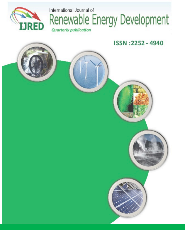
Contents list available at IJRED website
Int. Journal of Renewable Energy Development (IJRED)
Journal homepage: http://ejournal.undip.ac.id/index.php/ijred



Research Article

Impact of Module Degradation on the Viability of On-Grid Photovoltaic Systems in Mediterranean Climate: The Case of Shymkent Airport

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ABSTRACT. This paper presents the techno-economic feasibility analysis of an on-grid Photovoltaic Solar System (PVSS) subject to Mediterranean climate aging effects. The PVSS under study is considered installed on the roof of Shymkent airport, located in southern Kazakhstan. A PVSS performance degradation rate of 1.48%-per-annun was considered according to the Mediterranean climate prevailing in the location. A 25-year life-cycle cost analysis comparing the rated vs. de-rated on-grid PVSS led to a positive Net Present Value (NPV), a less than 9-year equity payback, and favorable internal rate of return (IRR) and Benefit-to-Cost (B-C) ratio in both conditions. However, the de-rated PVSS system underperformed in 16.2%, 43.5% and 20% the IRR, NPV and B-C ratio, respectively. The analysis demonstrates that despite the expected performance degradation associated to climatic aging, a convenient feed-in tariff (FIT) and attractive financial conditions, such as those present in Kazakhstan, conform a robust setting to promote on-grid PVSS in the country.

Keywords: Photovoltaic systems; PVSS degradation; Mediterranean climate; renewable energy; solar energy.

Article History: Received: 24th Sept 2020; Revised: 4th Nov 2020; Accepted: 8th Nov 2020; Available online: 11th Nov 2020
How to Cite This Article: Smagulov, Z., Anapiya, A., and Dikhanbayeva, D., Rojas-Solórzano L., (2021) Impact of module degradation on the viability of on-grid photovoltaic systems in Mediterranean climate: case of Shymkent Airport. *Int. Journal of Renewable Energy Development,* 10(1), 139-147.
https://doi.org/10.14710/ijred.2021.33485

1. Introduction

Air terminals are a fundamental part of the universal air transport framework, and they support and encourage the number of travelers and the travel industry all around the globe (DeVault *et al.* 2012). Moreover, even though in recent years there has been an increase in the attention directed towards the ecological effects of human activities, a threat to both the aircraft industry and the air terminal industry is its low capacity to develop and work on its environmental impact in the near future (Salameh 2014). Furthermore, there is also an increased concern on the effects that air terminals have on nature, and the air terminal industry is attempting to have more ecologically responsible air terminals (Fargione *et al.* 2008). On the other hand, the International Civil Aviation Organization (ICAO) estimates that global greenhouse gas (GHG) emissions derived from the civil aviation industry will rise 4 to 6 times by 2050 compared to the 2010 emissions because of both the increasing number of airlines and new airports construction (Jain *et al.* 2010).

However, some actions could diminish the environmental impact of air terminals, like the incorporation of energy-saving light-transmitting diodes (Plante *et al.* 2010). In addition, the use of sun-powered photovoltaic (PV) frameworks — also known as Photovoltaic Solar system (PVSS) — at air terminals is one of the best options because it diminishes the CO_2 production while producing energy (ICAO 2014). Additionally, one of the most widely recognized energy-saving structures installed on air terminals are on-grid PV boards, which are usually installed on rooftops. That is why installing PVSS clusters on the rooftop can give it both ecological and financial advantages to air terminals (Kellas 2012). Moreover, those PVSS clusters produce fewer CO_2, even though their generation, movement, establishment, decommissioning, and reusing produce CO_2 emanations. Besides, PV frameworks have a life expectancy of over 20 years and require low maintenance (Kellas 2012). Because of the advantages of PVSS, an increasing number of air terminals over the world have introduced sun-based powered frameworks (Swart *et al.* 2013). Furthermore, the world's first absolutely sun - based controlled airport is the Indian Cochin International Airport. Other examples are both the Hong Kong International Airport and the London Gatwick Airport, which also use solar power plants (Zaihidee *et al.* 2016). Thus, airports are suitable for the application of PVSS.

