Technical and Economic Prefeasibility Analysis of Residential Solar PV System in South Kazakhstan

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1 Introduction

Kazakhstan has substantial influence over energy supply of the world since it owns large natural resources (oil, gas, coal, uranium, and other commodities) and a 3% of the raw material available in the planet. According to statistics (EIA 2013), in 2012, the total power generation capacity of Kazakhstan was approximately 19.5 GW, 85% of which was coal-fired power and the remaining 15% was hydropower. Since 2010, the country decided to import electricity from Kyrgyzstan and Uzbekistan to supply its southern regions, since the installed power plants do not reach estimated load and, therefore, the consumption of electricity overcomes its production in the country.

Thus, within this framework, the country is currently devoted to the development of its renewable energy sector. Kazakhstan has important potential in power generation from wind, solar, hydrothermal, and small hydro sources. Indeed, the potential energy generation of Kazakhstan exceeds one trillion kWh per year which is about 10 times the annual energy consumption in the country to date (EIA 2013). By the year 2050, the milestone for renewable energy sources is targeted to reach 50% of total energy consumption (Kazenergy 2014).

At this moment, apart from partial use of hydropower, the potential for renewable energy is not used sufficiently, and a significant generation of electricity may be added by solar power resources according to the economic development targets of the country. For example, 2200–3000 sunny hours per year and 1300–1800 kWh/m^2/year are available due to solar radiation in the country (see Fig. 1 as a reference of the potential in the country) (Kazenergy 2014).

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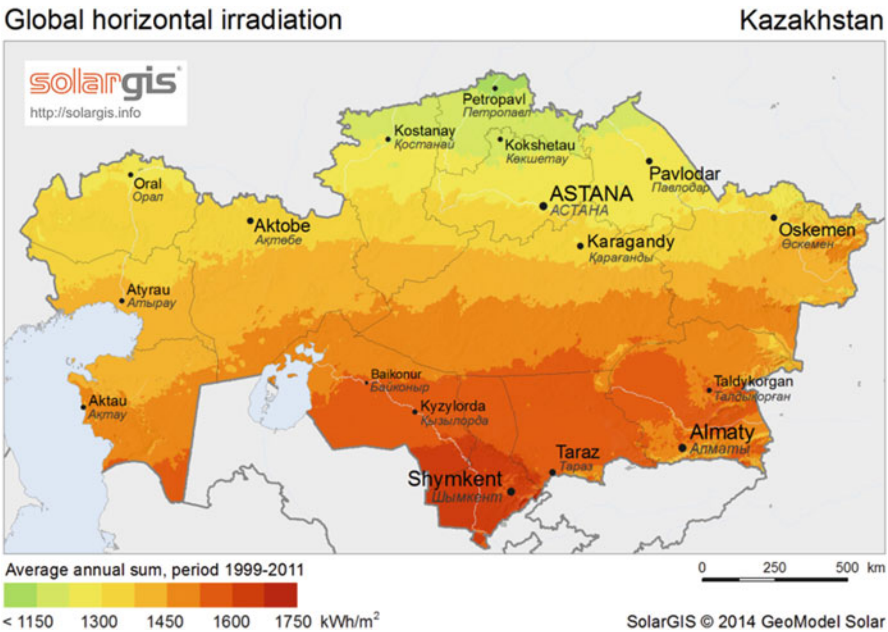

Fig. 1 Horizontal solar radiation on the territory of Kazakhstan (source indicated on the map)

The potential of solar energy in Kazakhstan is estimated at 340 billion tonnes of oil equivalent (toe) annually. However, despite this very attractive scenario for solar power generation this resource is still scarcely used in the country (Energy Charter Secretariat 2013).

Within these favorable conditions, photovoltaics (PV) today attract considerable attention, but on-grid PV market is not a profitable sector by itself (Dornfeldt 2014). It is dependent on the governmental support, which still must stimulate investment with subsidies. In recent years, rapid development in grid-connected building-integrated PV systems around the world, mainly in developed countries, is due to the government-initiated renewable energy programs aiming at the development of renewable energy applications and reduction of greenhouse gas emissions (Erge et al. 2001). For example, in 1990, Germany introduced a “100,000-roof program” (Ramana 2005). Japan came with a 70,000-roof program that started in 1994 and lasted for the rest of that decade (Yang et al. 2004). A PV system dissemination program has been very successful in the USA, and its 1 million solar-roof initiative is gradually advancing (SSE 2009). Grid-connected PV systems, thus, took off in the mid- to late 1990s, and since then, it has been the dominant application in the PV sector.

