In-Depth Assessment and Feasibility Study of a Solar PV Farm for a High-Altitude Region: Bridging the Gap Between Technical Potential and Market Barriers in Kyrgyzstan

[1]Fernanda Quintana, [1]Kedar Mehta, [1]Mathias Ehrenwirth, [1]Wilfried Zörner, [2] Florian Betz, [2]Magdalena Lauermann, [2] Bernd Cyffka, [3]Ermek Baibagyshov

[1] Institute of new Energy Systems, Technische Hochschule Ingolstadt (Germany)

[2] Applied Physical Geography, Catholic University Eichstätt-Ingolstadt (Germany)

[3] Department of Agrarian and Technological Disciplines, Naryn State University (Kyrgyzstan)

Abstract

Kyrgyzstan is known for being a high-altitude and cold climatic country of Central Asia. Due to mountainous characteristics and permanent glaciers, enormous water resources are abstracted at the county’s disposal. Because of the endowed water resources, the majority of the power is generated with hydropower facilities. However, the Kyrgyz power sector is facing energy insecurity because of the hydropower facilities. Despite social, environmental, and ecological and energy issues, the local government focused on building new hydropower plants. On the other hand, Kyrgyzstan is blessed with a great potential for solar energy because of its geographical characteristics which can ensure a sustainable power supply. To bring sustainability to the Kyrgyz power sector with the help of renewable energy, the presented work utilizes the untapped solar PV potential of Kyrgyzstan to perform a feasibility study with detailed techno-economic analysis by considering the latest energy legislation framework. The study shows that the solar PV farm is a suitable technology for sustainable electricity supply in Kyrgyzstan over hydropower plants. The study further identifies the solution to bridge the gap between the technical potential of solar PV and market barriers.

Keywords: high-altitude, grid integration, solar PV farm, sustainable energy, economics, markets & policy, feasibility study, Kyrgyzstan

1. Introduction

Kyrgyzstan is a high-altitude mountainous country situated in Central Asia. The Tien Shan mountain range covers more than 90 % of the Kyrgyz territory which results in a large number of glaciers and permanent snow. Therefore, Kyrgyzstan is blessed with abundant hydro resources. The plentiful water resources are responsible for the production of more than 90 % of the electricity with hydropower plants, which makes the Kyrgyz power sector highly dependent on hydro resources for meeting its conventional energy needs (Kalybekovich and Djumabekovich, 2012; Mehta et al., 2021).

However, the Kyrgyz power sector experiences a major challenge because of the growing and fluctuated inter-seasonal energy demand. Hydropower plants (HPP) in the Kyrgyz Republic generate the highest share of electricity during summer. Within this season, the installed hydro capacity is sufficient to address the demand as the water flow in rivers is sufficiently high. Because of the high-altitude and mountainous characteristics, Kyrgyzstan experiences a cold climatic zone with extended winter (-25 to -30 °C in the mountainous areas). As a result of the extreme winter conditions, the flow of water decreases in the rivers leading to reduced power production not being able to cover the electricity demand. Due to the long and harsh winters, the sizable amount of urban population resort to electric operated house heating systems which leads to high electricity consumption in winter. During this season, Kyrgyzstan is strongly dependent on the import of electricity from neighboring countries (Balabanyan et al., 2015; Mehta et al., 2021).

Access to electricity is currently covering the whole territory of Kyrgyzstan. However, the Kyrgyz power sector is not capable to meet the high demand in winters because of the high reliance on hydropower generation, and therefore, the Kyrgyz population experience persistent power shortages / outages (National Statistical Committee of the Kyrgyz Republic, 2017). According to the results of the quality of energy delivering services survey in Kyrgyzstan made by the NSC in 2015, only 11.8 % of households had uninterrupted power supply, while 64.4 % had power cut several times a year and 0.5 % had daily power cuts (National Statistical Committee of the Kyrgyz Republic, 2017). Electric power transmission and distribution losses were nearly 24 % of the total power output in 2017. Furthermore, most of the operating hydropower plants were built more than 30 years ago (Balabanyan et al., 2015). As Kyrgyzstan falls

doi:10.18086/swc.2021.21.01 Available at http://proceedings.ises.org

under active seismic zones, the old-age hydropower plants are most vulnerable to damage due to frequent earthquakes. 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 the case of the destruction of a large dam in Kyrgyzstan, large floods waves could go downstream generating huge devastation in the neighboring downstream countries (Havenith et al., 2017; Mussa, 2018).

Agriculture is a very important source of income that would be threatened by HPPs. Central Asian countries are important agricultural producers. Given the fact that they receive rare 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 (Havenith et al., 2017). The construction of new HPPs might represent a risk for Kyrgyzstan and it could make the water stress situation of the Central Asia downstream countries worse. Furthermore, the reservoirs of new HPPs take several years to refill, during that time, the downstream water would be reduced (Russell, 2018).

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 (Mussa, 2018). Other negative effects of HPP include: '*Decreasing of groundwater, changing of water quality, drying of natural lakes, influence on the physical and biological environment, landscape destruction, deforestation and microclimate changes, among others*' (Tsvetkov, 2018).

