Towards Sustainable Community Development through Renewable Energies in Kyrgyzstan: A Detailed Assessment and Outlook

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Abstract: In rural Kyrgyzstan, the energy need is usually derived from multiple natural energy resources such as firewood, charcoal, agricultural residues, animal dung, and wood branches, which are considered common and predominant practices. Because of the non-sustainable resources and heavy reliance on the environment, Kyrgyzstan is one of the most vulnerable countries to climate change in Central Asia. On the contrary, the great renewable energy potential in Kyrgyzstan is untapped, which could be the most promising solution to ensuring sustainable energy supply in the country. However, because of the lack of scientific knowledge, current energy policies, and the lack of infrastructure, renewable resources are mainly untapped. To exploit the country’s renewable energy potential, there is a need for a systematic diagnosis to develop a strategy to explore renewables in Kyrgyzstan, which is currently missing in the existing literature. In that regard, the presented study aims to assess the current status of renewable energy sources by considering the local energy context from a potential point of view. Further to this, it provides a comparative overview through a matrix of strengths, weaknesses, opportunities, and threats. Such novel analysis would be the fundamental base for formulating policy advice and a national plan to enhance the utilization of renewable energy in Kyrgyzstan. The presented analysis was carried out based on the extensive literature review, the country’s national plan, and the existing energy policies of Kyrgyzstan. The article found out that there is huge potential available for the renewable energy market. As compared to other renewable energy sources, solar energy has great potential and can be considered one of the pioneer sustainable sources for integration into the country’s power generation framework.

Keywords: Central Asia; energy services; high-altitude; Kyrgyzstan; renewable energy resources; sustainable energy

1. Introduction

1.1. Setting the Stage

Kyrgyzstan is known for its unique geographic location, as it is situated at a high elevation and covered by the long range of the Tien-Shan mountains. The exceptional geographic condition placed Kyrgyzstan as one of the cold climatic countries in Central Asia. The cold climate results in long and harsh winters in the country [1]. Hence, it is obvious that domestic space heating is the key and primary need for Kyrgyz people. For domestic heat supply, there is a provision of district heating networks (DHNs) in Kyrgyzstan, which can be considered a modern energy service. However, DHNs only connect households situated in the capital city (Bishkek) and neighbouring urban areas [2]. Rural areas are less likely to connect with such modern energy services due to their isolated location. Having the least developed energy infrastructure forces rural communities to use locally available, non-sustainable solid fuels (i.e., charcoal, firewood, cow dung), which have a comparatively low calorific value and high-ash content. The demand for space heating of single-family houses in Kyrgyzstan is typically covered by a conventional heating system (generation
of heat with non-sustainable solid fuels). In this context, rural households need to spend up to 50% of their income on heating. However, rural areas in Kyrgyzstan are situated far away from the country's major economic and energy generation centres (i.e., Bishkek and Osh). Hence, it is evident why job opportunities are scarce and/or absent from the constant income sources in rural areas. Non-sustainable solid fuel consumption from the household is one of the key contributors to air pollution [3,4]. Further to this, the heavy reliance on firewood turns out to have a negative impact on Kyrgyzstan’s riparian forest and increases the stress on the forest cover. The non-sustainable way to meet the energy demand is to place Kyrgyzstan as one of the most vulnerable to climate change in Central Asia [3,4]. On the contrary, Kyrgyzstan is endowed with alternative energy resources, such as hydro energy, solar energy, wind energy, and bioenergy because of its geographical characteristics [5].

The exploitation of renewable energy (RE) on a community level potentially helps to resolve the challenge in rural areas. However, the available sustainable energy resources are not yet exploited in favour of the local communities. As rural areas are characterised by low-population densities, it is favourable to assess the energy planning and solution at the community level. It is important to evaluate which concept has low cost and high viability in rural Kyrgyzstan [4]. Hence, to develop the RE sector in favour of local communities, there is a need to understand the available potential of RE and develop the basic mechanisms for the operation and conduction of sustainable sources in terms of legal and economic aspects. To decarbonise the Kyrgyz energy sector and foster sustainable development, there is a need for policies and measure support to expand the RE sector in Kyrgyzstan. However, such a policy/national plan formulation to integrate renewables into the energy sector requires reliable and accurate information, knowledge, and framework.

1.2. The Current State of the Art and Gap in the Research

The literature related to renewable energy in Kyrgyzstan is rather poor. Although limited, there is some previous research available in the context of new energy sources in Kyrgyzstan. The available research is briefly explained here.

Baybagyshov et al. [6] obtained the results of the possibility of using renewable energy in Kyrgyzstan. The results were derived by conducting preliminary surveys of residences and semi-structured interviews with representatives from the local village administration. The study outlined the potential and deployment of renewable energies in Kyrgyzstan and provided an overview of solar, wind, biomass, hydro, and geothermal energy.

