Modeling of the Solar Photovoltaic Systems to Fulfill the Energy Demand of the Domestic Sector of Pakistan using RETSCREEN Software

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***Abstract*--Pakistan is facing severe energy crisis even having a great potential of renewable energy resourcesespecially solar energy.Pakistan has~2.9 million MW potential of electricity generation using solar energy (PV) which is hardly exploited. Current articleis focused to analyze the implementation of solar photovoltaic for the domestic sector of Pakistan where blackouts of 6 to 7 hours are common. Current study is conducted for six major cities of Pakistan named Karachi, Islamabad, Lahore, Multan, Quetta and Peshawar occupying different climatic and geographical positionsusing RETSCREEN software. Weather information of these cities is imported from RETSCREEN software database reported by NASA. The role of solar irradiance and load correlation with respect to ambient conditions is compared and resultant solar fraction is observed.Modeling work is evaluated on the basis of NPV, IRR, payback periods and GHG emissions reduction obtained for pointing out the feasibility of solar PV implementation leading towards green growth of Pakistan.Results indicate that implementation of a 5kW standalone solar PV system will result in 0.6-0.7tCO_2 reductions in GHG emissions in different regions of Pakistan under prevailing climatic conditions. Installation of solar PV systems will contribute largely in sharing power loadthat will lead to improved energy situation and reduced environmental emissions concerns in the country.**

***Keywords:* Greenhouse gas, RETSCREEN, Renewable energy, solar photovoltaic.**

I. ABBREVIATIONS

PV	Photovoltaic
DC	Direct Current
GHG	Greenhouse Gas
NPV	Net Present Value
AC	Alternating Current
IRR	Internal Rate of Return
NASA	National Aeronautics and Space Administration
K_t	Clearness index
η_r	Nominal efficiency
T_c	Module temperature
T_a	Ambient temperature
T_r	Reference temperature
η_{inv}	Inverter efficiency
$NOCT$	Nominal operating cell temperature
β	Temperature coefficient for module efficiency

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II. INTRODUCTION

The word energy is central cohesive source behind all activities ofuniverse. Nature has gifted this universe with several non-replenishable energy resources that are enough to accomplish energy requirements of the world but the need of time is to explore them for efficient utilization. Energy is considered a key factor in the development of any country. The significance of energy in economic development has been recognized almost universally and recent studies have shown a strong relationship between the availability of energy and positive economic activity[1]. Developing and the emerging economies of the world are facing the dual energy challenge in the current century: Meeting the needs of billions of people who still lack access to life line energy while at the same time participating in a global transition to clean and environment friendly energy systems.According to International Energy Agency report, there would be 53% increase in global primary energy consumption up to 2030 and 70% of this value is expected to come from developing nations[2].As concerned with global transition to clean energy resources utilization; fossil fuels contribute 85-90% to world primary energy supply [3]. GHG emissions due to incomplete combustion of these high carbon content fossil fuels are main drive behind climatic changes. World Health Organization (WHO) reported that about 1.6 million people die each year due to climatic changes and this number could double by 2020 [4].To counter with energy and environmental issues, the whole world is searching for clean and environment friendly renewable energy resources. Although renewable energy resources can't replace the fossil fuel technologies but can serve as an add on to fulfill the energy needs to a substantial level [5].Pakistan isenergy deficient nation facing severe blackout problems due to~4GW [6]electricity deficit between supply and demandeven though Pakistan has indefinite potential of renewable energy resources[7] like solar, wind, hydro, biomass etc. Especially nature has gifted Pakistan with a location on world map where solar insolations are among highest [8].There are regions of southern Punjab, Sindh and Balochistan on Pakistan map where solar irradiance value ranges from 1500W/m^2/day to 2750W/m^2/day for a 10h-day throughout the economic year [9]. It is evident that Pakistan has solar PV potential of producing 45-83MW electric power/month from solar radiations falling over 100m^{2}area in certain southern Punjab, Sindh and Balochistan cities[9]. Fig.1 shows the solar map of Pakistan developed by NREL and USAID [6] [10].