Nevertheless, the government of Kyrgyzstan still focuses on developing and constructing new hydropower plants to improve the conditions of the power sector (IHA, 2018; Dikambaev, 2019). Naturally, the new hydropower plants will not be the most suitable solution due to the local boundary conditions. On the other hand, Kyrgyzstan presents an enormous solar energy potential due to its high-altitude characteristics. It has been estimated that the potential of solar energy in Kyrgyzstan is 60 % higher than in Frankfurt. Fig. 1 portrays the potential of solar energy in Kyrgyzstan. However, the great solar potential of Kyrgyzstan has not been exploited until now.

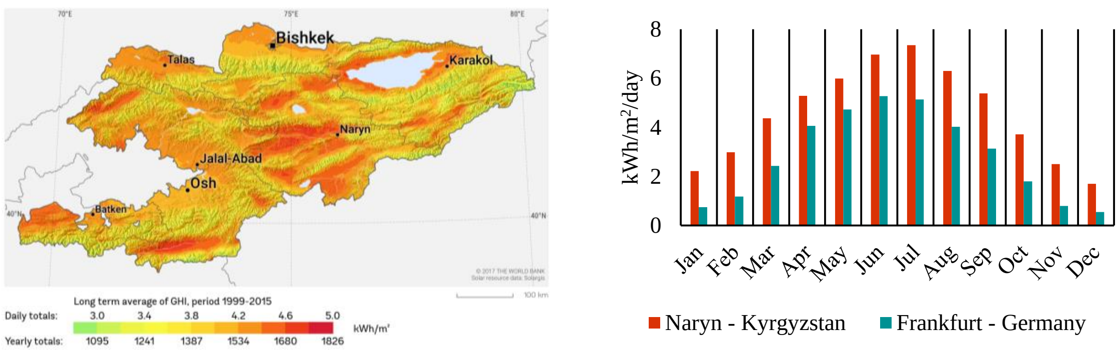

Fig. 1: The Global Horizontal Irradiation map of Kyrgyzstan (left) and comparison of solar irradiation between Naryn and Frankfurt (right), based on Solargis (2017)

2. Research objective and methodology

The current problems of the Kyrgyz power sector, as well as the untapped solar energy, have attracted more attention in the field of solar energy to supply sustainable electricity in Kyrgyzstan. Certainly, the utilization of unexploited solar energy to produce electricity through solar PV technology can suitably contribute to making the Kyrgyz power sector stable. However, there are very limited studies available that consider the in-depth assessment of a solar PV farm in Kyrgyzstan to identify its technical and economic viability under the special characteristics of the country. Therefore, the presented research focuses on developing a feasibility study to evaluate the technical and economic performance of a large-scale solar PV farm (100 MWp) in Kyrgyzstan, by considering particular conditions such as low-electricity tariff, minimal feed-in-tariff, cold climate, and high-altitude. Fig. 2 represents the methodology for the feasibility study divided into three main categories.

Firstly, a systematic diagnosis was carried out to assess the Kyrgyz power sector background and its challenges, as well as the technical potential of the available solar PV energy. Furthermore, the current Feed-in tariff (FIT) and market barriers in the country were identified and analyzed. Based on the systematic review, the feasibility study was performed, starting with the various site selection and the PV module. Moreover, the simulation model of a large-scale solar PV farm (100 MWp) was developed with the *Polysun* software (Vela Solaris AG, 2021). A detailed techno-economic analysis was done to evaluate the viability of the proposed solar PV farm in Kyrgyzstan.

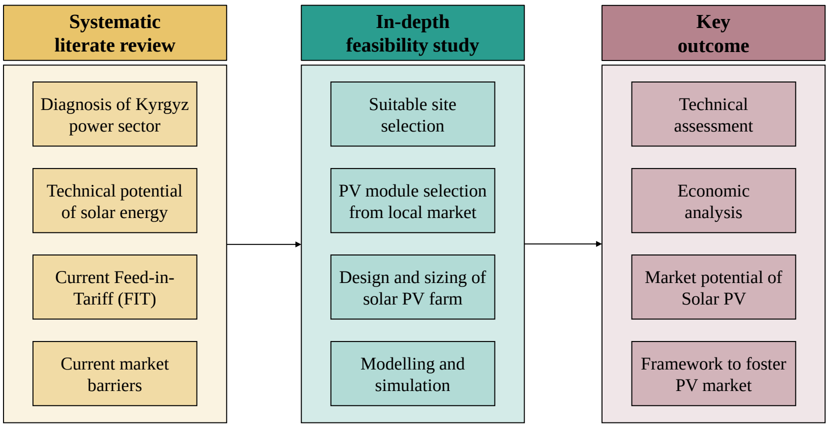

Fig. 2: Methodology of the feasibility study for a large-scale PV farm in Kyrgyzstan

3. Solar PV Farm Modelling

This chapter presents the modelling of a 100 MWp solar PV farm. The size was defined in order to identify the feasibility of the solar PV farm, as well as to evaluate the (simulation-based) performance of solar PV technology on a large scale for grid integration. In order to check the feasibility of a large-scale solar PV farm in Kyrgyzstan, the simulation study was performed by changing the locations through Kyrgyzstan that inevitably included the change in climatic condition as well as elevation.