Laldjebraev et al. [7] performed an intensive analysis of RE for the five Central Asian countries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The article provided information on the overview of the potential, deployment, and outlook, including small-scale hydropower, solar, wind, geothermal, and bioenergy. It also provided the barriers which hinder the RE development in Central Asia.

Shadrina et al. [8] discussed the current situation in the Central Asian countries in connection to their economic growth and development. The research identified that there is significant progress in the deployment of renewable energy technologies in Kazakhstan. There is very limited information available related to Turkmenistan and Uzbekistan. Because of the hydropower features, Kyrgyzstan and Tajikistan have considerable employment of hydropower generation. The research was performed with a comprehensive analysis of the installation of renewable energies in Central Asian countries.

Botapaev et al. [9] represented the existing situation of the Kyrgyz renewable energy sector, including legislation, as well as the information about academic education on renewable energy. The authors further identified that the government and energy policies are the crucial elements in the development of the renewable sector in Kyrgyzstan.

Liu et al. [10] found that the non-traditional renewable energy sources have emerged as a promising solution to bring sustainability to Kyrgyzstan. The research further identified existing barriers to the implementation of renewable energies in the country.
It can be identified from the literature review that the common research focus, in the context of RE in Kyrgyzstan, remains limited for the selected research field. So far, the available literature has focused on assessing the available RE assets from a very generalised point of view. In some of the cases, the research further derived several parameters, such as national policy and valuation study, from the impact, environmental, and/or economic point of view. However, as mentioned earlier, to foster the development of the RE sector in Kyrgyzstan, there is the need to provide an assessment of the available renewable energies in the local context to select the suitable renewable energy source (based on the suitability of each RE source with its pros and cons) for energy supply. It can be seen from the literature review that accurate and updated information is missing from the scientific community. This can be considered as the gaps in the research. This gap cannot provide detailed information to the international reader about the development potential of renewable energies in Kyrgyzstan. This scientific knowledge is necessary and can serve as basic input for policymakers and market players to operationalise renewable energies in Kyrgyzstan.

2. Research Design and Contribution to Knowledge

By considering the existing research gap and the need for scientific contribution, the presented research article sets itself the goal to perform a systematic diagnostic and strategic analysis, which has been overlooked thus far in the recent literature. Further to this, the research also characterised the dynamics of RE sources in Kyrgyzstan. Summing up, the presented article demonstrates the renewable energy potential of Kyrgyzstan.

In order to provide a toolkit of assessment of Kyrgyz RE sources, the presented study employs a SWOT analysis to evaluate the available renewable energy sources of Kyrgyzstan strategically. To achieve the research goal, the presented study employs a SWOT analysis to evaluate the available renewable energy sources of Kyrgyzstan strategically. The SWOT analysis is derived from its initials and is a well-structured strategy to assess the current status of the business in the market by evaluating its Strength (S), Weaknesses (W), Opportunities (O), and Threats (T). Therefore, the SWOT analysis is a systematic process that allows for the space to identify various factors that influence the overall strategy/planning. The data collection for the presented study was performed through an in-depth literature review and was subjectively evaluated from the local boundary perspective. Hence, the final presentation of the SWOT profile became more interactive. The strategic analysis, which has been overlooked thus far in the recent literature, is presented in the article. The presented study expands on the previous studies/existing recent theoretical developments by providing an extensive and detailed assessment of the available renewable energy landscape of Kyrgyzstan (i.e., solar energy, wind energy, biomass energy, hydro energy, and geothermal energy). Further to this, the research also characterised the dynamics of RE sources in Kyrgyzstan.

To maximize the value of renewable energy and amplify positive impacts to foster sustainable development, the presented article summarises the renewable energy potential of Kyrgyzstan and provides a comparative SWOT profile of the available renewable energy sources of Kyrgyzstan. The SWOT analysis carried out in the presented article was a first attempt to provide the pros and cons of renewable energy in the context of Kyrgyzstan. The performed SWOT analysis has determined the paradigm that is strongly linked to the policy of RE sector development and future RE sector development. This can be considered a novel contribution to the scientific community. The detailed research methodology is presented in Figure 1.
3. Renewable Energy in Kyrgyzstan

3.1. Solar Energy

Kyrgyzstan has a mountainous geography with altitudes that vary between 800 and more than 4000 m above sea level. These conditions have a clear advantage at producing a high amount of solar energy, since during the year the duration of solar radiation is around 2100 to 2900 h \[9\]. It was estimated that the annual radiant solar energy is approximately 4677 MWh, which equals 23.4 kWh/m\(^2\) \[11\], while the average solar irradiation per year is about 1500 to 1600 kWh/m\(^2\), which represents nearly 60% more irradiation than Germany \[7,12\]. However, these circumstances are not uniform across all the territory, as the intensity of solar radiation changes depending on the location, the elevation, sun exposure, and slopes. Those conditions remain constant, especially in the upland terrain, where the direct solar radiation has the highest peak sunshine hours during May and August with nearly 130 to 155 h per month \[6\].

