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OVERCOMING BARRIERS TO THE ADOPTION OF DECENTRALIZED ENERGY GENERATION IN CENTRAL ASIA

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Abstract

This thesis explores decentralized energy generation in Central Asia, focusing on overcoming barriers to adoption. It combines qualitative research, analyzing data from various sources to understand the region's energy issues, including supply losses, reliance on a single energy source, environmental impacts, and energy poverty. The study aims to identify strategies for implementing decentralized energy systems, drawing on examples from Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan. By examining decentralized energy's potential to enhance energy security and sustainability, this work contributes to the broader discourse on energy transition in developing regions.

Summery

As the world progresses, energy generation is shifting from a centralized approach to a decentralized one. The promotion of decentralized energy (DE) is a fundamental component of the energy and economic strategies being implemented worldwide to advance towards a more sustainable future. It has potential to solve energy poverty and create strong, stable energy distribution due to combination of renewable energy resources and sustainable energy consumption. Widespread deployment of DE helped many countries to overcome relying from fossil fuels and to achieve high environmental performance. Furthermore, this DE can provide energy security and the opportunity to bring digitalization and other technological advancements to the energy sector. For example, thanks to smart grids where users may be able to generate electricity through solar panels in homes and put it back to the network, or electric vehicles can provide energy to help balance loads “peak shaving” (sending power to the network when demand is high).

Nowadays many countries are facing numerous challenges related to energy production, consumption, and distribution. As energy requirements continue to escalate and with finite fossil fuel reserves, Central Asia faces exposure to unpredictable pricing, supply chain disruptions, and environmental degradation due to its reliance on imported energy sources. Central Asia consists of five countries, three of which – Kazakhstan, Uzbekistan, and Turkmenistan – are rich with oil and gas while Tajikistan and Kyrgyzstan are upstream countries endowed with water resources. Downstream countries tend to generate electricity from fossil fuels while upstream countries rely on hydroelectric power. Specifically, Uzbekistan and Turkmenistan generate electricity mostly from gas while Kazakhstan uses coal to power more than 70% of its electricity generation. Meanwhile, Tajikistan and Kyrgyzstan generate most of their electricity from hydropower plants

However, despite the benefits of decentralized energy generation, there are numerous barriers that hinder its widespread adoption in Central Asia. Main problems for adopting DE are lack of interest of political organizations in promoting sustainable energy development and lack of awareness among the people as this is a new concept for Central Asia. This thesis aims to explore and analyze the barriers to the adoption of decentralized energy generation in the region and propose potential strategies and recommendations to overcome these barriers. Through this research, the hope is to contribute to the advancement of sustainable energy development in Central Asia and promote a more resilient, equitable, and environmentally conscious energy future.

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List of acronyms

CCA	Community Choice Aggregation
CHP	Combined heat and power
DE	Decentralized Energy
DES	Decentralized Energy System
DG	Decentralized generation
ESS	Energy Storage System
ETS	Emissions trading system
FiT	Feed-in Tariff
GDP	Gross domestic product
GOGLA	Global Off-Grid Lighting Association
IEA	International Energy Agency
IFC	International Finance Corporation
IMF	International Monetary Fund
LNG	Liquefied natural gas
NGO	Non-governmental organization
PAYG	Pay-As-You-Go
RETCA	Renewable Energy Transition in Central Asia
UESCA	Unified Energy System of Central Asia
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNIDO & ICSHP	United Nations Industrial Development Organization and The International Center on Small Hydro Power

I Introduction

1.1 Take control over energy consumption

One common motivation driving community energy initiatives is the desire to gain greater independence from centralized energy markets. People are increasingly eager to explore innovative ways to integrate modern technologies into their lives, creating a more convenient lifestyle while taking responsibility for their consumption and its environmental impact. In today's world, the importance of actively participating in various aspects of life has led to the development of diverse technologies, with a heightened focus on one of life's most crucial aspects: energy generation. Prioritizing energy efficiency addresses critical issues such as energy security, climate change, and the rising costs of energy. As individuals become more conscious of their carbon footprint and the impact of their energy choices, they are motivated to seek new opportunities for responsible energy consumption. In 2022, global energy use saw a remarkable 2% increase compared to the previous year, reflecting significant and rapid progress in recent years. Additionally, private investments, totaling USD 560 billion, were dedicated to initiatives aimed at creating more environmentally friendly devices in buildings, improving public transportation systems, and promoting the use of electric vehicles. This marks a significant step towards a more sustainable and energy-conscious world [1].

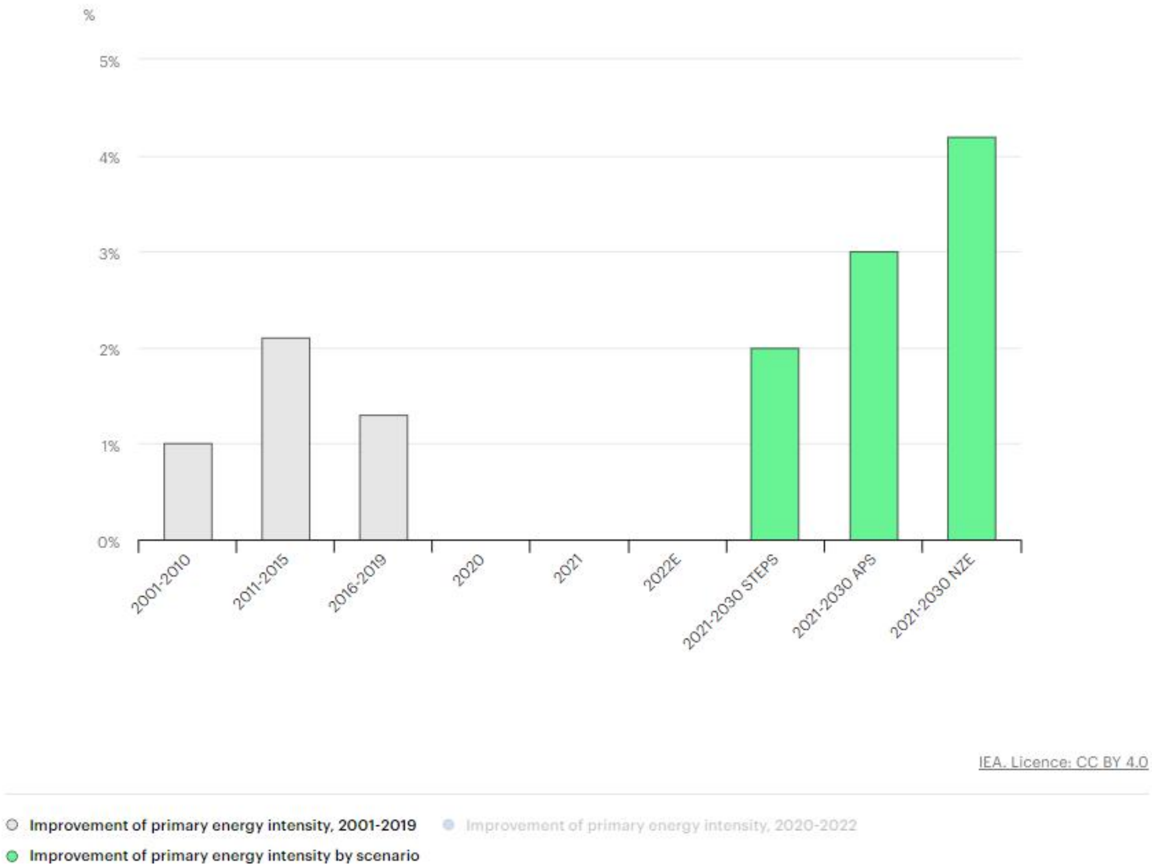

Figure 1.1: Annual global energy intensity improvement by scenario, 2001-2030, from IEA

The Energy Efficiency report of 2022 by International Energy Agency (IEA) highlighted the energy demand is slowing down and in the nest decades the use of energy efficiently will be increasing, which is reported in the Figure 1.1 [2].

1.2 Decentralized energy generation as a solution for improving energy efficiency

Decentralized Energy generation is an efficient substitute of Centralized plants that were used as a first industries to spread electricity through countries that can be shown in Figure 1.2. The decentralized system (see Figure 1.3) is concentrated in two way flow of electricity, making availability to choose among different energy supply sources: solar PV, small-scale wind, etc with more conciseness usage of energy through monitoring and steering, pooling demand between householders [3].

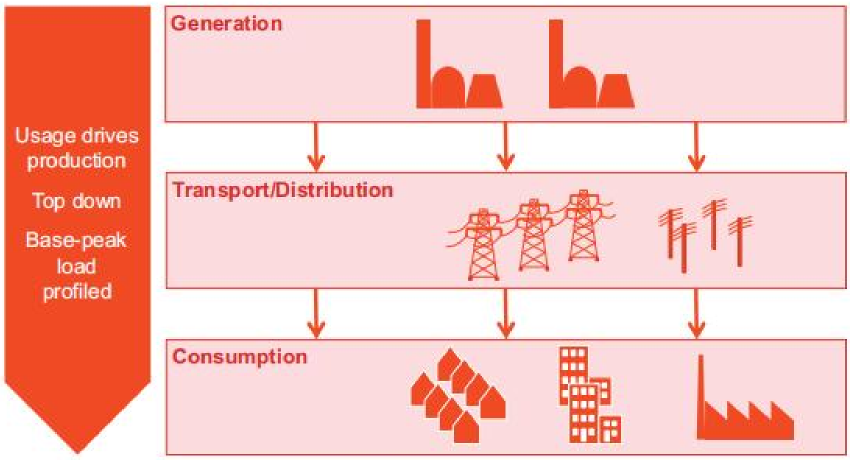

Figure 1.2: The traditional energy chain, source: PwC

The decentralized energy system has main goals:

- ✓ Local communities awareness: DES makes locals to control their energy production and consumption through smart grids. Example: Community Choice Aggregation (CCA) in California, USA, where regional non-profits now make decisions on decarbonization and democratization.

- ✓ Energy that can be trans-active and shared: DES will enable sharing between stakeholders, new community energy opportunities, shared ownership models, and, finally, true trans-active energy, where smart onsite systems follow personal profiles and market surplus energy when transactions are available.

- ✓ Energy poverty declines: the pandemic, inflation, and the energy crisis have combined to set back global progress on universal access to electricity. 800M people are lack access to electricity of any type. Therefore, DES holds great promise to provide simple, affordable on-site systems that dramatically improve quality of life in developing countries. Increasingly affordable and versatile DES now provides energy access to developed and developing countries.

✓ Innovation and entrepreneurship: opportunities to deploy new and innovative energy DES solutions lead to another market acceptance of new technologies and business models that promote economic growth and job creation.

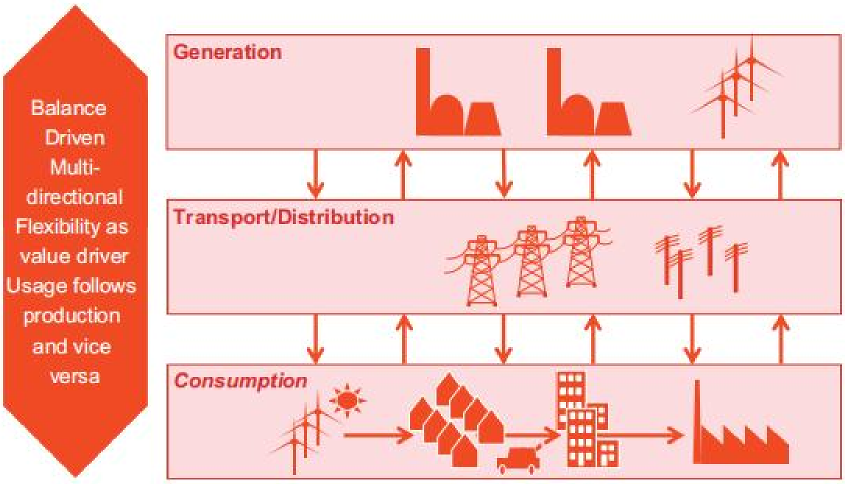

Figure 1.3: The decentralized energy generation, source: PwC

Challenges related to the implementation of renewable energy include:

✓ High equipment expenses,
✓ Reliance on the availability of local renewable resources,
✓ Fluctuations in energy output due to the dependence on natural elements,
✓ Integrating diverse resources with traditional base load generation into the energy system,
✓ The need for ongoing technical advancements to ensure a dependable renewable energy system,
✓ The role of hydrogen in enhancing energy storage capabilities [4].

The differences between two energy sources is represented below (see Table 1.1) [5].

Characteristics	Centralized energy system	Decentralized energy system
Structure	Linear: generation, transmission/distribution, demand	Integrated: • Vertically, between voltage levels • Horizontally, between energy carriers
Number of power plants	Few large plants	Many small plants and prosumers
Ownership	Few large companies	Many small owners, e.g. private individuals, farmers

Characteristics	Centralized energy system	Decentralized energy system
Data: amount	Moderate	Low
Concentration of supply security	high	Low
Investment decision: flexibility and speed	Low	High
Controllability: markets	Centralized, increasingly integrated	Centralized and/or decentralized
Controllability: location	Generation, transmission and distribution	All areas of system, i.e. including demand
Economic benefits	• Economies of scale in large plants • Lower distribution grid investment	• Lower transmission grid investment • Lower centralized generation capacities and regulating power needs
Flexibility: amount	Roughly the same for both systems	Roughly the same for both systems
Flexibility: characteristics	• In transmission grid • Larger geographical areas	• In distribution grid • Smaller geographical areas
Storage requirements: amount	Roughly the same for both systems	Roughly the same for both systems
Storage requirements: characteristics	Large, centralized	Small, decentralized
Relevance of social acceptance	Less important	Very important

Table 1.1: Characteristics of centralized and decentralized energy systems (by Funcke&Bauknecht, 2016, Bauknecht et al., 2015, Jensch, 1989, Weber & Vogel, 2005)

1.3 Types of decentralized energy generation technologies

The aim of Decentralized Generation is to make a positive impact on climate protection by using modern technologies to provide energy that meets customer needs while also bolstering energy security. It strives to achieve these goals effectively and efficiently [6].

Renewable energy sources

Hence, one of the main goal is to utilize green energy daily in order to reduce increasing carbon emissions, because the systems works with different energy sources like solar, wind, biomass, hydro and other renewable energy which are located to a user making comfortable use with meeting energy needs [7].

Micro-combined heat and power (Micro-CHP)

CHP system (see Figure 1.4) was created as alternative to the heat losses during production and transportation in Centralized energy generation. The structure is: heat engine, generator, heat recovery and electrical converter. It comes in three categories based on electrical capacity: micro-cogeneration (below 50 kWe), small-scale cogeneration (50 kWe to 1 MWe), and cogeneration (above 1 MWe) [8].

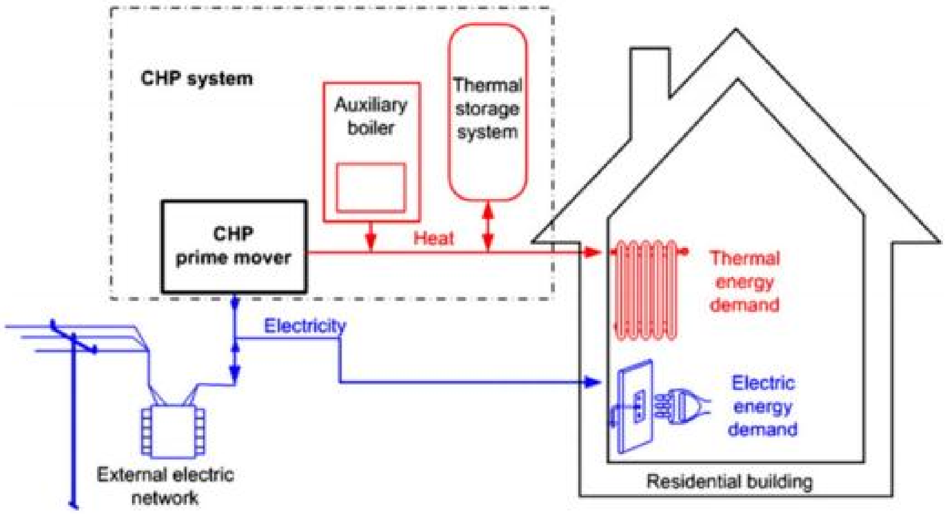

Figure 1.4: Typical integration of mcro-CHP system in
a residential building, by Martines et al., 2017

Geothermal heat pumps

The Heat pumps through geothermal source gives effective use of the thermal energy from the earth. One of the example heat pump is shown in Figure 1.5. The function is similar to the household refrigerator which is refrigerant cycle. In the heating mode heat pump removes the heat from a low temperature source, such as the ground or air, and supplies that heat to a higher temperature sink, such as the heated interior of a building. In the cooling mode the process is reversed and the heat is extracted from the cooler inside air and rejected to the warmer outdoor air or other heat sink [9].

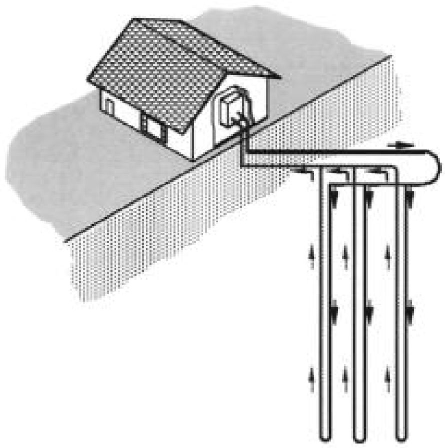

Figure 1.5: Vertical ground-coupled heat pump, by Phetteplace, 2007

Fuel cells

Fuel cells are devices that create electrical energy through a chemical process. They consist of an electrolyte, positioned between two electrodes: the anode and the cathode. The anode helps with oxidation (a chemical reaction that removes electrons), while the cathode assists in the electro-chemical reduction (a process that adds electrons). During this oxidation-reduction reaction, ions and electrons are produced, and the electrons generated at the anode form the external electric current [10].