3.1. Site selection

To observe the performance of the large-scale solar throughout the country, seven locations were selected from the seven regions of Kyrgyzstan. The climate and altitude vary across Kyrgyzstan and therefore such selection allowed to evaluate the performance of solar PV farm in various conditions. In addition to this, such a selection strategy was the first attempt in the context of Kyrgyzstan. Hence, the simulation results present a piece of novel information for local stockholders, private investors and policymakers. The selected locations are displayed on the regional map of Kyrgyzstan in Fig.3.

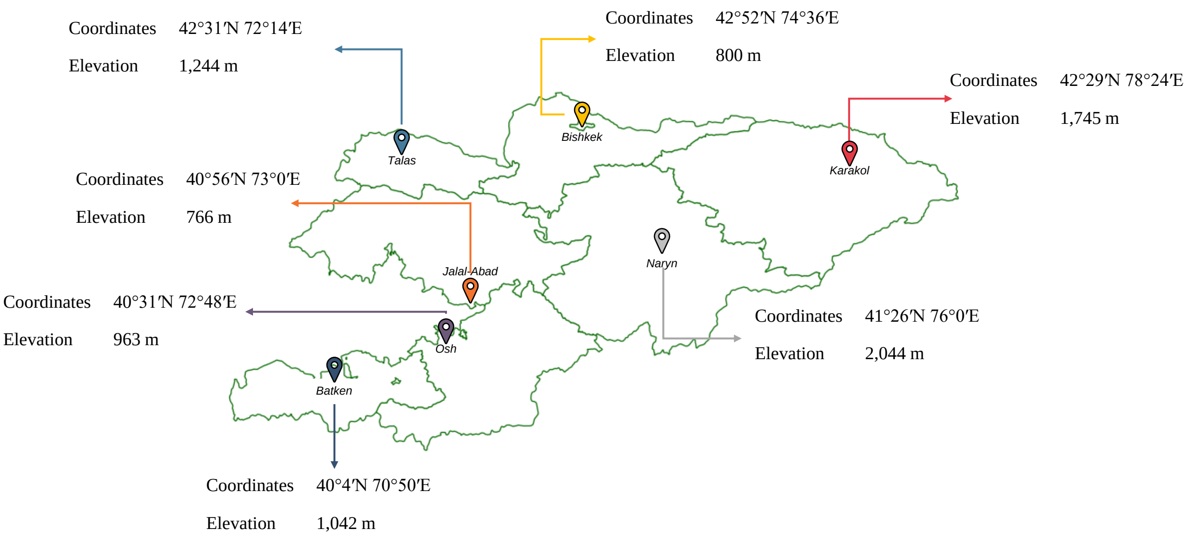

Fig. 3: Locations (site selection) for simulation of the large-scale solar PV farm

3.2. PV Module Selection

To select a PV module, a module selection analysis was carried out to identify suitable and available solar PV modules. There are several modules that were evaluated which are mostly available from neighboring countries (i.e., China and India). At the same time, the literature review identified that a Kyrgyz-German company called *New-Tek* manufactures PV modules. Hence, in order to reduce the import taxes as well as to assess the performance of locally manufactured PV modules, the presented research selected a PV module of New-Tek from Kyrgyzstan for further simulations. The selected module specifications are listed in Tab 1.

Tab. 1: Specifications of selected photovoltaic module [based on (New-Tek, 2020)]

PV module type	Efficiency [%]	Module area [m²]	Peak module capacity [W]	Short circuit current [A]
Mono-Crystalline	18.3	1.67	300	9.75

3.3. Simulation results

In order to get the most accurate results of the power output, a simulation of the 100 MWp solar PV plant has been developed. The solar PV system has been modeled with *Polysun* 11.3 simulation Software. After choosing the respective template (50a. Photovoltaics), the adjustment of specific parameters is required. The required technical specifications such as tilt angle, azimuth angle, declination angle, hour angle, zenith angle etc. were calculated based on Tiwari et al. (2016). One can review the mentioned literature for the equations and detailed calculation method. To design a 100 MWp solar PV farm the number of modules was calculated based on eq.1.

$$N_{modules} = \frac{P_{nom-plant}}{P_{nom-module}} \qquad \text{(eq.1)}$$

$P_{nom-plant}$: *Power of the PV plant=100,000 KWp* $P_{nom-module}$: *Module nominal power = 0.300 KWp*

In order to optimize the arrangement of the inverters (ABB Ltd. PVS800-0500kW-A), the number of modules was calculated as 334,400 (suggested by *Polysun*). To install large-scale PV farm, it is also necessary to calculate the required land area. The required PV farm area (to avoid shading) was calculated with eq. 2. The required area for a 100 MW solar farm is 58.19 ha (based on eq. 2).

$$A_{PV_{farm}} = (N_{modules} \cdot A_{module}) + [(Raw\ spacing\ factor \cdot Height\ of\ module) \cdot (N\_modules \cdot A\_module)] \qquad \text{(eq.2)}$$

A_{module}: $Area\ of\ the\ PV\ module = 1.67\ m^2$ $N_{modules} = 334{,}400$

$Height\ of\ module = 0.035\ m$ $Raw\ spacing\ factor = 1.2$

As stated by Baybagyshov and Degembaeva (2019), Kyrgyzstan's altitude varies from 800 to more than 4,000 meters above sea level. The difference in altitude of individual regions locations causes unequal availability of solar irradiation. The intensity of solar radiation is determined by climatic conditions, geographical location of the terrain, slopes exposure, and also the time of the year and the day. Direct solar radiation predominates in the highland region during the year. The peak of sunshine hours is reached between May and August, with about 130-155 hours of sunshine per month. Hence, the variable topography and climatic conditions of the country offer the variable PV power output for all selected seven regions. The simulation results are summarized in Tab 2. Also, Fig. 4 represents the detailed monthly technical performance indicators for all seven locations.