On the other hand, PV modules suffer degradation over time, which reduces the generation of electricity during their lifespan and increases the power levelized cost (Yahya *et. al* 2011). PV systems steadily degrade and

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lose their efficiency due to environmental stresses, including high temperature, humidity, and ultraviolet (UV) radiation. For example, Aly *et al.* (2019) determined that silicon-based PV panels are significantly affected by environmental factors such as ambient temperature, incident irradiance, wind speed and mounting configuration. According to observations gathered from field-aged PVSS, the degradation modes and catastrophic failures of the PVSS are caused by both the cracking and by the delamination (Aly *et al.* 2019; Kaplani 2012). Such failure modes will reduce the PV module's performance and shorten its service life. In fact, the cracking of the backsheet on the PV panel — that is caused by a reduction in tensile strength— causes a significant volume of moisture to infiltrate, and that is the most devastating mode of backsheet failure recorded to date. Since backsheet cracking enables both water vapor and liquid to penetrate the PV panel, it can have a significant effect on PV module performance and reliability. Thus, to ensure that the PV module retains its output over its lifespan, the estimation of degradation patterns is important.

Therefore, it is necessary to understand the mechanisms of degradation to predict electricity output over the lifetime of the PV modules, as well as to find solutions to prevent and reduce degradation. For these reasons, researchers have tested PVSS reliability, and they have found that, even if PVSS last more than 25 years outdoors, they degrade (Yahya *et al.* 2011; Chianese et al. 2003; DeGraaff *et al*. 2011; Wohlgemuth and Kurtz 2011; Vázquez and Rey-Stolle 2008; IEA-PVPS 2013; Halwachs 2017; Maish *et al.* 1997). Moreover, mechanical stress, moisture, elevated temperature, and ultraviolet radiation can lead to different failures in operation. Furthermore, the reduced solar cell performance due to damage appears even before its warranty finishes (Kato 2011).

On the other hand, there are cosmetic issues that do not affect the performance nor safety of the module (DeGraaff *et al.* 2011). Nonetheless, cosmetic issues can trigger or enhance other problems as well as reveal other non-visually detectable failures that affect power output. For example, "snail tracks" are discolorations on the solar cell, and even if there is no evidence yet that they cause a significant reduction in module performance, they are indicators of the presence of cell cracks (Parnham *et al.* 2017). That is important because glass breakage is one of the most frequent defects caused during transportation and deployment of a PVSS. Even if cell cracks do not directly affect cell performance, they still promote or even cause certain types of degradation, such as the deterioration of electrical insulation, corrosion, delamination, among others (DeGraaff et al. 2011). For example, Liu *et al*. (2019) performed quantitative analysis on two PVSS combining the equivalent-circuit model and optoelectronic characterization methods, and they found that the encapsulant discoloration in PVSS mostly contributes to its degradation. On the other hand, one of the major causes of PV deterioration is extreme climate conditions (Liu *et al.* 2019), with the degradation of short circuit current (Isc) being the largest contributor to the reduction of the maximum power point (Pmax) in most climatic areas.

The Isc degradation is mainly due to delamination, discoloration, and cracks present in the cells; however, a small percentage can be due to light-induced degradation (LID) and soiling (accumulation of dirt over the panels) (Bogdanski *et al*. 2010). In addition, Isc degradation is the largest contributor to the reduction of the maximum power point (Pmax) in desert climates (Smith *et al.* 2012). A minor factor in the degradation of Isc comes from the fill factor (FF), which is associated with breakage of corrosion and solder bond (Yedidi *et al.* 2014). Thus, it is necessary to consider PVSS deterioration when studying if the installation of PVSS is feasible in each climate zone, as the climate is a major factor in its performance.

In this paper, the degradation effect due to the Mediterranean climate on the PVSS that would be installed on the roof of the International Airport of Shymkent was analyzed using a life-cycle cost analysis performed in the RETScreen Expert platform (National Resources Canada, 2004). Shymkent is a city located in the southern part of Kazakhstan (Fig.1), with Continental-Mediterranean climate according to the Köppen climate classification (Ontustyk 2019).

The PVSS would be installed on the roof of the airport, and the top view of the airport roof was obtained using the Google Earth Pro software (Fig. 2). A total roof area of 2820 m² would be covered by PV panels and accessories.

Fig. 1 Location of Shymkent on the Kazakhstan map (Ontustyk 2019).

Fig. 2 Scheme of the airport rooftop area to be covered by PV panels (Google Maps view).

