateral trade, then trade within the region, as noted above [76].

USAID is not alone in supporting the development of CBET in the region. The five Central Asian countries and six of their neighbors are members of CAREC, which has a goal of improving energy security and service reliability in each member country by increasing regional interconnection of electricity and gas transmission systems by 2030 [74]. CAREC views CASA-1000 as the first step in developing a Central Asia Regional Electricity Market (CAREM),[11] which itself would be the central piece in a larger Central Asia-South Asia Regional Electricity Market (CASAREM) [16].

The Turkmenistan-Afghanistan-Pakistan-India (TAPI) gas pipeline project was intended to transport 33 billion cubic meters of natural gas annually from Turkmenistan to the three South Asian countries upon completion [84]. Although this is not an electricity project, access to Turkmenistan's plentiful gas supplies could encourage the South Asian countries to use that gas to generate electricity instead of seeking cleaner resources. However, ADB recently paused financing for this project due to the regional political situation.

4.2.1.3 New Regional Challenges; Future Prospects

Given the on-again/off-again tensions between them, Central Asian countries have been trying to strengthen their ties to South Asia for decades. But the Taliban takeover in Afghanistan has cast doubt on all of the planned CBET projects connecting the two regions, as a consequence of Afghanistan's central location as a transit country for all of the required transmission lines [72].

The primary driver for Central Asian nations to establish these transmission projects is economic, as indicated in the next few paragraphs. The authors found little evidence that reducing air emissions was a significant factor in the decision-making process.

Turkmenistan is experiencing chronic economic problems and the country is looking for ways to leverage its substantial natural gas resources, either by selling the gas directly or converting the gas to electricity and selling that to its neighbors [84]. The country's Concept of Electricity Sector Development for 2013-2020 includes plans to increase electricity exports to Iran [86]. If that hope doesn't materialize, the country may once again have to engage with the Central Asian electricity markets. The country is currently selling some electricity to Kyrgyzstan [87].

When the Taliban came to power, Uzbekistan's government immediately started discussions on restarting the Surkhan-Puli-Khumri transmission line project, which would allow Uzbekistan to export 70% more electricity to Afghanistan [39].

According to a World Bank study published in 2016, all countries in Central Asia could benefit from pooling energy reserves and expanding regional power trade [14]. In 2016, power sharing

[11] CAREC's vision for CAREM includes more than the five countries USAID is working with.

between Central Asian countries was only about 10% of the level reached in the early 1990s. The study evaluated the unrealized economic benefits for four Central Asian countries of the current power system over a five-year period (Turkmenistan declined to participate) and compared it to estimated benefits if a four-country CAPS system were fully operational. The report found that savings in fuel expenditures alone would have totaled approximately $1.5 billion. Adding the value of meeting otherwise unserved energy demand during the period raised the collective benefit to the five countries to roughly $6.4 billion. Additionally, if the countries operated together, they could have saved $400 million total, or $80 million annually, as a result of not needing to purchase reserves from outside the region at market prices. With each country operating in isolation, the study estimated that 1900 MW of system operating reserves would be required. By sharing the Kyrgyz and Tajik hydropower resources, only 800 MW would be needed. As the report points out, this "would not only bring considerable cost savings to all, but would effectively result in the whole regional system operating once again in the manner in which it was originally designed" [14, p. 20]. Had Turkmenistan participated in the study, the benefits from expanding regional power trade would have been greater [14].

Successfully implementing CBET appears likely on balance to lead to reduced emissions of air pollutants in the region, particularly in the longer term when the hydropower resources in Kyrgyzstan and Tajikistan could be more fully developed. In the short term, reestablishing power flows from Uzbekistan to Kyrgyzstan in the winter could possibly increase emissions, depending on whether the Uzbek gas-sourced electricity displaces any existing Kyrgyz hydropower or coal power, or simply allows Kyrgyzstan to consume more electricity. Except for that possible wrinkle, upgrades to international and domestic transmission in Central Asia would enable greater use of clean energy, allowing hydropower to address more of the daily and seasonal power imbalances across the region and offsetting or reducing some of the air pollution from thermal power plants.

4.2.2 Clean Energy Mandates

Government targets that require increased use of renewables, nuclear power, and other sources of cleaner energy can reduce air emissions if they are legislated (or regulated) and implemented. This category of indirect policies includes some climate-related targets because reducing GHG emissions from the electricity sector can also reduce atmospheric pollution.

When codified in law and enforced with noncompliance penalties, a clean energy mandate is one of the most effective policies for accelerating the adoption of cleaner renewable energy systems that can reduce emissions of air pollutants [46].