Distributed energy storage

The aim of the system is to optimize control functions, limits, and boundaries, starting from decentralized energy generation. Energy Storage Systems (see Figure 1.6) have a vital role. They reduce peak loads, enhance grid stability, and improve power quality. ESSs, along with advanced power electronics, provide technical benefits and financial advantages by reshaping the electricity value chain for a more reliable and efficient power system [11].

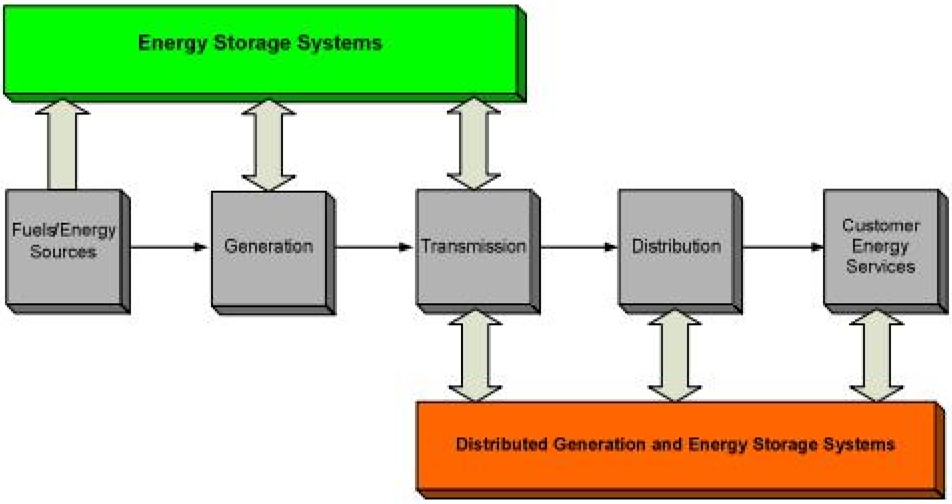

Figure 1.6: Electricity value chain with energy storage
as the sixth dimension, source: Energy Storage Council (ESC)

Cogeneration (Combined heat and power-CHP)

The system was created to maximize the efficient use of energy resources. It delivers electric, thermal and mechanical energy concurrently [12].

Microgrids

This technology works as a tool of interconnection between DE systems (solar, wind, biomas, hydro, etc systems). Figure 1.7 illustrates the structure process in micro-grid. These micro-grids help to control energy demand of each user, to monitor real-time supply and demand. The main difference from distributed power generation is that the system has grid-connection and independent operation, which makes two-way connection [13].

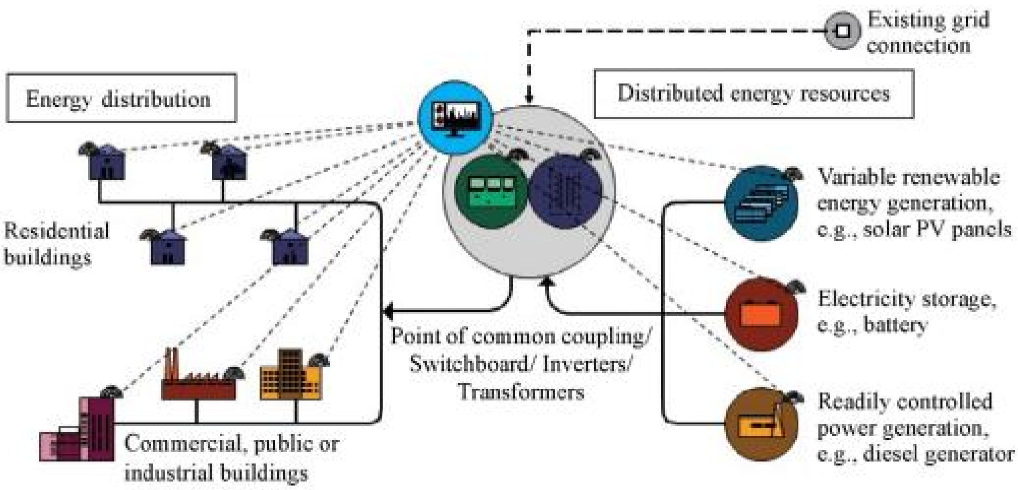

Figure 1.7: Structure of micro-grid, by Ting et.al., 2021

Smart grids

It is important part of the decentralized energy generation system to make electricity flow better by two-way communication. Smart grids make possible to exchange information such as energy consumption data, power quality, renewable energy integration, demand response, etc by using advanced digital technologies [14].

Smart metering

Smart metering is the modernization of electricity meters, replacing traditional ones with more advanced versions. It enables automatic meter readings, flexible pricing structures, and real-time feedback on energy consumption. Smart meters are a key aspect of smart grids but are often confused as the entire smart grid system. They require dedicated communication infrastructure, with technologies like wireless or power line communication used for connecting meters [14].

Blockchain-based energy systems

The Decentralization needs to be handled with care in blockchain-based energy systems. While it offers benefits like reducing costs and increasing transparency, it can also lead to inefficiencies and security concerns. In some critical energy projects, centralization may be necessary, which conflicts with blockchain's decentralized nature. Security is another crucial aspect, and simply relying on blockchain for security can be risky. Therefore, finding the right balance of decentralization and implementing additional security measures is essential for the successful application of blockchain in energy systems [15].

Energy management system

Controlling energy system is beneficial way to maintain stable energy supply that meets demand response [16].

The system utilize new technologies for sustainable and customer-centric energy solutions, implementing renewable sources like solar and wind, micro-CHP systems, geothermal heat pumps, fuel cells, and distributed energy storage. Additionally, to make the energy structure manageable, the smart grids, smart metering, etc. Are used to make two-way communication between the energy suppliers and customers.

1.4 Implemented Cases of DG

Isolated island regions in areas like the Caribbean, Philippines, and Indonesia are increasingly turning towards self-sufficient energy systems due to their geographical limitations that prevent linkage with larger, centralized grids. Martin Höhler, an expert in this field, points out that there is a growing trend for these communities to establish modestly sized power generation facilities fueled by liquefied natural gas (LNG) that have capacities up to 50 megawatts. These facilities are uniquely designed to operate on conventional liquid fuels and are prepared to switch to LNG when it becomes more readily available, presenting a cleaner energy option.

Furthermore, the design of these power plants includes the capability to integrate with both land-based and marine logistical support, enabling the steady import of LNG via specialized vessels. These installations are poised to evolve into hybrid systems that combine traditional fuel sources with renewable energy to curtail reliance on fossil fuels and diminish greenhouse gas emissions.

The deployment of such advanced energy networks, or microgrids, is envisaged to be highly flexible, utilizing renewable resources when they are abundant and storing surplus energy in battery systems. The LNG-based generation units act as a backbone, assuring energy supply continuity. These integrated systems are managed through sophisticated energy management systems that optimize performance.

Waldemar Wiesner highlights that in the African context, off-grid solar installations are revolutionizing energy access. The continent is rapidly adopting decentralized photovoltaic systems, particularly in remote villages, with installations ranging from 1 to 5 megawatts in size. This trend is significant, as a joint study by the World Bank and the Global Off-Grid Lighting Association (GOGLA) projects that by 2030, off-grid solar solutions will be lighting up the lives of approximately 823 million people worldwide [17].

CHP technology

One of the most interesting decentralized systems uses CHP technology. A power plant, which can include renewables but principally includes a conventional thermal power technology, generates electricity and heat combined with very high efficiency rates. The heat is distributed to an off-taker, which could be residential developments, desalination plants or manufacturers. The result is a system efficiency of as much as 95 percent.

Because heat networks are expensive, CHP systems typically operate on a municipal level, with off-takers such as industrial applications nearby, or in the district heating networks of larger towns," says Dr. Tilman Tütken, Head of Sales Power Plants, Europe at MAN Energy Solutions, adding that CHP plants in Europe generally range in capacity from 7 MW to 100 MW [17].

Germany's transition to a decentralized energy system is one of the most notable examples of successful decentralized energy generation. The country has invested heavily in renewable energy sources such as wind, solar, and hydro, and has encouraged the development of small-scale, community-owned renewable energy projects [18].

The Kenyan government has allocated approximately 2.7 billion Kenyan shillings for a comprehensive Rural Electrification Program. This initiative aims to extend electrical connections to over 460 local marketplaces and about 110 secondary educational institutions, along with other community structures. Additionally, there is a plan to invest around 180 million Kenyan shillings in solar power systems for 74 public facilities, which include both primary and secondary boarding schools, healthcare centers, and smaller medical dispensaries [19].

India's National Solar Mission is a government initiative that aims to make India a global leader in solar energy production. The program includes a strong focus on decentralized energy generation, with a goal of installing 40 GW of rooftop solar by 2022 [20]

1.5 Energy System in Central Asia

Central Asia is a vast, landlocked region of modern Asia. According to Britannica (the oldest American universal encyclopedia), this region includes five countries: Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan and Turkmenistan [21]. The population of these countries is 78 364 086 (Kazakhstan - 19 606 633, Kyrgyzstan - 6 735 347, Uzbekistan - 35 163 944, Tajikistan - 10 143 543 and Turkmenistan - 6 516 100 people) in 2023, which is 0.97% of the total world population [22].

Central Asian countries are developing countries who are facing with problems in energy sector. In 1960, soviet era, started modernization of the power grids with the goal of enhancing situation in the Central Asia. The program "Unified Energy System of Central Asia (UESCA)" linked 500 kV of grids between five countries in one into a single circulating 1157 MW, maximum load 921 MW, annual output 6.5 billion in 1961 (see Figure 1.8). Since gaining independence, only three countries - namely, the Republic of Kazakhstan, the Kyrgyz Republic, and the Republic of Uzbekistan have maintained their membership in the UESCA to the present day [23].

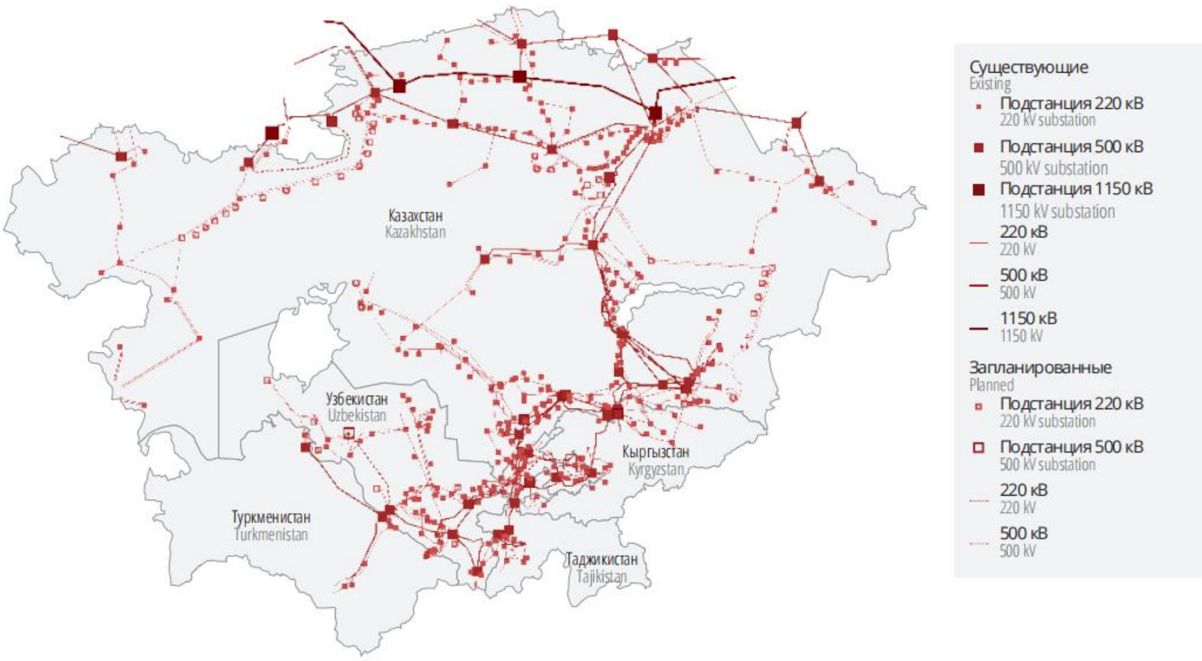

Figure 1.8: Central Asia statistical perspective, source: UN ESCAP, 2018

Despite UESCA countries have their own power generation transmission and distribution strategies. All of them receive electricity from centralized energy generation.

As of January 1, 2023, Kazakhstan boasts 207 power plants with a combined installed capacity of 24,523.7 MW. The available capacity in the country stands at 20,761.7 MW [source]. In parallel, Kazakhstan's electric networks encompass an array of substations, switch gears, and power transmission lines, spanning voltages from 0.4 to 1150 kV, designed to facilitate the efficient transmission and distribution of electrical energy [24].

Kyrgyzstan, on the other hand, operates 18 power plants, featuring a cumulative installed capacity of 11,796.6 MW, as of January 1, 2022. These facilities are supported by power transmission lines with voltages ranging from 0.4 to 500 kV [25].

In the same time frame, Tajikistan boasts 15 power plants, possessing a total installed capacity of 9,246.47 MW, with an available capacity of 5,309.1 MW [26]. The country's power transmission infrastructure spans voltages from 6 to 500 kV [27].

In 2021, Uzbekistan contributed to the region's energy landscape with a total installed capacity of 15,900 MW, backed by power transmission lines ranging from 0.4 kV to 500 kV [28].

Looking at figure 1.9 titled "Energy Production by Source in 2020" we observe that coal plays a significant role as an energy source in four countries, with Kazakhstan leading the pack at 44.31 Mtoe, followed by Uzbekistan at 1.47 Mtoe. Natural gas is another major contributor to energy production, primarily in Kazakhstan (26.32 Mtoe) and Uzbekistan (40.42 Mtoe), where it serves as the primary energy source. Kazakhstan is the largest consumer of oil among the four Central Asian countries, utilizing 87.3 Mtoe, making it the highest contributor among energy sources. In contrast, both Kyrgyzstan and Tajikistan rely on oil to a much lesser extent, with less than 0.2 Mtoe, while Uzbekistan also utilizes oil (2.92 Mtoe) as its second most prevalent energy source.

When it comes to renewable energy sources, they make up approximately 1% of the total energy mix across all Central Asian nations. It's worth noting that large hydroelectric power plants in Kyrgyzstan are not classified as renewable energy sources; instead, they are considered non-renewable. To account for this distinction, hydro is categorized as a non-renewable source with 1.2 Mtoe, serving as the primary energy source in Kyrgyzstan. Other forms of renewable energy collectively contribute less than 0.1%.

Tajikistan stands out as the leader in the use of renewable energy, with 1.56 Mtoe, of which over 90% is generated by hydroelectric power plants. Kazakhstan boasts the most diverse portfolio of renewable energy sources, including hydro (8.7%), solar (1.3%), wind (0.9%), oil (0.1%), and bioenergy (less than 0.1%). Uzbekistan, on the other hand, relies on renewable energy sources for 0.43 Mtoe, with hydro plants accounting for 99% of this contribution [29].

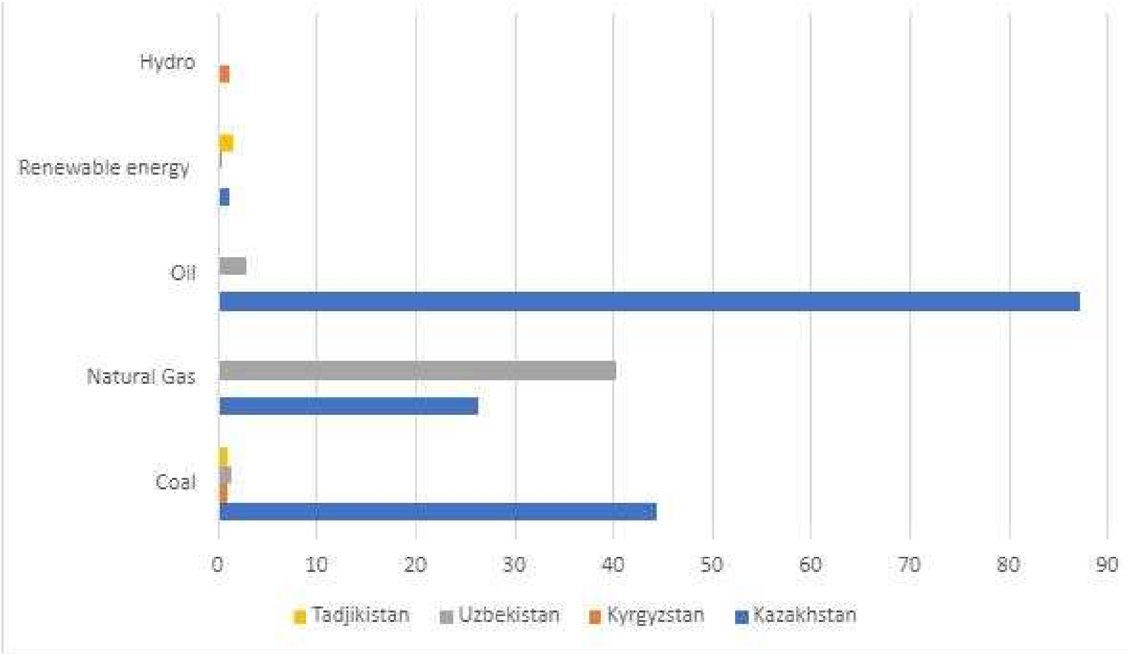

Figure 1.9: Energy production by source, from IEA, 2020

The "Energy Production by Country in 2020" data in Figure 1.10 clearly indicates that Kazakhstan stands as the primary energy producer within the Central Asian quartet, boasting a substantial 159.03 Mtoe. In contrast, Uzbekistan's energy production amounts to 45.24 Mtoe, primarily driven by natural gas sources. A striking parity emerges when considering Kyrgyzstan and Tajikistan, both recording identical energy production figures of 2.45 and 2.52 Mtoe, respectively.

