Stand-alone PV System Assessment for Major Cities of Pakistan Based on Simulated Results: A Comparative Study

Aamir Mehmood*[1], Adeel Waqas[1], Hafiza Tahira Mahmood[2]

[1]Solar Energy Laboratory, Center for Energy Systems, National University of Sciences and Technology, Islamabad-44000, Pakistan
[2]Department of Physics, University of Punjab, Lahore-54000, Pakistan
Corresponding Author, *aamir.mehmood08@gmail.com; Mob: +92-300-650-7809

Abstract

Pakistan is suffering from acute shortage of electricity and fuel that has adversely affected its industrial and agricultural progress in-spite of having ~2.9 million MW power potential can be harnessed from solar radiations. This paper aims on the study of technical and economic feasibility of stand-alone PV system in major cities of Pakistan. Current study is based on the results obtained by virtual modeling of a 5kW stand-alone PV System in RETScreen software developed by Canadian Energy Centre. The role of solar irradiance value, load correlation and ambient conditions are closely compared. A built in database in RETScreen uses climate information for simulation of PV system reported by National Aeronautics and Space Administration. Modeled system viability is examined on financial parameters like net present value, internal rate of return and payback period. The simulation results indicate that stand-alone PV system application can save millions being spent on conventional fuel purchasing to deliver base case power. These results demonstrate the feasibility of PV system in a realistic manner thus enlightening its benefits.

Keywords: Renewable energy, Stand-alone PV System, RETScreen, Solar fraction, NPV.

Abbreviations

PV	Photovoltaic
NPV	Net present value
IRR	Internal rate of return
GHG	Greenhouse gas
NASA	National Aeronautics and Space Administration

Introduction

Energy plays a vital role in improving the living standard of a nation and to strengthen all economy concerned matters. Nature has gifted this world with several abundant and non – replenish-able sources of energy that are large enough to accomplish current overall energy requirements. Within past few years mankind has encountered various challenges related to energy and environment. Depletion of conventional energy resources associated with environmental concerns has urged people living on this planet to exploit renewable and non - conventional resources.

International Energy Agency predicted an increase of~53% in global primary energy consumption up to 2030 and 70% of this value is expected to come from developing nations [1]. Pakistan is also one of the developing nations where gap of~3GW exists between electric power supply and demand [2] due to which people are facing severe blackout problems. Pakistan is naturally benefited part of world map where natural resources are in much excess that can be utilized to produce electricity. In Pakistan, daily solar radiations value ranges from 4.68kWh/m^2/d to 5.54kWh/m^2/d [3] and annual global solar irradiance value is~1900-2200 kWh/m^2 [2] that can be harnessed in form of electrical energy. Figure 1 shows the solar radiation map of Pakistan [4].

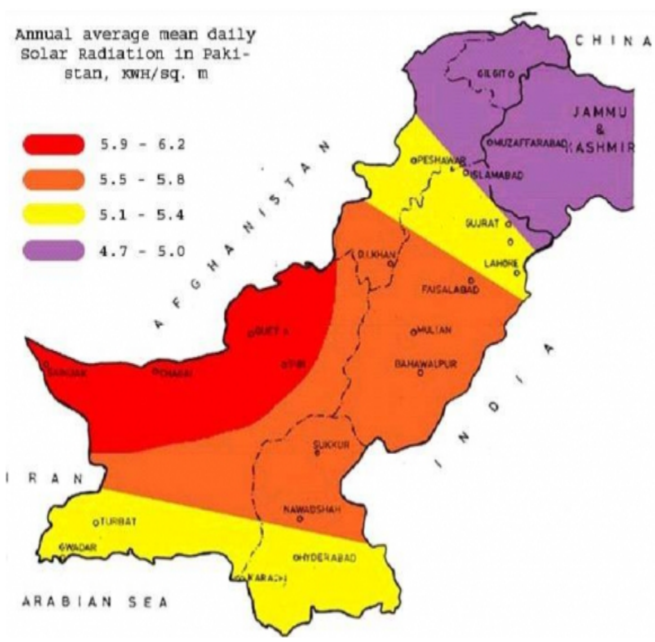

Fig 1: Solar Radiation map of Pakistan

PV technology has proved itself as a useful way of harnessing solar irradiance energy to generate electric power [5]. It can be used to supply electricity to remote areas as 45% people of Pakistan don't have access to electricity [6]. PV technology can also be used for utility peak load shaving, oil fields and gas oil separation plants located in remote locations, highway telephones and billboards, telecommunication towers, catholic protection in pipelines, water pumping in irrigation, park lighting, exterior home