2. Literature review

Financially, the degradation of a PV module or system is important because a higher degradation rate negatively affects power production, and it reduces the cash flow. Furthermore, if there are inaccuracies in the determined degradation rates, these can increase the financial risk. Technically, it is also important to understand the degradation mechanisms because they may eventually lead to failure. In PVSS, a 20% decline is typically considered a failure; however, there is no consensus on the definition of failure for these systems because a high-efficiency module with 50% of degradation may still have a higher efficiency than a non-degraded module that uses a less efficient technology (Weather-Atlas 2019).

As indicated by the National Renewable Energy Laboratory (NREL), PV modules can be affected by conditions like damp heat, UV exposure, thermal cycling, and humidity freeze (Omazic *et al.* 2019). Moreover, the way that PV modules are affected differ between these elements. For example, thermal cycling can cause weld bond degradations and splits in sun-powered panels; damp heat has been related to the corrosion of cells; humidity freezing can cause failures in the Junction box; UV exposure contributes to staining and back sheet debasement (Peng *et al.* 2012). When these problems appear, it is difficult to estimate the impact that they have.

Chianese *et al.* (2003) studied degradations that happened in the midlife of PV modules and estimated that 2% of the PV modules would not meet the producer's guarantee following 11-12 years of activity. That study found a very high pace of deformity in the interconnections in the module as well as degradations caused by PV module glass breakage.

One of the climates that leads to PVSS degradation is a hot and dry climate because PV modules are exposed to severe stress factors like intensive solar and UV irradiation, extreme temperature cycles, and sand. The most frequent failure processes in a desert climate are discolouration of the EVA encapsulant, followed by delamination above the cell, and a high degree of corrosion (Liu *et al.* 2019).

Lifetime reduction of PVSS performance is accentuated due to the extreme weather conditions in regions such as in South Africa, where the downtime can last up to four hours a day in the most severe months (Kellas 2012). In arid regions, dust is the main problem for PVSS. Gathered dust of 20 g/m^2 on the PVSS reduces short circuit current, open-circuit voltage, and efficiency by 15-21%, 2-6%, and 15-35%, respectively (Swart *et al.* 2013).

The installation of PV panels in airports and nearby territories is becoming trendier and taking off worldwide. This combination has many advantages. For example, the airport installations and parking space are usually large, and despite the neighbouring noise from aircraft makes them unusable for many alternative purposes, installing solar panels would be practical and could support part of the airport power demand and also feed the grid.

As one of the examples of successful implementation of solar PV panels in airports we have the San Diego International Airport (SDIA). A system with 5.5 MWp was installed at SDIA with an estimated generation of 9,200 MWh/year. Moreover, additional enhancements were made such as the installation of 2MW/4MWh of storage systems for the energy generated. According to the report, it decreases the airport's electricity cost by more than 40% (Renewable Energy World 2020).

Additionally, the administration of Cochin International Airport in India, which is the 4th busiest airport in the world serving more than 5 million people annually, has commissioned an on-grid 12-MWp solar PV plant in the airport premises, operating since 2015. The system has been able to generate enough energy to offset the airport annual consumption and with a positive Net Present Value (NPV) of the project (Sukumaran and Sudhakar, 2017). Many other airports in India are partially powered with solar PV systems to date, while Sukumaran and Sudhakar (2017) believe that most of the airports in the country could be fully solar-powered.

Furthermore, according to the Federal Aviation Administration, 500 airports in the USA would qualify the minimum requirements to install in average 2 MWp PV systems each, which could reach 1 GWp of installed capacity. These PV systems could be installed in a relatively short amount of time and could power 750,000 homes (FAA 2020).

Therefore, despite the installation of solar PV power plants in airports is technically viable and trendy, the degradation rate of the photovoltaic panels may adversely impact their economic viability according to the climate zone where the PVSS is installed. Hence, this investigation aims to determine the influence of the Mediterranean climate of Shymkent city in Kazakhstan on the feasibility of installing a PVSS in the local airport.

3. Methodology

The techno-economic analysis of the on-grid photovoltaic system is performed using the RETScreen analysis software (National Resources Canada, 2004). It is an intelligent decision support tool that helps to evaluate the performance of renewable energy projects. The platform allowed us to perform the analysis in 5 steps: energy model, cost budgeting analysis, greenhouse gas emission analysis, life-cycle cost analysis (LCCA), and sensitivity & risk analysis. These steps are described as follows:

- Energy model. This stage requires information regarding feed-in-tariff (FIT) and proposed PVSS, project location, type of energy used in the project, and regional resources. Based on conditions of the present case study, the platform provides the database with horizontal irradiance in situ and the estimation of electricity production using a fixed-slope PV system can be obtained. The calculation is corrected year after year, to include the degradation of PVSS panels accordingly.
- Cost budgeting analysis. This section pertains to the introduction of periodic, annual, and initial costs associated to the PVSS at year zero value.
- Greenhouse gas (GHG) emission analysis. This section provides an estimation of the CO_{2e} emissions avoided by each of the two considered PVSS scenarios (rated PVSS and de-rated PVSS). This analysis complements the financial impact of each solution with its environmental benefits.
- Life-cycle cost analysis (LCCA). This stage represents the model number-crunching using a standard cash flow analysis affected by all input financial parameters associated to the case of study, including: inflation and FIT escalation rates, and the minimum

return rate expected by investors in this sector (discount rate). The outcome of the LCCA determines for the two scenarios (rated PVSS and de-rated PVSS -subject to photovoltaic panels degradation-) decision-making cost-effectiveness indicators (e.g., Snell 1997), including the Net-Present Value (NPV), Internal Rate of Return (IRR), Equity Payback, and Benefit-Cost (B-C) ratio. Equations (1) thru (8) show the indicators:

$$C_n = C_{in,n} - C_{out,n} \tag{1}$$

$$C_0 = Incentives + Grants - Initial\ Cost \tag{2}$$

$$C_{in,n} = AEEGx\ FIT(1+r_e)^n \tag{3}$$

$$C_{out,n} = (O\&M + PC)(1+r_i)^n \tag{4}$$

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \tag{5}$$

$$B - C = \frac{NPV + Initial\ Cost}{Initial\ Cost} \tag{6}$$

IRR:

$$\sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} = 0 \text{ (i.e., ``r'' needed for NPV = 0)} \tag{7}$$

Equity Payback (EP):

$$\sum_{n=0}^{EP} C_n = 0 \ (i.e., year\_to\_0\ cumulated\ cash\ flow) \tag{8}$$

Where:
$AEEG$: annual energy exported to the grid
$C_{in,n}$: cash inflow
$C_{out,n}$: cash outflow
N : lifetime years
N : a given year within lifetime
R : discount rate
r_e : FIT annual escalation rate
r_i : inflation rate
$O\&M$: annual operating & maintenance cost
PC : periodic cost

- Sensitivity and risk (S&R) analysis. In this stage, the most determinant factors in the financial outcome of the project are determined. For this purpose, with an estimation of the uncertainty of each input parameter, a multivariable Monte Carlo (MC) analysis is performed to find out which are the most critical input parameters in determining the expected financial outcomes. The MC simulation is a method to develop a S&R analysis which considers input parameters and randomly selected values within an uncertainty range indicated by the analyst. The MC simulation consists of 2 steps: a) First, for each input parameter selected by the analyst, 500 random samples are generated using a Gaussian distribution with a mean value 0 and a standard deviation of 0.33. Once these values are generated, they remain fixed. b)Second, for each input parameter, the corresponding random values from (a) are multiplied by the uncertainty indicated by the user (as a percentage) of variability around the nominal value of the given input parameter. As a result, a matrix of 500 x number of input parameters will be created; therefore, 500 results will be produced in a histogram of frequency. Thus, for a given risk, an associated confidence range of an outcome financial indicator is determined, and its sensitivity to input parameters is graphically expressed through a tornado chart.

4. Results and analysis

4.1 Energy model

Shymkent is a city that receives a large average year-round daily irradiance in Kazakhstan. For comparison purposes, Table 1 presents the daily average solar irradiance in several cities of the country.

The PV panels to be installed in Shymkent airport are considered tilted 30° to maximize the average daily radiation received per year, which results in 5.06 kWh/m^2/d (see Table 2). Furthermore, the tilted PV arrangement allows rain to clean the solar panels, which reduced our assumed miscellaneous losses to 3% (Table 3). A total PVSS capacity of 300 kWp was assumed to fit the airport rooftop area of 2820 m^2. This capacity was estimated including the needed space for maintenance and inspection between solar panels. The overall characteristics of the PVSS are presented in Table 3.

Malvoni *et al.* (2017) estimated the performance deterioration of a PVSS that was exposed to Mediterranean climate outdoors using the Classical Seasonal Decomposition (CSD) method. Their experiments showed that the degradation rate of the PVSS was about 1.48 %/year. The CSD is a common technique used to calculate the degradation rate and does not have significant uncertainties. The reduction of the PV output power due to the annual degradation rate was introduced into the energy model with the lifespan of the project being 25 years.