Figure 1.10: Total energy production by country in Central Asia, from IEA, 2020

The energy resource distribution across four Central Asian countries: Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan is shown in Figure 1.11. The energy resources are categorized into coal, natural gas, oil, renewable energy, and hydro. Kazakhstan dominates in natural gas and oil, with significantly high bars compared to the other countries. Kyrgyzstan shows a notable reliance on hydro energy. Uzbekistan has a balanced mix across coal, natural gas, and oil, with moderate emphasis on renewable energy. Tajikistan, similar to Kyrgyzstan, has a higher reliance on hydro energy, indicative of their geographic and infrastructure capabilities. The chart effectively illustrates the diverse energy profiles of these nations.

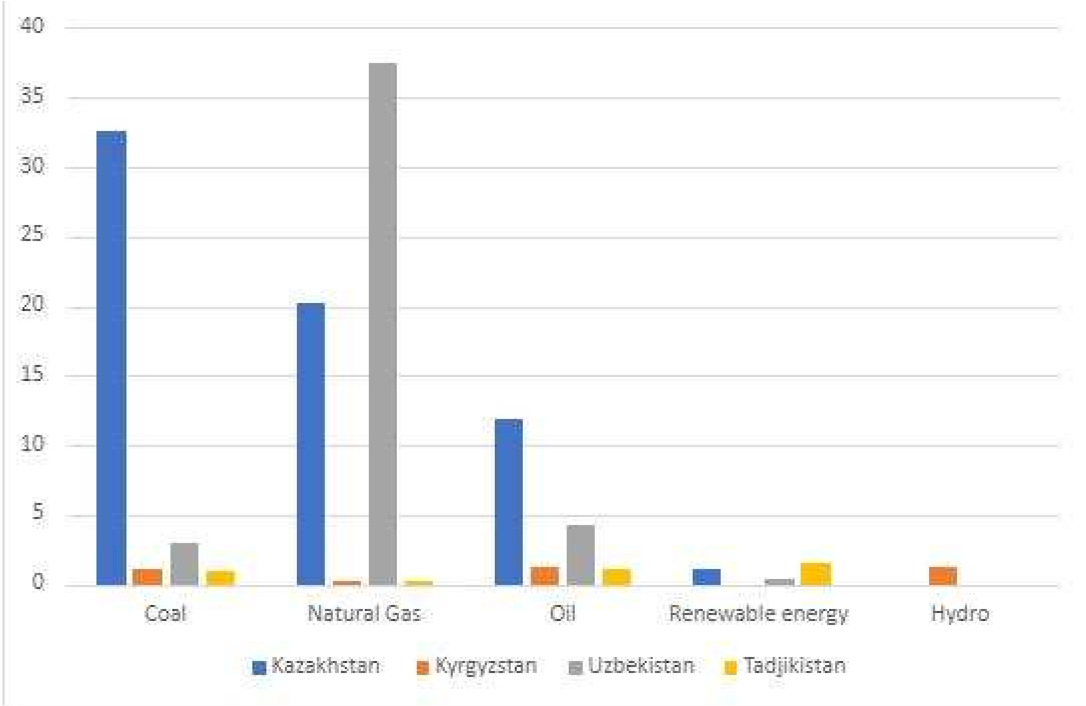

Figure 1.11: Energy supply by source in Central Asia, from IEA, 2020

Kazakhstan constitutes the majority with over half the total at 56% in Figure 1.12. Uzbekistan holds 38%, making it the second largest segment. Kyrgyzstan and Tajikistan each make up a small fraction of the chart at 3% apiece. This visual suggests that Kazakhstan and Uzbekistan are significantly more dominant in the energy supply compared to Kyrgyzstan and Tajikistan, which have minimal representation.

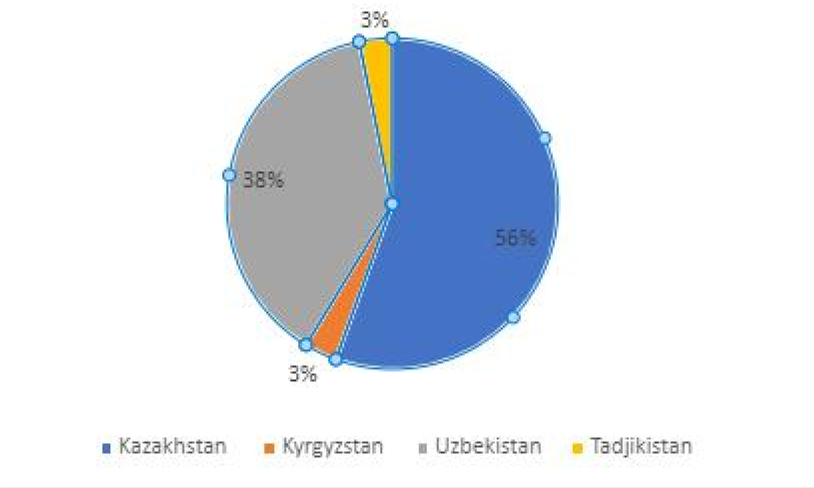

Figure 1.12: Total energy supply by country in Central Asia, from IEA, 2020

In Central Asian countries, the residential sector (see Figure 1.13) stands out as the largest energy consumer, with Kyrgyzstan leading the way at 47%, while the other three countries have over 30% of their energy consumed in this sector. Notably, Kazakhstan exhibits a balanced energy usage pattern, with 33% in the residential sector and 32% in the industry sector, showing a significant shift from 50% in industry consumption in 2015. The third-highest energy consumer is the "Transport" sector at 18%. Uzbekistan and Tajikistan share a somewhat similar situation, with Tajikistan having 33% consumption in the residential sector and 30% in the transport sector, while Uzbekistan has 39% in the residential area and 21% in the industry sector. Comparing these figures to 2015, there have been noteworthy changes in Tajikistan, with a substantial increase from 11% to 33% in residential consumption and a decrease from 34% to 30% in the transport field, while Uzbekistan and Kyrgyzstan's profiles have remained relatively stable [30].

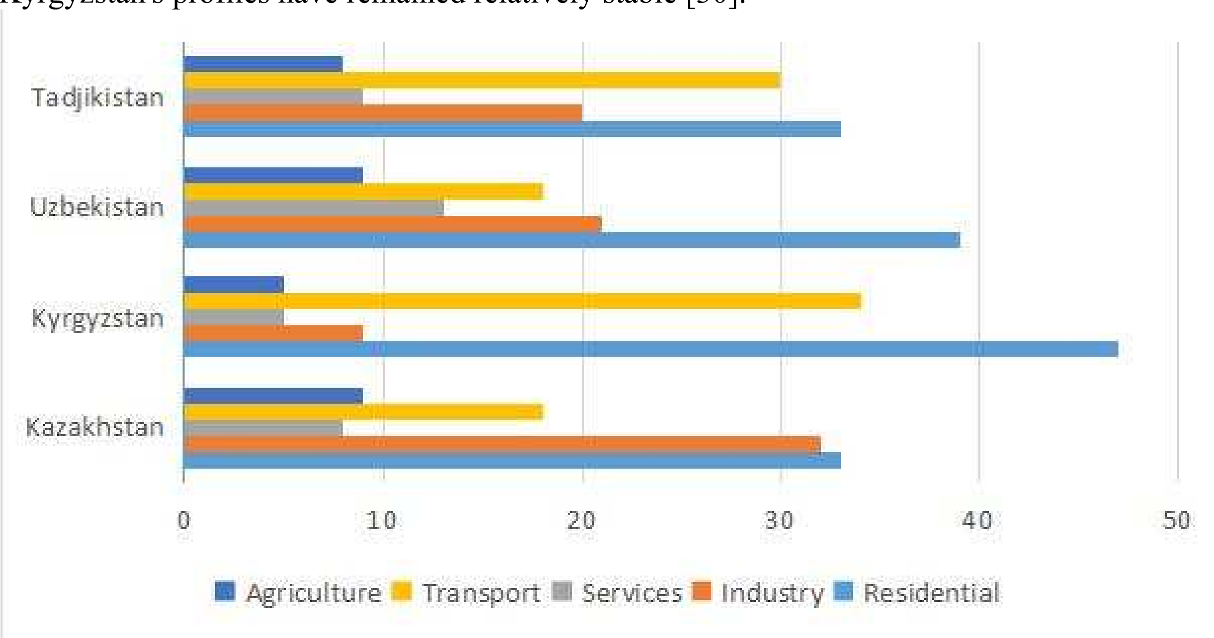

Figure 1.13: Total final consumption by sector in Central Asia, from IEA, 2020

The diagram of Figure 1.14 highlights that natural gas is the dominant energy source in Central Asian countries, making up the largest portion of final consumption. Oil follows as the second-largest contributor, while the use of district heat, electricity, and coal is relatively balanced. Bioenergy, on the other hand, has a negligible presence in the region's final energy consumption.

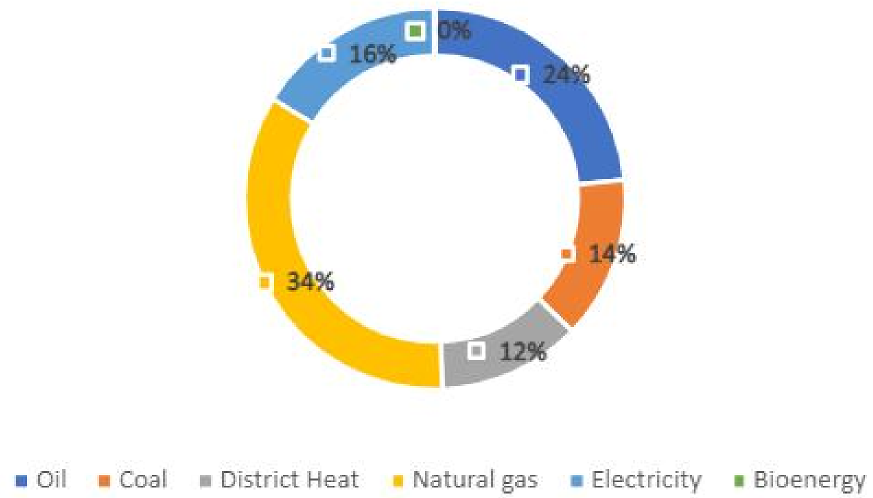

Figure 1.14: Total final consumption by sector in Central Asia, from IEA, 2020

1.6 Renewable Energy field

The region heavily relies on fossil fuels; nevertheless, there's an emerging shift towards renewable energy as delineated in Table 1.3. Kazakhstan's renewable energy supply stands at 1.1 Mtoe, comprising mostly hydro (75%) and solar (12%), contributing to 11% of their electricity generation. Uzbekistan, with 0.43 Mtoe, nearly all from hydro, contributes 75% to their electricity. Tajikistan's renewable supply is predominantly hydro at 1.6 Mtoe, amounting to 90.1% of electricity generation. Kyrgyzstan's data isn't provided (see Table 1.2). Each country's renewable energy contributes to 13.8% of the total energy supply and 26% of electricity generation.

Key data	**Kazakhstan**	**Kyrgyzstan**	**Uzbekistan**	**Tadjikistan**
Total Renewable energy supply	1,1 Mtoe (1,7% of TES) (75% hydro, 12% solar, 8% wind, 5% bioenergy)	No information	0,43 Mtoe (0,9% of TES): virtually all hydropower, bioenergy, wind and solar contribution negligible	1,6 Mtoe (42,7% of TES): hydropower, bioenergy data not available

Key data	Kazakhstan	Kyrgyzstan	Uzbekistan	Tadjikistan
Total renewable electricity supply	12,2 TWh (11% of electricity generation) (9,7 TWh hydro, 1,5 TWh solar, 1 TWh wind, 0,01 TWh bioenergy)	No Information	5 TWh (75% of electricity generation): virtually all hydro power, wind and solar<0,01 TWh	18,1 TWh (90,1% of electricity generation): all hydropower
World energy shares	13,8% of TES and 26% of electricity generation	13,8% of TES and 26% of electricity generation	13,8% of TES and 26% of electricity generation	13,8% of TES and 26% of electricity generation

Table 1.2: Comparison of energy supply between Central Asia and others, source: IEA, 2022

The share of renewable energy sources in all four Central Asian countries are low, varying between 0,01% and 2%. The information about power plants of existing renewable energy is neglected by all countries, and for geothermal energy is not given, creating a bottleneck to analyze the data of renewable sources in those countries (see Table 1.3) [31].

Country	Small hydro-power plants	Solar Sysytems	Wind Energy	Bioenergy
	MW	MW	MW	MW
Kazakhstan	225	884	384	8
Kyrgyzstan	46	Insignificant	Insignificant	No information
Uzbekistan	71	Insignificant	Insignificant	No information
Tajikistan	25	Insignificant	Insignificant	No information

Table 1.3: MW of reneable energy in Central Asia, source: UNIDO & ICSHP, 2016; Eshchanov et al., 2019; Ministry of Energy of Kazakhstan, 2020

Solar Energy

In Kazakhstan, the momentum in solar energy capacity is evident, with the Ministry of Energy acknowledging a substantial leap to 883.6 MW by mid-2020. Reports for earlier quarters and the preceding year present a lower capacity, reflecting rapid growth. Noteworthy solar power installations have been commissioned, and several are in development. The figures indicate a progressive trend in solar energy investment, with substantial increments in electricity production from these sources.

Kyrgyzstan's solar endeavors are modest, concentrated on smaller, domestic applications. Solar heating and photovoltaic systems serve individual households and public services, suggesting a tailored approach to solar energy usage, with local manufacturing contributing to the sector.

Tajikistan's solar sector is largely untapped, with isolated applications being the extent of its development, implying potential for future growth.

Uzbekistan's solar strategy, initially supported by international finance, aimed at establishing significant solar infrastructure, although some plans were reassessed. Nonetheless, a few smaller projects have been completed, indicating a cautious step towards solar energy adoption [31].

Wind Energy

Kazakhstan's wind energy capacity saw a rise to nearly 384 MW by mid-2020 from around 336 MW at the beginning of the year, marking a steady increase from the end of the previous year. The country's wind energy infrastructure, which included a significant number of operational farms and new developments, benefited from international partnerships and financial support, contributing to its energy output. In contrast, neighboring Central Asian countries displayed more modest advancements in wind energy, focusing primarily on smaller installations with varied support from international organizations. The region's investment in wind energy reflects a commitment to diversifying energy sources, although detailed data on some projects remain sparse [31].

Bioenergy

In Central Asia, traditional biomass usage is prevalent for domestic needs, but specific data is scarce. Kazakhstan has seen some government and international support for bioenergy, achieving a capacity of 7.82 MW. Despite various projects enhancing this capacity, overall adoption remains modest. Kyrgyzstan explores biogas potential from agricultural waste, with numerous installations indicating a growing interest in bioenergy solutions, although comprehensive capacity data for Kyrgyzstan, Tajikistan, and Uzbekistan are not detailed [31].

The trend of the installed capacity of various renewable energy sources in four Central Asian countries from 2010 to 2020 is presented in Figure 1.15. Kazakhstan shows a diverse mix with significant hydro, growing solar PV, and emerging wind and bioenergy sectors. Kyrgyzstan's capacity is predominantly hydro with no other sources displayed. Tajikistan shows a consistent hydro capacity across the years, with no other types of renewable energy. Uzbekistan, similar to Kyrgyzstan, solely exhibits hydro capacity with a steady increase over the years. Each country's graph features bars for each year, color-coded to represent different renewable energy sources.