Due to the abundant solar resources, there has been great potential available for solar thermal and photovoltaic energy \[11,13\]. Annual specific power generation by photoelectrical equipment has a potential of 300 kWh/m\(^2\). Kyrgyzstan also has considerable potential for solar thermal considering some studies claim that under the premise of the availability of affordable technologies, such as solar collectors, photoelectric converters, and modules, the specific productivity of hot water supply could be roughly 750 kWh/m\(^2\) (heat), which could be used for hot water supply to community heat networks, for example, that provide heating and hot water to households \[13\]. Hence, it can be recapitulated that there is great solar potential available in Kyrgyzstan. Figure 2 illustrates the Global Horizontal Irradiation (GHI) map of Kyrgyzstan.
Despite the significant solar potential in Kyrgyzstan, there is no record of a share of this source in the country’s energy mix, neither for large-scale photovoltaic installations nor solar thermal installations. Moreover, there is no exact information about small-scale facilities. Most of the existing plants are installed in households for self-consumption. One example of the existing installations is in Ken-Suu village of Dzumgal district in the Naryn region, which uses 15 units of panels of 300 W [15]. Another example is a project executed with United Nations Industrial Development Organization (UNIDO), United Nations Development Programme (UNDP), and World Health Organisation (WHO) support, which installed about 19 solar plants with capacities between 1.5 and 3 kW in health facilities in Bishkek [16].

According to Botpaev et al. [9], the solar thermal collectors installed were about 35,000 m² twenty years ago and up to date, it is calculated that there are nearly 60,000 m² of thermal panels installed in the country [17]; some of these solar thermal collectors are installed in Bishkek city with a capacity of 0.5 MW [18]. It is important to highlight that Kyrgyzstan has a variety of resources that are key for the development of solar energy. For instance, Silicon is an important component for solar panel construction, which is produced in local factories, such as the Kyrgyz Chemical & Metallurgical Plant in the Chui region. By 2016, a Kyrgyz–German company called NEW-TEK LLC opened a new factory in the country to produce high-efficiency mono and polycrystalline solar modules with a production capacity of 200,000 modules equivalent to 50 MW a year. The company plans to expand its market to the Commonwealth of Independent States, Europe, and the Middle East shortly [13].

3.2. Wind Energy

Kyrgyzstan has a mountainous geography with high reliefs, although the potential of wind power is limited because its territory has a permanent wide expanse of snow and glaciers covering nearly 3% of the land area [19]. Moreover, in the areas where the wind speed is sufficiently high for wind power generation, the locations are remote and far away from the populated areas, which is a key difficulty when transporting the special logistics required for wind turbine construction [19]. Despite the high altitude, Kyrgyzstan does not have strong winds. The Issyk-Kul region has the highest number of windy days and that is 120 days. Some studies claim that the wind speed in Kyrgyzstan is between 3 to 10 m/s and the average windy days are between 40 and 50 days [20]. Moreover, the specific energy of wind flow is within 170 and 1300 kWh/m² per year and the duration of the active

Figure 2. Global Horizontal Irradiation of Kyrgyzstan (own illustration based on [14]).
wind is almost 4000 to 7000 h a year [9,11]. In depth, the existing wind data shows that the Kyrgyz wind flow occurs in light and calm wind; this condition is extended in over 50% of the country. In addition, winds of around 2 to 5 m/s (light wind) are found in over 30 to 40% of the land, and in the remaining areas, the wind speed is between 6 and 10 m/s, the so-called fresh and moderate winds [5,11,21]. Figure 3 displays the wind speed atlas of Kyrgyzstan at 10 m in height.

Figure 3. Wind speed atlas of Kyrgyzstan at 10 m in height (own illustration based on [22]).

Other studies have shown that the average wind speed is around 4.6 m/s at 100 m and the maximum wind speed is 13 m/s (at 100 m height), which according to the source shows the potential of wind in foothills is small [6]. It is because a wind project is feasible when the wind speeds are over 8 m/s. Therefore, only the highland would be viable for the generation of wind energy. However, as it was explained before, those locations are remote and of difficult access [5,9].

On the other hand, other literature suggests that the wind energy potential is enough for the execution of small projects for wind self-consumption systems of around 1 to 10 kW to cover the energy demand in distant areas located in the foothills [6]. It is important to point out that wind data is taken from measurement stations that are located at heights of about 10 m or less so that the data is extrapolated to get the interest points at 50 to 100 m, which implies that the information required to study the feasibility of wind energy has a high degree of uncertainty [19].