Table 1 : Climate conditions of project locations in Pakistan

Property	Location Climate Data		
Location	Karachi	Lahore	Islamabad
Latitude	24.9°N	31.5°N	33.6°N
Longitude	67.1°E	74.4°E	73.1°E
Average Air Temperature	26.1°C	24.4°C	21.6°C
Daily solar radiations- horizontal	5.34 kWh/m^2/d	4.68 kWh/m^2/d	4.02 kWh/m^2/d
Heating Degree-days	0°C-d	352°C-d	659°C-d
Cooling Degree-days	5,861°C-d	5, 240°C-d	4,236°C-d

lighting and many other purposes [5]. Optimum electric power output value of PV array is largely affected by module operating temperature, solar irradiance conditions and azimuth angle of module [7].

In this comparative study, stand-alone solar PV system using NASA reported climate conditions is modeled in RET Screen software for three major cities of Pakistan named; Karachi, Lahore and Islamabad. Simulated system is evaluated on the basis of economic determinants like NPV, IRR and payback period and also analyzed that how much base case fuel saving is possible and GHG emissions can be reduced?

RET Screen Methodology

RET Screen international software developed by Canadian Energy Center has algorithms to evaluate different types of energy especially renewable energy projects using software calculated information like energy sources and their availability, initial project cost calculations, base case credits, on-going project costs, periodic costs, possible avoided cost of energy, income and finance taxes, GHG emissions effect on environment, cost effectiveness [8]. These embedded informative algorithms can be used for simulating different energy project models to calculate their output production, GHG emissions, fuel savings and their feasibility on the basis of financial parameters [9].

Climate Conditions

Canadian Energy Center has embedded recorded climatic conditions of almost all cities of the world map in form of location latitude, longitude, elevation, heating and cooling design temperatures, monthly and annual averaged daily solar radiations-horizontal, air temperature and wind speed reported by NASA. Climatic and geographical information of project location sare mentioned in Table 1.

Purpose of current study is to evaluate the viability of stand-alone PV system for different climatic conditions of Pakistan as revealed by climatic information like daily solar radiations-horizontal vary from 4.02kWh/m^2/d for Islamabad to 5.34kWh/m^2/d for Karachi.

PV Technology

RETScreen international software can simulate stand-alone systems for different PV technologies like mono-Si, poly-Si, a-Si, CdTe, CIS and spherical-Si fabricated by different manufacturers. Selection of PV model depends upon its PV technology type, optimum efficiency, nominal output temperature and solar collector area. PV models embedded in RETScreen databases are characterized on the basis of their optimum efficiency primarily can be calculated by using formula [10];

$$\eta_p = \eta_r[1 - \beta(T_c - T_r)] \quad (1)$$

Module temperature ($_cT$) and mean monthly ambient temperature ($_aT$) are related by Evan's formula as;

$$T_c - T_a = (219+832)K_t \frac{NOCT-20}{800} \quad (2)$$

For current study, model of mono-Si technologyis selected whose characteristic features are tabulated in Table 2.

Table 2 : Parametric characteristics of selected PV model

Property	Value
PV Technology Type	mono-Si
Efficiency	19.6%
Nominal Operating temperature	45°C
Temperature Coefficient	0.40%/ °C
Frame Area/PV Module	1.62 m^2
Control Method	Clamped

RET Screen Simulation

A case study stand-alone PV system working year around is modeled in RET Screen international software using power project model algorithms.Load characteristics of system designed for current study are described in Fig 2.