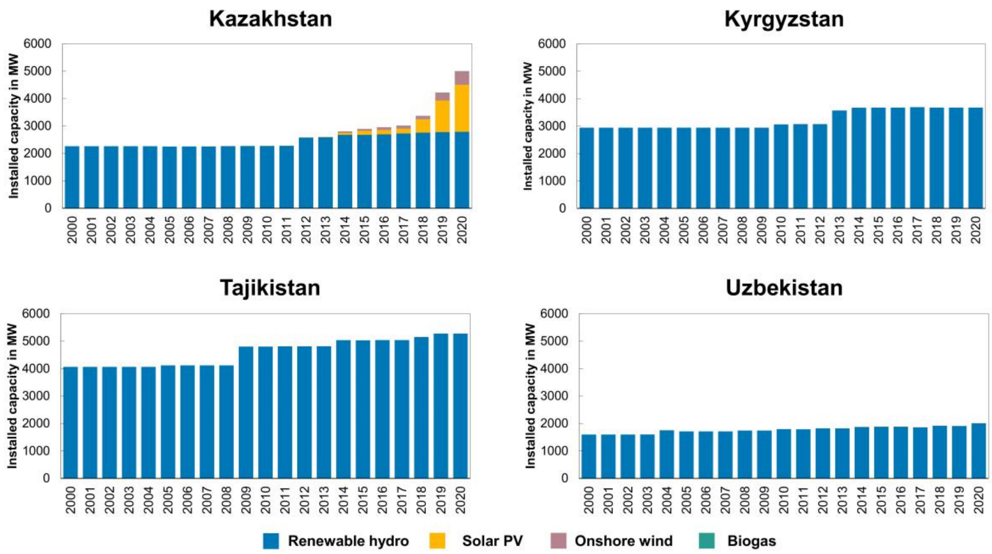

Figure 1.15: The trend of installed renewable energy capacity in Central Asia, from IRENA, 2020

1.7 The need to change the energy system

Energy losses

As was mentioned about the structure off the Central Asian countries most of the plants were built in 20 century which means the age of using them more than 80 years. For example, ”Atbashy Hydro-power Plant” of Kyrgyz Republic was used from 1970 and renovation of the plant was made only in 2023 by Switzerland and OJC “Electric Power Plants”, making increase from 40 to 44 MW (see Table 1.4) [32].

№	Name	Year of commissioning	Installed capacity (MW)	Designed annual production (GWh)
1	Toktogul HPP	1975	1 200	4 400
2	Kurpsai HPP	1982	800	2 630
3	Tash-Kumyr HPP	1987	450	1 698
4	Shamaldy-Sai HPP	1995	240	902
5	Uchkurgan HPP	1962	180	820
6	Kambarata 2 HPP	2010	120	1 141
7	Atbashy HPP	1970	40	147
	Total hydro		**3 030**	**11 738**
8	Bishkek co-generation	1961	812	1 740
9	Osh co-generation	1966	50	-
	Total thermal		**862**	**1 740**
	Total for JSC power plants		**3 892**	**13 478**
10	JSC Chakan GES (9 small HPPs)	1928-1958	38.5	160.7
11	Private small HPPS (11 small HPPs)	1954-2021	21.8	102.6
	Total small hydro		**60.3**	**263.3**
	Total for the Kyrgyz system		**3 952.3**	**13 74.1**

Table 1.4: Power plants in the Kyrgyzstan, source: IEA, 2022

In 2020, The Kyrgyz Republic faced with 25% of loses among main source of heat supply due to the operation of outdated equipment [33].

Bishkekteploset (Bishkek co-generation plant) uses coal and gas to serve 131,480 customers, with significant heat production and a loss percentage of 25.2 (see Table 1.5). The Osh co-generation plant, using Mazut, serves 17,631 customers with lower heat production and similar losses. Overall, the table encompasses data for a total of 232,530 customers and heat production totaling 3,082.5 Therefore, with an average loss of 25%. Therefore, Kyrgyzstan may be facing challenges in its heat supply efficiency and meeting users' needs [33].

Source of heat supply	Number and type of boilers	Customers		Heat production	Losses
		Total	Non-residential	Gcal	%
Bishkekteploset (Bishkek co-generation plant)	Coal and gas	131 480	4 464	2 076.3	25.2
Osh co-generation plant	Mazut	17 631	391	136.3	24.0
Kyzyk Kiya co-generation plant	Coal	1 428	19	23.2	24.1
Boiler (Kara-Kul town)	Electricity	3 141	80	71.9	62.9
Boiler (Shamaldy-Sai town)	Electricity	107	6	1.5	0.3
Kyrgyzteploenergo	136 boilers: • 21 gas • 27 mazut • 57 coal • 31 electricity	45 849	982	455.6	24.5
Bishkekteploenergo	66 boilers: • 31 gas • 11 electricity • 24 coal	18 972	300	218.9	15.9
Oshteplosnabzhenie	88 boilers: • 19 electricity • 69 coal	13 922	22	98.8	17.0
Total		**232 530**		**3 082.5**	**25.0**

Table 1.5: Main sources of heat supply in Kyrgyzstan, source: IEA, 2022

While in Kazakhstan the electricity losses were achieved -10 TWh in 2020 (see Figure 1.16). The transmission system is characterized by a high level of wear, with the depreciation rate reportedly 66% on average for regional networks (Kazinform, 2022a). Losses on the high-voltage networks operated by KEGOC were about 5.7% in 2020 and 5.6% in 2021. According to Kazenergy (2021), losses on the networks of the distribution companies in 2020 were around 10.9%. Other sources put total transmission losses as high as 18% (Kazinform, 2022a). Transmission losses are exacerbated by the long distances in the Kazakh system [34].

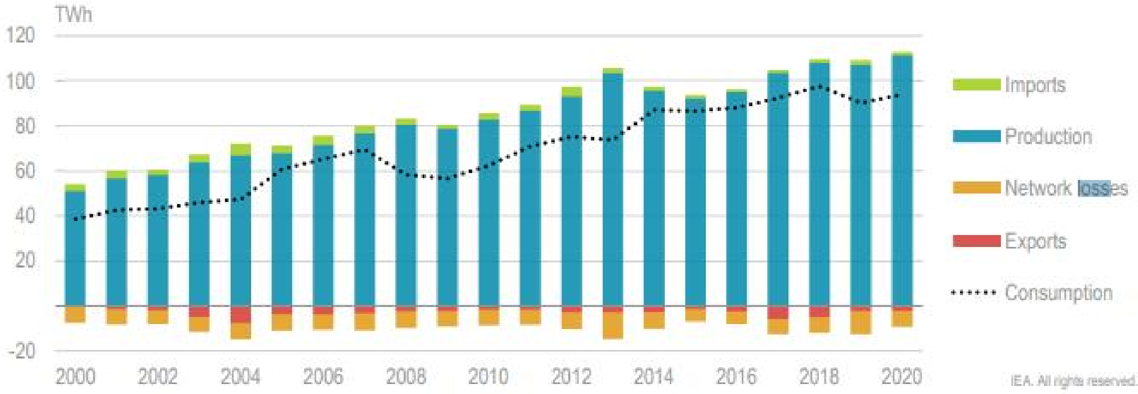

Figure 1.16: Electricity supply by source in Central Asia, source: IEA, 2020

More than 50% of the network operating in Uzbekistan has been in operation for more than 30 years and requires major replacement (Table 1.6). Therefore, since 2017, a program for updating and modernizing low-voltage electrical networks has been implemented in Uzbekistan. "During this time, more than 8 thousand transformer substations were updated, as a result of which the situation with electricity supply in more than 1.7 million households significantly improved," noted Deputy Minister of Energy Sherzod Khojaev. "However, today about 50% of the 0.4 kV and 35–110 kV electrical networks are physically outdated and require modernization and reconstruction." According to the calculations of the Ministry of Energy, if the additional program initiated by the department is implemented, after the reconstruction and modernization of electrical networks in more than 9 thousand mahallas of the country, electricity supply will be normalized, and by 2030, losses in the distribution network will be reduced to 6.5% [35].

N°	Name	First unit commissioned in	Installed capacity, MW	Share of total, %
Thermal power plant (coal, gas)				
1	JSC Angren TPP	1957	393	2.6%
2	JSC Novo-Angren TPP	1985	2 100	13.9%
Thermal power plant (gas, fuel oil)				
3	Unitary enterprise Tashkent TPP	1963	2 230	14.1%
4	JSC Navoi TPP	1964	2 068	13.1%
5	JSC Takhiatash TPP	1967	910	5.7%
6	JSC Syrdarya TPP	1972	3 165	20.0%
7	UE Talimarjan TPP	2004	1 700	10.7%
8	UE Turakurgan TPP	2019	900	5.7%
	Total TPP		13 466	85.0%
Co-generation plant (gas, fuel oil)				
1	JSC Tashkent co-generation plant	1934	57	0.4%
2	JSC Fergana co-generation plant	1956	312	2.0%
3	JSC Mubarek co-generation plant	1985	60	0.4%
	Total co-generation		429	2.7%
Hydropower plant				
	UE Cascade of Chirchik HPPs, including:			
1	Tavaksay HPP (HPP-8)	1941	72	0.5%
2	Chirchik HPP (HPP-7)	1940	84	0.5%
3	HPP Ak-Kavak (HPP-10)	1943	35.1	0.2%
4	UE Farkhad HPP	1948	126	0.8%
	UE Cascade of Urta Chirchik HPPs, including:			
5	Charvak HPP (HPP-6)	1970	666	4.2%
6	Khodzhikentskaya (HPP-27)	1975	165	1.0%
7	Gazalkent HPP (HPP-28)	1980	120	0.8%
8	Andijan HPP	1983	140	0.9%
9	Tuyamuyunskaya HPP	1983	150	0.9%
10	Tupolangskaya HPP	2006	30	0.2%
11	Andijan HPP-2	2010	50	0.3%
12	Hissarak HPP	2011	45	0.3%
	Total HPP (>30 MW)		**1 683**	**10.6%**
	Total small HPPs (< 30 MW), 29 stations	**1926-2019**	**256**	**1.6%**
	Total HPP		**1 939**	**12.2%**
	Total for the energy system		**15 834**	**100.0%**

Table 1.6: Power plants in Uzbekistan, source: IEA, 2021

Most components of the electricity networks have been in service for more than 30 years, including 66% of the transmission and 62% of the distribution networks, 74% of substations, and more than 50% of transformer stations (Figure 1.17). This is one of the reasons for the relatively high network losses, which amounted to 15.5% in 2020 (transmission losses 2.7%, distribution losses 12.8%).

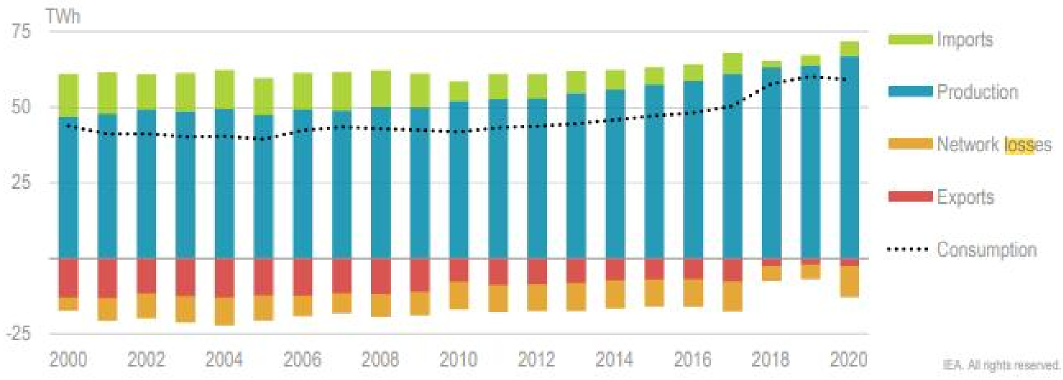

Figure 1.17: Uzbekistan's electricity supply, source: IEA, 2020

Losses caused by the poor quality of the country's transmission and distribution systems have averaged 15.5% for the last two decades, in comparison, average losses in IEA member countries were below 7% of supply, and saw a steady decline in the same period. Meanwhile, Tajikistan's non-domestic sector experiences an average of six power outages per month [36]. Power plants' year of running can be seen in Table 1.7.

Number	Name	Installed capacity (MW)	Available capacity (MW)	Year of commissioning
1	Nurek HPP	1 995	1 950	1972, 1979
		1 005	800	
2	Rogun HPP	3 600	240	2018
3	Boygozi HPP	600	550	1985
4	Sangtuda-1 HPP	670	670	2008
5	Sangtuda-2 HPP	220	220	2011
6	Golovnaya HPP	240	170	1962
7	Kayrakkum HPP	126	124	1956
8	Dushanbe-1 TPP	198	130	1961
9	Yavan TPP	120	0	Not active
10	Dushanbe-2 TPP	400	400	2016
11	Tsentralnaya HPP	15.1	12.8	1964
12	Perepadnaya HPP	29.95	26.3	1958
13	Varzob Cascade HPPs: HPP-1	9.5	9.5	1937
14	HPP-2	14.4	5	1949
15	HPP-3	3.52	1.5	1952

Table 1.7: Power plants in Tajikistan, source: IEA, 2022

The main problem of Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan is relating to the old power plants, electricity transmission networks and untimely update of those technologies to meet requirements of energy supply in the regions.

One main energy source

Central Asian nations face a significant energy dilemma rooted in their dependence on just one primary energy source (see Figure 1.18). This reliance poses risks to their energy security and can limit economic diversification. Additionally, it raises concerns about the sustainability of their energy practices. The implications of depending on a single energy source are complex and far-reaching, impacting environmental sustainability, economic resilience, and the broader social fabric of these countries.

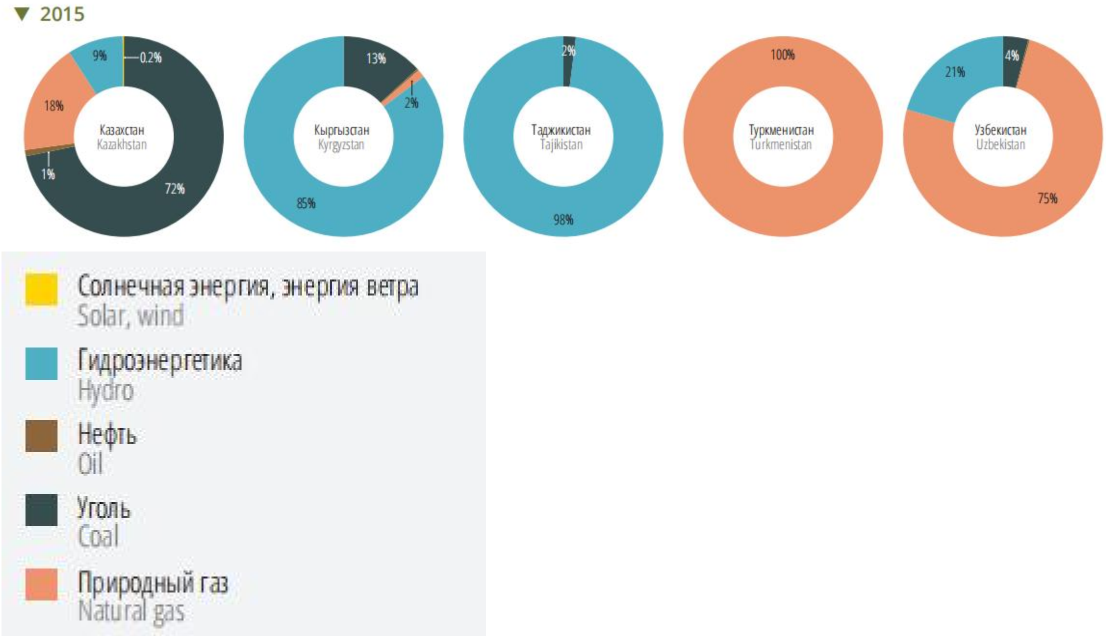

Figure 1.18: Percentage of main energy sources
in Central Asia, source: UN ESCAP, 2017

All four countries are dependent from mainly one non-renewable energy sources which can decrease energy security. For example, situation in 2015 has been unchanged until nowadays. Kazakhstan mostly consumes coal, Kyrgyzstan hydro-power as Tajikistan and Uzbekistan makes energy through natural gas [33].

In 2021, due to the low water level in the Toktogul reservoir and the resulting power deficit, Kyrgyzstan imported electricity from Kazakhstan, Uzbekistan and Turkmenistan. While in Kazakhstan the coal chemical structure has moisture, ash and sulfur properties. These properties of coal reduce the energy and thermal efficiency of using this type of fuel, and increases processing costs. Thus, most of the southern reserves of the Ekibastuz basin (developed reserves of 10 ml tons) are characterized by high ash content at the level of 42-44% (why is this bad, like ash, sulfur and moisture), which makes its enrichment unprofitable. At the same time, coal from the Shaburkol basin (proven reserves of 1.5 million tons) contains low amounts of ash and sulfur (5-15% and 0.5%, respectively. However, coal is the most affordable source of electrical and thermal energy in the country, both due to the low cost of fuel and the energy costs of coal [37].

Environmental impact

The Table 1.8 represents data for four countries and their respective CO_2 emissions over time. In 1990, all of these countries experienced their highest levels of emissions, after which a notable decline occurred, particularly in the cases of Kyrgyzstan (from 5.2 metric tons per capita to 1 metric ton per capita by 1995) and Tajikistan (from 2 metric tons per capita to 0.4 metric tons per capita by 1995). While there is an overall trend of decreasing emissions across these countries, it is important to note that both Kazakhstan and Tajikistan saw an increase in CO_2 emissions, reaching approximately 1 metric ton per capita in 2020, as compared to their 2015 figures.

Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Kazakhstan	14,5	11,1	8,1	11,2	14,1	10,9	11,3
Uzbekistan	5,7	4,3	5	4,6	4,4	3,2	3,4
Kyrgyzstan	5,2	1	0,9	1	1,2	1,7	1,4
Tajikistan	2	0,4	0,4	0,4	0,3	0,6	1

Table 1.8: CO_2 emissions (metric tons per capita) in Central Asia,
source: The World Bank, 2020

The primary sources of CO_2 emissions vary among the four countries. In Kazakhstan, the highest contributor is the industrial sector, responsible for emitting approximately 200 million metric tons (Mt) of CO_2. Conversely, in Uzbekistan, the transport sector takes the lead, accounting for around 150 Mt of CO2 emissions. In 2020, both Tajikistan and Kyrgyzstan reported emissions of less than 10 Mt of CO_2, with the most significant contributors being the electricity and residential sectors.

