Energy Situation in Central Asia

Subjects: Energy & Fuels

Contributor: Kedar Mehta

Despite plentiful domestically available energy resources, the energy supply in Central Asia is very unevenly distributed between urban and rural areas. Almost half of the total population of Central Asia lives in rural areas and there is a lack of access to modern energy services to meet primary needs.

Central Asia energy resources rural energy supply energy services renewable energy

1. Introduction

1.1. Background and Context

Universal access to affordable and clean energy access by 2030 is one of the goals defined in the United Nations' Sustainable Development Goals (Goal 7). To enable energy access, researchers have proposed several energy-related solutions to meet basic human needs, such as electricity, heating, cooling, clean cooking, etc., and in despite their work, billions of people are still deprived of even primary energy services [1][2][3][4]. Hence, universal energy access is considered as one of the most crucial targets among all Sustainable Development Goals.

Carrillo [4] identified that the issue of energy scarcity and energy security are especially critical for rural populations of developing countries. Also, Muhumuza et al. [5] recognised that provision of modern energy services remains a key problem and challenge for rural populations.

Research into energy security in the southern part of the world (especially South East Asia and Africa) has a long tradition, most of which focuses on electricity access in rural regions [6][7][8]. However, from the energy research point of view, Central Asia has received less attention than other Asian regions. Energy scarcity in Central Asia exists because of multiple dimensions including the geographical context, nature, environmental influence, and international factors [9].

Geographically, Central Asia is facing completely different energy situations as compared to the industrialised countries of the global north as well as the developing global south [10]. Central Asia is situated between the Caspian Sea in the west and China in the east and between Afghanistan in the south and Russia in the north. The region consists of the five different former Soviet republics called Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The basic statistics and demographics of the Central Asian countries are listed in Table 1, which helps to characterise the Central Asian republics from the socio-economic point of view.

Table 1. Key socio-economic indicators of the Central Asian countries in 2018 (data according to [11][12][13][14][15]).

Indicator	Kazakhstan	Turkmenistan	Uzbekistan	Kyrgyzstan	Tajikistan
Surface area in km^2	2,724,902	488,100	447,400	199,950	141,380
Population in million	18.2	5.8	32.95	6.3	9.1
Share of rural population in %	43	43	50	64	73
Gross Domestic Product in billion	USD 170	USD 40.761	USD 50.49	USD 8.0	USD 7.5
Gross National Income/capita	USD 7970	USD 6380	USD 2000	USD 1130	USD 990

Several geographical and geopolitical factors are unfavourable for economic development in Central Asia [16][17]. The Central Asian region is geographically distant from the foremost centres of world economic activity. Furthermore, all the Central Asian countries are landlocked with minimal transportation connections inside and outside their borders [18][19][20]. The limited connectivity between Central Asia and the outside world remains a major hindrance to expanding the trading and commercial sectors [16][21]. Hence, because of the limited economic activity, most of the Central Asian population make their living in the agriculture and forestry sectors [22][23].

Central Asia is a vast region (~4 million km^2 and has a total population of ~70 million), with a diverse range of geographical features and climates [24]. This includes high-altitude regions, a long-range of snowy mountains, sizeable and warm deserts, and plentiful water resources including two inland seas. Deserts mainly occupy the majority of the land area of Kazakhstan, Uzbekistan, and Turkmenistan. The major deserts in Kazakhstan (Kyzyl Kum and Taklamakan) have extreme temperature ranges with seasonal drought. The strong winds are responsible for dust storms in Kazakhstan which result in agricultural land erosion, and the same applies to the deserts in Turkmenistan and Uzbekistan [25][26][27].

On the other hand, water resources are an essential feature of Kyrgyzstan and Tajikistan. Both countries have extensive mountainous ranges including the Pamir mountain range (Tajikistan) and the Tien Shan mountain range (Kyrgyzstan). These elevated mountainous ranges (up to 7000 m) are responsible for the high-altitude characteristic and the cold climatic zone of these countries [28]. The major part of the mountain ranges is permanently covered with snow and glaciers. The glaciers are the origin of natural water resources which flow in different waterways (i.e., rivers, irrigation channels, water streams, etc.) in Kyrgyzstan and Tajikistan [15]. Downstream countries (Uzbekistan and Turkmenistan) are supplied with river water that is used for irrigation of agricultural fields from upstream countries (Tajikistan and Kyrgyzstan) [29][30].

Central Asia's climate is highly variable across the five countries and represents diverse topographical conditions. For instance, Kyrgyzstan has a cold climate and the majority of the land is covered with snow during the wintertime. However, Tajikistan's climate is mainly subtropical and semi-arid, with half of the country's elevations above 3000 m, while 80% of Turkmenistan area is flat desert [31]. Because of the mountain ranges in the east and southeast, winters are harsh and prolonged with a temperature range of −25 °C to 10 °C with a snow-covered landscape for more than half of the year. The summers across the Central Asian regions are generally warm to hot, with mean temperatures ranging from 10 °C to 40 °C [32].

1.2. A Framework of Energy Resources

Besides its unique geographical and climatic circumstances, Central Asia is endowed with abundant and diverse energy resources, such as natural gas, oil, raw coal, and plentiful untapped renewable energy resources, including hydro, solar, wind, and biomass energy [9][10]. Figure 1 indicates the available natural energy resources by country.

Resources	Kazakhstan	Kyrgyzstan	Tajikistan	Uzbekistan	Turkmenistan
Coal (bt)	31.3	0.9	3.6	3.3	-
Natural Gas (tcm)	2.4	0.006	0.006	1.8	7.5
Oil (bb)	30	0.04	0.01	0.594	0.6
Hydro (GW)	20	26	40	1.7	-

Figure 1. Available energy resources by country (bt = billion tons, tcm = trillion cubic meters, bb = billion barrels, MW = megawatts) (data according to [9][10]).

Kazakhstan is the largest and wealthiest country within the Central Asian region and possesses large oil and coal reserves. Uzbekistan is a significant fossil fuel producer in Central Asia, while Turkmenistan is also a significant energy player in Central Asia, as it has significant natural gas resources and an established thermal power sector [33]. In contrast, Kyrgyzstan and Tajikistan are the smallest and most impoverished countries in the region; however, the very large hydropower resource is concentrated at their disposal. The substantial deposits of fossil fuels are key resources to supply primary energy in Kazakhstan, Turkmenistan, and Uzbekistan. Figure 2 represents the total primary energy supply by various sources in the five countries over the last 25 years [34].