Tab. 2: Summarized simulation results for selected locations (Green = Highest, Orange = Medium, Red = Low)

Location	Annual global horizontal irradiation [kWh / m²]	Altitude [m]	Annual solar energy [GWh]
Bishkek	1,537	800	~ 152
Jalal-Abad	1,623	766	~ 154
Karakol	1,644	1,745	~ 163
Naryn	1,727	2,044	~ 174
Osh	1,607	963	~ 150
Batken	1,633	1,042	~ 154
Talas	1,699	1,244	~ 168

Fig. 4: Design performance indicators of 100 MWp solar PV farm at different locations in Kyrgyzstan [Monthly Global Horizontal Irradiation (GHI), Monthly solar energy production and monthly average temperature]

It can be seen from Tab 2 and Fig 4 that especially high-altitude regions have a high potential to produce more energy as compared to low-altitude regions. For example, the energy output of Naryn is 174 GWh/a, while the power plant in Bishkek can produce 152 GWh/a. Because of the geographical locations, high-altitude regions are blessed with a higher amount of solar irradiation. Concerning Chitturi et al. (2018), high altitude regions are endowed with a great solar energy potential, opposed to what is commonly thought. Even though high-altitude areas are usually characterized by cold temperatures and long winters, the highest solar irradiation areas usually match the highest altitude regions, like mountain ranges. Therefore, the greatest solar power generation is presented in cold geographical locations because the efficiency of PV panels rises with low temperatures. Hence, the high-altitude and cold climacteric regions of Kyrgyzstan (i.e. Naryn) are the most suitable locations to harness more energy from the sun for large-scale solar PV farms.

The presented simulation study demonstrated the prodigious technical potential of solar PV in Kyrgyzstan. However, economic viability is a key indicator that influences the real execution of the project. Furthermore, the feasibility analysis developed in research has the aim to avoid the construction of new HPPs. Accordingly, the next sub-chapter compares and outlines the economic performance of a solar PV farm and a hydropower plant of the same capacity in the context of Kyrgyzstan.

3.4 Comparative economic assessment

There are fewer pieces of evidence / measures available to quantify the cost structure of the solar PV farm and hydropower plant in connection to Kyrgyzstan. Even though, to provide a rough idea about the cost compression, a generalized cost estimation was calculated for solar PV farm and Hydropower plant of 100 MW. The initial investment costs of the solar PV farm were calculated as the sum of the following element cost: Equipment cost (PV modules and the inverter), the auxiliary, the mounting structure, the soft cost (installation, site preparation). It can be highlighted here that the land cost in Kyrgyzstan is significantly inexpensive as compared to European countries. Fabinyi et al. (2020) mentioned that 1 ha (10,000 square meters) of agricultural land cost about 1,500 €. The initial investment costs of the hydropower plant are calculated as the sum of the civil costs, the mechanical equipment costs, the planning costs, and the grid connection cost; times the size of the HPP. Fig. 5 shows the different costs taken into account for the calculation of the total initial cost of the PV Farm and the HPP. The values are calculated based on the sources Akker (2017), ENf (2020), IRENA (2019), International Finance Corporation (2015), Fabinyi et al. (2020).