According to the UNDP, the country’s potential for wind power is 1.5 GW [23]. Nowadays, there is no information on the share of wind energy in the country’s energy mix, and there is also no information on the existence of large-scale wind farms. In the past, a local plant called “Oremi” in cooperation with the Russian manufacturer “Arhangelsk” used to fabricate wind turbines with a capacity of 6 kW to 16 kW. Currently, even though the plant is still running, the production of those turbines stopped [9].
3.3. Hydro Energy

Due to the mountainous characteristics, enormous water resources are abstracted in Kyrgyzstan. The country counts more than 250 mountainous rivers with nearly 2047 rivers and streams. Some of those streams have lengths of more than 10 km. It increases the feasibility of hydropower [19]. The Naryn, Talas, Saryzhaz, Chatkal, Chu, and Karadarya are the principal rivers in Kyrgyzstan. The largest river in the territory is the Naryn river, which contains several reservoirs and has about 52% of the country’s large hydropower potential [6]. Figure 4 shows the water resources as well as the key hydropowerplants of Kyrgyzstan.

![Figure 4. Water resources of Kyrgyzstan and key hydropower plants of Kyrgyzstan (own illustration based on [24]).](image)

The Naryn River flows through the country and feeds the huge Toktogul water reservoir in the west and a series of downstream hydropower plants. Kyrgyzstan has a great number of large and medium-sized rivers offering substantial hydropower potential of which only 10% has been exploited [25]. Nowadays, the existing hydropower capacity is located mainly on the Naryn River. It is around 2870 MW with an energy production of nearly 12–15 billion kWh per year.

Regarding the potential of small hydropower in large and medium-sized rivers projected in 252 rivers with flow rates of 1.5 to 5 m³/s, the annual energy production is about 80 billion kWh [6]. However, Laldjebaev et al. [7] mentioned that those projections are overestimated. The hydropower potential of small rivers is calculated at about 5–8 billion kWh per year [7]. Moreover, Abidov et al. [11] identified that Kyrgyzstan has the potential to build nearly 180 MW distributed in 92 small hydropower stations with an annual energy output estimated at 1.1 billion kW/h and the potential to generate another 22 MW through refurbishing about 39 existing small hydropower plants able to produce 100 million kW/h yearly. In contrast, other studies estimate the hydro energy potential of 140–170 TWh [25].
Hydro energy is well established in Kyrgyzstan. However, hydropower brings critical issues in Kyrgyzstan. As stated in Havenith et al. [26], the main problems of hydropower plants in Kyrgyzstan are associated with significant filtration issues in the lower parts of the dams and the deterioration of hydromechanical, electro-technical equipment, and concrete structures. This is partly due to the frequent earthquakes, as well as the natural degradation of the dams because of their age, since many of these were built more than 30 years ago [27]. It is important to mention, that most dams in Kyrgyzstan were built in seismically active areas, which tend to develop landslides and mudflows. Moreover, most dams of the ‘Lower-Naryn’ hydropower plants cascade were built very close to well-known seismic active faults. To improve the condition of the power sector as well as to meet the growing electricity demand of Kyrgyzstan, the government still focuses on developing and constructing new hydropower plants [27]. The major future hydropower projects for new capacity have been developed and are detailed in Table 1.

<table>
<thead>
<tr>
<th>Region</th>
<th>Hydropower Projects</th>
<th>Capacity</th>
<th>Forecasted Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jalal-Abad</td>
<td>Construction of the remaining two units at Kambarata-2 (120 MW)</td>
<td>1920 MW</td>
<td>2018–2022</td>
</tr>
<tr>
<td></td>
<td>Building the Kambarata-1 HPP (1860 MW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naryn</td>
<td>Construction of the Verkhnne(Upper)-Naryn cascade.</td>
<td>240 MW</td>
<td>2018–2027</td>
</tr>
<tr>
<td></td>
<td>Akbulun HPP (87 MW)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Naryn HPP-1 (48 MW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Naryn HPP-2 (48 MW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Naryn HPP-3 (55 MW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Issyk-Kul</td>
<td>Building large HPP cascades at the Naryn and the Sary-Jaz River:</td>
<td>3665 MW</td>
<td>2030–2040</td>
</tr>
<tr>
<td></td>
<td>Kazarman HPP cascade at the Naryn River (1160 MW)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Susamyr–Kokormen HPP cascade (1305 MW)</td>
<td></td>
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<tr>
<td></td>
<td>Saryjaz HPPs at the Sary-Jaz River (1200 MW)</td>
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</tbody>
</table>

Central Asian countries are important agricultural producers. Given the fact that they rarely receive water from rainfall, they rely mostly on irrigation from the upstream countries. The countries of Central Asia have a total irrigated area of 100,000 km$^2$, requiring vast quantities of water.