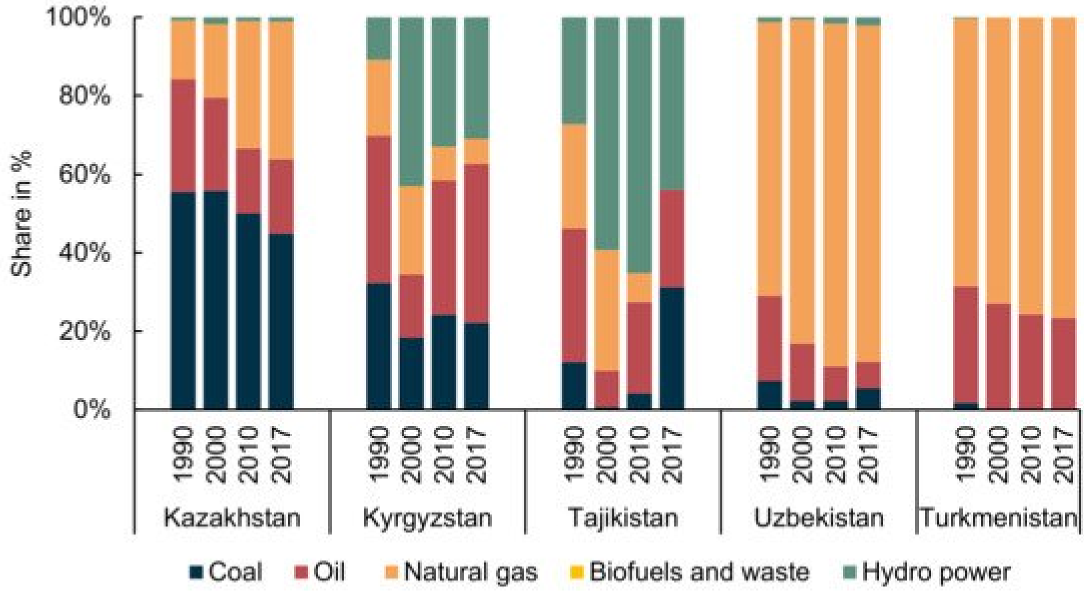


Figure 2. Total Primary Energy Supply in Central Asia by various sources (reproduced from [34], IEA (2019)).

It can be observed from Figure 2 that fossil fuel-based energy supply is a common practice for these countries for the last 25 years. In contrast, Tajikistan and Kyrgyzstan are underprivileged in terms of fossil fuel reservations but fulfil their energy supply mainly from concentrated hydropower. It can be observed from Figure 2 that besides hydropower, other renewable energy (RE) sources are not utilised for energy generation.

Despite its access to diverse energy resources (fossil and non-fossil), Central Asia is facing a complex energy security crisis [10]. The provision of modern, affordable, and reliable energy services remains a challenge, especially in rural Central Asian regions. Rural communities in these regions cannot meet their basic energy needs due to the poor infrastructure of the energy supply systems and geographical isolation from the major energy production centres.

The absence of suitable energy services leads people to use available natural resources to meet their basic energy needs. This heavy reliance on natural resources means considerable exposure to indoor and outdoor air pollution. Mountain societies in Central Asia are highly vulnerable to the impacts of climate change [35][36][37][38]. For example, Reyer [39] investigated the ways that Central Asia experiences climate change by presenting various sectors such as energy, water, food, and heat, and suggested that all of these factors will be severely affected by climate change.

1.3. Objective and Methodology

After independence in 1991, Turkmenistan and Uzbekistan have been on the track towards a speedy recovery in terms of infrastructural development and access to energy services because of their huge deployment of fossil-fuel resources. The export of the fossil-fuels to neighbouring countries (e.g., exports of natural gas to China and coal to Kyrgyzstan and Tajikistan) yields financial growth and stability to the mentioned Central Asian countries [16][33][40]. They then invest these capital inflows in their housing sectors as well as infrastructure development, especially in urban areas. Also, there are very limited information available related to the energy situation in Turkmenistan and Uzbekistan. Hence, this research article focuses on the remaining three countries (Kazakhstan, Kyrgyzstan, and Tajikistan) of Central Asia and investigates their rural energy supplies.

The available scientific information mostly focused on the effects of climate change, the water-energy nexus, and environmental issues in the context of Central Asia [41][42][43][44][45]. However, there is a gap in the literature regarding the distribution of energy services among urban and rural areas in Central Asia. Hence, the research described in this paper aims to perform a comparative analysis and assessment of the current status-quo of energy situation and challenges for selected case study countries of Kazakhstan, Kyrgyzstan, and Tajikistan.

Figure 3 displays the methodological approach of the presented article.

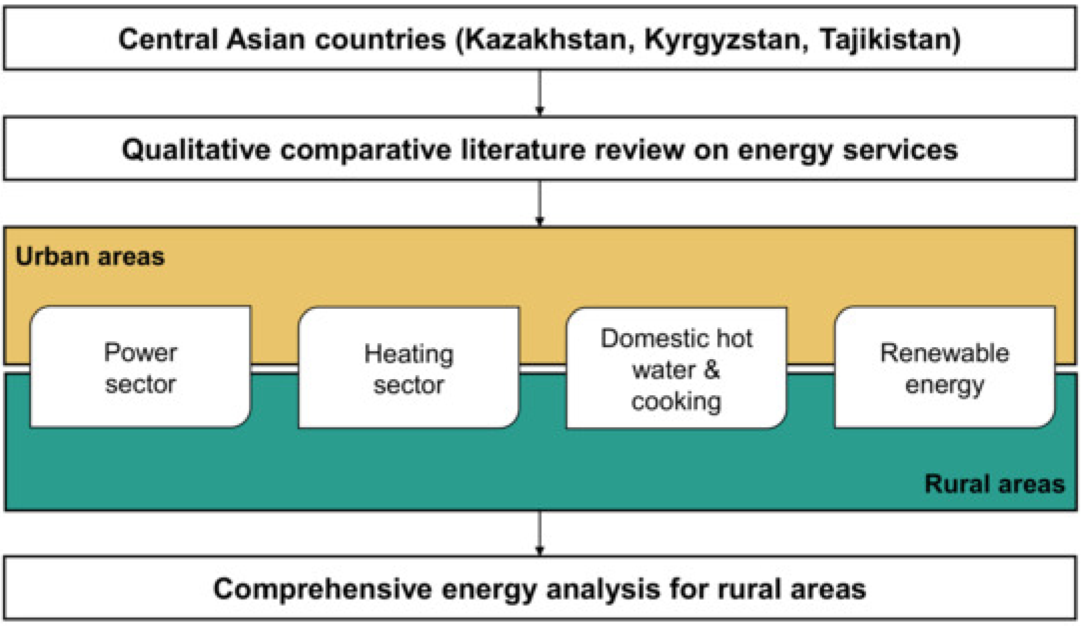


Figure 3. Graphical representation of the concept and structure of the presented review article.