Kazakhstan's government set both RE generation and capacity targets in 2016 (Table 5). It met the 2020 target of 3% of non-hydro renewable generation as a percentage of total electricity generation in 2021. Kazakhstan is now pursuing an even more aggressive clean energy agenda, planning to increase the amount of renewable electricity generation to 10% by 2030 and 50% by 2050 [59]. In January 2021, President Tokayev of Kazakhstan announced the goal of making the country carbon neutral by 2060 [43]. Tokayev also announced that, because he expects Kazakhstan to have a shortage of electricity by 2030, ensuring carbon neutrality would require the implementation of nuclear power in the country to meet the needs of the growing population and expanding economy [43]. Kazakhstan is the world's main source of uranium and has extensive uranium reserves, estimated at more than 300,000 tonnes [92].

Table 5. Kazakhstan's 2020 Renewable Energy Development Targets (2016) [47]

Development Area	Target
Non-hydro renewable generation as a percentage of total electricity generation	3%
Total installed capacity of renewable electricity facilities:	1700 MW
Wind energy	*933 MW*
Solar PV	*467 MW*
Hydropower	*290 MW*
Biogas	*10 MW*

Uzbekistan also has both generation and capacity targets for renewables. The country's near-term capacity targets, established in 2017, are shown in Table 6 [67]. Meeting these targets will increase the share of renewable generation in Uzbekistan's electricity mix to approximately 20% in 2025. Beyond that, Uzbekistan plans to generate 25% of its electricity from renewables by 2030, and plans to add a total of 5 GW of solar, 1.9 GW of hydropower and 3 GW of wind capacity [61]. Uzbekistan has also announced plans to introduce nuclear power, and passed its Law on the Use of Atomic Energy in 2019. The law provides a general framework for implementing nuclear power, including specific responsibilities and rights of the parties involved, but does not include specific targets or steps to build nuclear plants [91].

Table 6. Uzbekistan's 2025 Renewable Energy Development Targets (2017) [67]

Technology	Cumulative Capacity Targets (MW)				
	2018	**2019**	**2020**	**2021**	**2025**
New hydropower	601	158	383	602	1,240
Solar PV	100	200	--	300	450
Onshore wind	--	--	--	102	302

In Turkmenistan, according to ADB, "there is no legislation on RE specifically" although the government's National Strategy on Climate Change (2012) is likely to consider renewable generation as part of its long-term low-emissions strategy [94, p. 19].

4.2.3 Financial and Other Incentives for Power Generation from Clean Energy

Subsidies and other policies that incentivize the use of renewable and other clean energy sources in the electricity sector can reduce air pollution. Examples range from preferential access to transmission lines to tax breaks for solar plants. Countries in Central Asia appear to be leaning more heavily on the use of tax incentives, based on the evidence assembled below.

4.2.3.1 Tax Incentives and Subsidies

Common tax measures used to stimulate clean energy production globally include lower corporate income taxes and a wide variety of incentives, such as an investment tax reduction based on the initial cost of a renewable energy system, a production tax incentive based on actual energy produced, property tax reductions for properties with renewable or energy efficiency technologies installed, elimination of sales and value-added tax (VAT) for clean energy technologies (can be applied at scales from utility-scale generation to individual purchases of efficient appliances), reduced import taxes, and accelerated depreciation of renewable energy fixed assets [45].

In Uzbekistan, renewable energy facilities with a nameplate capacity of 0.1 MW or more are exempt from property taxes for a period of 10 years from the date of commissioning [65]. Households that install renewable energy systems and then disconnect from the grid are exempt from property taxes for a period of 3 years [65]. In addition, companies that construct renewable energy facilities are exempt from all taxes for a period of 5 years from their date of registration with the state [66].

Kazakhstan's 2013 Law on Supporting the Use of Renewable Energy provides investment stimuli to encourage construction of PV, wind, biomass, geothermal, and small hydropower plants (up to 35 MW) [94]. The stimuli include subsidies up to 30% of the costs associated with acquisition of land, project construction, and equipment purchases [94].

Tajikistan exempts hydropower equipment from customs duties and VAT. The government also gives tax exemptions to investors in renewable energy projects, for periods lasting from 2 to 5 years, depending on their level of investment in the project [68].

Kyrgyzstan waives licensing requirements for renewable electricity systems up to 1 MW of capacity [82].

While tax incentives are a relatively simple and highly flexible tool for stimulating the development of clean energy technologies, they are only of benefit to entities that have a tax burden or can partner with another organization that does [45].