For providing backup that will provide power in non-sunny time, 12V Ni-CD battery bank is designed for one day of autonomy with 80% suggested maximum depth of battery discharge. Financial case study parameters like economic determinants are of importance that influence the viability of a project with passage of time largely. Among economic determinants; fuel cost escalation rate in Pakistan is 4.10% [11], inflation rate is 7.75% [11] and discount rate has been

Description	AC/DC	Intermittent resource-load correlation	Base case load	Hours of use per day h/d	Days of use per week d/w
4 Lights	AC	Zero	160.00	10.00	7
2 Fans	AC	Zero	200.00	13.00	7
1 TV	AC	Zero	140.00	6.00	7
			500.00		

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh	0.00	0.00
Electricity - daily - AC	kWh	5.04	5.04
Electricity - annual - DC	Mwh	0.000	0.000
Electricity - annual - AC	Mwh	1.840	1.840

Fig 2: Load characteristics

raised to 9.5% [11, 12] according to State Bank of Pakistan report. Case study input parameters used for current study are mentioned in Table 3.

Table 3: Case study input parameters

Factor	Value
Days of autonomy	1 Day
Battery voltage	12.0 V
Maximum battery depth of discharge	80%
Temperature control method	Ambient
Solar tracking mode	Fixed
PV panel cost	120PKR/Watt
Fuel Cost Escalation Rate	4.10%
Inflation Rate	7.75%
Discount Rate	9.5%

The parameters assumed for modeling stand-alone PV system are;

- Slope of PV array [13] is assumed equal to absolute value of latitude of location as stand-alone system is modeled working year-round.
- Base case power technology assumed is reciprocating engine as more than 50% of electric load is supplied from thermal power stations.

Results and Discussion

Technical Analysis

Modeled stand-alone PV system is analyzed in terms of number of PV module units required to deliver 100% electrical load that directly corresponds to solar irradiance condition of location. Analysis shows that five PV module units system, designed on the basis of 5.04kWh-AC daily electricity demand, provides 1.95MWH (106.0%)electricity annually in Karachi. While in Lahore and Islamabad cities, six PV module units are required to design stand-alone PV system, on the basis of daily electricity demand equals to 5.04 kWh-AC, that produce 1.98MWh (107.6%) and 1.85MWh (100.6%) annual electric power respectively as depicted in Fig 3. Difference in number of PV module units required for delivering 100% power to load and in electricity output is mainly due to varying solar irradiance conditions from location to location. As solar irradiance value in Karachi is highest thus number of units required to deliver 100% load power are less than other cities. For Lahore and Islamabad, number of units required to fulfill 100% power demand are same but resultant solar fraction value is in accordance with solar irradiance value. That's why in Lahore resultant solar fraction value of six PV units is 107.6% while in Islamabad this value is 100.6%. Under current circumstances, Karachi is technically the most feasible location for stand-alone PV system application among these three major cities of Pakistan.

Economic Analysis

Economic analysis of a project speaks in terms of project feasibility on the basis of NPV, IRR, payback period and benefit-cost ratio [14]. Among economic determinants, NPV and IRR are of major concern according toeconomist's point of view. If NPV of project is positive, it is indication of project being feasible [14]. In terms of IRR, rate value should be greater than discount rate for declaring project viable [14].

Financial viability of modeled stand-alone PV system based on NPV and IRR is depicted in Figure 4. Analysis shows that Karachi is economically the most feasible location in comparison with Lahore and Islamabad while Lahore and Islamabad show same economic feasibility. Because in Karachi, less number of PV units are required to deliver 100% power load than in Lahore and Islamabad and consequently modelled PV system installation cost is minimum for Karachi region among these three cities. Overall, all locations are feasible having positive NPV and greater than discount rate IRR value.

Payback period is an important economic determinant with respect to investor's point of view and benefit-cost ratio is used in corporate finance sector. Simple and equity payback periods of modeled stand-alone PV system are depicted in Figure 5. Payback periods favor Karachicity as the most suitable location for installation of stand-alone PV system in comparison with Lahore and Islamabad,while Lahore and Islamabad show same feasibility for modeled system application. The reason is; modelled system installation cost in Karachi is least that's why payback period is shorter in comparison with Lahore and Islamabad cities. Same trend is analyzed regarding benefit-cost ratio (as shown in Figure 6) while evaluating the viability of modeled stand-alone PV system.