2. The Central Asian Power Sector

The availability of plentiful energy resources has resulted in universal electricity access of up to ~100 % in urban and rural areas of Central Asia [46]. The power grid of Central Asia was set up by the Soviets in 1980. However, the infrastructure of the Central Asian power sector is now outdated and is not capable of fulfilling the growing electricity demand of the individual countries [47]. During the 1980s, the power transmission network of the Central Asian countries was interconnected to form the Unified Energy System of Central Asia (UESCA). The UESCA interlinked approximately 83 power plants (30% hydropower plants and 70% thermal power plants with a total capacity of 25 GW) located across the Central Asian countries with 220 kV and 500 kV transmission lines. This interconnection allows power to flow across the republics [48][49]. However, after independence from the Soviet Union in 1991, the interests of independent Central Asian countries diverged, especially within the energy sector. Turkmenistan and Uzbekistan withdrew themselves from the Unified Energy System in 2003 and 2009, respectively. As a result, Tajikistan was left alone from the unified transmission ring of the Central Asian countries [47][49][50]. Figure 4 represents the integrated Central Asian power network [48].

Figure 4. Central Asian power structure [48].

Due to the pre-existing electricity distribution system, the regions remain physically interconnected but each country now has its own power generation transmission and distribution strategies. Electricity generation capacity is distributed unevenly in Central Asia. For example, mountainous countries such as Kyrgyzstan and Tajikistan use their water resources to produce hydroelectricity, whereas Kazakhstan produces more than 80% of its electricity with coal-fired power plants, as the country has large coal resources [51]. Figure 5 represents the distribution of energy resources for electricity generation in Central Asian countries. Despite the widespread access to electricity in the Central Asian regions, the power sectors of individual countries suffer from many problems, the most common of which is the seasonality of supply and demand.

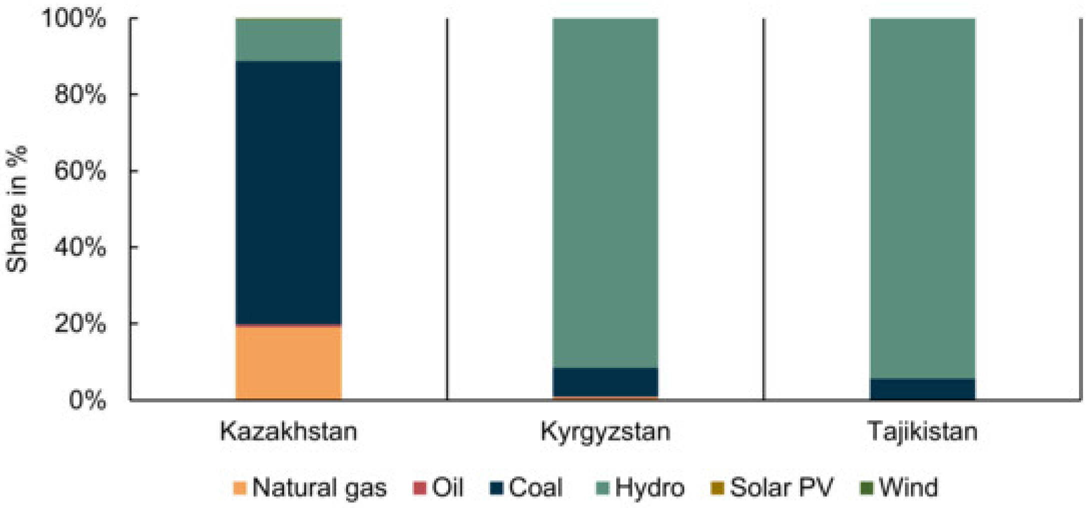


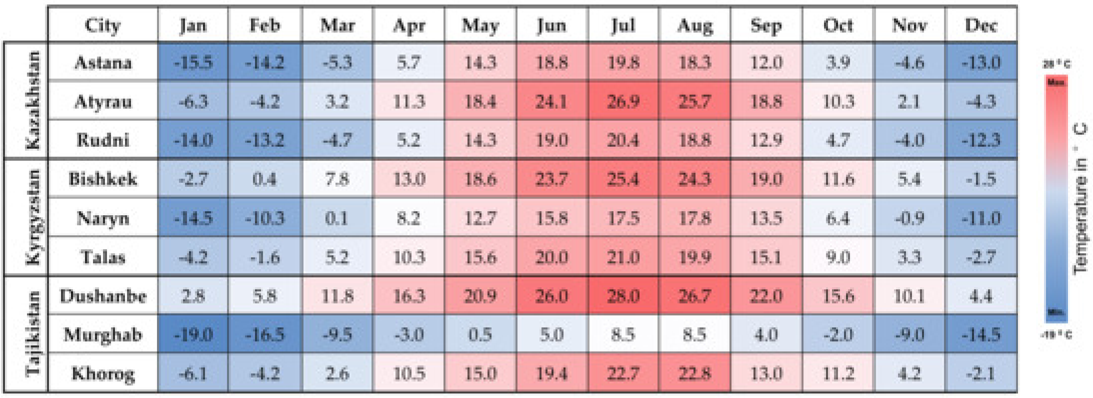
Figure 5. Distribution of energy sources in electricity production (reproduced from [51], IEA (2019)).

The power sectors of Kyrgyzstan and Tajikistan rely mainly on hydro resources, and the power demand of these countries is higher in the winter than in the summer. Due to the cold winters, the river flows decrease, which leads to reduced power production and power shortages. In the summer, the opposite is the case. The regions have therefore established an energy exchange in order to meet seasonal demand. Uzbekistan and Turkmenistan export natural gas to Kazakhstan, Kyrgyzstan, and Tajikistan, while Uzbekistan and Turkmenistan (downstream countries) have minimal water resources and therefore require water to flow from upstream countries (Tajikistan and Kyrgyzstan) for irrigation purposes during the summer and spring.

Kazakhstan, Uzbekistan, and Turkmenistan are directly dependent on their neighbours for water. Because of the winter power shortages, Kyrgyzstan and Tajikistan collect and store water for winter when they experience high power demand. As a consequence, the downstream countries do not receive enough water for agriculture. Because of the unequal and scattered distribution of the energy and water resources in Central Asia, significant tensions can arise between the fossil fuel-rich countries of Kazakhstan, Turkmenistan, and Uzbekistan; and the fossil fuel-poor countries of Tajikistan and Kyrgyzstan [47].