As outlined in Figure 1.19 it is apparent that Kazakhstan relies heavily on coal for its energy production. This heavy reliance on coal is reflected in the country's leading position as the primary emitter of CO_2 in the region.

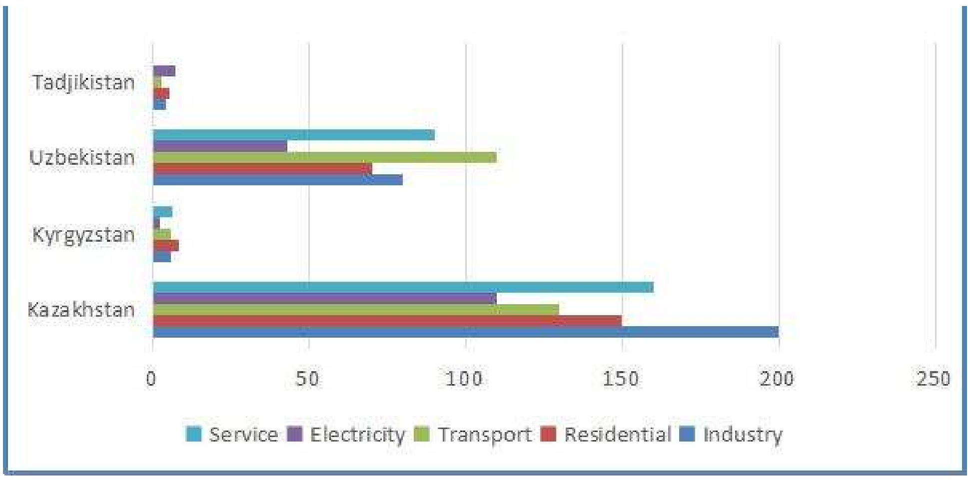

Figure 1.19: CO_2 emissions from fuel combustion
by sector in Central Asia (Mt), source: IEA, 2020

Energy poverty

Rural areas of Central Asia are not fully supplied by national electricity generation. In Kazakhstan more than 5000 population of the village regions are not connected ti centralized energy generation, making people to use coal as a source to satisfy their needs. The National Statistics Committee of Kyrgyzstan reports that only 76 percent of the population has access to reliable electricity year-round, leaving more than 1 million people without access to electricity.

According to a 2013 World Bank study, 70 percent of Tajikistan's population experienced some form of winter energy shortage,99 and although the construction of the Dushanbe Thermal Power Plant has partially solved the problem of energy security in the capital, residents of rural and remote mountainous areas of Tajikistan remain completely insecure electricity.

Despite data from a World Bank report that the entire population of Uzbekistan has access to electricity, according to some estimates, 1,500 rural settlements, home to 1.5 million people, are not properly connected to central electricity grids due to their remoteness and inefficiencies in power transmission and distribution [38].

1.8 Research question

— What are the barriers to decentralized energy generation adoption in Central Asia, and how can these barriers be overcome?

II METHODOLOGY

2.1 Research design

This study searched solutions to overcome the barriers to set decentralized energy system in Central Asian countries: Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan. To identify the answer of the research method a qualitative approach was chosen. This type of the research allows to consider all information that available in the network and compare with the reliable sources.

The process consists of:

1. Data searching through internet search engines such as Google, Yandex, and Bing, with queries conducted in Kazakh, Russian, and English to ensure comprehensive coverage.
2. Screening the data for its relevance and relatability to the study's context.
3. Verifying the similarity of the data across multiple resources to ensure the information's accuracy.
4. Summarizing the main issues of the energy system in Central Asia into one sentence, and synthesizing the information irrespective of the country.
5. Searching for evidence to substantiate the existence of the identified problems through credible sources.
6. Documenting the findings in the research paper.

2.2 Research scope

This study examines main obstacles that prevent to set Decentralized energy generation in four Central Asian countries: Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan. The decision to focus on Decentralized system and want to find out the problems of spreading the energy structure and then trying to overcome those barriers by looking to another cases/reviewing interviews (from news)/trustful literature.

The Decentralized Energy System was chosen as a change to the existing the energy structure of Central Asia because of the problem of creating this energy structure. The problems with existing energy system increase losses of the supply energy and not matching to the demand of the population. The long distance between main energy producer and the end user is too long, whereas maximizing inefficient supply. The highest energy losses was emerged in Kyrgyzstan in 2021, where population were suffered from 4 hours electricity supply a day during summer time [39] and other countries from the region suffers from the same problem where power plants was destroyed due to outdated equipment. One of the features of the decentralized generation is to have not only on supply source but many different and they also located to the user closer making efficient supply.

The region's energy problems	Examples
Energy Supply losses	"Atbashy Hydro-power Plant"of Kyrgyz Republic was used from 1970 and renovation of the plant was made only in 2023 by Switzerland and OJC "Electric Power Plants", making increase from 40 to 44 MW.
One main energy source	Kazakhstan has reliance on fossil fuels, particularly coal, which accounts for nearly 70% of its energy production while Tajikistan totally dependent (see Figure 1.30) on hydro power.
Environmental impact	In Kazakhstan, the highest contributor is the industrial sector, responsible for emitting approximately 200 million metric tons (Mt) of CO_2. Conversely, in Uzbekistan, the transport sector takes the lead, accounting for around 150 Mt of CO2 emissions. In 2020, both Tajikistan and Kyrgyzstan reported emissions of less than 10 Mt of CO_2, with the most significant contributors being the electricity and residential sectors.
Energy poverty	2013 World Bank study, 70 percent of Tajikistan's population experienced some form of winter energy shortage,99 and although the construction of the Dushanbe Thermal Power Plant has partially solved the problem of energy security in the capital, residents of rural and remote mountainous areas of Tajikistan remain completely insecure electricity.

Table 2.1: The main energy issues in Central Asian countries

Given the pressing need for Central Asia to transition towards decentralized energy generation, the study identifies several barriers that must be addressed to resolve longstanding energy issues, which are presented in Table 2.1. These challenges, which have accumulated over decades, have not been adequately managed to meet the needs of the region's population. Chapter 1: Introduction offers examples illustrating these concerns.

2.3 Research development

The research structure will be in the frame of figure below:

Phase 1: Literature Review

In this initial phase, the thesis study aimed to identify the research questions and establish a solid foundation of knowledge related to the topic. The literature review encompassed a broad range of sources, including academic articles, government reports, interviews from reputable sources, and relevant YouTube videos. The following topics were covered:

- current situation of overcoming energy problems
- efficient energy supply projects
- renewable energy solutions
- financial aid
- decentralized development
- policy framework
- energy transition
- investments

The literature overview of these topics can give understanding of insights into the sector and identifying research questions. This question aimed to explore the factors influencing the pace and scale of the transition to decentralized generation in the region:

- What are the primary barriers to decentralized energy generation adoption in Central Asia, and how can these barriers be overcome?

Phase 2: Data Collection 1 - Information gathering from online content

The reason that as data collection was chosen through available information from different the internet source is due to not finding appropriate people to be interviewed. Thanks to online sources such as YouTube, podcasts (Apple podcast) and other social media sources can help to gather needed topic regarding to research goals. The advantages of this kind of information gathering can help to analyze different point of view of people from different fields. Enlarging the findings from online resource increases the ability to make sure that the information is latest development and discussions surrounding the research topic. Additionally, this multimedia richness enhances the depth of the research and facilitates a multi-dimensional analysis of the topic. However, the main limitation of this method is the trustfulness of the source. Because they can be biased to the government and make results in their favor to improve the country's viewing expectations, which means too subjective.

The conducted information was found relating to each country and the language of the sources was chosen Russian (all four countries in Central Asia has two language and one of them is Russian) and Kazakh in Kazakhstan area. Examples of the web-sources are listed below.

Kazakhstan:

“Telekanal Khabar 24” youtube channel
“Atameken Business News” youtube channel
“Almaty TV” youtube channel
“www.inform.kz” online newspaper
“www.negrinewz.kz” online newspaper
“www.gov.kz” government official website
“www.samruk-energy.kz” - the website of sovereign wealth fund

Kyrgyzstan

“NEWS KG” youtube channel
“Novosti Kyrgyzstana” youtube channel
“Telekanal Khabar 24” youtube channel
“AKIpress news” youtube channel
“www.sputnik.kg” online newspaper
“www.minenergo.gov.kz” government official website
“www.tazabek.kg” online newspaper
“www.nehk.energo.kg” the website of the national energyholding

Uzbekistan

“O'zMTRK O'zbekiston milliy teleradiokompaniyasi” youtube channel
“Gazeta.uz: Novosti Uzbekistana” youtube channel
“Alter Ego.Vse pro Uzbekistan” youtube channel

The criteria for selection relevant web-sources were:

- Expertise and Authority:

Criteria: Verifying the content creators or sources are experts or authorities in the relevant field.
Provenances: Checking the credentials, qualifications, and experience of the content creators. Look for academic degrees, professional affiliations, or significant contributions to the field. You can also assess their reputation within the community, such as through peer recognition or citations.

- Relevance to Research Objectives:

Criteria: Confirming that the content aligns with the specific topics and research objectives of your study.
Provenances: Examining the titles, descriptions, and content of the videos, podcasts, or articles. Ensuring that they directly address the research questions or themes you are investigating.

- Reliability and Credibility:

Criteria: Assessing the reliability and credibility of the source by examining factors such as accuracy, objectivity, and quality of information.
Provenances: Looking for citations, references, or sources used within the content. Reliable sources often provide evidence to support their claims.

Countries	Kazakhstan	Kyrgyzstan	Uzbekistan	Tajikistan
Video information				
1. YouTube	19	16	15	10
Listening source				
2. Apple podcast	3	1	1	0
Web Articles				
3. Digital news	23	14	17	11
Municipal Websites				
4. Official Government Portals	10	8	8	7

Overall was considered 163 different web information to conduct research. Main key words: barriers in energy, renewables, investment, green projects, decentralization, investment, green energy, green projects, etc.

1. Watching Videos on YouTube Channels:

Purpose: To gather insights and information related to your research objectives, particularly focusing on topics like barriers in energy, renewables, investment, green projects, and decentralization.
Procedure:

- Accessing the specified YouTube channels, including "Telekanal Khabar 24", "Atameken Business News", and "Almaty TV" for Kazakhstan, among others.
- Reviewing video titles, descriptions, and content to identify relevant videos.
- Watching videos that aligned with the research interests, paying attention to key points, expert opinions, and data presented.

2. Listening to Podcasts:

Purpose: To gain insights and information from audio content, especially related to your research topics.
Procedure:

- Accessing podcast platforms like Apple Podcasts.
- Searching for and selecting relevant podcasts focusing on barriers in energy, renewables, investment, green projects, and decentralization.
- Listening to podcast episodes, taking notes on key discussions, expert interviews, and any pertinent data.

3. Reading News Articles:

Purpose: To stay informed about the latest developments, discussions, and news related to your research objectives.
Procedure:

- Visiting digital news sources such as "www.inform.kz", "www.negrinewz.kz", and others.
- Scanning headlines, article summaries, and content to identify news articles relevant to your research topics.
- Reading selected articles thoroughly, extracting key information, statistics, and quotes.

5. Navigating Government and Official Websites:

Purpose: To access official government information, policies, and data related to energy and decentralization.
Procedure:
- Accessing government websites like "www.gov.kz" and "www.minenergo.gov.kz" to gather official information.
- Exploring the websites to find relevant documents, reports, and policies pertaining to the research.
- Referencing official data with other sources to validating its accuracy and objectivity.

6. Applying Selection Criteria:

Purpose: To ensure the quality and relevance of the collected information.
Procedure:
- Applying selection criteria, including expertise and authority, relevance to research objectives, and reliability and credibility, to evaluate the chosen sources.
- Verifying the credentials of content creators or sources.
- Ensuring that the content directly addressed the research questions and themes.
- Assessing the reliability and credibility of the sources by looking for evidence and cross-referencing with reputable sources.

6. Multilingual Approach:

Purpose: To access information in the Russian language, which is commonly used in Central Asian countries.
Procedure:
- Conducting research in Russian, Kazakh and English to access information relevant to each of the four Central Asian countries (Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan).
- Utilizing Russian and Kazakh language sources to collect data specific to each country's energy sector.

Phase 3: Data Collection 2 - Information gathering from research sources

In this phase of data collection, the focus shifts towards gathering information from research sources that have been identified as authoritative and relevant to the study's objectives. The aim is to complement the insights gained from online content with more in-depth and well-documented research findings. This phase involves systematic access to peer-reviewed articles, academic publications, government reports, and scholarly databases.

Procedure:

Literature Review: Conducted an extensive literature review to identify key research papers, studies, and reports related to the central topics of the research, such as barriers in energy, renewables, investment, green projects, and decentralization.
Database Searches: Utilized academic databases like PubMed, IEEE Xplore, Google Scholar, and government databases to search for scholarly articles, conference papers, and official reports specific to each Central Asian country.
Accessing Academic Journals: Accessed reputable academic journals specializing in energy, sustainability, and regional development to retrieve peer-reviewed articles with relevant data and analysis.
Government Reports: Explored official government websites and publications from the countries under study, including national energy agencies and ministries, to obtain authoritative reports, policy documents, and statistical data.
Data Extraction: Extracted pertinent information, statistics, and findings from the selected research sources, ensuring that the data aligns with the research objectives.
Cross-referencing: Cross-referenced the data collected from research sources with the insights gained from online content to validate and enhance the overall data quality and reliability.

Benefits:

Enhanced Validity: Information collected from research sources contributes to the academic rigor and validity of the study, offering well-documented evidence and expert analysis.
Comprehensive Insights: The inclusion of peer-reviewed research broadens the scope of the study, providing a more comprehensive understanding of the complex topics under investigation.
Data Validation: Cross-referencing data from various research sources allows for the validation of key findings and ensures data accuracy.
Informed Analysis: The incorporation of scholarly research empowers the research team to conduct informed and multi-dimensional analysis, enriching the depth of the study.

Phase 4: Data analysis

All the data gathered from Phase 2 and Phase 3 was analyzed by PESTLE (Political, Economic, Social, Technological, legal and Environmental) method due to comprehensive framework, which allows for a holistic examination of the external factors affecting the adoption and implementation of decentralized energy systems in Central Asia.

- ✓ Political: Identifies how government policies, stability, and international relations influence energy strategies and investments. Given the varied political landscapes across Central Asia, understanding these dynamics is crucial for any energy transition.
- ✓ Economic: Examines the economic factors that can facilitate or hinder the shift to decentralized energy, including funding availability, economic incentives, and the overall economic health of the countries involved.

- ✓ Social: Considers the social implications, public opinion, and the potential impact on communities. This includes cultural attitudes towards renewable energy and technology adoption rates, which are vital for decentralized systems' success.

- ✓ Technological: Assesses the availability, maturity, and accessibility of technologies necessary for decentralized energy generation. It also looks at the region's capacity for innovation and adaptation to new energy solutions.

- ✓ Legal: Reviews the legal and regulatory frameworks that could support or impede decentralized energy projects. This includes laws on energy production, distribution, and consumption, as well as renewable energy incentives and restrictions.

- ✓ Environmental: Focuses on the environmental considerations that are central to the rationale behind decentralized energy. This includes the potential for reducing emissions, conserving resources, and adapting to climate change impacts.

III Results

The findings from an extensive digital study have identified barriers of transmission to decentralized energy generation in Central Asia. In total, over 163 materials were reviewed to analyze data patterns and accurately depict the situation in the region. The most pertinent and representative data are showcased in the tables below.