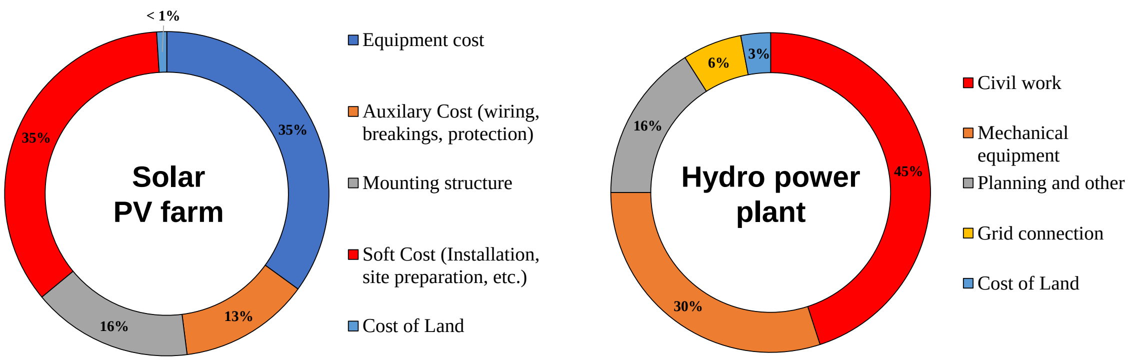

Fig. 5: Initial investment cost of the solar PV farm and HPP

The total initial cost for hydropower projects, according to IRENA (2019), is ~ 1,500 €/kW for HPP in the range of 101-150 MW of capacity. While based on the preliminary calculation, it was evaluated that the initial cost for a 100 MW solar PV farm is ~ 1,600 €/kW. Ideally, the costs are comparable for HPP and PV in Kyrgyzstan. But when it comes to sustainability, solar PV farm is a more liable and secure energy generation source in Kyrgyzstan. As Kyrgyzstan falls under the high-seismic zone, the hydropower plants are more vulnerable to the risks. The existing HPP power generation facilities already got affected by frequent earthquakes in Kyrgyzstan and this naturally affect the power output. With the aim of comparing the risk involved in the generation of solar and hydropower in Kyrgyzstan, Tab. 3 states the major impacts of both technologies on the five capitals. Both given systems were considered to be most vulnerable to some particular disasters, given the technology, location and recent examples. This disaster vulnerability is indicated in the right-hand column of Tab. 3. McLellan et al. (2012) use a five-capital framework as the basis of their assessment, with the capitals being described in Tab. 3.

Tab. 3: Major impacts of solar and hydro energy systems on the five capitals based on McLellan et al. (2012)

	Hydro	**Solar PV**
Human	Health (dam break and flash flooding risk)	Health (electrocution risk)
Social	Minimal to major impacts associated with loss of electricity; flooding destruction	Minor impacts associated with loss of electricity
Economic	Minimal to major impacts. Loss of electricity and flooding; Loss of workforce, revenue, consumer base	Minor impacts associated with loss of electricity; Cost of repair could be significantly proportional to supply
Manufactured	Loss of infrastructure by flash flooding	N/A
Natural	Silt and relocated water patterns impact on ecology	N/A
Disaster vulnerability	Earthquake; Severe flooding	Flooding; Tsunami; Gale force winds

As reflected in Tab. 3, the highest impacts for the five capitals are related to hydro energy generation. This gives a clear insight into the advantages of solar energy over hydro energy. It is important to highlight that the disaster vulnerability of solar energy systems does not include earthquakes, which are a continuous hazard in Kyrgyzstan due to the presence of high seismic intensity in the area.

4. Discussion

4.1 Viability analysis

The policies and legislation analysis of Kyrgyzstan revealed information regarding energy-related strategies and programs. However, the objectives of many programs were hard to achieve, and some programs requirements could not be implemented or enforced effectively. Implementing electricity tariffs that fully recover the real costs is a prerequisite to achieving the main objective of the strategies. Moreover, the monopoly strategy of the Kyrgyz government and the low FIT (0.03 €/kWh for all the RES) result in limited investments in the renewable energy sector. The provisions of the *Law on Renewable Energy Sources* theoretically make the renewable energy sector attractive for investors. Under a FIT, eligible renewable electricity generator / private investors are paid a cost-based price for the renewable electricity they produce. However, the amendment made in July 2019 in FIT reduces the coefficient for all renewable energy sources (0.03 €/kWh) (Government of Kyrgyzstan, 2019). Previously (before July 2019), the FIT used to be different for each RE source, and consequently, the highest FIT was provided for solar energy (0.16 €/kWh) (Government of Kyrgyzstan, 2019). Certainly, an initial situation before the law’s modification was more attractive for investors, especially for those who wanted to invest in the solar sector. Naturally, the current FIT for solar energy of Kyrgyzstan does not bring the economic feasibility that was expected to get, especially considering the great solar PV potential of the country, and there is negligible chance to get any payback for private investors.

4.2 Conceptual framework for bridging the gap between technical potential and market barriers

Kyrgyz power sector suffers from outdated infrastructure and is not capable to fulfil the growing and fluctuating inter-seasonal energy demand. The Kyrgyz electricity users face an irregular supply of electricity as well as fluctuations in voltage because of reduced power production in the winter season. Also, the majority of the hydropower generation facilities are outdated and not capable enough to produce the rated power. The presented article as well as recent theoretical development identified that hydropower development is not favorable in Kyrgyzstan. Further to this, the cold climatic conditions are the key hurdle for reduced power production. Hence, the Kyrgyz power sector is facing the issue of sustainability and availability.

On the contrary, the presented feasibility study identified the great technical potential for solar PV electricity generation in Kyrgyzstan. Identified that integration of renewable energies can bring stability and sustainability to Kyrgyzstan. However, because of the current energy policies as well as the limited market opportunities the solar energy sector is not yet developed. To foster the solar PV development in Kyrgyzstan, the presented article proposed a conceptual framework presented in Fig 6. The framework was developed based on the analysis of the results of the literature review.