3. The Central Asian Heating Sector

Especially in the high-altitude and cold mountain Central Asian regions, more than half of the annual precipitation falls as snow during the winter (generally from November to March) [52]. The heating period is semi-annual in most of the Northern and Central Asian regions, resulting in around 6000 heating degree days [53]. Figure 6 represents the monthly air temperature of selected cities of the case study countries.



	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kazakhstan	Astana	-15.5	-14.2	-5.3	5.7	14.3	18.8	19.8	18.3	12.0	3.9	-4.6	-13.0
	Atyrau	-6.3	-4.2	3.2	11.3	18.4	24.1	26.9	25.7	18.8	10.3	2.1	-4.3
	Rudni	-14.0	-13.2	-4.7	5.2	14.3	19.0	20.4	18.8	12.9	4.7	-4.0	-12.3
Kyrgyzstan	Bishkek	-2.7	0.4	7.8	13.0	18.6	23.7	25.4	24.3	19.0	11.6	5.4	-1.5
	Naryn	-14.5	-10.3	0.1	8.2	12.7	15.8	17.5	17.8	13.5	6.4	-0.9	-11.0
	Talas	-4.2	-1.6	5.2	10.3	15.6	20.0	21.0	19.9	15.1	9.0	3.3	-2.7
Tajikistan	Dushanbe	2.8	5.8	11.8	16.3	20.9	26.0	28.0	26.7	22.0	15.6	10.1	4.4
	Murghab	-19.0	-16.5	-9.5	-3.0	0.5	5.0	8.5	8.5	4.0	-2.0	-9.0	-14.5
	Khorog	-6.1	-4.2	2.6	10.5	15.0	19.4	22.7	22.8	13.0	11.2	4.2	-2.1

Figure 6. Monthly air temperature heat map of various cities (reproduced from [54], Meteonorm (2018)).

Snow precipitation during winter as well as the cold climatic characteristics of Central Asia with long winters define heating as the primary need of the local people. Therefore, residential energy has a sizable portion in the overall energy consumption framework in Central Asia. It can be observed from Figure 7 that in Kyrgyzstan, residential buildings have the highest share of energy consumption and for Tajikistan and Kazakhstan, residential buildings are the largest energy consumers, followed by the industry sector [55].

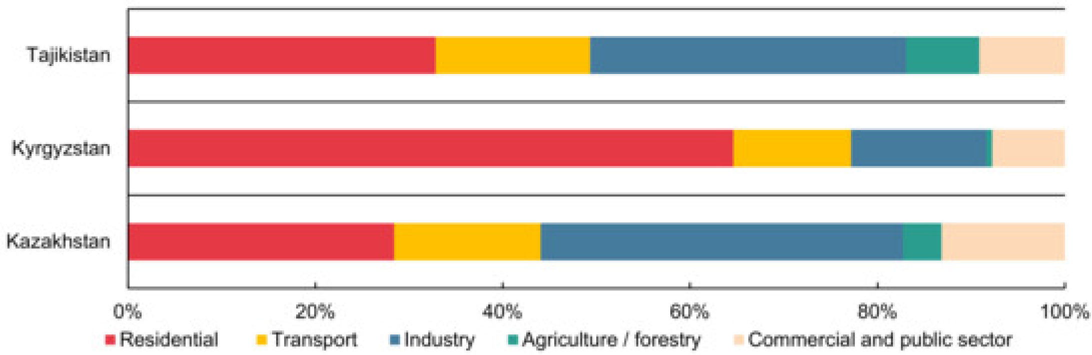


Figure 7. Central Asian total final energy consumption by sectors in 2018 (reproduced from [55], IEA (2020)).

It is estimated that almost 60% to 80% of buildings in Central Asia are earthen buildings built mainly from soil, clay, and adobe without proper building codes [56]. The age of dwellings in combination with vernacular architecture is a key reason for the high energy utilisation in the residential sector for heating in Central Asia. The absence of modern heat energy supply services, low-income, and high heat demand of low energy-efficient building stocks in rural localities promote solid fuel consumption for house heating [53][57]. House heating with solid fuels is common practice in rural Central Asian regions. Generally, rural households used to fuel coal, wood, wood branches, and self-made cow dung in low-efficient traditional heating stoves with a typical thermal efficiency below 40% [58].

4. Hot Water Preparation and Cooking in Central Asia

4.1. Domestic Hot Water

Rural areas in Central Asia are less likely to connect with the centralised water supply system and therefore a limited portion of the rural population has access to piped water in the house for drinking water and for other purposes (i.e., domestic hot water preparation, washing, cleaning, etc.). Freshwater resources in Central Asia are mainly classified as surface water bodies and groundwater. The high proportion of usable water comes from high-land rivers (Kyrgyzstan and Tajikistan), which are transboundary rivers [59][60]. Table 2 represents the proportion of population with access to drinking water for the urban and rural population in Kazakhstan, Kyrgyzstan, and Tajikistan.

Table 2. Access to drinking water for population (%) (reproduced from [59], MDPI (2016)).

Area	Kazakhstan	Kyrgyzstan	Tajikistan
Urban area	78	85	93
Rural area	>35	58	49

It can be concluded from Table 2 that generally, urban areas are supplied with drinking/usable water. In contrast, because of their distant location, rural areas are not strongly connected and have limited access to the central water supplies. Instead, the rural population fetches drinking water from irrigation canals, ditches, and rivers [60]. The low access to the availability of piped water results in limited consumption of hot water. Low-income rural households generally use traditional heating stoves to prepare hot water with a cooking pot (this can be seen in Figure 13) and/or use an electric kettle. Further to this, due to the absence of piped water connections as well as limited income opportunities, typically, rural homes do not have an in-built shower room to take a shower. Rural people use a central/community bathhouse (Banya) to take a shower. Therefore, water consumption in rural areas is limited. The same situation applies with hot water for cooking, washing dishes washing and clothes.

As a result of this very limited hot water use, there is no authentic data source found by the authors which helps to characterise the domestic hot water consumption in urban and rural areas. The households do have precise data on hot water consumption because they fetch the water from outside. Therefore, no water meter is available to measure hot water usage.

4.2. Cooking Methods and Fuel Sources for Cooking

The energy sources and access to modern fuels for cooking differ from region to region in Central Asia. In Kazakhstan, because of the widespread availability of Liquified Petroleum Gas (LPG) and electricity, urban populations use them for cooking purpose [61]. However, rural households in Kazakhstan have lower access to gas networks, hence these areas mainly rely on solid fuels (coal and wood) and/or electricity for cooking. Typically, rural people use a combination of fuels for cooking in the same way as for space heating according to their financial capabilities and the season [62].