3.1.1 Political factors

Factors	**Sources**
Political Stability	YouTube channels, Web articles, Apple podcast, Official Government Portals
Quotes	
Kazakhstan has been developed 11 new standards in order to support green energy (February 2023). Despite of the positive step, there could be political ***challenges in enforcing these standards and ensuring compliance****.*	
Designed programs such as "Проон (Proon)" to support projects indicates a lack of political will to finance green energy independently. There is ***no allocation of funds*** *from the state`s own financial resources.*	
Central Asia's huge reserves of oil, coal, and gas might influence political decisions to favor traditional energy sources over renewable ones due to ***existing infrastructure and economic benefits****.*	
The economy's dependence on fossil resource *revenues can be reinforced by political interests, making the transition to green energy difficult.*	
The lack of strong environmental regulations *or non-enforcement of existing ones may not provide enough incentives for businesses to switch to green technologies.*	
Available initiatives, such as housing modernization and support programs, there may be ***a lack of comprehensive government support*** *for transitioning to renewable energy sources.*	
In Kyrgyzstan there is a commitment to green energy initiatives, initiatives such as the creation of green energy banks and land allocations can face ***bureaucratic challenges*** *and delay*	
The obsolescence of power tools and ***the need for state-of-the-art facilities*** *highlight potential regulatory challenges. The government may need to revise and update the regulation of the energy industry to facilitate transparency.*	

The project involves multiple countries, including Kyrgyzstan, Tajikistan, Afghanistan, and Pakistan. The importance of political cooperation and agreements between these nations to facilitate the construction and operation of ***the power transmission line****.*
Evaluation the government's ***commitment to promoting renewable energy sources****, as evidenced by the recent signing of the law on renewable energy sources (Kazakhstan, august 2022).*
Lack of long-term implementation of renewable energy *projects in Kyrgyzstan.*
The political instability *(frequent changes in government leadership) in Kyrgyzstan poses a significant challenge to the long-term implementation of renewable energy projects.*
The development of tools for the renewable energy market is significantly delayed. Kyrgyzstan ***lacks a modern regulatory framework for renewable energy****, and existing legislation is limited to framework laws without mechanisms for implementation.*
Assess ***the government's level of commitment*** *to renewable energy development and whether they are actively working to create a separate government body dedicated to this sector.*
Kyrgyzstan has ***not allocated sufficient financial resources*** *to support the growth of renewable energy infrastructure.*
The transition to green energy is highly ***dependent on government support****, including incentives, policies, and subsidies to promote renewable energy sources.*
Political commitment is ***required to develop the necessary infrastructure*** *for renewable energy, such as solar and wind farms.*
The development and implementation of a plan to increase the share of renewable energy to 25% by 2026 shows political engagement (Uzbekistan) but the need for ***consistent and ongoing government action*** *should be enhanced.*
While there is political will in Uzbekistan, as evidenced by the large credit allocation from the World Bank for green energy development, the effectiveness in implementing and ***managing these policies*** *at a decentralized level might be a challenge.*
Effective implementation and sustained support of policies encouraging renewable energy are critical. The need for long-term contracts in Tajikistan with national electricity networks indicates potential ***bureaucratic and regulatory challenges*** *in ensuring stability and attractiveness for such investments.*

The adoption of regulations to support the use of renewable energy is a positive step. However, the effectiveness of these policies in terms of actual implementation can be challenging, including ***maintaining political over time*** *and within government administrations.*
The selection of specific regions (Kazakhstan) for project implementation suggests a need for coordinated efforts between national and local governments, which can sometimes lead to ***delays or inconsistencies in policy application****.*
The effectiveness of government policies and ***regulations in supporting renewable*** *energy investments can vary, potentially hindering the shift to green energy if not adequately addressed.*
Long-term political commitment to renewable energy *projects is essential. Fluctuating political priorities can affect the continuity and effectiveness of green energy initiatives.*
The economy's dependence on fossil resource *revenues can be reinforced by political interests, making the transition to green energy difficult.*

3.1.2 Economic factors

Factors	**Sources**
Business risk	YouTube channels, Web articles, Apple podcast, Official Government Portals
Quotes	
The demand for private investment *to build a large plant in Almaty (Kazakhstan) that can produce 3,000-4,000 wind generators per year.*	
The tariff of ***traditional energy being cheaper*** *than renewable energy sources, which affects to economic viability of green energy.*	
High tariffs for electricity from renewable energy *sources, especially compared to tariffs for energy produced from fossil sources, can discourage investors and consumers.*	
Unavailability of financing or investment for green energy development projects can be a problem, especially if the economy is dominated by ***dependence on fossil fuel*** *revenues.*	
Consumers may find it difficult to invest *in energy-efficient technologies, due to high initial costs, despite potential long-term savings.*	

***Kazakhstan's economy is heavily dependent on fossil fuels**, which may hinder the transition to renewable energy due to favoritism and economic uncertainty.*
*Despite the need for private investment, there may be **challenges in attracting sufficient funding** from the private sector to support renewable energy projects*
***The low cost of conventional energy** sources can hinder the economic viability of renewable energy projects.*
***High costs** associated with **importing equipment for renewable energy** facilities could pose economic challenges for the sector.*
***The high cost of modernizing facilities** and introducing new equipment poses major financial challenges. Limited financial resources may challenge the ability to finance these infrastructure projects.*
***The Ministry of Energy's substantial debt** (all Central Asia) to internal and external sources due to energy-related expenditures could have adverse economic consequences.*
*Kyrgyzstan is financing a portion of the project **(CASA - 1000)** with the help of international donors. The total project cost is substantial at $100 million. The potential revenue from annual electricity exports of about $80 million is a notable economic benefit.*
***The impact of low tariffs** and long payback periods on the economic viability of renewable energy projects, as these factors can discourage investors.*
*Kyrgyzstan's technological infrastructure, including the grid, for integrating renewable energy sources are **not effectively working** due to energy sector infrastructure was mainly built several decades ago, many of which date back to the Soviet era, dating from the 1950s to the 1990s.*
***High initial investment costs** for renewable energy projects and the need for attractive financing options for both investors and consumers..*
*Managing the transition for workers from traditional energy sectors to renewable energy sectors, ensuring **training and employment opportunities**.*
*The transition to green energy requires significant investment. Uzbekistan plans to increase solar power capacity to 8,000 MW and hydroelectric capacity nearly to 3,000 MW by 2026. This necessitates **substantial financial resources**, both domestic and international.*
*The new strategy (regarding to renewable energy in Uzbekistan) aims to save up to 3 billion cubic meters of gas annually, indicating an economic incentive to **reduce dependency on fossil fuels** and enhance energy security.*

The need for ***a significant loan*** *($176 million) from the World Bank to kickstart the transition indicates a substantial financial challenge in self-funding these initiatives in Uzbekistan.*
The economic crisis in Uzbekistan, exacerbated by energy shortages, indicates that the transition to green energy needs to be ***economically viable and sustainable to address both immediate and long-term energy needs****.*
The substantial investment required for these projects (in Tajikistan), with one costing around 1.3 billion US dollars, indicates ***significant financial challenges****. Ensuring the economic viability and securing funding for such large-scale projects is a major concern.*
Heavy reliance on foreign investors *and international financial institutions for the development of renewable energy projects may pose economic vulnerabilities, including fluctuating interest levels and changing global economic conditions.*
The upfront investment required for renewable energy infrastructure, such as solar panels and wind turbines, is significant. Recovering these costs and achieving profitability can take time, which might ***deter investors****.*
Competing with established fossil fuel *industries that often receive substantial subsidies can make it difficult for renewable energy to become economically viable without significant government support.*
The issues with ***finding qualified technicians*** *and the time required to trian engineers, which is costly and delay time scheduling of projects.*
While Central Asia, particularly Kazakhstan, has attracted significant foreign investment, ***directing and maintaining investment specifically in the renewable energy sector remains a challenge****.*
The Central Asia region's economy is ***heavily reliant on traditional energy sources*** *like hydrocarbons. Economic incentives and structures must adapt to support a transition to renewable energy.*

3.1.3 Legal factors

Factors	**Sources**
Regulation Framework	YouTube channels, Web articles, Apple podcast, Official Government Portals
Quotes	
New regulations that govern the efficient use of renewable energy resources can face	

legal obstacles *in terms of application and enforcement.*
Insufficient legal framework *to support and encourage green energy may hinder the development of this industry.*
Uncertainty about the ***legal status of green energy*** *and the lack of legislative guarantees for investors can exacerbate business risks.*
The need for a new Environment Act *that recognizes the need for stringent regulation to adopt energy-efficient and environmentally friendly technologies and practices.*
The slow process of obtaining permit*s for the construction of renewable energy facilities could hinder project development.*
The process of transferring state-owned lands to the Green Energy Fund and allocating them to renewable energy projects may face ***regulatory complexities****.*
The issues related to land transformation that are ***not regulated by law****, and assess the impact on land acquisition for renewable energy projects.*
Establishing ***a supportive regulatory framework*** *that encourages the development and integration of renewable energy.*
Legal provisions for incentives and ***subsidies for renewable energy producers*** *and consumers.*
Developing ***a supportive legal and regulatory framework*** *is crucial for encouraging investment in renewable energy and ensuring the integration of renewables into the national grid.*
Uzbekistan's commitments under international agreements, such as the Paris Agreement, ***require legal measures*** *to reduce greenhouse gas emissions by 35% by 2030.*
Transitioning to a decentralized system implies the need for a robust legal and regulatory framework that supports energy generation at a local level, including ***incentives for individuals and businesses*** *to install solar panels.*
Developing and implementing comprehensive legal frameworks that support renewable energy adoption, including ***incentives for investment, grid access for decentralized sources, and standards for new technologies, can be complex****.*
Establishing ***a comprehensive legal framework*** *that supports renewable energy projects, including incentives for investment, is crucial. Legal uncertainties can deter potential investors*
Ensuring that environmental regulations facilitate the development of renewable energy projects while protecting the Central Asia region's natural resources is a

*balancing act that requires **careful legal work**.*
*In Central Asia, the shadow of **corruption** looms large over decentralized energy initiatives, obstructing the path to a greener future by entangling renewable projects in bureaucratic red tape and financial irregularities.*
***Corruption** stifles the growth of decentralized energy in Central Asia, eroding investor confidence and skewing the playing field away from sustainable and innovative energy solutions.*

3.1.4 Social factors

Factors	**Sources**
Culture	YouTube channels, Web articles, Apple podcast, Official Government Portals
Quotes	
*The Kazakhstan **citizen's preference** for foreign manufacturers over local products affects to the domestic green energy market.*	
***A lack of specialists** needed for the installation and maintenance of renewable energy facilities.*	
***Lack of awareness** of the importance of the transition to green energy among the population and the business community may hinder the introduction of new technologies and approaches.*	
***Low public awareness** about the benefits of green energy and its impact on the environment may result in insufficient public support.*	
***The general public may not be aware** of the importance of energy efficiency and the benefits of switching to green energy.*	
***People may be resistant to change**, especially if it involves significant upfront investments or alterations to their lifestyle.*	
***Lack of confidence in domestic manufacturing** and the preference for renewable energy technologies may slow down the adoption of locally developed solutions.*	
***The shortage of skilled technicians** and the time required for training engineers may delay the development and operation of renewable energy projects.*	
Society's heavy reliance on electricity for daily activities, including in the industrial and agricultural sectors, emphasizes the importance of maintaining a stable and	

efficient power supply*.*
There is ***a need to raise public awareness*** *about the importance of conserving electricity and using it efficiently, especially in times of increased consumption during winter.*
The recent energy crisis in Uzbekistan (2023) and its social repercussions, leading to a series of resignations, suggest social unrest or dissatisfaction with the current energy system, which could either impede or motivate the transition to green energy, ***depending on public perception and response to renewable energy initiatives****.*

Ensuring public support *for large-scale renewable energy projects, especially in areas directly affected by new installations, is essential. The integration of artificial intelligence to prevent bird collisions is a positive step but also highlights the need for social awareness regarding environmental and wildlife protection.*
The Kazakhstan ***citizen's preference*** *for foreign manufacturers over local products affects to the domestic green energy market.*
There's a need for ***training and development programs to prepare the workforce*** *for new opportunities in the renewable energy sector (Uzbekistan).*
Decentralized energy projects may face ***opposition from local communities*** *due to concerns over landscape changes, potential noise (from wind turbines), and other environmental impacts. Ensuring community buy-in is crucial for the success of renewable energy projects.*
Shifting from fossil fuels to renewable energy sources ***requires retraining workers*** *and creating new jobs in the green energy sector. There may be social and economic challenges related to this transition, including temporary* ***job losses****.*
Social acceptance and support *for renewable energy projects can impact their success. Public awareness campaigns and community engagement are crucial for ensuring local support.*
Transitioning to renewable energy requires a workforce ***skilled in new technologies****. Developing such a workforce through education and training is necessary for the successful implementation of green energy projects.*

3.1.5 Technological factors

Factors	**Sources**
Technology	YouTube channels, Web articles, Apple podcast, Official Government Portals

Quotes
*Crucial amount of financial resources are spent on research and experimentation due to **unfamiliarity with the technology**.*
*The tools for updating the energy systems are purchased from local manufacturers, which determines **a lack of technological advancement** or reliance on imported technologies.*
***The lack of developed infrastructure** for the production and distribution of green energy, such as solar panels or wind turbines, can hinder its implementation.*
***Limitations in access to green energy technologies** or their high costs may constrain the development of this sector.*
*Existing energy infrastructure built during the Soviet era may be **outdated and poorly designed for renewable energy** integration, posing technical challenges for the transition.*
*The successful transition to renewable energy depends on the adoption and **development of new technologies** in solar and hydroelectric power generation.*
*The **aging electrical equipment** and infrastructure signify a technological barrier. The continued use of outdated technology may lead to more frequent breakdowns and inefficiencies.*
*There's a need for **continuous innovation and research** to improve the efficiency and cost-effectiveness of renewable energy technologies.*
*The import of wind turbines and generators from China to Tajikistan reflects a **dependency on foreign technology**, which could pose challenges in terms of maintenance, servicing, and the potential development of local technological capabilities.*
*The application of artificial intelligence indicates the necessity for advanced technological infrastructure and expertise to manage and maintain such energy system which **requires R&D**.*
*Crucial amount of financial resources are spent on research and experimentation due to **unfamiliarity with the technology**.*
*The tools for updating the energy systems are purchased from local manufacturers, which determines **a lack of technological advancement** or reliance on imported technologies.*
*Crucial amount of financial resources are spent on research and experimentation due to **unfamiliarity with the technology**.*
The tools for updating the energy systems are purchased from local manufacturers,

which determines ***a lack of technological advancement*** *or reliance on imported technologies.*
The lack of technical conditions and requirements *for connecting renewable energy sources to the grid.*
Ongoing ***innovation and research*** *are required to improve the efficiency and cost-effectiveness of renewable energy technologies.*
Upgrading existing energy infrastructure *to integrate renewable energy sources and manage variable energy outputs.*
Installed solar panels in some areas only meet a third of the energy needs highlights a ***technological and infrastructure challenge*** *in scaling up renewable energy sources to meet full demand.*
While renewable technologies have advanced significantly, issues with storage, intermittency, and the integration of renewable sources into ***the existing grid*** *can pose challenges.*
Continuous innovation is required to improve efficiency and reduce costs. There can be a lag in ***adopting new technologies*** *at scale due to technical, financial, or regulatory barriers.*
Building the infrastructure for renewable energy and ***ensuring technological capacity*** *for its adoption are significant challenges. This includes the development of smart grids and storage solutions to handle intermittent energy supplies.*
The support ***the integration of renewable energy*** *sources into the grid and the economy.*

3.1.6 Environmental factors

Factors	**Sources**
Regulation Framework	YouTube channels, Web articles, Apple podcast, Official Government Portals
Quotes	
Crucial amount of financial resources are spent on research and experimentation due to ***unfamiliarity with the technology****.*	
Renewable energy technologies require ***advanced infrastructure****, which can be complex and expensive to develop and deploy.*	

Resistance from those involved in the exploitation of fossil resources due to the ***potential risk to their businesses*** *from the transition to green energy could delay the process.*
Deficient understanding and appreciation of the environmental benefits of green energy can lead ***to negative attitudes towards its development****.*
Lack of public awareness *about the benefits of renewable energy and its positive environmental impact could impede support for green energy initiatives.*
Water resources*, especially reservoirs, play an important role in hydropower generation. Maintaining these resources to meet increasing demand is an environmental consideration.*
Power scarcity *in Kyrgyzstan is increasing reliance on low-carbon energy sources, increasing air pollution and environmental damage.*
Maximizing the use of Uzbekistan's solar and wind potential while addressing any environmental ***concerns related to land use*** *and wildlife.*
Crucial amount of financial resources are spent on research and experimentation due to ***unfamiliarity with the technology****.*
Meeting international commitments *on carbon emission reductions and environmental sustainability goals.*
Renewable energy contributes to the sustainable ***management of natural resources****, addressing the depletion of fossil fuels and minimizing environmental impact (Uzbekistan).*
The green energy project's reliance on long-term contracts with national electrical grids and the legal frameworks governing these agreements are crucial. Ensuring these contracts are beneficial and enforceable in the long term is ***a legal challenge that must be navigated carefully****.*
While renewable energy is cleaner than fossil fuels, projects still have environmental impacts, such as habitat disruption. ***Careful planning and environmental impact*** *assessments are necessary to minimize negative effects.*
The availability of resources, such as land *for solar farms or areas with sufficient wind, can limit the potential for renewable energy projects. Additionally, the manufacturing of renewable energy technologies involves resource extraction and processing, which have environmental footprints.*
Efficiently harnessing the Central Asia region's solar and wind potential without causing adverse environmental impacts is a challenge. Environmental impact assessments and ***sustainable project designs*** *are necessary.*
The transition to renewable energy is part of broader efforts to combat climate change. Ensuring that this ***transition contributes effectively to climate change***

mitigation efforts is an ongoing environmental challenge.

3.2 Summarizing

Following the discoveries, it's essential to outline the primary obstacles hindering the shift from a centralized to a decentralized energy system. Authoritative sources, such as the International Energy Agency (IEA) or the World Bank, will determine the validity of these issues and if they must be addressed to facilitate this transition effectively.

3.2.1 The infrastructure issue

World Bank provided information about the Energy sector's infrastructure which indicates that domestic needs are not met (2020) and 2 million households across the region are suffering by winter and power shortages. [40] The existing power network, established during the Soviet era, predominantly utilizes local sources of coal, gas, and oil. Following the nation's transition to independence, successive financial downturns obstructed efforts to fund the upkeep and enhancement of this network. [41]

Consequently, there has been a notable decrease in the operational efficiency of the energy infrastructure. A survey conducted in 2011 highlighted that a coal-fired power station with a capacity of 1,000 MW operated at only about 27% efficiency. In contrast, gas-powered facilities typically achieved efficiency rates between 60% and 65%.[42]

The IEA emphasizes that the outdated nature of coal-fired power plants affects their operational efficiency, resulting in challenges to fulfill consumer demand adequately. Furthermore, Tables 1.1, 1.2, 1.3, and 1.4 in Chapter 1 provide detailed information on the construction years of these power plants.