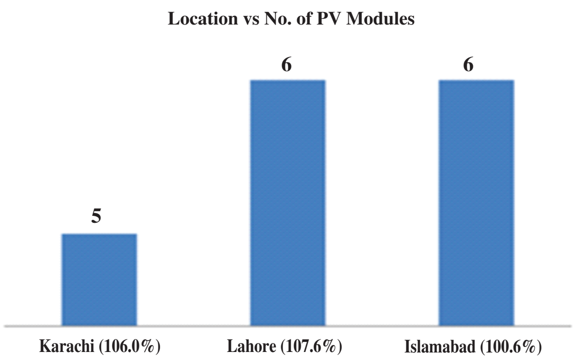

Fig 3: Project location vs number of PV modules required

Overall, all of three cities are suitable for modeled stand-alone PV system installation having payback period value even less than the half of the projected 20 years project life and greater than one benefit cost ratio [13] for all cases.

Environmental Analysis

GHG emissions remained the most concerned issue during last decade and still world is worried about it a lot. That's why many protocols and standards are developed to control the emissions. PV technology introduction leads towards reduction in fossil fuel combustion that ultimately would result in GHG emissions reduction. Installation of a modeled stand-alone PV system would result in 2.9-3.0tCO_2 net annual GHG emission reduction in all of three cities that's equivalent 6.7 barrels of crude oil being not used.

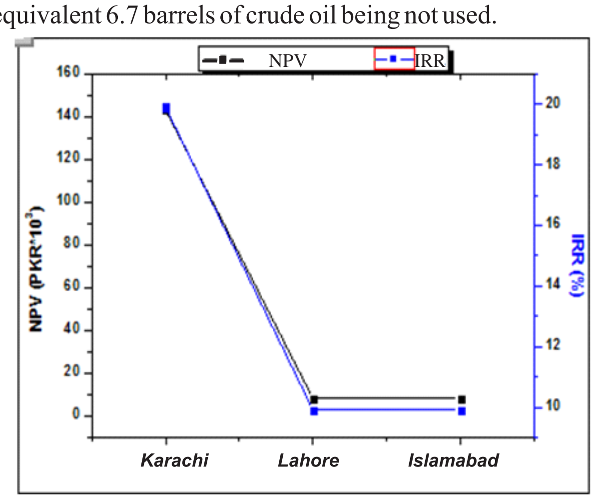

Fig 4: NPV and IRR of stand-alone PV system

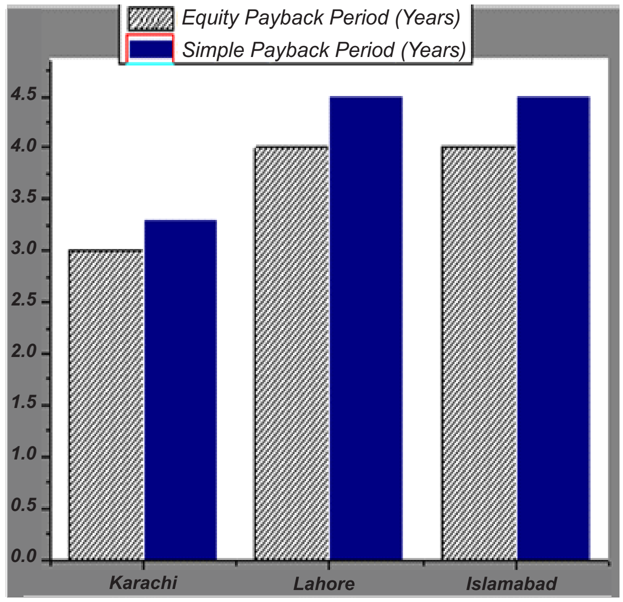

Fig 5: Equity and simple payback periods of stand-alone PV system

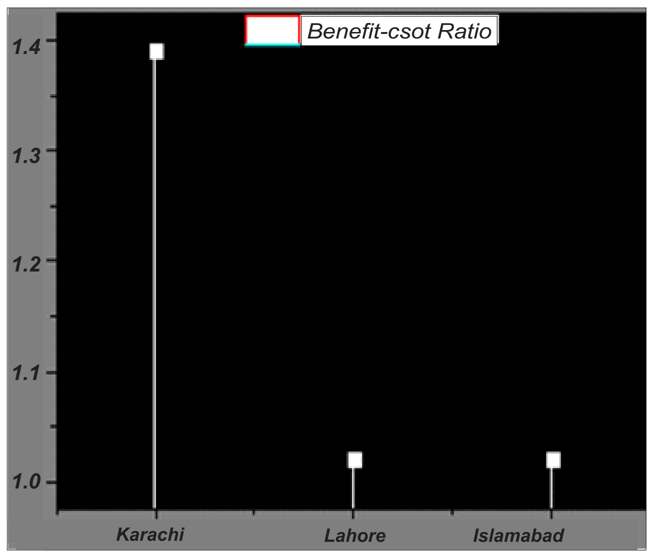

Fig 6: Benefit-cost ratios of stand-alone PV system.