Moreover, irrigation uses considerable amounts of water, and that makes agriculture the biggest water user sector in Central Asia. Therefore, agriculture is a very important source of income that would be threatened by hydropower plants [26]. The construction of new hydropower plants might represent a risk for Kyrgyzstan, and it could make the water stress situation of the Central Asian countries downstream worse. Furthermore, the reservoirs of new hydropower plants take several years to refill; during that time, the downstream water would be reduced [28].

A relevant study stated that the destruction of any dam as a result of a natural disaster (earthquake or landslide) could bring harmful consequences, including human life losses in countries in the Central Asia region. In the case of the destruction of a large dam in Kyrgyzstan, large flood waves could go downstream generating huge destruction in all the neighbouring downstream countries [26]. Moreover, hydropower projects can have several negative impacts on the environment. Hydropower dams impede the natural flow of rivers, and, therefore, create migration barriers. Migratory animals require different environments for different phases of their life cycle. This effect may lead to the loss of biodiversity and ecosystems which are essential for humans [29].
3.4. Biomass Energy

The Kyrgyzstan energy mix does not consider the share of biomass energy [5] but is probably underestimated since biomass energy, particularly dung and wood (solid biomass) is used to produce heating for households, especially in rural areas [6]. For instance, in 2013, the Kyrgyz Ministry of Energy claimed that 30% of the gas for households in those rural areas is generated by biomass [7]. Even though Kyrgyzstan has an extensive forest area of about 1.2 million hectares, which accounts for 5.6% of its total land area, and the highest economic sector is agriculture, which allows the generation of considerable amounts of farm waste, the energy potential of forest biomass is not very promising. The high cost of production is mainly caused by the matter of transportation expenditure from remote areas, as well as the likely risks of agricultural intensification that makes the forest biomass unfeasible. Furthermore, the conversion efficiency is low in comparison with the energy produced with non-renewable sources [6,8,30].

On the other hand, the principal source of biomass energy in Kyrgyzstan is livestock from sheep, cattle, and horses, with a yearly production of 2.5 million tons of animal waste produced mostly by around 1.5 million head of cattle. It has the potential to generate high amounts of energy between 1.3 TWh to 14.7 TWh [7,9,30], with a capacity of 200 MW [7,23]. Figure 5 displays the cropland and forest area of Kyrgyzstan.

![Figure 5. Cropland and forest areas in Kyrgyzstan (based on [31]).](image)

The availability of raw matter, its promising projection, and the fact that biogas plants are the renewable energy in the Kyrgyz Republic with the fastest payback period, as reported by the United Nations, has boosted the rise in biogas production during the last years. What is more, numerous non-profit organizations, such as “Fluid”, “Energy-saving technologies”, “Center on problems of using renewable energy sources-KUN”, have promoted and carried out different campaigns to encourage the construction of biogas plants [9]. The active agricultural land and pasture land are also responsible for the great availability of livestock. Figure 6 characterises the average production (in tons) of major agricultural products and the average number of livestock in Kyrgyzstan of the last 25 years (1991–2016) based on national statistical committee of the Kyrgyz Republic.

Regarding existing plants, it is possible to find several Biogas installations from commercial organizations and non-commercial companies [9]. Most of the plants are medium sized with bioreactors from 20 to 150 m$^3$ and small-scale biogas plants with bioreactors that vary between 3 and 10 m$^3$ [7].
Regarding existing plants, it is possible to find several Biogas installations from commercial organizations and non-commercial companies [9]. Most of the plants are medium-sized with bioreactors from 20 to 150 m³ and small-scale biogas plants with bioreactors that vary between 3 and 10 m³ [7].

3.5. Geothermal Energy

In Kyrgyzstan, at the time of the former Soviet republics, more than 20 geothermal springs were dug, those geothermal resources showed low potential since all the temperatures did not surpass 60 °C, that is because in large scale geothermal applications the temperatures should be 200 °C to 350 °C; in another kind of application, such as Binary cycle geothermal power generation plants, the fluid temperature can be below 200 °C and typically between 120 °C and 150 °C [5,6,32].

Although low-capacity streams can be used along with heat pumps to supply heat, unfortunately, those applications are not of common use in Kyrgyzstan due to the lack of knowledge of those technologies and the absence of companies with experience in heat pumps. Moreover, despite the low electricity tariff, low-income families from rural Kyrgyzstan cannot afford the price; this reduces the chances for acceptability of heat pumps. Despite the limited temperatures of the geothermal resources available in the country, the potential energy production is nearly 170 GJ/year, while other sources claim that the total annual production would be around 22 GJ taking into consideration the economic feasibility [6,7,32]. Figure 7 represents the available selective geothermal resources in Kyrgyzstan.
On the other hand, most of the geothermal resources are situated in the Issyk-Kul region, where most of those resources are used in resorts for heating and water supply, which is the case of Issyk-Ata and Teplye Klyuchi, where the streams reach not too high a temperature. In contrast, regions, such as Karakol have sites including Ak-Soo, where the use of geothermal energy is favourable thanks to its immediacy for populated areas. In the region, there are streams with temperatures of about 55 °C that are barely feasible because of low temperatures and low flow rates [5–7].