South Kazakhstan is situated between 42.3° and 44.9° north latitude and 65.5° and 71.4° east longitude with an area of 726 km^2, which is an ideal location for solar energy utilization, as previously shown in Fig. 1. Daily solar radiation varies in the range of 4–4.45 kWh/m^2. Thus, densely populated cities like Shymkent, Taraz, and

Kyzylorda could be electrified by PV on-grid systems using the inexhaustible and pollution-free solar energy with locally available technologies. Extra benefits, such as supporting a weak grid and reducing CO_2 emissions, could be also accounted as potential incomes once the program is in mass scale.

Additionally, Kazakhstan has also established at the end of May 2014 a new feed-in tariff (FIT) law – "On Supporting the Use of Renewable Energy Sources." This policy is expected to further increase the installation of grid-connected photovoltaic (PV) systems. Such policy has been implemented and also has been studied in a number of countries such as the UK, Ukraine, Australia, Spain, Taiwan, Germany, Tanzania, and other countries, with very positive results (Erge et al. 2001). As city-level FIT laws for promoting solar photovoltaic panels are very recent and its suitability has not been thoroughly examined yet (Renewable Market Watch 2014), the fundamental objective of this investigation is to analyze technical and economic prefeasibility of implementing residential photovoltaic system in South Kazakhstan, taking into account the diversity in the southern region and new regulations, as no systematic study has been done to justify the viability of solar power generation in this region to date. As an alternative solution, financial incentives could be obtained if the project is included in the list of priority sectors of the "Business Road Map – 2020" that is one of the "DAMU Entrepreneurship Development Fund" projects. This initiative has as its main goal to provide governmental support for projects of non-primary sectors of the economy (Halyk bank 2013).

2 Solar Energy Resource Potential

2.1 Theoretical Potential

The average sunny hours per day and monthly solar radiation were found, based on an average solar radiation data taken from NASA, for three widespread locations in South Kazakhstan available through RETScreen workbench tool (SSE 2009). According to the climate database from NASA, South Kazakhstan receives approximately 1185 GWh of solar energy every year, which is more than 30 times higher than the current electricity generation in those cities. However, in the course of exploitation, constraints such as land use, geographical area, and climate are encountered. Theoretically, a great potential for developing solar power system is considered when the average daily radiation is above 4 Wh/m^2/day on an average per year (Energy Charter Secretariat 2013).

2.2 Technical Potential

There is a clear market potential for grid-connected PV systems in the densely populated urban and electrified areas, i.e., for solar home systems are central-grid households. Locally available PV system specifications and financial assumptions, according to current conditions and trends in Kazakhstan, were entered in the RETScreen workbench. Then, the expected generation of electricity by the solar power home system was calculated on a yearly basis under different scenarios of feed-in tariff (FIT) in place.

Local company Astana Solar is currently producing Poly-Si photovoltaic modules using Kazakhstani silicon (Astana Solar 2012). The efficiency of the PV array is about 16% and Astana Solar guarantees that its products have a lifetime of at least 25 years. Table 2 shows the detailed technical specifications of the solar panel that was used in this study.

3 Economic Viability of Grid-Connected Solar PV System

3.1 Global Solar Radiation

Due to limited availability of solar radiation data in Kazakhstan, a NASA data set for the period from 1985 to 1995 was used. Ten-year averaged NASA global solar radiation data from three widespread South Kazakhstan locations (Table 1) were used for the technical-economic analysis of grid-connected solar PV systems (SS 2009).