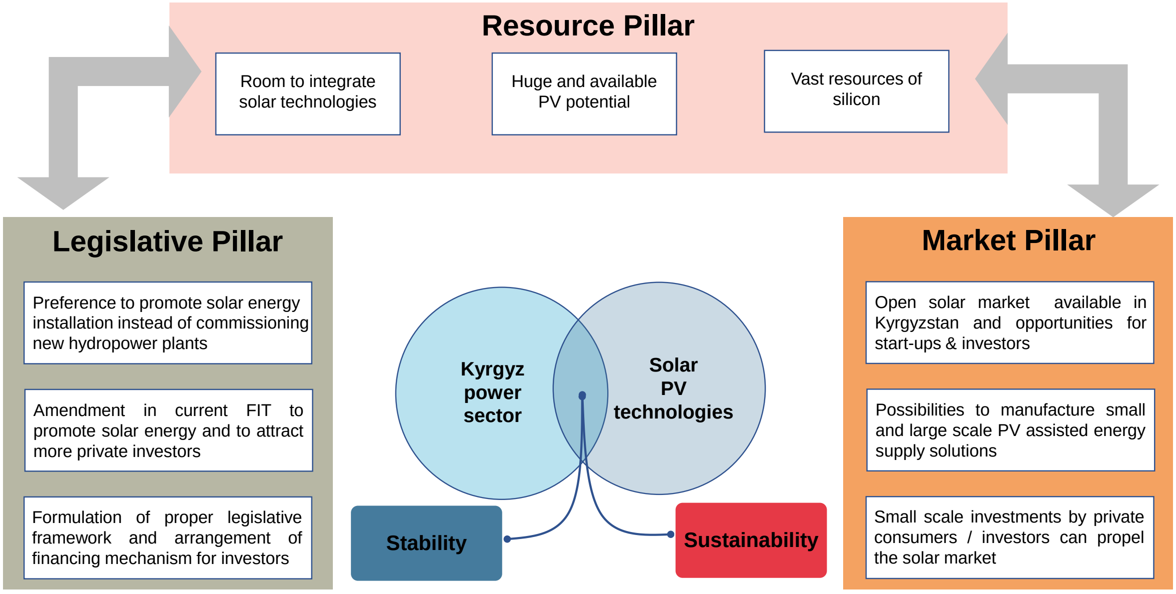

Fig. 6: Conceptual framework to foster solar PV in Kyrgyzstan to secure existing power sector

- **Resource pillar:** Kyrgyzstan has a vast silicon resource this has a great opportunity to develop a manufacturing market within the country's territory. Also, because of the special geographical condition, Kyrgyzstan is blessed with more than 300+ solar days. As shown in Fig 1, the solar potential of Kyrgyzstan is 60% higher as compared to European solar potential. In addition to that, the current Kyrgyz power sector has a huge deficit to meet the high and growing demand of Kyrgyzstan. The Kyrgyz power sector already faces a critical issue with the intersessional demand. Hence, there is room for more power production as the country is required it immediately (Kelpšaitė et al., 2018).
- **Legislative pillar:** The policymakers should make the FIT more attractive to invite investors to invest in solar-assisted power generation to expand the RE sector in Kyrgyzstan. Consequently, the government should give preference to promoting solar energy instead of focusing on hydro energy. The absence of the regulatory framework and particular authority in the context of renewable energies does not provide enough knowledge and information to the private investors. Hence, it is necessary to develop a suitable legislative framework (Government of Kyrgyzstan, 2019).
- **Market pillar:** The current solar PV market is not yet developed because the available solar energy is unexploited. There are negligible manufacturers available who are dealing with the manufacturing of solar technologies. This yields a great opportunity for market development. Private consumers, investors, the government can take part in the emerging solar market. Also, Kyrgyzstan has a huge agricultural field and there is a great chance for the agro-PV market.

The above-mentioned pillars are the imperative parameter to decode / understand the complex situation of untapped solar energy and the solar market in Kyrgyzstan. It also provided detailed insight into the current market situation, energy legislative framework and scrutinizes the theoretical (and potential) framework to develop solar PV acceptable in Kyrgyzstan.

4.3. Strategies to foster renewable energy generation

Although FIT usually represents a powerful mechanism to incentive the growth of renewable energy generation, it is believed that this role will reduce shortly, until diminishing completely in some regions except for new technologies. Currently, countries like the UK, Germany, Sweden, Spain, and Netherlands present projects that are being built or are already operating under subsidy-free or near subsidy-free conditions (Clifford Chance, 2018).

According to Sikandar et al. 2021, Research and Development (R&D) have been categorized as an incentive to foster renewable energy generation. R&D can bring promising opportunities for Kyrgyzstan to improve existing -and develop new -technologies. Accordingly, the country could grow the industry of solar panels already developed and eliminate completely the costs of material importing. Given the high solar energy potential of Kyrgyzstan, investing in R&D should represent the first phase to boost renewable energy growth.

Besides the gradual reduction of subsidies for renewable energy generation, the decarbonization target of different industries has developed trends for funding clean energy projects. One of the trends that could be successfully applied to the Kyrgyz energy market is the corporate Power Purchase Agreements (PPAs), where large companies purchase clean energy for their own consumption or trading from renewable energy generators. As it might seem challenging to get companies involved in long-term commitments for clean energy generation, the benefits of below-market price power cost for businesses with high energy consumption can bring large savings on their energy bills through PPAs. Fixed prices, discounts, and green certificates are in return for taking the risk related with intermittent power production from renewable sources (IRENA, IEA and REN21, 2018).

