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Current energy resources in Kazakhstan and the future potential of renewables: A review

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Abstract

Kazakhstan is rich in natural resources including coal, oil, natural gas and uranium and has significant renewable potential from wind, solar, hydro and biomass. In spite of this, the country is currently dependent upon fossil fuels for power generation. Coal-fired plants account for 75% of total power generation leading to concerns over greenhouse gas emissions and impacts on human health and the environment. Recent economic growth in Kazakhstan has driven increased demand for energy services making the construction of additional generating capacity increasing necessary for enabling sustained growth. In this context, renewable energy resources are becoming an increasingly attractive option to help bridge the demand-supply gap. Despite significant wind, solar, hydro and biomass potential, these resources have not been sustainably captured and deployed due a range of technical, institutional, social and economic barriers. This article reviews the current energy situation in Kazakhstan including fossil energy and renewable resources and investigates policy drivers for the energy sector. The barriers to adoption of renewables are analysed within the context of national climate and energy goals. Recommendations are presented for the promotion, development and implementation of renewable energy resources in Kazakhstan.

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Keywords: Fossil fuels; renewable energy; hydro; wind; solar; bioenergy; biomass; Kazakhstan.

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1. Introduction

Kazakhstan emerged from the dissolution of the Soviet Union in 1991 and is currently an upper middle income country of around 17.4 million people [1] spread unevenly over an area of 2.7 million km^2 [2] with 47% of the population living in rural areas [3]. Kazakhstan is located in the center of the Asian continental land mass and consists of steppe grassland and pastureland in the north, desert and semi-desert in the central and western catchments of the Caspian and Aral Seas and with high mountains in the Tien Shan and Pamir ranges, which are nationally important sources of water, fringing the south of the country. Agricultural land comprises 76.5 million hectares with 61% permanent pastures and 32% arable land producing grain and livestock [4]. The climate of Kazakhstan is continental [5], characterized by intensely cold winters with January air temperatures ranging from -18.5°C, in the north of the country, to -1.8°C in the south, and hot summers with July air temperatures ranging from 19.4°C in the north to 28.4°C in the south [6]. Energy consumption reflects the impact of the challenging continental climate with harsh winters necessitating space heating and hot summers air conditioning, which places an increasing demand on power supplies.

Kazakhstan's economy benefits from its natural resources (particularly oil, gas and uranium), heavy industry (ferrous and non-ferrous metals) and agricultural sectors. The petroleum and mining industries accounted for 33% of GDP in 2010 and 82% of exports [7]. GDP increased from 16.9 billion USD in 1999 to 224.4 billion USD in 2013 [8] and the favorable economic environment and rapid per capita income growth had contributed to an impressive reduction in poverty from 47% of the total population living in poverty in 2001 to 3% in 2013[9]. However, in common with many developing countries, rapid economic growth in the past decade has led to a sharp upswing in electricity consumption and power shortages in the winter periods where demand on electric loads has necessitated restrictions on consumption that have had an adverse impact on regional economic development [9]. Primary energy consumption has risen from 26.92 Mtoe in 1999 to 62.03 Mtoe in 2013 [10] while total annual power generation has increased from 45 TWh in 1999 and is forecast to reach 97.91 TWh in 2014 [11]. The total installed capacity is 19.8 GW [11], while the available capacity is about 15 GW [12] principally due to aging equipment and lack of maintenance [13]. Approximately 13% of Kazakhstan's power is generated by hydroelectric power stations along the Irtysh River, whilst 87% is from thermal-powered plants (75% coal-fired stations and 12% gas-fired plants) [11]. Renewable sources such as wind, solar, small hydro and bioenergy currently contribute less than 1% of Kazakhstan's energy mix [14] however there is considerable potential in renewable power generation and the government expects the total share of renewable power generation to rise to 11% by 2030 with 1,040 MW of renewable energy capacity by 2020 [11].