In Kyrgyzstan, LPG is favourable energy source for cooking in urban areas (45% of total households) and electricity for rural areas (60% of total households). However, the sizable population in the rural provinces (34%) burns solid fuels for cooking (most commonly wood, followed by cow-dung and agricultural waste) [63].

Due to frequent shortages as well as seasonal interruptions in electricity in Kyrgyzstan and Tajikistan, most rural households prefer to rely on locally available solid fuels. Therefore, according to the availability of electricity, Tajik people prefer electricity for cooking, followed by natural gas (42% and 17% of rural households, respectively). In addition to this, around 37% burn solid fuels for cooking in Tajikistan [64].

5. The Potential of Renewable Energy in Central Asia and Current Trend

Shadrina [65] identified the potential of non-hydropower forms of renewable energy (i.e., solar, wind, biogas etc.) in Central Asia, and revealed that despite their enormous potential, non-hydropower renewable energy is yet to be unleashed. Besides its ample fossil fuel resources, Central Asia has a high potential for RE, which can generate energy sustainably. The abstracted dense river networks in Tajikistan and Kyrgyzstan make them superior for hydro energy [66]. Apart from hydro resources, both countries are blessed with a high potential for solar energy because of their high-altitude characteristics [67]. The potential for solar energy is available in a wide spectrum in Kazakhstan, Uzbekistan, and Turkmenistan as well. Considerable wind energy potential is available in Kazakhstan and Turkmenistan, followed by solar energy [68][69][70][71].

Kyrgyzstan formulated an energy-related policy in 2008 to accelerate these alternative energy sources. However, there was no remarkable progress achieved to expand the Kyrgyz RE sector. Baybagyshov and Degembaeva [72] mentioned that the low solvency as well as limited incentives from the government for RE technologies are the key reasons for the limited expansion of RE in Kyrgyzstan to date. Similarly, Tajikistan also adopted several program documents to expand the RE sector. However, there are inconsistencies for meeting the target in Tajikistan. To meet their growing demand, Kyrgyzstan and Tajikistan keep increasing the installed capacity of hydropower because of their abundant hydro resources. In contrast, other RE resources are mainly untapped. Uzbekistan also uses very limited hydro resources to produce electricity. In addition, its major solar energy potential is untapped and it has no industrial-scale solar power plants. Also, wind potential has not been studied scientifically and is considered as a gap in local research. To foster RE development, Uzbekistan is taking selective measures to establish proper energy legislation. RE development in Turkmenistan is negligible, as Turkmenistan is heavily reliant on natural gas power generation [73].

Figure 8 portrays the trend of the installed renewable energy capacity in Central Asia over the last 20 years. Because of the insignificant contribution of RE sources, Turkmenistan is excluded from the representation. It can be determined from Figure 8 that apart from hydro energy, the employment of other RE resources is mainly untapped. However, Kazakhstan has noticeable progress in RE development.

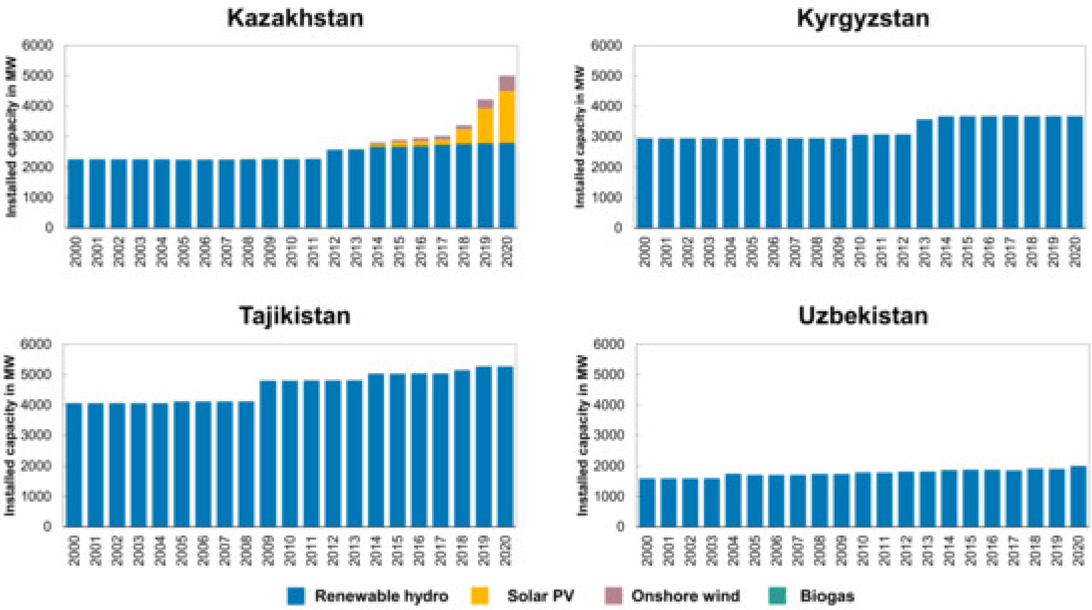


Figure 8. The trend of installed renewable energy capacity in Central Asian countries (reproduced from [74], IRENA (2020)).

On the other hand, a growing body of literature provided evidence that the available RE sources have a phenomenal potential to generate energy to meet unmet demand in Central Asia. Table 3 characterises the literature matrix of selected research articles that focuses on individual countries and their RE potential. It is not practical to present the study of an individual country's RE profile. Therefore, the literature matrix can guide a list of key literature to understand the RE profile of individual republics (Kazakhstan, Kyrgyzstan and Tajikistan) as well as Central Asia as a whole (which covers Uzbekistan as well as Turkmenistan). The detailed investigation in Table 3 identifies that the unique characteristics of the Central Asian region offer a significant potential for renewable energies, which include hydro energy, solar energy, wind energy, biomass energy, and geothermal energy according to the geographical location of the region. However, the available RE sources are usually not exploited in favour of local rural communities. The current energy policies and legislative framework, especially in Kyrgyzstan and Tajikistan, are considered as key barriers to producing electricity with RE sources. The non-cost-effective electricity tariff is significantly below the estimated cost of energy generation from alternative sources. Therefore, investors are not motivated enough to invest in the RE sector. Furthermore, it has been commonly observed in Central Asia that potential investors struggle to obtain loan/finance from regional banks. As a result of this limited financial support, the high capital investment cannot be supported by the investors. Besides investment complexity, special and technical knowledge of RE is either missing or lacking in Central Asia, as there are limited technology providers and knowledge distributors in the local RE sector [68][69][75].

Table 3. Literature matrix to assess the potential of renewable energy in Central Asia.