Therefore, the electricity generation during the first year was estimated through the RETScreen platform using the selected technology of PV panels tilted at fixed 30°, including the panel temperature de-rating as per average monthly temperature, the inverter efficiency and the miscellaneous losses previously indicated in Table 3.

From second year and thereafter, the annual generation was decreased year after year to reflect the deterioration of the PV module performance, i.e., the electricity exported to the grid was reduced by 1.48% in each subsequent year after the first year, as indicated in Fig. 3.

Table 1
Comparison of average daily solar radiation in different Kazakhstan regions

City	Region	Daily Solar Radiation – horizontal (kWh/m^2/d)
Astana	North	3.55
Almaty	Southeast	3.59
Shymkent	**South**	**4.45**
Taraz	South	4
Kyzylorda	South	4.21
Uralsk	Northwest	3.55
Pavlodar	Northeast	3.51
Karaganda	Central	3.71
Aktau	Southwest	3.92
Kokcetav	North	3.36
Semipalatinsk	East	3.81

Source: National Resources Canada (2004)

Table 2
Daily solar radiation for horizontal and tilted PV modules in Shymkent

Month	Daily solar radiation -horizontal kWh/m²/d	Daily solar radiation -tilted kWh/m²/d
January	1.77	2.86
February	2.58	3.60
March	3.95	4.81
April	5.31	5.72
May	6.5	6.39
June	7.24	6.84
July	7.25	6.97
August	6.35	6.61
September	5.11	6.04
October	3.52	4.84
November	2.14	3.42
December	1.52	2.47
Annual	**4.45**	**5.06**

Source: National Resources Canada (2004)

Table 3
Technical characteristics of PVSS components

Component or feature	Technical specification
Photovoltaic type	Mono-Si
Power capacity (kWp)	300
Temperature coefficient (%/°C)	0.4
Efficiency (%)	11
Solar collector area (m²)	2727
Miscellaneous losses (%)	3
Inverter efficiency (%)	86%

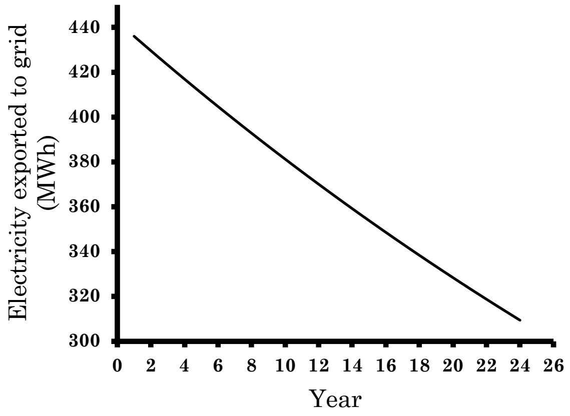

Fig. 3 Electricity exported to grid affected by PV module degradation in each year (de-rated PVSS)

4.2 Cost budgeting analysis

The cost of PV modules was estimated in the lower limit of the range 1-3 US$/W suggested by Malvoni *et al.* (2017), given the fast drop in PV prices experienced in recent years. Hence, the cost of PV panels was taken as 1 US$/W (388.29 KZT/W @ 2019); i.e., 1000 US$ (388,290 KZT) per one kW.

Table 4
Initial costs for the installation of the PVSS modules in the rooftop of the Shymkent airport

Initial costs	Quantity	Unit cost (KZT)
Engineering cost	1	1,242,892
Photovoltaic system	300 kWp	388,290
Transportation	1	700,000
Subtotal		118,429,892
Contingencies	5%	5,921,495
Total initial costs		**124,351,387**

Transportation of all the PV modules was assumed to cost 700,000 KZT, and 5% of contingencies were added. Engineering cost is assumed to be 1% of the total initial cost (1,242,892 KZT). Therefore, including all these expenses, the total amount of initial cost is 124,351,387 KZT (see Table 4).

Inverters usually cost 10% of the total cost (Plante 2014), so it is included as an extra initial cost of 12,435,139 KZT in this study. A periodic cost for replacement or refurbishment of inverters is considered in year 15. Operating and maintenance (O&M) costs are included to cover labour costs of approximately 480,000 KZT per year to consider one technician checking and maintaining the PVSS. This cost includes cleaning the PVSS after snow and dust storms, among other tasks. All annual and non-annual periodic (O&M) costs are shown in Table 5.