80% of total electricity is produced in the industrial north by power plants located near coal mines [12] however electricity transmission networks across the country are inefficient with losses during transmission and distribution estimated at approximately 15% of energy produced, although the actual value may be higher [11]. The electricity transmission and distribution system is divided into three networks with two in the north connected to Russia, and one in the south connected to the Unified Energy System of Central Asia [11]. Growth in the demand for electricity is forecast to reach between 120-180 TWh by 2030 [13]. Given Kazakhstan's rapid economic development and the associated increasing electricity demand, significant modernization of existing power facilities in addition to construction of new power generation plants of ~20 GW is needed by 2020 [14]. Improving energy efficiency is also important; a recent study demonstrated that improving the efficiency of electricity and heat systems can cut almost one third of electricity and heat consumption in Kazakhstan's residential and commercial sectors at an average cost for end users of about 1$/GJ [15]. The industrial sector currently accounts for approximately 70% of the total end-use electricity consumption, with the residential sector 10%, the commercial and service sectors cumulatively 9%, transport 6% and agriculture 2% [16]. To encourage an increase in efficiency and to cope with the challenging demand-supply situation, the Kazakhstan Government enacted an Efficiency Law in 2012 and in 2013 launched an Energy Efficiency Program 2020 aimed at reducing the energy intensity of the national economy by 10% by 2015 and by 25% by 2020 [1].

Kazakhstan's energy sector is responsible for carbon dioxide emissions of 275 $MtCO_2$ in 2011 with 80% derived from the energy sector from heat and power generation due to the low efficiency and aging generating and network assets [17]. In order to decrease emissions and meet the increasing electricity demand, a decentralized, efficient and environment friendly energy supply system based on diverse renewable resources is urgently needed [18].

Renewable energy is an important mechanism [19] for achieving sustainable development [20] and Kazakhstan has abundant resources (solar irradiance, wind energy, hydroelectric power, biomass and organic wastes and residues) suggesting that adequate utilization of these resources could complement the country's energy portfolio. Renewable energy also contributes to significant reductions in greenhouse gas emissions [21], local air pollution, and minimizes the impact on the landscape, and physical, geographical and natural environments [22].

2. Conventional energy resources in Kazakhstan

Kazakhstan possesses significant reserves of oil, gas, coal and uranium. These resources are unevenly distributed across the country and their production, transportation and use has been challenging for grid connectivity [13], the environment [23] and regional geopolitics.

2.1. Coal

Kazakhstan's coal reserves comprise c. 37 billion tons (4% of world estimated reserves) [3] of mostly anthracitic and bituminous coals. Mines are located in central Kazakhstan principally in the 2000 km^2 Karaganda [24] and 63 km^2 Ekibustuz basin coalfields [25] and the sector is said to have enough reserves to last over 100 years [26]. In the east, southeast and southwest of the country, there are smaller deposits of coal, but to date these have been poorly exploited. Coal production is currently 120 Mt of which 97 Mt (80%) is consumed domestically for electricity and heat production in thermal power plants with the remaining 22 Mt exported [27]. The Government of Kazakhstan plans to increase coal production from 120 Mt in 2010 to almost 200 Mt by 2030 [7]. Coal is used in coal-fired boilers for drying coal, heating mine facilities and ventilation air [28], production of coke for industrial use and in thermal plants for heat and power. Kazakhstan coal is predominantly high ash and also polluting since thermal power plants are not routinely fitted with sulfur and nitrogen oxide flue gas scrubbers [26]. Coal-bed methane and coal-mine methane have potential to be captured and used as a fuel and a pilot plant in the Lenina mine in the Karaganda basin has been developed to generate 1.4 MW of electricity from coal-mine methane [29] and this is an area of potential future growth. Technologies such as carbon capture and storage [30] and underground coal gasification are not currently planned in Kazakhstan.