3.2 Proposed 6.6 kW Solar PV System and Financial Assumption

The proposed solar PV grid-connected system is an array with a total power capacity of 6.6 kWp consisting of 30 fixed panels with a total area of 49.2 m^2 (Table 2). The size of the array was chosen such that it fits the estimated roof area of a South Kazakhstani residence. The solar array system costs 2354 US$/kWp (Astana Solar 2012). The PV array is faced toward south and is inclined at a

Table 1 Average daily solar radiation in South Kazakhstan

City name	Elevation (m)	Latitude	Longitude	Radiation (NASA) (kWh/m^2/day)
Kyzylorda	130	44.9°	65.5°	4.21
Taraz	655	42.9°	71.4°	4
Shymkent	604	42.3°	69.7°	4.45

Table 2 Technical specification of solar PV panels used in the analysis

Item	Specification
Manufacturer	Astana solar LLP
PV module type	Multi-Si
Module number	KZ PV 230 M60
Efficiency	16%
Rated power (P_{max})	220 Wp/module
Number of modules	30 (6.6 kWp array)
Voltage at P_{max}	29.4 V
Current at P_{max}	7.5 A
Short circuit current	8.3 A
Open circuit voltage	36.5
Frame area	1.64
Dimension	1.649m × 0.992m × 0.40 m
Weight	19.5 kg

Table 3 Financial assumption and data for the study

Parameter	Value (currency at year 2014 value)
Solar panel	2354 US$/kWp
Inverter cost	220 US$/kWp
Annual O&M	US$168
Inflation rate	5.4%
FIT	191.4 US$/MWh
FIT escalation rate	8%
Debt ratio	80%
Debt interest rate	17%
Debt term	10 years
Project life	25 years

42°angle, equal to the site latitude. Zero azimuth angles were taken for all the studied locations. DC-into-AC string inverters were utilized in the proposed system with a total capacity of 5.94 kW, with an efficiency of 90%. The cost of the inverter is 220 US$/kWp (Astana Solar 2012). The economic feasibility analysis was performed using data on initial costs associated with the implementation of the proposed system, and prevailing loan interest, inflation, and energy escalation rates were prevalent in the country.

In this study, project life is assumed to be 25 years. As this project is in prefeasibility level, calculation of the total cost has been simplified. With respect to total expenses, *development* represents 5%, and *engineering* 15% of the total cost. Annual O&M is about 1% of total initial cost. The cost of the construction phase would be 75% of the total initial expenses. Table 3 provides some details and assumptions considered for the entire financial analysis, based on the current market and financial situation of the country (The National Bank of Kazakhstan 2015). Feed-in tariff (FIT) is specially included according to new government policies starting on the generation of power from renewable sources, in place since 2014 (Ministry of Energy of Kazakhstan 2014). Therefore in this analysis, the FIT will be assumed as 191.4 $/MWh.

3.3 Results

3.3.1 Electricity Generation

The amount of equivalent DC electrical energy actually generated by the proposed 6.6 kWp solar grid-connected system to the utility was calculated for all three locations in the annual electricity production. The highest electricity annual production was obtained in Shymkent with about 8.9 MWh. The lowest production was obtained in Taraz with an annual electricity generation of 8.1 MWh. For an average city in South Kazakhstan, an estimate of 6.1 MWh/year of electricity can be delivered using the proposed PV system.

3.3.2 Economic Feasibility Indicators

The decision making indicators from the financial analysis throughout the PV system lifetime are presented as follows (see also Table 4):

Internal rate of return (IRR): The maximum IRR of 17.9% was observed in Shymkent, while the minimum IRR of 9.9% was observed in Taraz. Therefore, an IRR of 16% can be obtained from an average city in South Kazakhstan.

Net present value (NPV): The highest NPV was about $14,523 for Shymkent, and the lowest was about $11,366 for Taraz.

Benefit-cost (B-C) ratio: The B-C ratio was found to be highest (9.65) in Shymkent, while the lowest (7.84) was found in Kyzylorda.

Simple payback (SP): It was found that on an average, an SP of about 9.9 years can be obtained from any location of South Kazakhstan.

Table 4 Economic indicators for 6.6 – kWp solar PV system for three locations, South Kazakhstan

Financial results	Shymkent	Kyzylorda	Taraz
IRR on equity	17.9%	17.3%	16%
Net annual income	$1191	$1078	$973
Net present value	$14,523	$13,741	$11,366
Payback period	9.9	10.2	10.8
Benefit-cost ratio	9.65	9.03	7.84

3.4 Sensitivity Analysis

A Monte Carlo analysis, based on a sample of 500 scenarios, allowed finding the probable outcomes under known uncertainty of input parameters. In this study, a ± 10% uncertainty is assumed for the initial cost, O&M, FIT, and debt ratio, while an uncertainty of ±20% was assumed for debt interest rate and debt term, as debt parameters vary widely with current Kazakhstani bank services that depend on project scope.