4.2.3.2 Feed-In Tariffs

A feed-in tariff (FIT) is a performance-based incentive that typically provides a fixed price per kilowatt-hour of electricity supplied. In some countries, FITs for renewable generators include other policy elements such as a guaranteed connection to the grid, a power purchase guarantee, and standardized power purchase contracts. Through guaranteed long-term fixed renewable electricity prices, FITs are one of the most effective tools to support increased investor confidence and expanded deployment of renewable energy [45].

Uzbekistan was the first country in Central Asia to introduce a renewables FIT, as part of its 1997 Law on Rational Energy Utilization [94]. However, those FITs were negotiated on an individual project basis to allow "sufficient return on the capital invested, the future operation costs, and other technical costs for RE facilities;" in other words, Uzbekistan's FIT is site-specific, not a national policy [94, p. 19].

Kazakhstan's 2013 renewable energy law establishes a preferential FIT through 2028 for electricity generated by PV, wind, biomass, geothermal, and small hydropower plants (up to 35 MW) [94]. Tajikistan is considering introducing a similar FIT, guaranteed for up to 15 years, for electricity from the same renewable sources as Kazakhstan, except that it defines "small hydropower" as plants with a capacity up to 30 MW [94].

Kyrgyzstan adopted a law in 2008 that sets a feed-in tariff multiplier of 1.3 (compared to actual costs) for independent producers of all forms of renewable electricity [68]. However, the government has not yet created interconnection rules or other supportive legislation, so there are no independent power producers in the country as of 2020 [68]. As explained by ADB, "the law is not fully functioning, because the essential bylaws explaining the calculation of tariffs and other aspects have not been adopted" [94, p. 16].

4.2.3.3 Expedited Interconnection and Permitting for Renewable Energy Systems

Grid interconnection standards and regulations are often technology- and hence emissions-agnostic. However, some countries have developed interconnection policies that are specifically designed to make it easier to connect renewable generation systems to the grid. Some of these policies target larger utility-scale projects but most are aimed at smaller systems that are less likely to have negative effects on the distribution grid. Similarly, some countries have created simpler permitting processes for renewable energy systems. If they work, such policies are another tool to reduce emissions from the electricity sector.

Kazakhstan is currently in the process of developing an expedited interconnection process for renewable systems up to 100 kW, specifically to encourage self-generation by households and small businesses [59].

Uzbekistan does not require any permits for off-grid renewable energy systems and is also developing standardized interconnection rules for renewable systems [66]. This is part of its 2019 Resolution of the Cabinet of Ministers No. 610 "On approval of the regulations for connecting to the unified electric power system of business entities that produce electric energy, including from renewable energy sources" [88].

Kyrgyzstan's Law on Renewable Energy intends to improve access to the grid for independent power producers but has yet to pass supporting legislation implementing this change as of 2020 [68].

4.2.3.4 Net Metering and Net Billing

Net metering and net billing policies both allow grid-connected end users to offset all or part of their power utility's electricity bill with electricity produced by on-site distributed generation (DG) systems. Most countries require that the DG system uses renewable resources, so this policy tends to reduce emissions. With net metering, the value of the electricity credits is typically at, or close to, the retail electricity rate. With net billing arrangements, the value of the electricity fed back into the grid is usually lower than the retail rate [45].

The authors of this report could find no examples of net metering or net billing legislation in Central Asia; other researchers had the same outcome [108]. In Kyrgyzstan, for example, net metering cannot move forward until the country passes legislation to allow independent power producers [68].

4.2.3.5 Reverse Auctions

A tender or reverse auction is a competitive bidding process used to establish a long-term fixed-price contract for electricity supply by an independent power producer (IPP). Developed by a government or utility, a well-designed auction process lowers electricity costs by encouraging competition among suppliers. Auctions may include various project specifications, including the generating capacity, technology used, job creation requirements, and more [45].

In 2018, with significant technical assistance from USAID, Kazakhstan started using a reverse auction process that brought tenders (offers) from more than 30 countries for various renewable energy projects, and drove solar power plant capital construction costs down to one-third of what they had been two years earlier [59]. Despite the exceptionally low, subsidized electricity tariffs in the country, which are about 20% of the kilowatt-hour cost in the EU, the Kazakhstan Energy Association reported that the electricity prices from the new power plants are competitive with the tariffs for fossil fuel generation [59, 60]. By May 2020, the country had 90 renewable energy facilities (hydro, wind, solar, and biopower) and decided to slow its auction process, buying time to improve its aging power grid to handle their output [59].

In 2019, Uzbekistan introduced a law requiring all renewable electricity tariffs to be determined through a competitive bidding process [66].

4.2.4 Financial Disincentives for Combustion-Based Generation

Taxes and other policies that penalize the continued use of fossil energy sources in the electricity sector can reduce air pollution.