$_t$	Clearness index
$_r$	Nominal efficiency
$_c$	Module temperature
$_a$	Ambient temperature
$_r$	Reference temperature
$_{inv}$	Inverter efficiency
NOCT	Nominal operating cell temperature
β	Temperature coefficient for module efficiency

Conclusions

Stand-alone PV system is modelled in RETScreen software for three major cities occupying different geographical locations on Pakistan map. Comparative analysis reveals that modelled stand-alone PV system application is more viable in Karachi city than Lahore and Islamabad. Overall, all of three cities are feasible for modelled PV system application economically and technically.

Results reveal that viability of PV technology application in certain region is function of solar irradiance condition prevailing there. Higher the value of solar radiations falling on surface is, larger the potential of PV technology implementation would be. Installation of a modeled stand-alone PV system will result in 1.85-2.0MWh electric powersavings per home annually in terms of diesel oil being combusted to provide base case power. Reduced combustion of diesel oil would also be helpful in reducing GHG emissions. Installation of a modelled 5kW stand-alone PV system will lead to 2.9-3.0tCO_2 net annual GHG emissions reduction. Hence, these types of projects are need of time especially for Pakistan like countries to stabilize the energy sector situation and to promote green growth.

References

1. V. Applasamy, "Cost evaluation of stand-alone residential photovoltaic power system in Malaysia", IEEE-Xplore Proceedings of IEEE Symposium on Business, Engineering and Industrial Applications (ISBEIA), Langkawi, Malaysia, 2011, pp. 214-218.
2. K. Harijan, M.A. Uqaili and M. Memon, "Renewable energy for managing energy crisis in Pakistan", Wireless Networks, Information Processing and Systems, Vol. 20, 2009, pp. 449-455.
3. A. Khalid and H. Junaidi, "Study of economic viability of photovoltaic electric power for Quetta-Pakistan", Renewable Energy, Vol. 50, Feb 2013, pp. 253-258.
4. S. Stevanovic and M. Pucar, "Financial measures Serbia should offer for solar water heating systems", Energy and Buildings, Vol. 54, 2012, pp. 519-526.
5. S. Rehman, M. A. Bader and S. A. Al-Moallem, "Cost of solar energy generated using PV panels", Renewable and Sustainable Energy Reviews, Vol. 11, 2007, pp. 1842-1857.
6. M. Asif, "Sustainable energy option for Pakistan", Renewable and Sustainable Energy Reviews, Vol. 13(4), 2009, pp. 903-909.
7. A. Mehmood, A. Wasy, A. Waqas and J. I. Song, "Development and computational flow analysis of GSM based automated solar water pump",Proceedings of 9th International Conference on Fracture and Strength and Solids, Jeju, Republic of Korea, June 2013.pp.281.
8. F. Iacobescu and V. Badescu, "The potential of the local administration as drivingforce for the implementation of the national PV systems strategy in Romania", Renewable Energy, Vol. 38, 2011, pp. 117-125.
9. A.H. Mirzahosseini and T. Taheri, "Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran", Renewable and Sustainable Energy Reviews, Vol. 16, 2012, pp. 2806-2811.
10. D.L.Evans, "Simplified method for predicting photovoltaic array output",Solar Energy, Vol. 27, No. 6, 1981, pp. 555–560.
11. Govt. of Pakistan Statistics Division, Pakistan Bureau of Statistics, "Press release on inflation rate",2013. http:www.pbs.gov.pk/
12. State Bank of Pakistan, "Monitory Policy Statement", Sep2013.
13. A. Walker,"Solar Water Heating", Whole Build. Des. Guid. 2012.
14. R.ABrealey, S.C. Myers,"Principles of corporate finance", 6th Edition, Irwin McGraw-Hill, 2008.