2.2. Oil

Kazakhstan has proven on-shore oil reserves in the west of the country which will enable oil extraction for over 30 years [26], estimated at 30.0 billion barrels (3.9 billion tons) of oil [3] representing 1.8% of global reserves [9]. At the current time, Kazakhstan has 172 oil and 42 gas condensate fields around the Caspian Sea with total production in 2013 at 81.8 million tons [31]. There are three major oil refineries at Pavlodar, Atyrau and Shymkent mostly handling domestic oil [31]. Over 50% of oil production derives from the large Tengiz, Kashagan and Karachaganak Fields [29] and approximately 85% of all the oil produced in Kazakhstan is intended for export [7]. However Kazakhstan is a landlocked country and transportation costs are high [32] and the lack of export routes presents a potential bottleneck for Kazakhstan's development plans [31]. At present Kazakhstan exports oil via pipelines, tankers and railways to Russia, the Mediterranean coast of Turkey via Azerbaijan and Georgia and to China with the main routes being: (i) the Tengiz-Novorossiysk pipeline linking the Tengiz Oil Field via the Caspian Pipeline Consortium's 1510 km pipe to Russia's oil terminal in the Black Sea coast; (ii) the Kazakhstan Caspian Transportation System which consists of three segments (a) the Yeskene-Kuryk pipeline which connects Tengiz and Kashagan oil fields with Kuryk on the Caspian Sea (b) where a system of oil tankers and oil terminals are used to transport the oil across the Caspian to Baku in Azerbaijan (c) where the oil can be moved via the Baku-Tbilisi-Ceyhan pipeline through Georgia and Turkey to the port of Ceyhan on the south-eastern Mediterranean coast; (iii) the 2228 km Kazakhstan-China pipeline which connects Atyrau to Alashankou in the Xinjiang Uigher Autonomous Province in NW China [31]. In common with natural gas, control of oil export routes provides significant influence

over the security and political outcomes and policies of the Caspian states [33] and other neighboring countries [34] and thus geostrategic power [32], and Kazakhstan's very ambitious oil export plans heavily rely on viable routes to enable export growth [33].

According to the 2010-2014 'National Program of Forced Industrial and Innovative Development', Kazakhstan's government envisages production will increase to approximately 3.8 million barrels per day by 2020 [7]. Future development of the domestic oil sector depends on developing the Kazakh sector of the Caspian Sea, where forecasted reserves are expected to last for over 50-60 year [18].

2.3. Natural gas

Kazakhstan's proven natural gas reserves comprise around 1.3 trillion m^3 [10] located in the west of the country in oil, oil-gas, and gas condensate fields [7] and it has been estimated that reserves will last 75 years [26]. Natural gas (NG) and associated petroleum gas (APG) production in 2013 totaled 42.3 billion m^3, up 5.5% year-on-year, of which 22.8 billion m^3 were produced as marketable gas [31]. Kazakhstan's gas reserves are dominated by APG, meaning that the gas is produced with oil and for this reason, several Kazakhstan oil and gas fields including the large Karachaganak field re-inject significant quantities to enhance oil recovery [35]. Natural gas production in 2013 was estimated at 18.48 billion m^3 [10] and combined NG and APG production is expected to rise to 45 billion m^3 by the end of 2015 [31]. However there is a lack of proper infrastructure linking the demand centers to production areas and as a result the country continues to depend on gas imports to meet domestic demand [35]. However in 2013 it was announced that Kazakhstan's Line C Gas Pipeline would connect to the Asia Gas Pipeline LLP (AGP) to power the flow of natural gas through, part of the vast 1,833 km long Central Asia-China Gas Pipeline network connecting Turkmenistan, Uzbekistan and Kazakhstan to China transporting 55 billion m^3 of gas each year to China by 2016 [36] and also meet some domestic needs. At present Kazakhstan is not contributing significantly to the Nabucco gas pipeline which connects the Caspian Sea producing countries of Azerbaijan and Turkmenistan to the European natural gas grid via Turkey [37]. The Nabucco pipeline can be seen as a geopolitical initiative from Europe in response to the impression that Russia uses natural gas as a political weapon [38] causing concerns over energy security [37]; for Kazakhstan this may provide a useful future export market.

2.4. Uranium

Kazakhstan is the world's leading uranium producer. It holds 15% of the world's uranium resources with current production at 22,550 tonnes per year (2013) comprising 38% of the global total production [39]; 90% of the total uranium production is currently exported [40]. Kazakhstan's sole nuclear power plant, the 90-MW Mangyshlak fast reactor at Aktau was shut down in April 1999 after 27 years of operation however a cooperation deal with Russia on commissioning a new nuclear power station was signed in May 2014 [39].