As discussed in Section 2, some countries don't only set NAAQS; they also regulate specific point sources, such as air emissions from power plants. This is the case in every Central Asian country, all of which officially choose to regulate air quality by imposing financial charges on pollution above the "maximum allowable concentrations" (MACs) at each facility, an approach they inherited from the Soviet Union [24, 96]. Article 101 of Kazakhstan's environmental code established payments for all types of environmental emissions, referred to in Article 160 of the code as "obligatory payments to the [government] budget for emissions into the environment, including for above-established standards;" however, that law was recently rescinded (June 2021) [98]. Article 11 of Turkmenistan's Law on the Protection of Atmospheric Air states: "Classification of pollutants by hazard classes is carried out to determine the amount of payments for emissions of pollutants into the air, the amount of compensation for harm caused to the environment by emissions." [107]. Kyrgyzstan updated its pollution charges in 2011 [68]. Unofficially, however, without monitoring and verification systems, there is no way to know if pollutant limits have been exceeded.

Uzbekistan is encouraging a switch to renewable energy by taxing fossil fuel extraction at the rate of 30% for natural gas (which is what the country uses to produce more than 80% of its electricity), 20% for oil, and 4% for coal. [65]

4.2.5 Energy Conservation, Energy Efficiency Mandates, and Improvements

Mandates requiring the use of more energy-efficient equipment *outside* of the power generation sector may *indirectly* lead to a reduction in overall electricity use and, hence, a reduction in air pollutants. (By contrast, efficiency improvements to generation equipment used *inside* the power generation sector, such as a more efficient engine in a power plant generator set, reduces the consumption of fuel for a given power output, which in turn *directly* leads to a reduction in pollutants.) The following are examples of mandates leading to indirect reductions in pollutants.

In 2017, Uzbekistan passed a wide-ranging resolution codifying existing energy conservation and efficiency regulations and mandating additional actions [67]. The country has already adopted energy labeling of household appliances and is in the process of converting street lights and lamps in buildings to more energy-efficient alternatives. Uzbekistan has also banned the sale of incandescent lamps rated higher than 40 watts [67]. From 2016-2017, the country conducted a pilot program to see if it could reduce energy intensity in primary industries and succeeded in saving 1,200 GWh of electricity and cutting the energy intensity of GDP by roughly 11% year over year [67]. The government is planning to expand the program to include all businesses, with a goal of sustaining 8-10 % annual reductions in the energy intensity of GDP. Uzbekistan is introducing modern electricity meters to better track energy use. The resolution also authorized the replacement of 2,400 pumps and electric motors in the country's water distribution system with energy-efficient versions, which is expected to save 807 GWh of electricity annually [67]. Given Uzbekistan's heavy reliance on fossil fuels, these actions are likely to substantially reduce the air emissions from the country's electricity sector.

Kyrgyzstan's National Strategy for Sustainable Development for 2018-2040 mandates the use of energy efficiency technologies in all new construction; the government also plans to retrofit older buildings [68]. Potential energy savings in the buildings sector are expected to be at least 15% [68].

Article 8 of Kazakhstan's law on energy efficiency and conservation requires energy efficiency labeling of appliances and "the mandatory use of energy-saving materials, the installation of metering devices for energy and water resources, and automated systems for regulating heat consumption" in new "construction of facilities that consume energy and water resources" [97].

Finding ways to reduce line losses in the electricity T&D system is a way to reduce overall emissions as a result of not wasting electricity. Kyrgyzstan's National Strategy to 2040 calls for a reduction in electricity line losses of 11% by 2023 [68]. The country currently has line losses of roughly 20%; if reduced, the improvement in electricity delivery to customers would reduce emissions from the electricity sector per unit of energy consumed [86]. Power distribution losses are also high in Tajikistan (17%) and Turkmenistan (12%) [58].

4.2.6 Combined Heat and Power and District Heating/Cooling Requirements

Central heating and cooling systems based on geothermal heat pumps or combined heat and power (CHP) plants can offset air emissions from lower-efficiency building and district heating and cooling (DHC) systems. Policies and regulations for central heat systems, including tariff policies, building codes, and heat distribution network requirements can indirectly reduce the air emissions from building and DHC systems, and CHP plants [36]. Note that, because district heating is usually mandated at the municipal level, many countries do not have national-level district heating policies.

Fossil fuels are still the primary resource used to heat and cool buildings, releasing harmful particulates and exacerbating air pollution. Today, only 10%[12] of the world's heating and cooling needs in buildings and industrial processes are supplied by renewable energy, largely due to a

[12] See [37] for details: 10.4% of heating and cooling needs are met by "modern renewables" (i.e., excluding traditional biomass, nonrenewable electricity, and fossil sources).

lack of supporting policies in these sectors [37]. Instead of developing and installing separate systems for HVAC needs and electricity generation, combining the two yields substantial efficiency gains, reducing the amount of electricity consumed and thereby indirectly reducing emissions of air pollutants.