The impact tornado graph, presented in Fig. 2, shows how much of the variation in the financial parameter can be explained in each input parameter. The impact

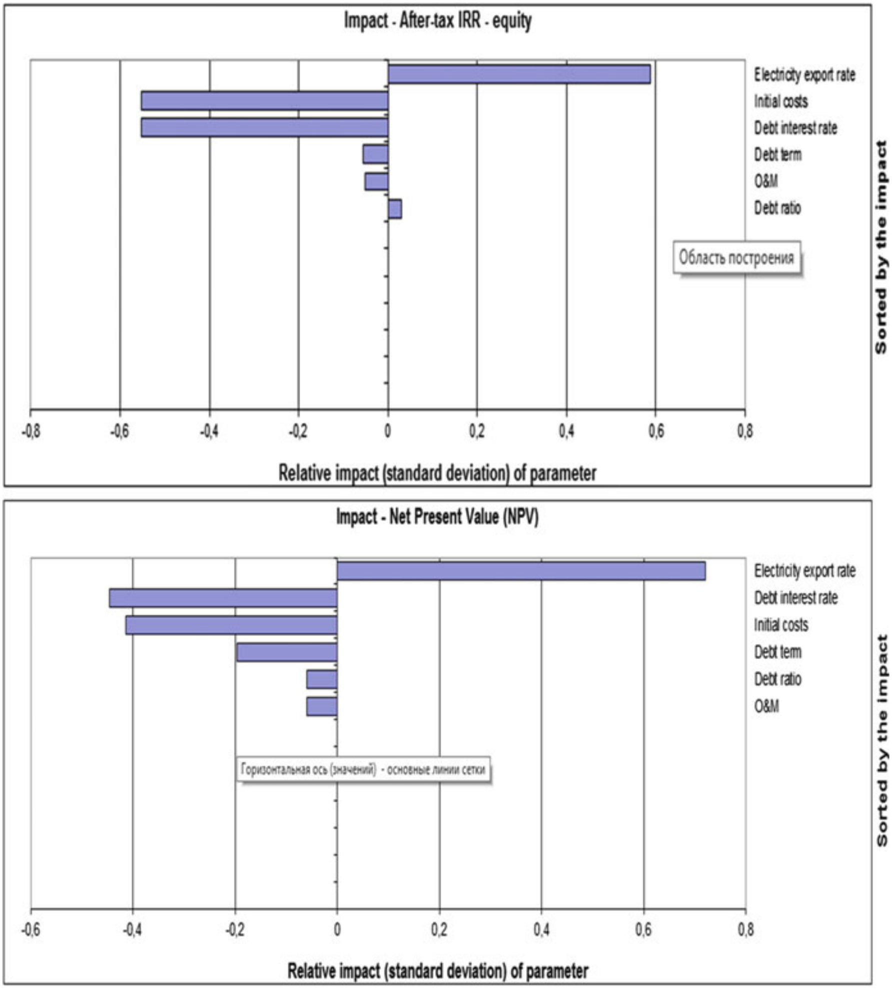

Fig. 2 Impact results of NPV and IRR for Shymkent

Table 5 Comparison of financial viability

Financial results	Residential PV in Shymkent	Residential PV in Shymkent with government subsidy
IRR on equity	17.9	18.1
Net annual income	$1191	$2523
Net present value	$14,523	$26,220
Payback period	9.9	5.5
Benefit-cost ratio	9.65	4.12

analysis demonstrates that the changes in NPV and IRR are largely due to variation of FIT, followed by initial cost and debt interest rate in about the same level of importance, as shown in Fig. 2.

Since residential solar PV has no analogies within the country, this analysis should be used as a support mechanism to stimulate implementation of these types of projects in the country.