3. Renewable energy resources and potential in Kazakhstan

Despite an energy mix dominated by fossil fuels there is an increasing interest in renewable alternatives due to their environmental sustainability and economic development potential [41].

3.1. Hydro Power

Hydropower accounts for approximately 13% percent of Kazakhstan's total generating capacity delivering around 7.78 TWh from 15 large (>50 MW) hydro power stations [7] with a total capacity of 2.248 GW [42]. Large hydro power plants comprise the Bukhtyrma (750 MW), Shulbinsk (702 MW) and Ust-Kamenogorsk (315 MW) plants on the Irtysh river, the Kapshagai (364 MW) plant on the Ili River, the Moinak (300 MW) plant on the Charyn river and

the Shardarinskaya (104 MW) plant on the Syrdarya River [43]. Small (1-10 MW) and medium-scale (10-50 MW) hydropower projects have become more popular because of their low cost, reliability and environmental friendliness [44]. There are seven small hydropower plants (<10 MW), with a total installed capacity of 78 MW and an estimated potential of 13TWh, from east and south Kazakhstan, Zhambyl and Almaty provinces (Table 1) [45].

Table 1. Small hydropower projects in Kazakhstan (Source: German Agency for Technical Cooperation [45])

Regions	Number of projects	Projected installed capacity (MW)	Annual production (GWh)
East Kazakhstan	68	349	1700
Almaty province	n.a.	1762	8700
Southern Kazakhstan	112	421	1800
Zhambyl province	77	175	700
Total	257	2707	12900

3.2. Wind Power

Kazakhstan's steppe geography makes it suitable for wind energy applications [46] and the estimated potential of wind energy that can be economically developed is about 760 GW [47]. About 50% of Kazakhstan's territory has average wind speeds suitable for energy generation (4–6 m/s) with the strongest potential in the Caspian Sea [46], central and northern regions [48]. The most promising sites are in the Almaty region in the Djungar (Dzhumgarian) Gates, 600 km northeast of Almaty close to the Xinjiang border and the Chylyk Corridor 100 km east of Almaty. It has been estimated that these locations have wind potentials of 525 Wm^2 in the Djungar Gates and 240 Wm^2 in the Chylyk corridor with power production from wind turbines potentially achieving 4400 kW/h/MW and 3200 kW/h/MW, respectively [49]. Other sites with potential are shown in Table 2. Construction of the first wind plant in Kazakhstan is underway at Yerementau in the Akmola region with 22 FWT2000 2MW turbines delivering an installed capacity of 45 MW and a generating capacity of 172.2 kWh [51].

Table 2. Prospective Regions for Wind Power Development in Kazakhstan (Source: [50]).

Location of potential wind farms	Region	No.wind generators	Projected installed capacity [MW] [MW]	Annual production [billion kWh]
Mangystau mountains	West	8,000	210	0.4
Peak Karatau	South	7,800	190	0.23
Chu-Ili mountains	South	6,800	180	0.27
Mount Ulutau	Central	3,400	90	0.13
Yerementau mountains	Central	2,100	50	0.01
Mugojary mountains	West	400	10	0.01
Djungar gates	South	1,100	200	0.66
Total		29,600	930	1.71

3.3. Solar energy

Kazakhstan has areas with high insolation that could be suitable for solar power, particularly in the south of the country, receiving between 2200 and 3000 hours of sunlight per year, which equals 1300-1800 kW/m² annually [50]. Both concentrated solar thermal and solar photovoltaic (PV) have potential. There is a 2 MW solar PV plant near Almaty and six solar PV plants are currently under construction in the Zhambyl province of southern Kazakhstan with a combined capacity of 300 MW [52]. In addition to solar PV, concentrated solar thermal is advantageous given it does not require water for operation so can be used in desert and semi-desert areas, the materials (steel, glass, and

concrete) are domestically produced in Kazakhstan and readily available, and solar thermal plants store energy in the form of heat, which is far more efficient than the batteries used in PV systems and allows electricity to be produced on demand, even after the sun has set, enabling both base and peak loads to be met [53]. There are no current plans to install a concentrated solar thermal plant although the government plans to create 1.04 GW of renewable energy capacity by 2020 [52].