DHC systems can easily use renewable resources but have traditionally used the heat from power plants or industrial processes burning coal or natural gas. In most cases, the systems that have switched to renewables have done so as a result of policy changes, and mostly in Europe. However, some DHC systems use biogas from sewage treatment plants and others use geothermal energy, either tapping into hydrothermal resources or using geothermal heat pumps [36].

In 2019, Uzbekistan passed national legislation designed to encourage the production of heat, electricity, and biogas from renewable resources by using tax breaks and other measures to stimulate the sector [66].

In Kyrgyzstan, four cities have district heating systems, with electric boilers being the primary source of heat [68]. However, the coal-powered DHC system in Bishkek, Kyrgyzstan, is responsible for most of the city's air pollution during the winter months [3]. In January 2021, the local government called for the main heat- and power-plant to be converted from coal to natural gas to improve air quality [7].

4.3 Other Relevant Issues

4.3.1 Inconsistent or Absent Clean Energy Policy Regimes

One of the significant challenges encountered in the preparation of this report were the policy inconsistencies. There are official policies and unofficial policies. Some policies and governing decisions are made by government ministers on an ad hoc basis, often without involving stakeholders or subject matter experts, and sometimes without reference to existing standards or prior guidance. The consequence is a patchwork of incomplete formal policies and regulations within some countries, along with potentially conflicting informal policies and one-off rulings by officials. Evidence is provided below.

A 2020 research report from the School of International Liberal Studies at Waseda University in Japan found that, in Kazakhstan, "a significant gap exists between official goals and efforts made to achieve them" [58, p. 11]. In Tajikistan, according to OECD, the government approves projects without screening them against its overall development goals, and the regulatory environment suffers from discrepancies "between all kinds of documents (master plan, program, strategy) in both time-horizon and target-setting" [58, p. 12]. Turkmenistan's development policy documents don't include quantitative targets, and Uzbekistan's government won't set any binding long-term targets [58]. The issues are exacerbated by a lack of institutional capacity to address the challenges and a lack of authority to implement change where the institutions do exist.

In Turkmenistan, a 2019 OECD report lists several policies that are essentially visions for the country's future, such as reducing reliance on natural gas, but points out that these policies do not assign responsibility to any state organization or set out actions to ensure they are accomplished [86]. There is no process for stakeholder engagement and citizens have little access to information regarding policies and regulations, which also made them difficult for the authors of this report to identify [86]. This is beginning to change. In December 2020, Turkmenistan passed its Law on Environmental Information, which gives citizens the right to request data on environmental pollution from any public or private monitoring organization [54].

Inconsistent or poorly designed policies and regulations can be an obstacle to implementation, regardless of whether the goal is to increase the use of fossil or clean energy resources. But given that three of the countries in the region are currently heavily reliant on fossil fuels, in Central Asia the result is likely to reduce development of lower-emissions technologies, which delays emissions reductions.

4.3.2 Cryptocurrency Mining

Cryptocurrencies are digital money that exists as decentralized data on the internet rather than in the form of printed banknotes or numbers on a balance sheet at your financial institution. The data is encrypted with strong cryptography, hence the term cryptocurrency. Making more of any cryptocurrency ("crypto") requires electricity. Traditional cryptocurrencies, of which Bitcoin is perhaps the best-known example, use what's called a "proof of work" concept to "mine" (make) more of the currency. This process of cryptocurrency mining requires substantial amounts of electricity, with associated air emissions [79, 80]. Bitcoin has a carbon footprint larger than the entire country of New Zealand [80] and, according to the Cambridge University Bitcoin Electricity Consumption Index, uses more electricity each year than the Netherlands [80].

Today, Kazakhstan is the world's second largest cryptocurrency miner, after the United States [40]. Reversing earlier bans, the government passed a law in 2020 designed to attract crypto miners, in part hoping to benefit from increased income from both taxes and electricity sales at higher tariff rates due to go into effect in 2022 [40]. China was the number-one host to crypto miners until the summer of 2021 when it banned cryptocurrencies outright. Kazakhstan's friendly policy environment and low existing electricity tariffs encouraged crypto miners to move into the country [40]. According to Kazakhstan's energy minister, Magzum Mirzagaliyev, national consumption of electricity jumped 5% from September 2020 to September 2021 solely due to crypto mining, and the country was having trouble keeping up [40]. Air emissions from the electricity sector would also have increased as a result, given Kazakhstan's primary reliance on fossil fuel power generation. On September 30, 2021, Mirzagaliyev proposed limiting power to each server farm to 1 MW and instituting a 100 MW cap for the cryptomining sector as a whole [40]. In October 2021, shortly after the energy minister suggested limiting electricity supplies to crypto miners, the national grid utility started rationing electricity to them [40]. This is another example of a formal policy in Central Asia that is simply ignored or overridden by an informal policy established by an individual in a position of power.