4.3 GHG Emission analysis

The GHG emission factor in Kazakhstan's grid is 0.582 tCO_{2e}/MWh (The World Bank 2018). However, the World Bank suggests that the electric power transmission and distribution losses (T&D) in Kazakhstan in 2014 was 7% per year (Solar Reviews n.d.), and when the T&D is included, the GHG emission factor increases to 0.626 tCO_{2e}/MWh. In the present analysis, the GHG emission reduction results from the calculated emissions avoided from the grid assuming a zero-emission kWh injected to the grid by the PVSS. Therefore, the net annual GHG emission reduction is equal to 253.9 tCO_{2e} per year during the first year. Notice that even if we include the degradation rate in the PVSS, the emissions would be reduced by the same amount in the first year since the production of electricity is unaffected by PV degradation during the 1st-year. However, by the 25th year, due to its accumulated degradation, the production of electricity by the de-rated PVSS would only avoid 174.9 tCO_{2e} of emissions. For the financial analysis, zero GHG reduction credits during the project lifetime were taken.

Table 5
Operating & Maintenance, and Periodic costs

Annual costs (O&M)	Quantity	Unit cost (KZT)
Labor	2	480,000
Subtotal		960,000
Periodic costs (O&M)	**Frequency (Year)**	**Cost (KZT)**
Replacement of inverters	15	12,435,139

Table 6
Input parameters in the financial analysis

Parameter	Value
Inflation rate (%)	7.31
Discount rate (%)	11
Project life (years)	25
Incentives and grants (KZT)	0
Electricity export escalation rate (%)	7.31
Feed-in Tariff (KZT/kW)	34
Annual electricity exported to the grid per year (@year 1) (MWh)	436

4.4 Life-cycle cost analysis (LCCA)

The average inflation rate in Kazakhstan in the last ten years has been 7.31% per year, and this value was used for this study (Asian Development Bank 2017). On the other hand, the feed-in-tariff (FIT) in Kazakhstan is equal to 34 KZT/KWh (Plecher 2019). The electricity escalation rate was considered as 7.31%, which is the same percentage as the estimated average inflation rate. No loans or grants are considered. Based on the last five years, the discount rate is assumed as 11.1%, according to the National Bank of Kazakhstan (Kursiv 2019). Table 6 presents a summary of the input parameters for the financial analysis. The airport is owned by the governmental “Airport Management Group” company, so there are no taxes to be considered (National Bank of Kazakhstan 2019).

4.4.1 LCCA for rated or standard PVSS

Results of the life-cycle cost analysis demonstrate that the base case (rated or standard PVSS) is feasible. As can be seen in Table 7, it was determined that the equity payback period is 6.7 years. In addition, the IRR on equity is 17.9%. Moreover, the NPV is positive and reached a total of 96,158,481 KZT, with a B-C ratio of 1.8.

Table 8 shows the overall cash flow of the project, and it can be seen that the equity payback period of the project would be of seven years; i.e., the total investment would be paid completely in the seventh year of the project. Moreover, in the last year, 80,955,664 KZT would be obtained from the project. In total, 824,550,467 KZT would be earned, which is almost seven times the investment cost.

4.4.2 LCCA for de-rated PVSS

The overall cash flow, considering the 1.48% degradation rate of PV panels, is shown in Table 9. Thus, the electricity exported to the grid decreases 1.48% each year compared to the previous year.

Table 7
Results of financial analysis for rated PVSS

Financial indicator	Value
IRR	17.9%
Equity payback period	6.7 years
Net present value (NPV)	96,158,481 KZT
Benefit to cost ratio (BCR)	1.8

In this case, the cumulative cash flow becomes positive in the 8th year of the project instead of the 7th year, as it happened for the rated PVSS case. If we compare the cash flow in the 25th year between rated and de-rated PVSS scenarios, it can be observed that the cash flow in the rated PVSS is 244,375,066 KZT higher than in the de-rated PVSS (Tables 8 and 9, respectively), which reflects the expected cash flow reduction when the PV panel degradation is included.

Additionally, Table 9 reflects the annual increase of FIT and O&M costs associated to escalation and inflation rates (valid similarly for both rated and de-rated scenarios). As a result of the LCCA for the de-rated PVSS, an IRR of 15%, NPV of 54,298,008 KZT, and B-C ratio of 1.44 are obtained (Table 10). Therefore, the positive NPV, higher-than-one B-C ratio and favorable IRR demonstrate that a de-rated PVSS in Shymkent airport, due to its Mediterranean climate, is still a techno-economic viable solution. Moreover, given that previous studies about PVSS in southern Kazakhstan did not consider PV degradation (e.g. Assamidanov et al. 2018), the present work reaffirms the primary importance of solar energy projects in the future of the Mediterranean climate zone of Kazakhstan.