Those resources are also used for medicinal purposes, especially in the coastal zone of Issyk-Kul Lake. Moreover, on the northern and southern coast of Issyk-Kul Lake, there are mineral water springs with valuable properties with a depth of 800 to 1960 m. Moreover, there is information of about 50 places available to produce water and heat supply. The water composed of carbon dioxide can be found in the territory of the Fergana Range, in the basins of the rivers Jazy, Tar, Arpa, Kara-Kulzhy, and in the Ak-Say, Jumgal, Issyk-Kul valleys [6].

4. SWOT Profile of Kyrgyzstan’s Renewable Energy Sector

According to Madurai Elavarasan et al. [33], SWOT analysis is a vital tool to perform a systematic assessment of each renewable energy to identify its strength, weakness, opportunities, and threats. In the context of Kyrgyzstan, there is thematic yet scattered knowledge available about the potential of local renewable energies. The information is rather limited and provides various statistical information. To provide knowledge on S (Strengths), W (Weaknesses), O (Opportunities), and T (Threats) of individual RE sources, this chapter plots a SWOT profile of locally obtainable energy resources. This profile is a suitable method for discussing the outcomes of the various renewable energy sources. The SWOT profile of Kyrgyz renewable energy resources has been represented in Table 2. It is clustered by various renewable energy resources and represents an individual SWOT profile.
Table 2. SWOT Analysis of Renewable Energy in Kyrgyzstan.

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Strength (S)</th>
<th>Weaknesses (W)</th>
<th>Opportunities (O)</th>
<th>Threats (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Energy</td>
<td>• Abundant resources availability</td>
<td>• Weak energy policies</td>
<td>• Huge potential to meet the gap between supply and demand</td>
<td>• Low FIT (current energy policy)</td>
</tr>
<tr>
<td></td>
<td>• Available rich land resources</td>
<td>• Limited scientific/engineering knowledge available</td>
<td>• Reduction in GHG emission</td>
<td>• The predominant use of solid fuels</td>
</tr>
<tr>
<td></td>
<td>• 300 + solar days</td>
<td>• The shortfall of industrial chain for the production/installation</td>
<td>• To develop a PV market in the country (no/less market competition)</td>
<td>• High capital cost in the context of the earning opportunities</td>
</tr>
<tr>
<td></td>
<td>• Potential to deliver sustainable energy (heat and/or electricity)</td>
<td>• Lack of financial mechanism</td>
<td></td>
<td>• Subsidised electricity price (~0.01 €/kWh)</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>• Vast scope for research and development in wind energy</td>
<td>• The less strong wind throughout the country</td>
<td>• Windy areas (i.e., Issyk-Kul) have an opportunity to install small scale</td>
<td>• Most of the weather stations record wind data at a height of 10 m or less</td>
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<td></td>
<td>• Selected areas in Kyrgyzstan have preferable conditions (i.e., windy days,</td>
<td></td>
<td>wind farms</td>
<td>above ground level. The extrapolation of mean wind speed to a height of</td>
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<td></td>
<td>windy speed) to install a wind farm</td>
<td></td>
<td></td>
<td>interest of wind energy (30 to 70 m) introduces significant uncertainties</td>
</tr>
<tr>
<td>Hydro Energy</td>
<td>• Kyrgyzstan is endowed with enormous water resources</td>
<td>• Water flow reduced in the freezing winter led to reduced power production</td>
<td>• Huge potential available for micro-scale hydropower plants</td>
<td>• Conflicts on water-energy issues with neighbouring countries</td>
</tr>
<tr>
<td></td>
<td>• Already established technology</td>
<td>• Lack of policies for large scale hydropower plants</td>
<td></td>
<td>• Disturbance in biodiversity and local eco-system (negative impact on the</td>
</tr>
<tr>
<td></td>
<td>• The key player in the current energy generation framework</td>
<td></td>
<td></td>
<td>ecology)</td>
</tr>
<tr>
<td>Biomass Energy</td>
<td>• Huge agricultural areas/land</td>
<td>• Lack of knowledge and competence</td>
<td>• Opportunity to develop small scale biogas plants for domestic cooking</td>
<td>• Difficult to establish a suitable energy market</td>
</tr>
<tr>
<td></td>
<td>• Availability of energy crops</td>
<td>• Absence of a clear and successful example (i.e., an established biogas plant)</td>
<td>• This will allow for better forest management and priority to forest development</td>
<td>• Lack of special provision in the current energy policy</td>
</tr>
<tr>
<td></td>
<td>• A huge involvement of local people in the agriculture and forestry sector</td>
<td></td>
<td></td>
<td>• High cost and low conservation efficiency</td>
</tr>
<tr>
<td>Geothermal Energy</td>
<td>• Environment friendly</td>
<td>• Lack of specialised companies which can help with the installation of</td>
<td>• Opportunity to develop small scale heat pump market</td>
<td>• There is no/negligible use of heat pump because of low electricity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>geothermal energy-assisted heat pumps.</td>
<td></td>
<td>tariff, lack of knowledge and modern residential heat supply technologies</td>
</tr>
</tbody>
</table>
The individual characteristic is mentioned in Table 2. To summarise and discuss the key essence of the SWOT profile, the consequent information was derived. According to the presented analysis, there is a considerable potential available for all available renewable energy sources, such as solar, wind, biomass, hydro, and geothermal. This can be considered as a strength of all resources. However, while considering the potential, solar energy comes on top according to the various literature resources. As compared to solar energy, from the potential point of view, wind and geothermal energy have low potential as they are concentrated in specific regions of Kyrgyzstan. When it comes to weakness, the article articulated that the lack of scientific knowledge, information, technical skills, and proper financial mechanism becomes a hindrance to expanding the RE sector. Further to this, the remote and high-altitude terrain makes transportation and connection difficult in the rural provinces of Kyrgyzstan. As the RE market is not yet developed, there is a vast scope for private investors to establish markets in RE sectors. This can be a common opportunity for all RE resources. Hydro energy is already dominating the Kyrgyz energy generation framework. However, as presented in the article, the development of hydro energy in Kyrgyzstan brings serious issues related to biodiversity and the local ecosystem that can be a considerable threat.