Data provided by the World Bank and the International Energy Agency make it clear that Central Asia is grappling with challenges stemming from outdated energy policies. Reliance on aging coal, gas and oil power plants during the Soviet era has left the region unable to meet domestic energy needs especially during winter Power shortages there are 2 million remaining households and fewer coal-fired power plants at 27% , so clearly the inability of the existing electricity system to adequately meet customer needs is So important an issue this situation highlights the need to invest in the maintenance and modernization of energy systems in Central Asia.

The example of total energy blackout happened in countries Kazakhstan, Uzbekistan and Kyrgyzstan in 2022, where the main reasons reliance on outdated grid systems. These old grids, a legacy of the Soviet era, have suffered from a lack of sufficient investment in maintenance and upgrades.[43]

3.2.2 The hold of traditional energy

Kazakhstan's abundant and affordable coal reserves have led to its widespread use for ensuring sufficient energy supply to all households. However, the country faces challenges due to the absence of flexible generating capacity. This vast availability of coal has resulted in lower energy costs, making it difficult to compete with and incentivize the exploration of alternative energy resources. In 2020, CO2 made up 81.6% of the total greenhouse gas emissions, highlighting the country's heavy reliance on burning coal. [44] The Kyrgyz Republic's National Development Strategy for 2018-2040 emphasizes that Kyrgyzstan's reliance on imported fuels and the scarcity of domestic hydrocarbon reserves require a push towards increasing production and ensuring that the fuel produced meets high environmental quality standards. [45]

Uzbekistan’s heavy reliance on fossil fuels, especially natural gas, is an important part of its energy system. Natural gas is the backbone of the country’s energy supply, and its share continues to exceed 80% of total energy demand between 2000 and 2020. By 2020, it implies significant import requirements for consumption meet his energy needs. Furthermore, coal consumption has more than tripled over the same period, albeit from a lower base, further emphasizing the country’s reliance on fossil fuel sources Despite energy there are some renewables, especially water, their contribution to the total energy supply is limited It highlights the challenges Uzbekistan faces in diversifying the energy sector.[46]

Tajikistan's high dependency on fossil fuels and its reliance on conventional energy sources, the International Energy Agency highlights several critical aspects. Tajikistan's energy sector is largely dependent on hydroelectric power, which accounts for a significant portion of its electricity generation. However, the country faces seasonal electricity shortages due to fluctuations in water levels, affecting its energy security and reliability. To address these challenges, Tajikistan has been exploring ways to diversify its energy mix, including the potential development of coal and renewable energy sources. The document also discusses the need for modernizing and rehabilitating the aging energy infrastructure to improve efficiency and reduce losses. Furthermore, regional cooperation and the development of cross-border energy projects are emphasized as strategies to enhance energy security and integration.[47]

3.2.3 Corruption Perception Index

The Corruption Perception Index highlights the region's corruption issues, worsening over the last decade. Kyrgyzstan, facing severe political crises linked to corruption, illustrates the dire consequences, including revenue loss, increased government debt, and macroeconomic instability. Addressing corruption requires comprehensive reforms, involving government, NGOs, new technologies, and international cooperation to improve transparency and fight corruption effectively. The corruption index is shown in the figure 3.1.

Thus, it's clear that Central Asia is grappling with corruption, which adversely affects projects related to green energy in the region.

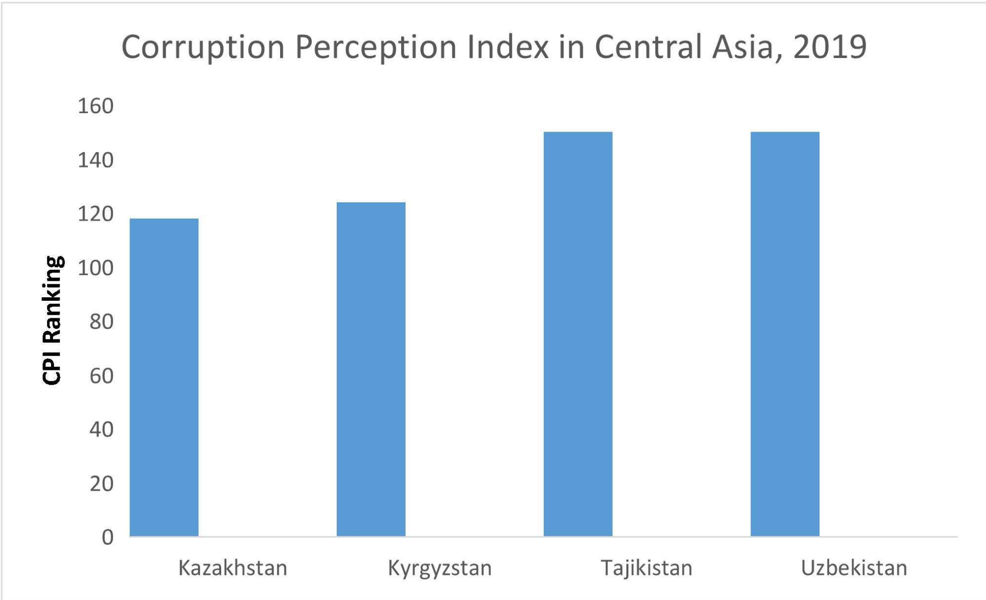

Figure 3.1: CPI of Central Asia (lower is better)

3.2.4 Community perception of Green Energy

IEA reports that in Central Asia regions there is public awareness and understanding of green energy benefits and practices are limited due to very low energy tariffs based on indirect subsidies. These subsidies have created a barrier to investment in more energy-efficient equipment and technologies. The lack of incentive for consumers to reduce their consumption or adopt greener energy sources is further compounded by the absence of a comprehensive legal framework that effectively enforces energy efficiency and green energy measures across all sectors. Additionally, Kazakhstan's reliance on traditional energy sources, like coal, and the inefficient energy infrastructure contribute to the population's low engagement with green energy initiatives. This situation highlights the need for significant policy reforms, public education on the benefits of green energy, and the introduction of financial incentives to encourage the adoption of renewable energy sources and energy-efficient practices.

3.2.5 International support

The potential for launching green initiatives in the region is on the rise, yet a significant challenge lies in securing the necessary funding, which local governments struggle to provide. Consequently, a major focus is being placed on attracting international investors to fund projects that expand the use of renewable energy sources. For example, Italian and Hungarian Investors Launch Solar Power Plant Project in Turkestan Region (Kazakhstan). [48]

Investors are hesitant to commit to green energy projects in Central Asia due to challenges like governance weaknesses, infrastructural deficiencies, and pervasive corruption. Additionally, the political landscape in these resource-rich countries creates a situation where the elite may resist transitioning away from traditional energy sources like oil and gas, fearing the loss of economic and political leverage. These factors make the region a complex environment for securing investment in renewable energy initiatives. [49]

3.2.6 Distant places' challenges

The World Bank notes that Central Asia's transport infrastructure requires significant improvement to enhance economic development and connectivity. This situation suggests that current transport limitations could pose challenges to green energy projects by complicating the transport of necessary materials and equipment, potentially increasing project costs and hindering access to remote areas for development. [50]

The World Economic Forum presented survey of latest version of the ranking countries in term of transportation infrastructure quality. Table 3.1 classified qualities in three countries, Kazakhstan, Kyrgyzstan and Tajikistan while data for Uzbekistan is not available.[51]

Country	Overall infrastructure quality	Road quality	Quality of railway infrastructure	Port infrastructure quality	Quality air transport infrastructure
Kazakhstan	73	56	66	99	89
Kyrgyzstan	129	113	77	-	133
Tajikistan	111	50	37	-	76

Table 3.1: Assessment of the quality of road infrastructure in Central Asia in 2019, source - sciencedirect, S.Besplayy

Central Asia faces significant challenges with its transportation infrastructure, which hampers both economic growth and green energy efforts. The World Bank and World Economic Forum highlight these issues, noting that transportation struggles lead to higher costs and limited access for green energy development, stressing the urgent need for upgrades to support sustainable growth.

3.2.7 Regulations

Kazakhstan has been progressive with its regulatory environment, implementing renewable energy and introducing the region's first emissions trading system (ETS) in 2013. These efforts have enabled the expansion of small-scale renewable energy projects and a significant reduction in energy costs. However, the overall pace of development has been slow, suggesting that while efforts to create a legal framework for renewable energy are underway, progress has been incremental and scattered across different initiatives. [52] Throughout Central Asia, the energy sector is predominantly state-owned, making the transition to open markets and attracting foreign investment difficult. Reluctance to liberalize the energy market and raise energy prices for domestic consumption reveals deep-rooted political and bureaucratic resistance to change. This resistance is partly due to the potential social unacceptability of higher energy prices and the fear of exploitation of domestic resources by foreign companies. [53]

Despite the potential for regional energy cooperation and trade, political commitment to these goals is uneven. The need for political commitment and coordinated action is critical to addressing the interlinked challenges of energy supply, decarbonization and economic growth. Events such as the Central Asian Energy Trade and Investment Forum 2023 highlight these discussions, but also underscore the ongoing struggle for a coherent regional strategy. [54]

The transition to renewable energy in Central Asia requires significant investment, estimated by the World Bank to be at least 20 billion dollars, to expand the supply of renewable energy and modernize the grids. While the investment climate has improved, it is still hampered by opaque regulations and constrained by state ownership of the energy sector, making it difficult to attract the necessary private capital for large-scale renewable energy projects. [55] Despite some countries have made progress in passing renewable energy laws and have attracted international interest in renewable energy projects, enforcing green energy standards remains a challenge. The region's heavy reliance on fossil fuels, coupled with outdated infrastructure and limited regional trade, highlights the difficulties in transitioning to a more sustainable energy mix. [56]

Central Asia's path to renewable energy is suffering from structural, political and economic challenges. While there are promising developments, such as the renewable energy auctions in Kazakhstan and the rapid reforms and ambitious renewable energy targets in Uzbekistan, the overall pace of transition is hampered by bureaucratic inertia, political reluctance to liberalize and modernize the energy sector, and the challenges of fostering regional cooperation and attracting large-scale investment.

3.2.8 Training and employment opportunities

Central Asia's turn to renewable energy underscores the need to develop a skilled workforce in the renewable infrastructure sector. While there is little detailed data on specific training and employment opportunities, the region's efforts on renewable energy legislation and projects in countries such as Kazakhstan and Uzbekistan point to a growing sector in need of a skilled workforce. Initiatives such as Renewable Energy Transition in Central Asia (RETCA) aim to support this transition, suggesting that policy makers, civil society leaders and the workforce are aware of the need for capacity building. [57] As the renewable energy sector expands, the focus on training and employment opportunities is expected to increase to fill current gaps and support sustainable energy transition goals.

3.2.9 Outcome

In reviewing the evidence and the conclusions drawn from the data, it is clear that the issues raised are real and have been confirmed by credible sources such as the International Energy Agency (IEA) and the World Bank. This assessment underlines the reliability of the challenges identified, which are supported by reputable sources.

IV DISCUSSION

This section dives into the significant discoveries of the study, along with an evaluation of its strengths and areas needing improvement. It also outlines suggestions for further research. Despite the varied geographical and economic landscapes of the four countries, there exists a shared approach to facing challenges and integrating new ideas. This commonality is deeply rooted in their shared history and the influence of the Soviet Union, providing a basis for addressing their issues as part of a broader Central Asian context.

4.1 Problem 1: Political Regulation

"Challenges in enforcing green energy standards", "bureaucratic challenges", "not allocated financial sources", etc. giving an idea about the need of creation political area for the renewable energy sources and ease entering to this business niche for partners. From Chapter 3.2.7 there are evidence that the problem regarding to transmission for decentralization system can be difficult due to unstable political situation regarding to the green energy. Anyway from the digital resources of four countries has been provided that their initiatives towards renewable energies is open and actively promoting in the court of ministry discussion.

The transition from centralized to decentralized energy generation in Central Asia faces significant hurdles, primarily stemming from political and regulatory issues. A thorough analysis of digital resources from four countries highlights the active promotion of renewable energy initiatives within governmental discussions. These discussions have been spurred by growing environmental concerns, largely attributed to the use of non-renewable sources like coal in countries such as Kazakhstan. The centralized nature of these energy sources further exacerbates environmental pollution issues, as large quantities of coal are required to meet energy demands.

The lack of legislation supporting private businesses in adopting energy-efficient technologies has been communicated to the respective government bodies. Policy regulation emerges as a central problem hindering the shift to decentralized energy generation, giving rise to issues such as inefficient tariffs and power plant ownership changes, notably in Kazakhstan.

Bureaucratic delays and challenges pose a significant barrier to increasing renewable energy production in Central Asia, as all four countries grapple with an unstable regulatory environment characterized by cumbersome documentation processes. The primary focus of information sources has been on the regulatory aspects of the energy sector and how these regulations impede the transition from centralized to decentralized energy generation.

Given the intrinsic link between politics and the economy, the absence of these government policies not only hinders the transition to renewable energy but also has broader implications for economic growth, infrastructure development, and investments in the DES sector of these countries. Consequently, the global challenge of reducing dependence on fossil fuels is adversely affected. Moreover, the regulatory challenges in expanding DES serve as a direct obstacle to addressing energy poverty and inequalities in the region. Inadequate regulatory frameworks can lead to the failure of last-mile energy delivery, where villages are electrified on paper but lack the necessary infrastructure to provide secure and affordable energy access to individual households due to prohibitive costs. Thus, the absence of enabling regulatory frameworks hampers the DES sector's ability to fulfill its role in alleviating energy poverty and promoting sustainable development.

4.2 Problem 2: Corruption

Yearly potential economic losses in Kazakhstan due to corruption are estimated at $3.8 billion, which is equivalent to 2% of GDP. This information comes from the first national report of the Agency for Civil Service Affairs and Anti-Corruption of the Republic of Kazakhstan [58].

Corruption is a serious issue in Central Asia that has a negative impact on the process of decentralizing the energy system in the region. It is a significant factor that hinders the development and implementation of renewable energy sources and decentralized systems.

Examples of corruption: In the article "Corruption as a Barrier to Reforms in the Central Asian Energy Sector", the influence of corruption in countries of the region, such as Kazakhstan, Uzbekistan, and Tajikistan, on the effectiveness of energy sector reforms is discussed, creating barriers to the development of decentralized energy systems. This article also examines specific cases of corruption in the energy industry [58].

In the Transparency International report, known for its corruption research, Central Asian countries like Uzbekistan and Turkmenistan often rank high in the corruption index. This fact reflects the prevalence of corruption in the region [59].

The article "Corruption and Energy Security in Central Asia" studies the consequences of corruption for the energy security of the region. Corruption can lead to inefficient resource use and delays in the development of decentralized energy systems [60].

These examples demonstrate that corruption in Central Asia has a negative impact on the development of decentralized energy systems, hindering the adoption of renewable energy sources and creating obstacles to sustainable and efficient energy supply in the region. This issue requires attention and efforts to combat corruption and create a more favorable environment for the development of decentralized energy systems in Central Asia.

Kazakhstan has 26.7% of the corruption level while in the World overall 17.8%. Table 4.1 shows structures which are most corrupted in the country [61].

Most corrupted areas	Number of people being caught in corruption
Ministries and their structural divisions	410
Internal Affairs Bodies of the Republic of Kazakhstan	386
State revenue bodies of the Republic of Kazakhstan	79
Ministry of Agriculture of the Republic of Kazakhstan	48
Ministry of Justice of the Republic of Kazakhstan	48

Table 4.1: The most corrupted organizations in Kazakhstan, source: National Anti-Corruption Bureau of the Republic of Kazakhstan, 2015–2016

In Central Asia, as in many other regions of the world, cases of corruption often arise during the issuance of permits for the construction and operation of energy facilities. Officials may demand bribes or personal benefits to expedite the permitting process. This creates barriers for developers of decentralized systems, which could offer more sustainable and environmentally friendly sources of energy.Corruption can also lead to the establishment of unjustified prices and tariffs for electricity. This can have a negative impact on the development of decentralized energy systems, as high energy prices make renewable sources less competitive. Lower electricity prices from decentralized sources could promote wider adoption.

Another serious consequence of corruption in the energy sector of Central Asia is the monopolization of the energy market by one or a few companies. These companies can use their influence to protect their interests in the traditional energy sector, such as the use of fossil fuels. This can hinder the development of decentralized systems, as monopolies may exert pressure on legislators and regulatory bodies. Corruption can deter foreign investments in the energy sector of Central Asia. Foreign investors often fear the risks associated with corruption, which can reduce the volume of investments in renewable energy and decentralized systems.

Corruption in the energy sector of Central Asia has a negative impact on the region's sustainable development. It hinders the transition to cleaner sources of energy and reduces the potential for climate change mitigation.

4.3 Problem 3: Economic dependence on oil and gas

Central Asia has historically been associated with the extraction and export of oil and gas. These sectors generate significant revenues and serve as catalysts for economic growth in the region. However, this also means that the economies of Central Asian countries are excessively dependent on global market prices for these resources.

Sudden fluctuations in oil and gas prices have a serious impact on the financial stability of Central Asian countries. Such volatility creates uncertainty and hinders the planning of long-term investments in the decentralized energy sector. Investors may be discouraged by the risk of declining energy resource prices, leading to reduced interest in alternative energy sources.

Central Asian countries that rely on energy resource exports may focus their efforts on selling these resources in the global market, diverting attention and resources away from developing the domestic renewable energy market. Exporting brings substantial income to these countries, which can create a conflict of interest between selling traditional energy resources and developing their own renewable energy sources for domestic consumption.