The Renewable Portfolio Standard (RPS) is a regulatory mechanism that can be implemented in the Kyrgyz power sector to foster renewable energy generation. RPS replaced the FIT system in 2012 in South Korea to build a competitive market in the energy sector. South Korea made 13 large power generation companies raise their renewable energy mix in 12 years gradually through the regulations of RPS. The targets of RPS, meaning the percentage of power generation from renewable sources, are reviewed, and adjusted if necessary, every three years in South Korea (IEA, 2020).

The concept of RPS is applicable not only for independent producers but also for government-owned electricity generation companies, as is the case of the Kyrgyz power sector (Ali et al.,2021). European countries, the USA, China, Australia, India, and many others have supported the policy of RPS with tradable Renewable Energy Certificates (REC). A REC is usually given to a power generator company for each MWh of energy produced from renewable sources. The certificates are often traded between the companies to meet the goals of the RPS determined for the year. In this way, Kyrgyzstan could have a boost to invest in new renewable energy projects in the power sector by compromising the power generator companies to increase their renewable energy mix supported by policies of compliance and enforcement. (IRENA, IEA and REN21, 2018).

4.4. Limitations of the study

The study was the first attempt to demonstrate the potential of a large-scale solar PV farm. From a technical point of view, the results were achieved based on the simulation models. Moreover, to check the economic viability, the presented article approached to perform the comparative economic assessment of hydro and solar. However, there are no common sources are available to acquire the prices for the technologies. The presented values are calculated based on the different sources and have a low tendency to be accurate. Therefore, it is recommended to use the same sources to get an accurate idea about the price. This is the weakness of the presented study and is considered as a scope for future research work. Nevertheless, the performed economic analysis can provide a rough idea to the reader. Even with the limitation, the presented feasibility study was successfully identified great technical potential for large-scale solar PV farm in Kyrgyzstan.

5. Conclusions

Currently, Kyrgyzstan generates 92 % of its electricity from hydropower plants. Nevertheless, the infrastructure of the energy sector is outdated and presents frequent breakdowns, due to the damages in the existing hydropower facilities generated by the frequent earthquakes in the region. Nevertheless, the Government of Kyrgyzstan still focuses on the construction of new hydropower plants close to the seismic areas, with the potential to generate high-risk situations. In response to that, the presented study performs the feasibility study of a large-scale solar PV farm in Kyrgyzstan. The simulation of the PV farm was developed by using the modeling software tool *Polysun*. The results of the simulation displayed great potential for solar energy, especially for a high-altitude region.

The analysis of the economic parameters gave an insight into the economic feasibility of both power systems and, accordingly, demonstrated the advantages of the solar PV farm over the hydropower plant. Likewise, the construction of a new hydropower plant involves more negative environmental impacts and a bigger risk for the community and the neighboring countries. Conclusively, exploiting the solar PV potential of Kyrgyzstan could help to improve the power quality and, thus, stabilize the power sector.

Future research should be directed towards the improvement of the legislation related to renewable energy in Kyrgyzstan. As a recommendation, the current FIT should be increased and differentiated for each renewable energy source and further research should be directed to new strategies to foster energy generation from renewable sources. With the expansion of R&D and other policies, the investment in new projects can become feasible even for government-owned companies. The presented article suggested a new proposal for the FIT of solar energy. The policymakers should make the FIT and other new policies more attractive to invite investors to invest in RE-based power generation to expand the RE sector in Kyrgyzstan. Another recommendation would be that the electricity tariff should be leveled to reflect the real cost of electricity in Kyrgyzstan. With more income and a reasonable FIT, the investment in the renewable energy sector and grid maintenance becomes more profitable and can bridge the gap between technical potential and market barriers in Kyrgyzstan.

6. Acknowledgments

The work presented in this paper was funded by the Federal Ministry of Education and Research (BMBF) of the Federal Republic of Germany within the CLIENT II funding programme International Partnerships for Sustainable Innovations under the project "ÖkoFlussPlan" (Project ID 01LZ1802A-F). The overall aim of ÖkoFlussPlan is to preserve the alluvial forests along the Naryn river and to implement sustainable energy solutions for the local population.

7. References

Akker, D.V., 2017. Overview of costs of sustainable energy technologies. Energy production: on-grid, mini-grid and off-grid power generation and supply and heat applications. Advisory Services on Climate, Energy and Development Issues. https://jhavdakk.home.xs4all.nl/ASCENDIS%20Cost%20of%20energy%20v2a.pdf. Accessed 11 October 2021.

Ali, A.; Al-Sulaiman, F.A.; Al-Duais, I.N.A.; Irshad, K.; Malik, M.Z.; Shafiullah, M.; Zahir, M.H.; Ali, H.M.; Malik, S.A. Renewable Portfolio Standard Development Assessment in the Kingdom of Saudi Arabia from the Perspective of Policy Networks Theory. J. Processes 2021, 9, 1123.

Balabanyan, A., Hofer, K., Finn, J., Hankinson, D., 2015. Keeping warm: Urban heating options in the Kyrgyz Republic. Summary report (English). The World Bank Group, Washington, DC. http://documents.worldbank.org/curated/en/555021468011161504/pdf/97409-WP-P133058-Box391503B-PUBLIC-Heating-Assessment-for-Kyrgyz-P133058-Final.pdf. Accessed 27 November 2020.