The current framework of the energy policy is considered as one of the key threats to the development of the RE sector in Kyrgyzstan. Due to the current provision of minimal feed-in tariff for all RE sources (EUR 0.029/kWh), investors are not motivated enough to invest in the RE sector. Due to the low electricity tariffs and the strength of hydropower, other renewable energy sources have not been developed in Kyrgyzstan. The current electricity tariff (−EUR 0.01/kWh) does not support new capital investment in the renewable energy sector in Kyrgyzstan. Table 3 describes the technical electricity generation potential and estimated electricity generation cost as well as the feed-in tariff of various renewable energy resources.

Table 3. Potential and estimated generation cost of energy by renewable energy source (data according to [7,23,34].)

<table>
<thead>
<tr>
<th>Renewable Sources</th>
<th>Technical Potential</th>
<th>Estimated Electricity Generation Cost in €/kWh</th>
<th>Feed-in-Tariff in €/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV energy</td>
<td>267,000 MW</td>
<td>0.27</td>
<td>0.029</td>
</tr>
<tr>
<td>Solar thermal energy</td>
<td>750 kWh/m²</td>
<td>Not available</td>
<td>0.029</td>
</tr>
<tr>
<td>Wind energy</td>
<td>1500 MW</td>
<td>0.17</td>
<td>0.029</td>
</tr>
<tr>
<td>Biomass energy</td>
<td>200 MW</td>
<td>0.17</td>
<td>0.029</td>
</tr>
<tr>
<td>Small hydro energy</td>
<td>1800 MW</td>
<td>0.16</td>
<td>0.029</td>
</tr>
<tr>
<td>Geothermal energy</td>
<td>170 GJ</td>
<td>Not available</td>
<td>0.029</td>
</tr>
</tbody>
</table>

The presented study identified the (i) existing potential of renewable energy in the Kyrgyz Republic for energy production, (ii) latest deployment of renewable energies, (iii) ongoing activities in the Kyrgyz energy sector, (iv) assessment of RE in the local context based on the SWOT analysis and provided the comparative profile to decide the suitable renewable energies for the employment.

On the other hand, the presented article outlined that (i) meeting energy needs through non-sustainable solid fuels is the key preference for local people, especially in rural Kyrgyzstan, (ii) the energy sector of Kyrgyzstan is mostly hydro focused and, therefore, the future strategies continue to support hydropower development (iii) the universal grid access is available but electricity supply is based on hydroelectricity generation, which directly depends on the variable hydrology due to cold and long winters.
5. Discussion and Outlook

5.1. Future Perspectives of Renewable Energy Development

The conducted research identified that in order to foster the RE sector in Kyrgyzstan, the energy laws should be adapted in favour of the expansion of renewables. Because the RE law, which has been in effect since 2009, provides a general framework to support RE, it needs further elaboration and detailed provisions to regulate the RE sector. The responsible authorities, procedural steps, and duration of projects are often not clear or specified within the law. For example, the available tender process is regulated mostly in relation to hydropower plants but no other RE systems. There is no financial method available for compensating extra costs associated with RE, hence distributors are not interested in purchasing RE. There are no legally binding targets for renewable energies that exist. Unclear plans for RE with inappropriate binding targets result in a higher risk to investment return and doubt in investing in RE projects in Kyrgyzstan. As discussed earlier, it can be clearly outlined that government policies mostly focus on the development of hydro and micro–hydropower plants as compared to other RE systems. There is a need for coherent policies for solar PV, wind, biogas, and other RE sources. Moreover, to provide attraction to the private investors, RE producers should receive high tariffs for selling electricity. However, based on the “maximum effective electricity tariff”, FIT is very low. Therefore, private investors receive far less money for selling electricity in the public grid which reduces the attraction of people to invest in RE projects [13].