Author	Research Title	Research Aim	Key Findings	
Central Asia	Shardina (2020) [65]	Non-Hydropower Renewable Energy in Central Asia: Assessment of Deployment Status and Analysis of Underlying Factors	This paper aimed to assess the reasons behind the untapped and limited development of RE sectors in Central Asian countries.	The article summarises that RE sources are distributed unevenly, and the author also suggested policy implications to improve the commitment to RE in Central Asia.
	Nurdavletova and Akatayeva (2018) [69]	The renewable energy in the regional development of Central Asia	The main objective of the article was to investigate the available alternative sources in Central Asia and inter-regional complexity.	The article provided a glance at the potential of the RE sector in individual countries and key hurdles in detail for the implementation of RE in Central Asian republics.
	Abylkasymova (2019) [76]	Wind Power Potential of the Central Asian Countries	Theoretical wind power supply capacity as well as existing wind power installations were investigated as a key aim of the article.	Wind power has significant theoretical potential in all Central Asia countries. Over 70% of regional total wind potential is concentrated in Kazakhstan.
	Gubaidullina et al. (2017) [77]	Renewable energy and the regional prospect on sustainable	The paper aimed to provide useful information on the issues of renewable energy in Central Asia, as well as the insight of RE status for individual countries.	The most rapid development in the field of renewable energy is noticed in Kazakhstan and the least developed

Author	Research Title	Research Aim	Key Findings	
		development of Central Asia		sphere of RES is in Turkmenistan.
	Kiseleva et al. (2017) [78]	Efficiency estimation for the grid-tie photovoltaic stations construction in some regions of Central Asia and Transcaucasia	This techno-economic assessment evaluated the construction of network PV farm (5 MW) in selected regions of Central Asian countries.	By consideration of local feed-in tariffs, the simple payback period was determined to last 4–6 years in different regions of Central Asia for small scale PV farms (5 MW).
Kazakhstan	Zavadskiy and Revalde (2020) [79]	Problems of development of renewable energy facilities in rural regions on the example of Kazakhstan	This manuscript presents an outline of the difficulties and problems with the development of renewable energy sources in the rural regions of Kazakhstan	Kazakhstan possesses great renewable energy potential, especially in rural areas (solar, wind and bioenergy). The research article also recommends employing a special programme/policy to promote RE in Kazakhstan.
	Vakhguelt (2017) [80]	Renewable Energy Potential of Kazakhstan	The article presents the recent status quo of available potential of hydropower, wind power, solar power, geothermal energy, and bioenergy and their available operations in Kazakhstan.	Kazakhstan has a great potential for renewable energy production. Most of the Kazakh territory has great solar potential as well as considerable wind energy.

Author	Research Title	Research Aim	Key Findings	
	Karatayev et al. (2016) [81]	Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy	With the help of the analytical hierarchy process, this paper investigates and ranks the different barriers towards the adoption of renewable energy in Kazakhstan. Also, it provides interesting insights into the country's legal framework.	It was identified that sustainable and affordable RE systems toned to be introduced in Kazakhstan for low carbon energy generation. Despite abundant available RE resources renewable energy currently contributes to less than 1% of the country's power generation.
Kyrgyzstan	Abidov et al. (2020) [82]	Comparative Analysis of Some Types of Renewable Energy Sources	The article discussed the current state and possibilities of using alternative energy in Kyrgyzstan. It also assessed non-traditional renewable energy sources as well as the economic efficiency and its payback period.	The article identified that each type of RE source has its positive benefits in various regions of Kyrgyzstan. It also explained the reasons behind the insufficient use of RE in Kyrgyzstan.
	Baybagyshov and Degembaeva (2019) [72]	Analysis of the usage of renewable energy in Kyrgyzstan	The manuscript defined the analysis results of the opportunity of using renewable energies (Solar, wind, hydro, biomass, and geothermal) in Kyrgyzstan.	The analysis showed that the country has a great potential for renewable energy, which is unexploited. The use of renewable energy for Kyrgyzstan should be considered as a solution to population's socio-economic problems in

Author	Research Title	Research Aim	Key Findings	
				the decentralised high-altitude regions region.
Tajikistan	Schulz et al. (2014) [83]	The energy supply for mountain settlements in Tajikistan based on renewable energy sources	This article investigated the electrification of mountain settlements/communities of Tajikistan by means of combined forms of renewable energy sources (i.e., a small hybrid hydropower station, small PV station).	The article claimed that there is an immediate need to solve the seasonal deficiency of the Tajik power sector. It suggests that a small-scale hybrid power station operated by combined RE sources will be suitable for sustainable electricity supply for remote settlements in Tajikistan.
	Doukas et al. (2012) [84]	Promoting renewables in the energy sector of Tajikistan	The document presented multi-dimensional approach to identify the suitability of decentralised heat production in Tajikistan.	Technically, a low-pressure solar water heater is a more suitable design for Tajikistan. Also, the paper identified the hurdles for further development of decentralised heat production.

7. Hostettler, S.; Gadgil, A.; Hazboun, E. Sustainable Access to Energy in the Global South; Springer International Publishing: Cham, Switzerland, 2015; ISBN 978-3-319-20208-2.

8. Mainali, B.; Silveira, S. Alternative pathways for providing access to electricity in developing countries. Renew. Energy 2013, 57, 299–310.

9. Shadrina, E. Renewable Energy in Central Asian Economies: Role in Reducing Regional Energy Insecurity; ADBI Working Paper 993, Tokyo. 2019. Available online: (accessed on 5 April 2020).

10. World Bank. Central Asia—Water and Energy Program: Working for Energy and Water Security (English) No. 141508, Washington. 2019. Available online: (accessed on 24 October 2020).