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

Chitturi, S.R.P., Sharma, E., Elmenreich, W., 2018. Efficiency of photovoltaic systems in mountainous areas, in: 2018 IEEE International Energy Conference (ENERGYCON). IEEE, pp. 1–6.

Clifford C., 2018. Renewable Incentives Guide: Towards a Subsidy-Free World? 6th Edition. https://www.cliffordchance.com/content/dam/cliffordchance/briefings/2018/11/renewable-incentives-guide-towards-a-subsidyfree-world-6th-edition.pdf. Accessed 13 February 2022.

Dikambaev, S., 2019. National Sustainable Energy Action Plan of the Kyrgyz Republic. United Nations, Bishkek (Kyrgyzstan). https://unece.org/fileadmin/DAM/project-monitoring/unda/16_17X/E2_A2.3/NSEAP_Kyrgyzstan_ENG.pdf. Accessed 20 September 2021.

ENf, 2020. Product Directory.

Fabinyi, M., Hayward, P., Canlas, I.P., Kalmuratov, S., 2020. Changing inland waterbody livelihoods in Issyk-Kul, Kyrgyzstan. JMIC 9 (1).

Government of Kyrgyzstan, 2019. Law of the Kyrgyz Republic. On amendments to some legislative acts in the field of renewable energy sources. http://cbd.minjust.gov.kg/act/view/ru-ru/111946?cl=ru-ru. Accessed 5 October 2021.

Havenith, H.-B., Umaraliev, R., Schlögel, R., Torgoev, I., 2017. Past and potential future socioeconomic impacts of environmental hazards in Kyrgyzstan. Nova Science Publishers.

IHA, 2018. Hydropower Status Report. International Hydro Association. https://www.hydropower.org/publications/2018-hydropower-status-report. Accessed 11 September 2021.

International Finance Corporation, 2015. Utility-Scale Solar Photovoltaic Power Plants, Washington, DC. https://www.ifc.org/wps/wcm/connect/a1b3dbd3-983e-4ee3-a67b-cdc29ef900cb/IFC+Solar+Report_Web+_08+05.pdf?MOD=AJPERES&CVID=kZePDPG. Accessed 15 October 2021.

IEA, 2020. Renewable Portfolio Standard (RPS). https://www.iea.org/policies/4837-renewable-portfolio-standard-rps. Accessed 14 February 2022.

IRENA, 2019. Renewable Power Generation Costs in 2019. International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf. Accessed 10 October 2021.

IRENA, IEA and REN21, 2018. Renewable Energy Policies in a Time of Transition. IRENA, OECD/ IEA and REN21.

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_IEA_REN21_Policies_2018.pdf. Accessed 15 February 2022.

Kalybekovich, T.S., Djumabekovich, O.A., 2012. Development the renewable energy sector of the Kyrgyz Republic. JESTR 5 (2), 60–62.

Kelpšaitė, J.T., Mooldijk, S., Brückmann, R., Blajin, C., 2018. Analysis of the potential and market entry barriers to solar power projects in Kyrgyzstan. eclareon GmbH, Berlin. https://www.eclareon.com/en/references/enabling-pv-kyrgyzstan.

McLellan, B., Zhang, Q., Farzaneh, H., Utama, N.A., Ishihara, K.N., 2012. Resilience, Sustainability and Risk Management: A Focus on Energy. Challenges 3 (2), 153–182.

Mehta, K., Ehrenwirth, M., Trinkl, C., Zörner, W., Greenough, R., 2021. The Energy Situation in Central Asia: A Comprehensive Energy Review Focusing on Rural Areas. Energies 14 (10), 2805.

Mussa, M., 2018. Environmental Impacts of Hydropower and Alternative Mitigation Measures. CIACR 2 (2).

National Statistical Committee of the Kyrgyz Republic, 2017. Baseline review of statistical data on energy in the context of SE4All, Bishkek. https://unece.org/fileadmin/DAM/project-monitoring/unda/16_17X/Nat.Baseline.RevReport/Baseline.Review.SED.Kyrgyzstan.pdf. Accessed 5 October 2021.

New-Tek, 2020. Product Catalog. http://newtek-schmid.com/en.

Russell, M., 2018. Water in Central Asia. An increasingly scarce resource. European Parliamentary Research Service. https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/625181/EPRS_BRI(2018)625181_EN.pdf. Accessed 27 September 2021.

Sikandar, A. Q.; Hessah, A.; Furqan, T.; Luluwah, A. Incentives and strategies for financing the renewable energy

transition: A review. J. Energy Reports 2021, 3590–3606

Solargis, 2017. Solar resource maps of Kyrgyz Republic. The World Bank Group. https://solargis.com/maps-and-gis-data/download/kyrgyz-republic. Accessed 1 June 2021.

Tiwari, G.N., Tiwari, A., Shyam, 2016. Handbook of Solar Energy. Springer Singapore, Singapore.

Tsvetkov, P., 2018. Energy Systems and Environment. InTech.

Vela Solaris AG, 2021. Polysun.