Table 8
Cash flow of the project for rated PVSS

Year	Annual Cash Flow (KZT)	Cumulative Cash flow (KZT)
0	-124,351,387	-124 351 386
1	14,889,584	-109 461 803
2	15,978,013	-93 483 790
3	17,146,005	-76 337 784
4	18,399,378	-57 938 407
5	19,744,373	-38 194 034
6	21,187,686	-17 006 347
7	**22,736,506**	**5,730,159**
8	24,398,545	30,128,704
9	26,182,079	56,310,782
10	28,095,989	84,406,771
11	30,149,805	114,556,576
12	32,353,756	146,910,333
13	34,718,816	181,629,148
14	37,256,761	218,885,909
15	4,149,674	223,035,582
16	42,902,785	265,938,367
17	46,038,979	311,977,346
18	49,404,428	361,381,774
19	53,015,892	414,397,666
20	56,891,353	471,289,019
21	61,050,111	532,339,130
22	65,512,875	597,852,005
23	70,301,866	668,153,870
24	75,440,932	743,594,802
25	80,955,664	824,550,467

Table 9
Cash flow for de-rated PVSS

Year	Electricity exported to grid (MWh)	FIT ($/MWh)	O&M (KZT)	Periodic costs	Annual Cash flow (KZT)	Cumulative Cash flow (KZT)
0					-124,351,387	-124,351,387
1	436.00	34,000.00	960,000.00		13,864,000	-110,487,387
2	429.55	36,485.40	1,030,176		14,642,025	-95,845,362
3	423.19	39,152.48	1,105,481		15,463,453	-80,381,908
4	416.93	42,014.53	1,186,292		16,330,686	-64,051,222
5	410.76	45,085.79	1,273,010		17,246,256	-46,804,965
6	404.68	48,381.56	1,366,067		18,212,837	-28,592,128
7	398.69	51,918.25	1,465,927		19,233,245	-9,358,882
8	**392.79**	**55,713.48**	**1,573,086**		**20,310,454**	**10,951,572**
9	386.97	59,786.13	1,688,079		21,447,596	32,399,169
10	381.25	64,156.50	1,811,477		22,647,978	55,047,147
11	375.60	68,846.34	1,943,896		23,915,083	78,962,230
12	370.05	73,879.01	2,085,995		25,252,586	104,214,816
13	364.57	79,279.56	2,238,481		26,664,362	130,879,179
14	359.17	85,074.90	2,402,114		28,154,495	159,033,674
15	353.86	91,293.88	2,577,709	12,435,139	17,292,154	176,325,829
16	348.62	97,967.46	2,766,139		31,387,294	207,013,807
17	343.46	105,128.88	2,968,344		33,139,284	240,153,090
18	338.38	112,813.80	3,185,330		34,988,309	275,141,400
19	333.37	121,060.49	3,418,178		36,939,685	312,081,085
20	328.44	129,910.01	3,668,047		38,999,017	351,080,103
21	323.57	139,406.43	3,936,181		41,172,212	392,252,315
22	318.79	149,597.04	4,223,916		43,465,495	435,717,810
23	314.07	160,532.59	4,532,685		45,885,425	481,603,236
24	309.42	172,267.52	4,864,024		48,438,915	530,042,151
25	304.84	184,860.27	5,219,584		51,133,249	581,175,401