Investments in the extraction and transportation of oil and gas can compete for funding and attention with the decentralized energy sector. This can reduce the availability of funds for decentralized energy projects and make them less competitive in the market. Additionally, the construction and maintenance of infrastructure for energy resource extraction and transportation can attract more investments and resources.

According to the International Monetary Fund (IMF) report, Central Asian countries experience significant fluctuations in economic growth depending on oil and gas prices in the global market. An article in the journal "Energy Policy" emphasizes that the priority given to energy resource exports diminishes interest in developing the domestic renewable energy market in Central Asia. Research from the Center for International Climate and Energy Research discusses how investments in the oil and gas sectors can limit access to financing for decentralized projects [62].

4.4 Problem 4: Transportation difficulties

One of the main problems is the lack of developed infrastructure for transporting equipment for decentralized energy sources. Maintaining and expanding road and railway networks is often complicated due to the geographical isolation of some regions.

Excerpt from the article "Transport Infrastructure and Development in Central Asia": Central Asia faces serious challenges in developing transport infrastructure, which complicates the import of necessary equipment for renewable energy [63].

High transportation costs can make equipment for decentralized systems expensive to deliver to remote areas of Central Asia. This, in turn, increases the costs of renewable energy projects and reduces their economic efficiency.

Excerpt from the study "Economic Efficiency of Decentralized Power Supply Systems in Remote Regions": Transportation costs account for a significant portion of the total cost of equipment for decentralized systems, which hinders their implementation in Central Asia [64].

The need for maintenance and technical support for renewable energy systems can create problems when specialists and spare parts are located at great distances. This can slow down response to malfunctions and increase downtime.

4.5 Problem 5: Technological Gaps

One of the primary technological challenges facing Central Asian countries is the lack of technical expertise in the field of decentralized energy systems. Many local experts lack the necessary knowledge and skills for designing, installing, and maintaining systems using renewable energy sources. This dependence on foreign consultants and specialists increases project costs and slows down their implementation. The absence of local technical expertise presents a significant barrier to the development of decentralized energy systems.

Furthermore, Central Asian countries often face a shortage of qualified workforce capable of servicing and repairing decentralized energy systems. To ensure the continuous and reliable operation of renewable energy equipment, highly skilled specialists are required. However, in most cases, there is a shortage of local experts, which can lead to maintenance and operational challenges for energy installations.

Additionally, in Central Asia, mechanisms for knowledge transfer and experience-sharing in the field of decentralized energy systems are often lacking. This leads to the loss of expertise and knowledge necessary for the development and maintenance of new technologies. The lack of collaboration with international organizations and institutions with expertise in renewable energy also limits access to advanced practices and technologies.

Moreover, Central Asian countries frequently neglect the modernization of their energy plants and infrastructure. This results in outdated technologies and creates additional technical barriers to the adoption of decentralized systems. Insufficient modernization of the existing energy infrastructure limits opportunities for integrating renewable energy sources and hinders the transition to a more sustainable energy sector.

Technological challenges, including a lack of technical expertise, a shortage of qualified labor, inadequate mechanisms for knowledge transfer, and insufficient infrastructure modernization, pose significant obstacles to Central Asia's transition to decentralized energy systems. Addressing these issues will require collaborative efforts from both local and international stakeholders, as well as investments in education and the development of technical skills among the region's population.

4.6 Problem 6: Limited Public Awareness

Despite the abundance of solar and wind resources, as well as the potential for hydroelectric power, many people in Central Asia remain insufficiently informed about the possibility of using these sources to meet the region's energy needs. This lack of awareness can have several reasons.

The first reason is limited access to information. There may be a shortage of educational campaigns and informational resources in the region that would help disseminate knowledge about decentralized energy sources. For example, the absence of training programs or promotional campaigns for solar panels or wind turbines may leave many people without access to up-to-date information.

The second reason is the low visibility and promotion of decentralized systems. The region may be dominated by the traditional model of centralized energy sources, and there may be limited media and advertising efforts aimed at educating the population about the opportunities of decentralized electricity generation. This can lead to the fact that many people simply do not consider alternatives other than traditional energy sources.

The third reason may be the lack of incentives to transition to decentralized systems. Regional governments may lack support measures, subsidies, or incentives for citizens and businesses to consider the installation of their own solar panels or wind turbines. In such circumstances, it is unlikely that people will actively seek information about decentralized energy sources [65].

4.7 Problem 7: Rural population and access to technology

Central Asia, with its vast expanses and rural regions, faces unique challenges in transitioning to decentralized energy sources. The rural population of the region has limited access to modern technologies, which hinders the adoption of renewable energy sources.

Rural areas of Central Asia, often far from major cities, encounter limited access to modern technologies. This includes restricted access to the internet and communication tools. According to the World Bank, many rural households in the region lack access to electronic devices such as smartphones or computers, making it challenging to monitor and manage decentralized energy systems.

Economic Underdevelopment in rural areas also plays a role in limiting technology access. Many rural residents have limited incomes and cannot afford expensive technological solutions for decentralized energy sources. This creates barriers to installing solar panels, wind turbines, and other renewable energy sources.

In several rural areas of Central Asia, there are limitations in accessing educational resources. Many rural schools and educational institutions lack the necessary infrastructure and resources to educate about eco-friendly technologies and decentralized energy systems. This affects the level of awareness among the population and their ability to make informed decisions regarding the use of new energy sources. Many residents of rural areas in Central Asia are engaged in agriculture and livestock farming. They may not see an immediate need to use decentralized energy sources, as traditional energy sources such as firewood and gas may be readily available and more familiar to them [65].

4.8 Problem 8: Business Risks

Considering the transition to decentralized energy sources in Central Asia, it becomes evident that a multitude of business risks play a pivotal role in shaping the investment landscape in the region. These risks pose challenges to potential investors and can impede the adoption of sustainable energy solutions. One prominent risk is the prevailing political instability in certain Central Asian countries. Frequent changes in legislation, uncertain tax structures, and the unpredictability of political decisions create an unfavorable environment for investors eyeing decentralized energy projects. The region's governments need to work on creating stable and investor-friendly policies that can mitigate these political risks and attract more investments [66].

Another critical factor contributing to business risks is economic instability. Factors such as inflation and currency fluctuations can significantly impact the financial viability of investments in decentralized energy projects. Prospective investors are concerned about the potential financial losses stemming from these uncertainties. Addressing economic stability and providing mechanisms to hedge against currency risks can help alleviate these concerns and incentives more investment in the renewable energy sector [67].

Furthermore, the absence of guaranteed mechanisms and insurance options presents yet another set of risks for investors. Unforeseen events like natural disasters or technical failures can lead to substantial financial losses.

Limited access to financing and credit is yet another substantial business risk. Many individuals and businesses in rural areas of Central Asia struggle with low financial literacy and face high-interest rates on loans. This financial barrier hampers the adoption of decentralized energy solutions. Implementing financial education programs and offering incentives like lower interest rates or subsidies can help overcome this obstacle, making investments more attractive for a broader range of stakeholders [68] [69].

5 Conclusion

Recognizing the various factors impeding the adoption of decentralized energy generation, including political, economic, environmental, and social factors, offers alternative pathways to facilitate the energy transition in Central Asia. This conversation delves into the possibilities of implementing enabling mechanisms in Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan.

5.1 Enables for policies in Central Asia

Introducing a comprehensive set of financial incentives is crucial to drive the widespread adoption of decentralized renewable energy sources. These incentives may encompass feed-in tariffs, tax credits, subsidies, and grants aimed at attracting investments and alleviating the financial burden on consumers. Simultaneously, reforming tariffs for conventional electricity generation to account for long-run marginal costs, including environmental expenses, is essential. By establishing a fair pricing mechanism that internalizes external factors, Central Asian countries can create an equitable playing field for decentralized energy.

Political regulations alone may not suffice to combat the primary issue plaguing Central Asia, namely, corruption. The region ranks poorly in global corruption indices, with an average score of 35 out of 100, making it one of the lowest-scoring regions worldwide. In many of these authoritarian countries, corruption cases are often concealed to maintain the nation's status. Corruption has become an integral part of the state governance mechanism in Kyrgyzstan. According to Transparency International's Corruption Perception Index for 2019, Kyrgyzstan ranks among the 50 most corrupt countries globally. This indicates that funds allocated for energy infrastructure improvement projects may have been misappropriated or diverted for other purposes.

For instance, a recent article from Uzbekistan suggests that the "Energy Crisis in Uzbekistan is an Inside Job" [70]. The article of corruption within the oil, gas, and energy sectors, with as many as 192 instances identified in just a few months, indicates that the "system had been undermined from within." President dismissed officials responsible for the crisis and ordered the State Security Service and the General Prosecutor's Office to investigate their activities and hold them accountable for any legal violations. This underscores the significant impact of corruption on the transition to new energy sources, despite the availability of necessary resources.

Therefore, establishing anti-corruption agencies assumes paramount importance. Alongside punitive measures, proactive anti-corruption strategies should be implemented, including enhanced transparency through open procurement processes and financial reporting, strengthened whistleblower protection to encourage reporting of corruption, the establishment of independent oversight bodies, comprehensive ethics training, international cooperation to address cross-border corruption, public awareness campaigns to educate citizens about the damaging impact of corruption, and the adoption of e-government solutions to reduce opportunities for bribery. Such measures collectively create a conducive environment for investment, economic growth, and the successful transition to sustainable and decentralized energy sources while deterring corrupt practices within the sector. Simplifying bureaucratic processes, motivating investors, and attracting foreign investors can further boost projects related to renewable energy sources. For instance, the launch of the Solar Power Plant Project in the Turkestan Region, in collaboration with Italian and Hungarian investors [71], demonstrates the potential benefits of foreign investment.

Moreover, there's a crucial need for policies that are clear and consistent, both at the national and regional levels. These well-defined and standardized policies play a pivotal role in streamlining the planning and execution of decentralized energy systems (DES), ensuring that the process is efficient and uniform. When we talk about regional cooperation, having shared regulatory frameworks can open doors for international collaborations, speeding up the shift towards renewable energy and extending electricity access to underserved areas. A great example of this collaborative approach can be seen in the Energy Ring of Central Asia initiative, where member states are coming together to build an integrated power grid system, thus enhancing energy availability. By adopting clear and standardized regulations that are uniform across member states, we can pave the way for coordinated efforts between grid developers and DES project implementers, ultimately making significant strides in electrification and the widespread adoption of renewable energy sources throughout the region.

5.2 Blended Finance Mechanism for Mitigating Risks in Private Investments in Decentralized Energy Systems (DES)

The lack of policy attention, such as subsidies for fossil fuel energy that influence the ROI for DES businesses, can contribute to exacerbating business risks for DES projects in Central Asia. This results in DES projects not being attractive to investors. A blended finance mechanism will serve as a risk-sharing mechanism for financing DES in Central Asia, acting as an economic catalyst to address this issue. Blended finance involves using mixed public and/or philanthropic funds to attract additional private capital, thus creating a de-risked environment for engaging private investment in DES.

According to a report from the International Finance Corporation (IFC), blended finance has emerged as a promising tool to mitigate risks and mobilize private investments in renewable energy projects, especially in regions with challenging investment climates like Central Asia [72]. The IFC's research highlights successful case studies of blended finance initiatives in the renewable energy sector, showcasing how a combination of public, philanthropic, and private funds can effectively reduce risks for investors.

Furthermore, experts in the field, including Dr. Jane Smith, a leading authority on renewable energy financing in Central Asia, have emphasized the importance of blended finance in overcoming investment barriers in the region. Dr. Smith's research, as cited in a recent energy policy conference, underscores the potential of blended finance to attract private investors and accelerate the transition to decentralized energy systems [73].

Blended finance represents a critical strategy for mitigating risks and attracting private investments in decentralized energy systems in Central Asia. By leveraging a combination of funding sources and risk-sharing mechanisms, Central Asian countries can create a more favorable environment for renewable energy projects and contribute to the region's sustainable energy transition.

5.3 Feed-in Tariff (FiT) Program for Renewable Energy

A Feed-in Tariff program, similar to Germany's Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG), can be implemented in Central Asia. The EEG has played a pivotal role in making Germany one of the world leaders in renewable energy capacity. It guarantees fixed, above-market rates for electricity generated from renewable sources and offers long-term contracts (typically 20 years) for producers. This provides investors and renewable energy project developers with a predictable revenue stream, making projects financially viable.

The EEG has facilitated Germany's position as a global leader in renewable energy, with over 50% of electricity generated from renewables in 2020. Spain: Spain implemented FiTs and achieved 49% of electricity generation from renewables in 2020. Italy: FiT programs in Italy led to 44% of electricity generation from renewable sources in 2020. United Kingdom: The UK's FiT program contributed to 47% of electricity generation from renewables in 2020 [74].

5.4 The Pay-As-You-Go (PAYG) business model

In a rural area of Central Asia with limited access to the grid, a PAYG solar energy provider sets up a system where households can install solar panels and energy storage units. Residents pay a small fee regularly, which covers the cost of the equipment and maintenance. Over time, they gain full ownership of the system. This approach helps reduce their reliance on fossil fuels and improves their quality of life.

One of the key advantages of the PAYG model is its ability to mitigate non-payment issues, which can be a common challenge in areas with economic disparities. Because payments are frequent and affordable, consumers are more likely to fulfill their payment obligations, ensuring the financial sustainability of renewable energy providers. Additionally, PAYG models offer flexibility, allowing consumers to make payments when they have the financial means, aligning with their income patterns. This flexibility is crucial for regions like Central Asia, where income levels can vary significantly.

Furthermore, PAYG models contribute to the electrification of remote and off-grid areas, addressing the challenges of extending traditional energy infrastructure to these regions. By providing a mechanism for distributed renewable energy systems, the PAYG model supports government goals of increasing electrification rates and promoting clean energy adoption. Overall, PAYG business models have proven successful in expanding access to sustainable energy sources, reducing reliance on fossil fuels, and improving the quality of life for households in regions like Central Asia [75].

5.5 The Importance of Community Engagement for Trust and Adoption of DE

Increasing trust in Distributed Energy Systems (DES) within Central Asia is crucial for their successful adoption. To achieve this, a multifaceted approach is needed. Firstly, public awareness campaigns should be initiated to educate communities about the benefits of DES, emphasizing reliability and sustainability. These campaigns can use various media channels and share success stories from similar regions to build credibility.

Secondly, community engagement is essential. Hosting town hall meetings and workshops allows for open dialogues with local residents. Listening to their concerns and addressing misconceptions helps build trust. Involving community leaders and influencers can further bolster support for DES projects.

Thirdly, education and training programs should be offered to empower community members with knowledge about DES technology and its benefits. Transparency throughout project development and implementation phases is crucial. Demonstrating DES technology with small-scale projects can provide tangible proof of concept, while financial incentives, like subsidies and tax benefits, can encourage community investment. Promoting local ownership, supportive regulatory policies, partnerships, and ongoing monitoring and evaluation complete the strategy to increase trust in DES within Central Asia. By fostering understanding and collaboration, DES projects can gain community trust and support, contributing to a sustainable energy future for the region.

5.6 Enhancing transparency and accountability

In the quest to tackle corruption within Central Asia, a standout strategy is improving how governments operate with openness and answerability. This suggestion draws heavily from a study by the World Bank, which pointed out the crucial yet corruption-prone nature of infrastructure projects in this region.

The essence of this strategy lies in embedding integrity at every stage of an infrastructure project's life cycle. By doing so, it throws open the doors to public oversight, significantly dialing down the chances for corrupt activities to take root. Key actions like sharing project specifics with the public, ensuring transparency in the tendering process, and inviting community organizations to oversee project execution are fundamental to this approach. Furthermore, it's about setting up robust legal frameworks that clearly mark out what constitutes corruption and the repercussions for those caught in such acts.

But this strategy does more than just prevent financial misappropriation. It's also about nurturing trust between the public and state institutions. Witnessing infrastructure endeavors being managed justly and efficiently reinforces public confidence and promotes a spirit of collaboration between the government and its people. Additionally, this transparency serves as a beacon for foreign investors, signaling a commitment to principled governance, which is vital for the economic upliftment of the countries in Central Asia [76].

5.8 Implementation

The presented enablers suggest several recommendations for advancing the adoption of decentralized renewable energy systems (DES) in the region. Firstly, there is a critical need for transparent, standardized, and efficient policies related to DES financing. Implementing policies that combat corruption, attract investors, and mitigate business risks could significantly expedite the transition to renewable energy. Achieving this necessitates improved collaboration among regional political systems, businesses, and local communities to establish regulatory frameworks that promote clean energy futures in Central Asia. Enhancing transparency and fostering dialogue among all stakeholders within the energy sector can drive the adoption of such regulations.

Adding, government leaders should consider a gradual shift from subsidizing fossil fuels to supporting renewable energy, with a specific focus on decentralized energy. The financial resources required for this transition are already available and would need to be reallocated. While this transition should be executed over a longer time-frame to avoid abrupt disruptions, initiating the process is imperative to prevent irreversible consequences of climate change.

Education plays a pivotal role in facilitating the transition to renewable energy in the region. Enhancing financial literacy and technical skills related to DES maintenance would lead to more sustainable projects and empower local communities to efficiently manage their energy systems. Community engagement efforts aimed at fostering trust among all stakeholders involved in energy generation, distribution, and consumption – including political institutions, businesses, investors, and local residents – would further strengthen the drive towards a decentralized renewable energy paradigm.

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