4.3.3 Energy-Water Nexus

Hydropower plants run exclusively on water; thermal power plants (including nuclear plants) need water to produce steam for their turbines and for cooling. Non-thermal (i.e., without cooling needs) and non-hydropower electricity generation sources, such as wind and solar PV power plants, have been shown to have minimal water requirements [101]. Extracting fossil resources requires significant amounts of water, especially fracking for natural gas. And water is also needed for human consumption, animals, and irrigation of crops. This nexus of energy and water demands is creating system inefficiencies and political tension within and between countries.

In Central Asia, the three fossil-rich countries are also highly dependent on water from outside their borders: Turkmenistan is 94% dependent, partly driven by the fact that its economy is almost entirely based on cotton production [13]; Uzbekistan is 77% dependent; and Kazakhstan is 42% dependent on cross-border water [58]. Much of that water comes from Tajikistan and Kyrgyzstan, which cannot satisfy the demand from their neighbors as they are having difficulty meeting their own needs [58]. Kyrgyzstan's Toktogul reservoir was developed during the Soviet era to provide irrigation water to downstream countries in the summer but in the face of its relative isolation from its neighbors, the country has had to prioritize power generation for its citizens [68]. This also reduces the amount of clean hydroelectricity it can share with its neighbors. According to ADB, "the water-energy nexus leaves national energy policymaking susceptible to sometimes arduous regional consensus" [94, frontmatter].

5. Key Findings and Future Work

This report describes standards and policy instruments used to reduce air pollution from fossil fuel combustion in the electricity sector and provides examples of countries in Central Asia that use those instruments, where they could be identified. The authors were not able to analyze the effectiveness of the policies or investigate other important related issues, such as air pollution from the transportation sector and climate-related impacts from air emissions in the power sector, as these issues were out of scope for this initial research project.

The report includes descriptions of (1) policies that *directly* regulate air quality by limiting emissions from specific point sources (by restricting operating hours, for instance) and (2) *indirect* policies that incentivize or disincentivize polluting activities (such as policies to encourage fuel switching, for example).

Like South Asia, the subject of an earlier sister publication to this report[13], Central Asia is certainly not a homogeneous region. Available energy resources, the condition and extent of national power grids, and seasonal access to power generation vary widely. Such factors need to be considered when developing policies to tackle air pollution. Solutions that are helpful in one country are not necessarily appropriate in another. This section presents a few key observations noted during the authors' research; for information on the policy instruments covered, see Sections 3 and 4.

5.1 Economic Development vs. Pollution Control

As mentioned in the Introduction, many emerging economies are less focused on reducing air pollution and are more intent on providing electricity as a basic necessity for their citizens and as an engine of economic growth. This certainly seems to be the case in Central Asia; the authors found little evidence that countries in the region are addressing *national* air emissions in a systematic fashion, although they are making efforts to improve egregious *local* air quality problems, especially in urban environments.

Controlling polluting air emissions need not harm economic development or the economy. However, depending on the strategies used, powering economic development and reducing air emissions from the electricity sector can be at odds. Like many emerging economies, Kyrgyzstan seems to have adopted an "all of the above" approach to meeting its growing need for electricity. Current energy policy is focused on improving both energy security (self-reliance) and the stability of the country's electricity supply [68]. Kyrgyzstan aims to do this by developing its indigenous resources (primarily coal and hydropower) and improving the electricity grid to minimize losses. The country is also promoting energy efficiency [68].

Interestingly, as described in Sections 4.1.1 and 4.2.2, while Uzbekistan is planning an increase in coal power production, it has also passed other legislation to foster clean renewable and nuclear electricity generation. This includes a presidential decree in October 2019 that approved the country's Strategy for the Transition of the Republic of Uzbekistan to the Green Economy for the Period 2019-2030 [110], which includes a wide range of proposed actions that could reduce harmful air emissions, including energy efficiency measures in small businesses, increased

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[13] https://www.nrel.gov/docs/fy21osti/80156.pdf

adoption of renewable energy, decreasing the carbon intensity per unit of GDP, reducing the consumption of water for agriculture (which increases the water available for hydropower production), and assigns responsibility for implementing this strategy to the Ministry of Economy and Industry—a critical step for advancing any legislation.