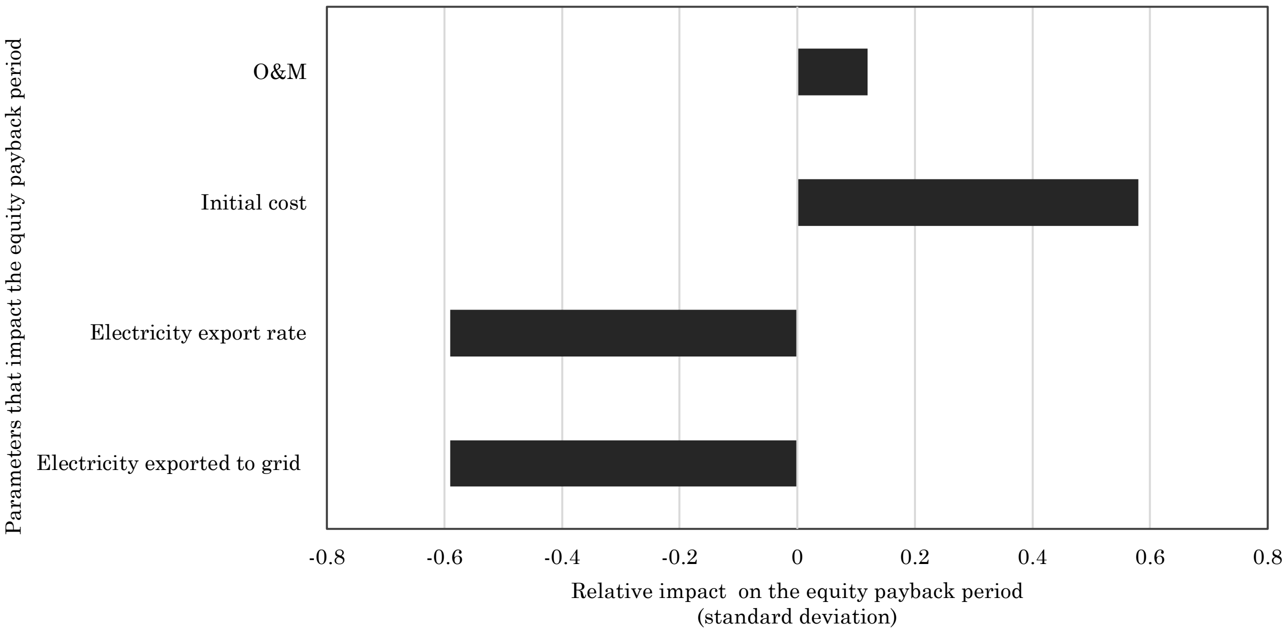

Fig. 4 Relative impact of parameters on the equity payback period for de-rated PVSS (as extracted from RETScreen Expert)

Table 10
Comparison of the financial indicators for both Rated and De-rated PVSS

Financial indicators	Rated PVSS	De-rated PVSS	Reduction
IRR (%)	17.9	15	16.2%
NPV (KZT)	96,158,481	54,298,008	43.5%
B-C ratio	1.8	1.44	20%

Table 11
Risk analysis of the equity payback for de-rated PVSS

Equity payback risk parameters	Unit	Value
Median	yr	6.7
Level of risk	%	5
Minimum within level of confidence	yr	6.19
Maximum within level of confidence	yr	7.4

4.5 Risk and Sensitivity Analysis for de-rated PVSS

A Monte Carlo analysis was performed with 500 different scenarios within a range of +/-10% of uncertainty variation in the input parameters for the de-rated PVSS scenario. Results show that with a risk of 5% the equity payback period would be between 6.19 and 7.4 years, and the equity payback period would be shorter than ten years (Table 11). On the other hand, according to the tornado chart (see Fig. 4), the initial cost, FIT, and electricity exported to the grid have the higher impact on the equity payback period. Furthermore, higher initial costs would lead to longer equity payback. In contrast, higher values of FIT and electricity exported to the grid would lead to a decrease of the equity payback period. As a final remark, as renewable energy technologies are becoming more efficient and inexpensive over the time, the equity payback period is likely to be reduced in the future which would increase the feasibility of these type of projects (Otyrar 2018).

5. Conclusion

On this study, the impact on the performance of on-grid PVSS affected by module degradation in Shymkent, a southern city in Kazakhstan was evaluated. Shymkent has a Mediterranean climate, and the analysis considered the feasibility of installing a PVSS at the roof of the International Airport of this city.

The degradation in PVSS performance due to local climate was estimated to be 1.48% per year, and its consideration leads to a significant deterioration of the feasibility of the system.

Moreover, if the PVSS degradation is included, the IRR, NPV, and the B-C ratio of the investment would be reduced by 16.2%, 43.5%, and 20%, respectively. Thus, the degradation rate of PVSS in Mediterranean climate zones has a significant influence on the technical and financial performance of the system. Nevertheless, even after considering the degradation, our estimations suggest that the PVSS is feasible, and this study can be used as a reference for future PVSS, not only in the Mediterranean climate regions of Kazakhstan but also in any other areas of the world that are subject to a similar climate.

Acknowledgments

The authors acknowledge the support provided by the School of Engineering and Digital Sciences at Nazarbayev University facilitating the use of computer and academic license of RETScreen Expert decision-support software needed in this study.

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