3.4. Bioenergy

Kazakhstan has 76.5 Mha agricultural land, 10 Mha forest and 185 Mha steppe grasslands providing abundant biomass wastes and residues which have the potential to generate a range of bioenergy services [54]. Kazakhstan produces and exports crops such as wheat (winter and spring), rye (winter), maize (for grain), barley (winter and spring), oats, millet, buckwheat, rice and pulses, with an average grain yield of 17.5-20 Mt, which equates to roughly 12-14 Mt of biomass wastes [55]. Biomass wastes are currently poorly exploited and only ~ 10% of the total volume of the residues is used, mostly as a feed additive for livestock; the proportion of rural households using biomass cook stoves for cooking and heating is currently unknown. Organic wastes are also a potential source of energy and at least 400,000 households are known to keep cattle, horses and sheep [7]. It has been estimated that electricity generation potential in Kazakhstan from biomass is 35 billion kWh per year and heat generation potential is 44 million Gcal per year [56] Various external funding agencies (UNDP, GEF, HIVOS Foundation) have supported the development of biogas initiatives including the Biogas Training Centre at the Eco-museum in Karanga (2002-2003) and the 'Azure Flame' Central Kazakhstan Biogas Education Centre (2004-2005) however despite this promotion there is only one large scale biogas unit currently in operation in the country which is a 360 kWe biogas plant run at Vostok village in the Kostanai region. The Vostok biogas unit consists of two 2400 m^3 digesters operating with a feedstock of 40 t/day cow, sheep and camel manure and grain reside and 1 t/day of slaughterhouse waste [57]. The plant was installed in 2011 by Karaman-K Ltd and Zorg Biogas with an aim of delivering 3 million kWh of electricity annually [57].

4. Kazakhstan's Vision 2050

To meet its obligations under the Kyoto Protocol Kazakhstan has agreed to reduce carbon emissions by 15% by 2020 and by 25% by 2050 compared to its 1992 level [55]. The 2013 'National Concept for Transition to a Green Economy up to 2050' focuses on transitioning the economy and power sector towards sustainable development and aims to bring the share of renewable energy in electricity generation to 3% by 2020 rising to 30% by 2030 and 50% by 2050 [55]. While the government is adopting new legal frameworks to encourage the transition towards renewables there are still significant barriers to address including a lack of awareness of the opportunities associated with renewable energy, a lack of technical expertise and capacity, insufficient governmental support to overcome high initial financial and capital requirements and investment disincentives due to subsidies of other energy sources (primarily fossil fuels) [41]. The financial barriers including the low price of electricity in the country, uncertainties with the long term power purchasing tariffs, difficulties in attracting foreign investment and a lack of access to credit for both consumers and investors are currently acting against rapid adoption. Institutional barriers include the absence of a clear national program for renewable energy development, a lack of specific action plans and instruments, a lack of concrete competitive legislation and regulation relating to the newly developed renewable energy market. Given the increasing success of the oil and gas sector, Kazakhstan will require significant government leadership to meet its vision for 2050.

5. Conclusion and Recommendations

The domestic energy sector of Kazakhstan is heavily dependent on fossil fuels (coal, oil and gas) and large hydro plants to deliver its power and electricity needs. Increasing electricity demand associated with rapid economic growth coupled with concerns about environmental pollution is driving a new interest in renewable alternatives. It is argued that Kazakhstan has the necessary natural, climatic, and economic conditions to develop sustainable bioenergy solutions [42] but broad and flexible regulatory support mechanisms and investment incentives are required to encourage adoption of these technologies in light of the success of the oil and gas export industry. Wind power, small and medium-scale hydro and solar technologies also have significant potential and given that 47% of the population is rural, small-scale renewable decentralised energy systems offer good opportunities to transition away from a dependence on fossil fuels and to enable further economic growth. Renewable energy also offers Kazakhstan increasing energy security in the complex interdependencies and geopolitics of the 'Central Asian Energy Game' [58].

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