Countries in Central Asia vary widely in the extent to which they are trying to shift their domestic electricity generation to help improve air quality using policy instruments. Turkmenistan, for example, has promulgated NAAQS but has no clean energy legislation at all that could help achieve those air quality standards [94].

5.2 Consequences of Hazy Legal Environments

Central Asia does not have a robust policy environment in general, not just regarding electricity production, which can become an obstacle to both providing adequate electricity supplies and to improving air quality in the region.

According to the Asian Development Bank, in Kyrgyzstan, "political instability, high corruption, and poor implementation of laws undermine the population's trust in governance institutions" [90, p. 15]. Corruption isn't limited to the government. A study released in November 2021 by the NGO, Evidence CA, found that one in three entrepreneurs in the capital, Bishkek, had to pay bribes to get their businesses connected to an electricity supply [103].

According to the U.S. Department of Commerce, Kazakhstan has "poor governance and an opaque operating environment" that will "likely curb investment into the renewables sector" and "few investors are willing to enter the market amid concerns that graft and corruption are a major risk to project realization. To this end, the [extent of] enforcement of regulation, legislation and concessions in the energy sector is difficult to evaluate" [105, see Market Obstacles].

In many cases, potential polluters are expected to police themselves. Article 17 of Turkmenistan's Law on the Protection of Atmospheric Air states: "Legal entities and individuals whose activities are related to the emission of pollutants into the atmospheric air and harmful physical effects on the atmospheric air are obliged to ... ensure the efficient operation of structures and equipment to reduce emissions of pollutants into the atmospheric air and harmful physical impact on the atmospheric air and exercise control over them [and] ... keep track of the amount and composition of emissions of pollutants into the atmospheric air" [107]. Self-policing is not effective at limiting air pollution, and the authors found little evidence of independent monitoring of air emissions in Central Asia outside of dense urban environments.

5.3 Benefits of Cross-Border Electricity Trade

Unlike South Asia, Central Asia started out with a well-functioning cross-border electricity transmission system that allowed for effective balancing of supply and demand across the five member countries. The system did not incorporate market signals, and did not provide national-level energy security given that it was not possible for any one country to operate completely independently of the others, both factors that led to its downfall. However, all of the Central Asian countries have recently expressed interest in reviving some version of the CAPS grid.

While some countries are making progress on emissions reduction by themselves, others, including those where energy security is impacted by a mismatch between seasonal demand and resource availability, could benefit from expanded cross-border electricity trade (see Section 4.2.1). Easy access to Central Asia's plentiful hydropower resources could enable pollution reduction across the region. One way to reduce air pollution from the electricity sector in Central Asia would be to reestablish an improved version of the CAPS regional power trading system that served the region during the Soviet era. The prospects for such a solution are improving: "Because of its geographical position, Uzbekistan holds the key to energy cooperation in Central Asia: a more open and region-oriented policy in Uzbekistan since 2017 has improved the prospects of such cooperation" [94, p. 6].

Other CBET initiatives include linking Central Asia to South Asia through the CASA-1000, TAP and TUTAP initiatives. CASA-1000 has excellent stewardship and funding (see Section 4.2.1.2), and would be an important link in a larger grid that integrates the region. This possibility is actively being explored via discussions within the CAREC organization. However, it is a challenging task because there also needs to be appropriate supporting legislation to make cross-border electricity trade possible. Each national legislature would need to develop and adopt a common set of technical and market regulations, standards, and rules that could support large-scale cross-border electricity trading.

If a five-country CAPS could be reestablished as a Central Asian Regional Electricity Market (CAREM), USAID has identified several benefits, paraphrased here [77, p. 4]:

- Supply cost reductions and improved security and quality of service arising from:
    - Optimal use of diverse primary resources: water in Tajikistan and Kyrgyzstan; abundant hydrocarbons in Kazakhstan, Uzbekistan, and Turkmenistan
    - Complementarity and diversity of marginal costs (i.e., large benefits from trading)
    - Resources to provide ancillary services (flexible hydro in Tajikistan and Kyrgyzstan) and system adequacy (sharing of reserves)
    - Effective rules for mutual support during power emergencies
    - Financial benefits of CBET could be \$150 million to \$1200 million per year.
- Operation of CAREM leads to optimal use of renewable generation, while the economic dispatch leads to emissions reductions.