11. World Bank. Surface Area (sq. km). Available online: (accessed on 24 October 2020).
12. World Bank. Population. Available online: (accessed on 20 February 2019).
13. World Bank. GDP (current US$). Available online: (accessed on 30 October 2020).
14. World Bank. GNI per Capita, Atlas Method (Current US$). Available online: (accessed on 30 October 2020).
15. Pohl, B.; Kramer, A.; Hull, W.; Blumstein, S.; Abdullaev, I.; Tais, K.J.R.; Strikeleva, E.; Interwies, E.; Görlitz, S. Rethinking Water in Central Asia: The costs of Inaction and Benefits of Water Cooperation; Swiss Agency of Development and Cooperation (SDC): Berlin, Germany, 2017.
16. Batsaikhan, U.; Dabrowski, M. Central Asia—twenty-five years after the breakup of the USSR. Russ. J. Econ. 2017, 3, 296–320.
17. Dowling, M.; Wignaraja, G. Central Asia after Fifteen Years of Transition: Growth, Regional Cooperation, and Policy Choices, Philippines. 2006. Available online: (accessed on 5 April 2020).
18. Batsaikhan, U.; Dabrowski, M. Central Asia at 25. Available online: (accessed on 24 February 2020).
19. Raballand, G.; Kunth, A.; Auty, R. Central Asia's transport cost burden and its impact on trade. Econ. Syst. 2005, 29, 6–31.
20. Linn, J.F.; Blaxall, M. Central Asia Human Development Report 2005: Bringing Down Barriers: Regional Cooperation for Human Development and Human Security; UNDP Regional Bureau for Europe and the Commonwealth of Independent States: Bratislava, Slovakia, 2005; ISBN 92-95042-34-4.
21. Russell, M. Connectivity in Central Asia: Reconnecting the Silk Road. Available online: (accessed on 5 April 2020).
22. Bobojonov, I.; Aw-Hassan, A. Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. Agric. Ecosyst. Environ. 2014, 188, 245–255.
23. Hamidov, A.; Helming, K.; Balla, D. Impact of agricultural land use in Central Asia: A review. Agron. Sustain. Dev. 2016, 36, 77.
24. USAID. Climate risk profile: Central Asia: Fact Sheet. Available online: (accessed on 30 October 2020).
25. Asian Development Bank. Central Asia Atlas of Natural Resources; Asian Development Bank: Metro Manila, Philippines, 2014; ISBN 978-971-561-886-1.
26. Orlovsky, L.; Orlovsky, N.; Durdyev, A. Dust storms in Turkmenistan. J. Arid Environ. 2005, 60, 83–97.

27. Indoitu, R.; Orlovsky, L.; Orlovsky, N. Dust storms in Central Asia: Spatial and temporal variations. J. Arid Environ. 2012, 85, 62–70.

28. Frenken, K. Irrigation in Central Asia in Figures: AQUASTAT Survey—2012; Food and Agriculture Organization of the United Nations: Rome, Italy, 2013; ISBN 978-92-5-107660-6.

29. Rahaman, M.M. Principles of Transboundary Water Resources Management and Water-related Agreements in Central Asia: An Analysis. Int. J. Water Resour. Dev. 2012, 28, 475–491.

30. Zou, S.; Jilili, A.; Duan, W.; Maeyer, P.D.; Van de Voorde, T. Human and Natural Impacts on the Water Resources in the Syr Darya River Basin, Central Asia. Sustainability 2019, 11, 3084.

31. FAO. AQUASTAT Country Profile—Tajikistan, Rome (Italy). 2012. Available online: (accessed on 5 April 2020).

32. Mueller, L.; Saparov, A.; Lischeid, G. (Eds.) Novel Measurement and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia; Springer: Cham, Switzerland, 2014; ISBN 978-3-319-01016-8.

33. Aminjonov, F. Re-Thinking Central Asian Energy Security: Pitfalls of Export Diversification Policies, Kazakhstan. 2016. Available online: (accessed on 16 December 2019).

34. IEA. Total Primary Energy Supply (TPES) in Central Asia. Available online: (accessed on 5 April 2020).

35. Christmann, S.; Aw-Hassan, A. Should agricultural research in Central Asia and Caucasus (CAC) re-prioritize its agenda with view to climate change? Agric. Ecosyst. Environ. 2011, 140, 314–316.

36. Qi, J.; Bobushev, T.S.; Kulmatov, R.; Groisman, P.; Gutman, G. Addressing global change challenges for Central Asian socio-ecosystems. Front. Earth Sci. 2012, 6, 115–121.

37. Ariza, C.; Maselli, D.; Kohler, T. Mountains: Our Life, Our Future. Progress and Perspectives on Sustainable Mountain Development from Rio 1992 to Rio 2012 and Beyond; Centre for Development and Environment, University of Bern: Bern, Switzerland, 2013.

38. Xenarios, S.; Gafurov, A.; Schmidt-Vogt, D.; Sehring, J.; Manandhar, S.; Hergarten, C.; Shigaeva, J.; Foggin, M. Climate change and adaptation of mountain societies in Central Asia: Uncertainties, knowledge gaps, and data constraints. Reg. Environ. Change 2019, 19, 1339–1352.

39. Reyer, C.P.; Otto, I.M.; Adams, S.; Albrecht, T.; Baarsch, F.; Cartsburg, M.; Coumou, D.; Eden, A.; Ludi, E.; Marcus, R.; et al. Climate change impacts in Central Asia and their implications for development. Reg. Environ. Change 2017, 17, 1639–1650.

40. Kampakis, A. Divesting from fossil fuels in Central Asia: Factors affecting Renewable Energy Transition in Kazakhstan, Kyrgyzstan, Tajikistan. Master Thesis, Vrije Universiteit, Amsterdam, The Netherland, 2015.

41. Abbasi, Z.A.K.; Nawaz, A. Impact of Climate Change Awareness on Climate Change Adaptions and Climate Change Adaptation Issues. PJAR 2020, 36.

42. Zhang, M.; Chen, Y.; Shen, Y.; Li, B. Tracking climate change in Central Asia through temperature and precipitation extremes. J. Geogr. Sci. 2019, 29, 3–28.

43. Qi, J.; Kulmatov, R. An Overview of Environmental Issues In Central Asia. In Environmental Problems of Central Asia and their Economic, Social and Security Impacts; Qi, J., Evered, K.T., Eds.; Springer Netherlands: Dordrecht, The Netherlands, 2008; pp. 3–14. ISBN 978-1-4020-8959-6.

44. Junxia, L. Investments in the energy sector of Central Asia: Corruption risk and policy implications. Energy Policy 2019, 133, 110912.

45. Chen, H.; Liu, H.; Chen, X.; Qiao, Y. Analysis on impacts of hydro-climatic changes and human activities on available water changes in Central Asia. Sci. Total Environ. 2020, 737, 139779.

46. World Bank. Access to Electricity (% of Population). Available online: (accessed on 5 March 2021).

47. Toralieva, G. Destruction of Central Asian Electricity Grid: Causes and Implications. Available online: (accessed on 5 April 2020).

48. GICA. Central Asian Power System (CAPS). Available online: (accessed on 23 September 2020).

49. Asia Pacific Energy Portal. Energy and Development in Central Asia: A Statistical Overview of Energy Sectors in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Available online: (accessed on 10 April 2020).

50. World Bank. Central Asia Energy-Water Development Program: Annual Report 2017; No. 132036, Washington D.C., 2018. Available online: (accessed on 10 April 2020).

51. IEA. Electricity Generation by Source. Available online: (accessed on 10 February 2020).

52. Gerlitz, L.; Steirou, E.; Schneider, C.; Moron, V.; Vorogushyn, S.; Merz, B. Variability of the Cold Season Climate in Central Asia. Part I: Weather Types and Their Tropical and Extratropical Drivers. J. Climate 2018, 31, 7185–7207.