According to these results, an even better solution for Shymkent could be obtained if the project is included in the list of priority sectors of the "Business Road Map – 2020" that is one of the "DAMU Entrepreneurship Development Fund" projects. This initiative has, as its main goal, to provide governmental support for projects of non-primary sectors of the economy. In this particular case, if implemented, the government may subsidize 50% of the initial cost of project, and the remainder is taken completely as loan (100% debt ratio, i.e., no equity needed) from the bank by the owner at 7% of debt interest rate (Halyk bank 2013). As it can be observed in Table 5, there are significant differences in financial results when government provides subsidies. All financial parameters indicate that government subsidy is a very beneficial approach to promoting residential solar PV (Fig. 3).

4 Conclusions

This study analyzes the technical and economic potential of solar photovoltaic-grid connected system in South Kazakhstan. The technical assessment considers several locally manufactured PV systems. The study focuses on polycrystalline solar cells (poly-Si) due to its optimal financial and technical specifications for South Kazakhstan climatic conditions.

The analysis determined that with a 6.6 kWp PV array it is possible to generate and export to the grid a minimum of 8.9 MWh in Taraz, and a maximum of 9.1 MWh in Shymkent. Financial indicators from the life cycle cost analysis for all sites showed favorable conditions for the development of the proposed residential solar

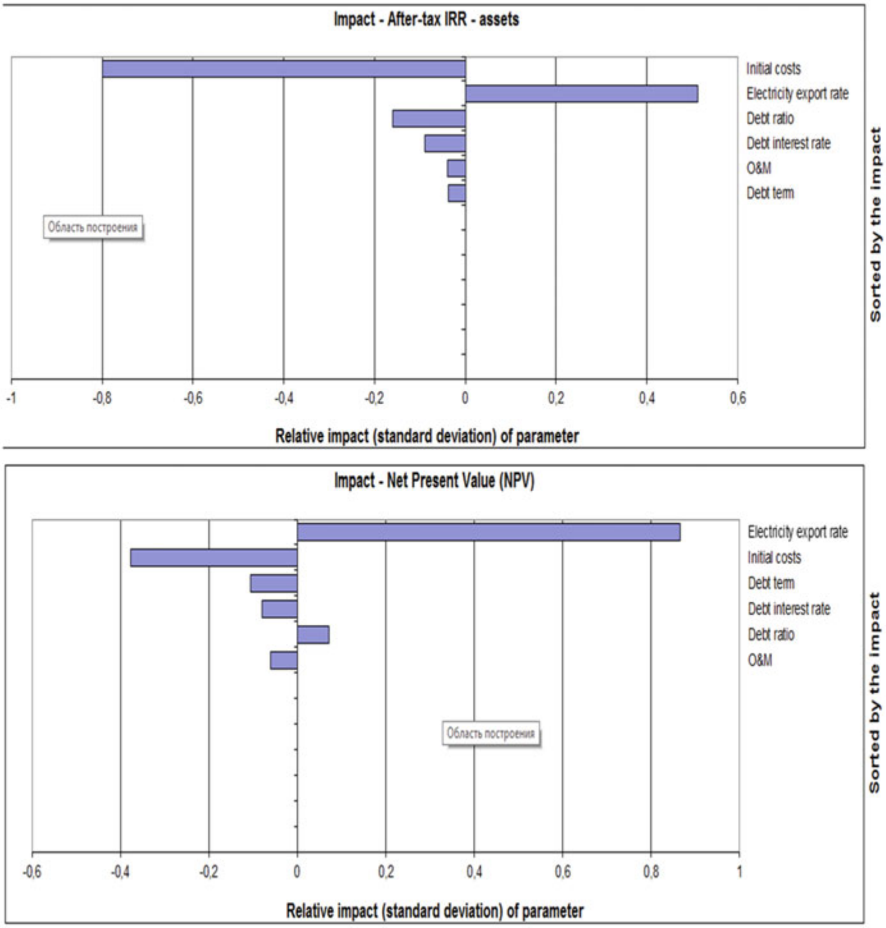

Fig. 3 Impact results of NPV and IRR for Shymkent with government support

PV system in South Kazakhstan, proving that on a lifetime frame of 25 years, the application of solar PV for residential grid-connected systems is quite feasible financially.

A new policy in conjunction with the feed-in tariff (FIT) is envisioned from the study. The economic analysis suggests that a subsidy of 50% of total initial cost should be considered to maximize the advantage for the residential owner of the PV-system in southern regions. This will also help to support the weak grid in the region, under constant threat of breakdown during peak load hours.

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