5.4 Potential Future Work

There are substantial air pollution policy gaps in many countries across Central Asia, and providing technical assistance with development of both direct and indirect policies could help this region improve its air quality. Indirect policies are less commonly recognized as opportunities to improve air quality, but the variety and customizability of such policy instruments (see Section 4 for examples) allows for well-targeted outcomes and could increase their adoption if their potential efficacy in each country could be demonstrated. It would be helpful to identify cost-effective technological solutions that could improve air pollution in the short-term. Proposing realistic measurement and verification systems that could help government institutions ensure compliance with policies identified in this report would also be a natural next step. Further studies could quantify the air quality improvement and associated health benefits expected from implementation of specific policies and the anticipated implementation costs for each country. Other studies could potentially quantify the air-quality improvements from integrating additional non-emitting renewables into the national grids.

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Appendix A.

A.1 Brief Description of Emission Control Devices Referred to in This Report

This section provides a brief description of the working principle of various methods and technologies used for lowering emissions of NOx and other pollutants as mentioned in Table 3 (Section 3.2) and Table 4 (Section 3.3) [1, 10, 70].

Electrostatic precipitators (ESPs)—A device used to remove fine particulate matter. ESPs use the principle of ionization of the contaminated flue gas and a subsequent capture of charged particles by oppositely charged plates (collecting electrodes). ESPs are highly efficient, with efficiency reaching as high as 99%.

Cyclones—Cyclone separators use the centrifugal and inertial forces to remove and capture particulate matter from flue gas. Based on design specification, cyclones can be used to capture larger particles (PM_{10}) as well as fine particles ($PM_{2.5}$). Though the efficiency of these devices depends on specific design parameters and use conditions, they are more effective in removal of particles with relatively larger aerodynamic diameters.

Fabric filters—Capture the dry particles in flue gas by using a filter bag. The fabric does some filtration, but the accumulated dust is also an important particulate removal medium.

Flue gas desulfurization (FGD)—Uses chemical scrubbing to remove sulfur dioxide from the flue gas. Given that SO_2 gas is acidic, an alkaline scrubbing agent (e.g., limestone) is often used to remove SO_2 from flue gas. Some SO_2 removal processes are regenerative, where the removed SO_2 is recovered as a useful product, whereas others are throwaway processes.

Selective catalytic reduction (SCR)—A very efficient NOx control device. In an SCR-based NOx control, ammonia is used to chemically break down NOx into nitrogen (N_2) gas and water vapor. The SCR catalyst used more efficiently facilitates the chemical reaction of ammonia with NOx. Efficiency of SCR is generally dependent on the temperature of exhaust gas, and ammonia slip is also an issue. SCR and SNCR are often used in combination with low-NOx burners and over fire air burners.

Selective non-catalytic reduction (SNCR)—The working principle of SNCR is similar to SCR, except that the catalytic agent is absent. However, due to several practical reasons, this often results in lower removal efficiency of NOx. SCR and SNCR are often used in combination with low-NOx burners and over fire air burners.

Overfire air burners—In this technique, the fuel is combusted in two or more stages. The primary flame zone is fuel rich and the following flame zones are fuel lean. This results in oxygen-deficient zones of partial combustion, resulting in lower temperatures and thus lower NOx formation.

Low NOx burners—In low NOx burners, NOx formation is inhibited by controlling the mixing of air with fuel, with a subsequent reduction of the peak flame temperatures. Reduced flame temperatures result in reduced NOx formation from combustion.

Burner out of service—When multiple burners are used, oftentimes some 'burners are kept out of service' (i.e., they are not fed with fuel, but used for supplying air or flue gas). This results in a staged combustion with lower temperature compared to the temperature when all the burners are in service, thereby reducing the amount of NOx produced.

Air staging—As the name implies, the combustion is staged by dividing air into two different streams. The first stream is mixed with fuel such that the net result is a reducing flame (that is, with low oxygen content); the second stream, which has slightly excess air (compared to the fuel-air stoichiometric ratio), is injected downstream. NOx formation in this method is controlled by limiting the availability of O2, O and radicals (OH).

Fuel staging—In this method, combustion is staged using fuel instead of the air (as in the 'air staging' method above). In the first stream used for primary combustion, the conditions are reducing (low oxygen), and the second stage of combustion is slightly oxidizing. Excess fuel in the primary combustion stage reduces the peak temperatures and the downward stream oxidizes the fuel while reducing NOx to N_2.

Low excess air—Excess air denotes the air above the stoichiometric requirement and was used to achieve good fuel combustion. Owing to less-than-ideal fuel-air mixing, some excess air is always used. A few decades ago, the excess air used could be as much as 50%–100%; however, with rising fuel prices, this was reduced to 15%–30% (which was a practical limit to achieve good combustion). However, EPA research indicated reduction of NOx formation potential when the amount of excess air is lowered and thus subsequently low excess air started being used as a NOx control measure.