Besides the energy policy, the social aspect is also a key parameter to consider. Local people think of renewable energy as being inconvenient and not sufficient for their needs. The absence of consumer awareness and lack of information about the benefits of the RE systems is affecting the development of RE systems in rural Kyrgyzstan. By virtue of having less information available and a lack of education, rural people are usually not aware of the fact that renewable energy is useful for them. People would like to see a demonstration if somebody installs an RE system and would like to understand the benefits of installed RE. Hence, it is worth preparing education integration of renewable energies in the study program. Hence, the upcoming generation can easily understand the knowledge about sustainable energies within the educational period. Furthermore, for the general public, it is a nice idea to have workshops, organize conferences, and demonstrate the existing RE facilities. The increased knowledge in society should result in greater support for RE [3,4].

Also, the economic situation in rural areas of Kyrgyzstan does not support the development of RE. Many people in rural areas cannot afford the cost of RE systems, and also alternative financial mechanisms are not available widespread. Rural families usually earn less money, which is not even sufficient for their annual family needs, hence, they cannot invest much in RE systems. People have to go for micro-loans which take more interest over a longer period. The lack of credits for purchasing RE systems and the non-availability of sufficient subsidies for RE systems also affect the development of RE projects in rural areas of the country. Adequate credit programs/subsidy programs for renewable energy should be operationalized [3,4,35].

Last but not the least, the government should focus on bringing renewable energies (except hydro) to the mainstream for energy generation. The addition of sustainable energy resources to the energy mix can ensure energy security and, therefore, sustainable energy development in Kyrgyzstan.

5.2. Limitations of the Study

Despite providing in-depth assessment of renewable energies and SWOT analysis, the presented study has plausible limitations.

The presented literature review about the potential was derived from the existing literature. It was noticed that the potential estimation of various renewable energies was calculated differently and, therefore, comes with different numbers. Hence, it is difficult to perform a critical analysis of the existing literature review. However, the comprehensive analysis of the available literature served as basic input to plot the SWOT profile. Further to
this, the presented comparative SWOT analysis was the first attempt to display the thematic knowledge about renewable energies in Kyrgyzstan. Surely the presented results can serve as a base for decision making. Although, a detailed technical and economic analysis can be considered to make the results stronger. The SWOT analysis based on techno-economic analysis is strongly recommended as a scope for future work.

6. Conclusions

Kyrgyzstan is endowed with the great potential of renewable energy resources, which can be harnessed to provide sustainable energy to Kyrgyz citizens. The presented study evaluated the detailed outlook of Kyrgyzstan's renewable energy potential and deployment based on an intensive literature review. However, there is a gap in research about systematic knowledge/assessment which provides pros and cons of the available energy resource. Hence, the article extended the research and attempted to outline the SWOT profile of renewable energy sources. The geographical location of Kyrgyzstan avail high solar irradiation (available throughout the whole country), strong wind (limited to a particular region), biomass, and geothermal resources, which are positive for the development of specific renewable energy technology. At the same time, there are serious weaknesses as well as threats that hinder development. Such issues require serious attention from policymakers. Summing up, based on the literature and performed SWOT analysis, solar energy can be considered a suitable available energy source because of the following reasons:

- The significant potential is available throughout the country (terrain, remoteness, and regions are not the hurdles for it). The solar irradiation of Kyrgyzstan is 60% higher than European countries.
- The primary need of Kyrgyz people is heating (i.e., space heating and hot water preparation) that can be easily provided by solar energy-assisted technologies. For example, low-cost solar thermal air collectors, evacuated tube collectors, and solar PV-assisted electric radiators.
- As compared to hydro resources, solar energy has fewer environmental side effects. In that aspect, solar energy can be considered a robust technology as compared to others when it comes to installation.

The presented study provided a comprehensive analysis of the various identified issues, based on the available literature and findings, that help in decision making for policymakers and private investors. However, the presented study does not identify and assess the economic aspect (i.e., Levelized Cost of Electricity) of various RE sources. This can be considered as a limitation of the work and proposed as future scope of the work. However, the presented research provided sufficient information to prioritise key issues, challenges, scope, and risks based on SWOT analysis that can serve as a piece of basic information to foster the RE sector in Kyrgyzstan. The derived SWOT profile can also be helpful for selecting appropriate energy sources according to the application. The results of the SWOT analysis highlighted the importance of solar technology development as well as the requirement for amendments to the existing energy policies.

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