53. Kerimray, A.; de Miglio, R.; Rojas-Solórzano, L.; Gallachóir, B.Ó. Household Energy Consumption and Energy Poverty in Kazakhstan; International Association for Energy Economics: 2017. Available online: (accessed on 4 October 2020).

54. Meteotest AG. Meteonorm; Meteotest AG: Bern, Switzerland, 2018.

55. IEA. Total Final Energy Consumption by Sectors in Central Asia. Available online: (accessed on 5 April 2020).

56. Fodde, E. Traditional Earthen Building Techniques in Central Asia. Int. J. Archit. Herit. 2009, 3, 145–168.
57. Howie, P.; Atakhanova, Z. Household Coal Demand in Rural Kazakhstan: Subsidies, Efficiency, and Alternatives. Energy Policy Res. 2017, 4, 55–64.
58. World Bank. Fueling Kyrgyzstan’s Transition to Clean Household Heating Solutions; World Bank: Washington, DC, USA, 2020.
59. Bekturganov, Z.; Tussupova, K.; Berndtsson, R.; Sharapatova, N.; Aryngazin, K.; Zhanasova, M. Water Related Health Problems in Central Asia—A Review. Water 2016, 8, 219.
60. Russell, M. Water in Central Asia: An Increasingly Scarce Resource. Available online: (accessed on 4 October 2020).
61. Kerimray, A.; de Miglio, R.; Rojas-Solórzano, L.; Ó Gallachóir, B.P. Causes of energy poverty in a cold and resource-rich country: Evidence from Kazakhstan. Local Environ. 2018, 23, 178–197.
62. Kerimray, A.; de Miglio, R.; Rojas-Solórzano, L.; Gallachóir, B.Ó. Incidence of District Heating and Natural Gas Networks on Energy Poverty across Kazakhstan. In Proceedings of the 1st IAEE Eurasian Conference; Energy Economics Emerging from the Caspian Region: Challenges and Opportunities; Baku, Azerbaijan, 28–31 August 2016, 2016.
63. FAO. National Gender Profile of Agricultural and Rural Livelihoods—Kyrgyz Republic: Country Gender Assessment Series. Ankara (Turkey). 2016. Available online: (accessed on 20 August 2018).
64. FAO. National gender profile of agricultural and rural livelihoods—Tajikistan: Country gender assessment series. Available online: (accessed on 4 October 2020).
65. Shadrina, E. Non-Hydropower Renewable Energy in Central Asia: Assessment of Deployment Status and Analysis of Underlying Factors. Energies 2020, 13, 2963.
66. Abylkasymova, A.; Eshchanov, B.; Overland, I.; Moldokanov, D.; Aminjonov, F.; Vakulchuk, R. Hydropower Potential of the Central Asian Countries; Central Asia Data-Gathering and Analysis Team. 2019. Available online: (accessed on 4 October 2020).
67. Petrov, G. Resources and Use of Renewable Energy in Tajikistan; 2010. Available online: (accessed on 4 March 2021).
68. Nabiyeva, K. Renewable Energy and Energy Efficiency in Central Asia: Prospects for German Engagement; Michael Succow Foundation: Greifswald, Germany, 2015.
69. Nurdavletova, S.; Akatayeva, A. The renewable energy in the regional development of Central Asia. SSI 2018, 162–185.

70. Eshchanov, B.R.; Grinwis Plaat Stultjes, M.; Eshchanov, R.A.; Salaev, S.K. Prospects of renewable energy penetration in Uzbekistan—Perception of the Khorezmian people. Renewable and Sustainable Energy Reviews 2013, 21, 789–797.

71. Karimov, K.S.; Akhmedov, K.M.; Abid, M.; Petrov, G.N. Effective management of combined renewable energy resources in Tajikistan. Sci. Total Environ. 2013, 461-462, 835–838.

72. Baybagyshov, E.; Degembaeva, N. Analysis of usage of the renewable energy in Kyrgyzstan. IOP Conf. Ser. Earth Environ. Sci. 2019, 249, 12021.

73. IEA. Uzbekistan Energy Profile. Available online: (accessed on 29 April 2021).

74. IRENA. Trends in Renewable Energy: Installed Capacity. Available online: (accessed on 29 April 2021).

75. Yoshino, N.; Taghizadeh-Hesary, F.; Youngho, C.; Le, T.-H. (Eds.) Energy Insecurity in Asia: Challenges, Solutions and Renewable Energy; Asian Development Bank Institute: Tokyo, Japan, 2020; ISBN 978-4-89974-111-4.

76. Abylkasymova, A.; Moldokanov, D.; Eshchanov, B.; Overland, I.; Aminjonov, F.; Vakulchuk, R. Wind Power Potential of the Central Asian Countries. Available online: (accessed on 29 April 2021).

77. Gubaidullina, M.; Balaubaeva, B.; Karimova, S. Renewable energy and the regional prospect on sustainable development of Central Asia. IRILY 2017, 80, 4–17.

78. Kiseleva, S.V.; Popel', O.S.; Tarasenko, A.B.; Avezov, R.R. Efficiency estimation for the grid-tie photovoltaic stations construction in some regions of Central Asia and Transcaucasia. Appl. Sol. Energy 2017, 53, 306–311.

79. Zavadskiy, V.; Revalde, G. Problems of development of renewable energy facilities in rural regions on example of Kazakhstan. In 19th International Scientific Conference Engineering for Rural Development Proceedings; Latvia University of Life Sciences and Technologies, Faculty of Engineering: Jelgava, Latvia, 2020.

80. Vakhguelt, A. Renewable Energy Potential of Kazakhstan. DDF 2017, 379, 189–194.

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

82. Abidov, A.; Ryspaev, T.; Satybaldyev, A.; Gorbacheva, A. Comparative Analysis of Some Types of Renewable Energy Sources. Industrija 2020, 46, 93–111.

83. Schulz, D.; Ahrorova, A.D.; Halimjanova, M.K.; Kholov, K.H. The energy supply for mountain settlements in Tajikistan based on renewable energy sources. In Energy Production and Management in the 21st Century; ENERGY QUEST 2014, Ekateringburg, Russia, 23–25 Apr.

2014; Brebbia, C.A., Magaril, E.R., Khodorovsky, M.Y., Eds.; WIT Press: Southampton, UK, 2014; pp. 971–978.

84. Doukas, H.; Marinakis, V.; Karakosta, C.; Psarras, J. Promoting renewables in the energy sector of Tajikistan. Renew. Energy 2012, 39, 411–418.