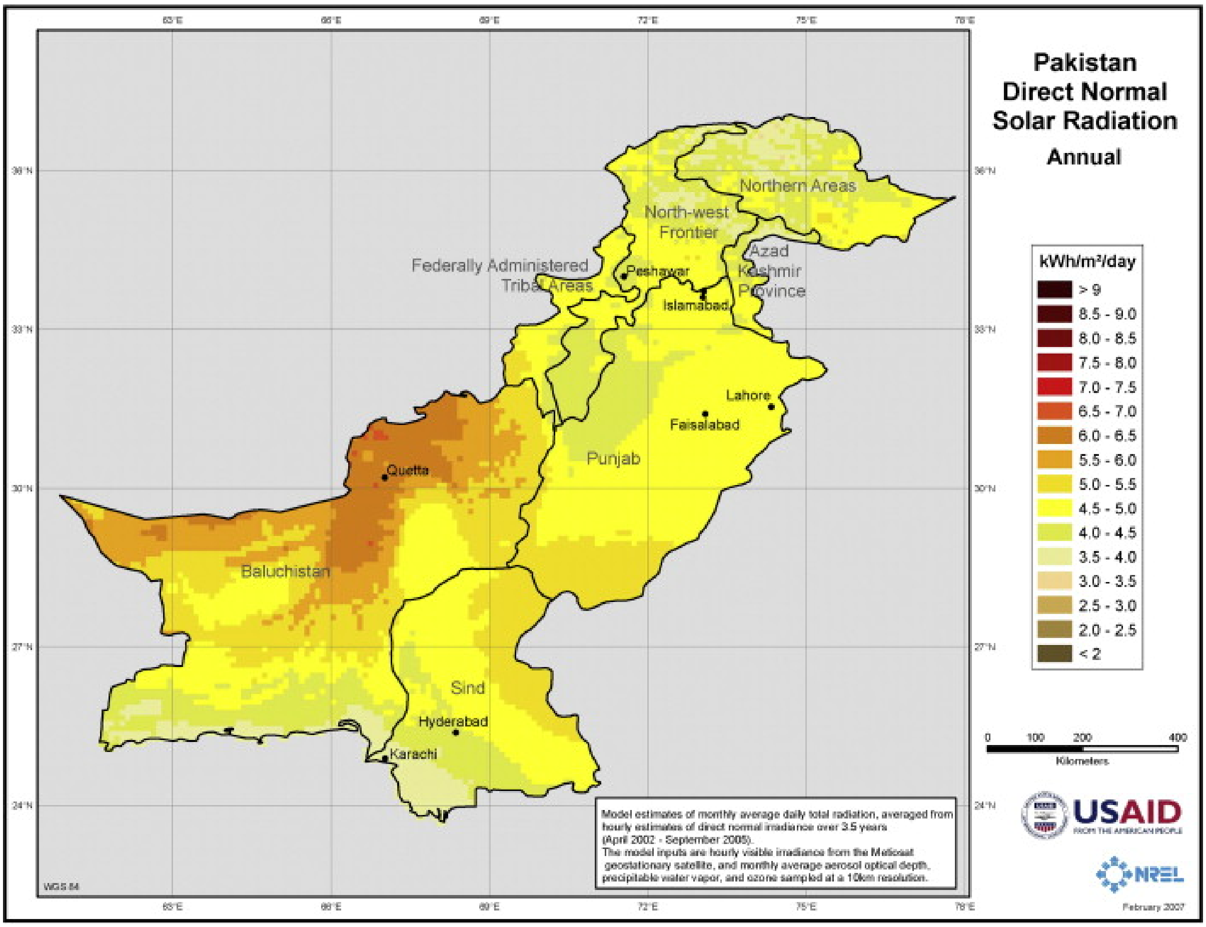

Fig. 1. Pakistan Solar Map [6], [10]

PV technology is a proven sourcefor harnessing solar irradiance in from of electricity [11] to meet future energy challenges as PV is among fastest growing industries across the world [12]. PV technology is being used efficiently in the remote areas, telecommunication towers, water pumping for irrigation, off-grid cottage/s, highway telephones, cathodic protection on pipelines, municipal park lighting, utility peak load shaving, exterior home lighting and many other usages[11]. Life cycle performance of PV array is largely affected by solar irradiance value [13] falling on array aperture area, corresponding operating temperature and azimuth angle [14].

In the current study, standalone PV system is analyzed for different climatic conditions of Pakistan to fulfill domestic energy needs. RETScreen software is used to model 5kW standalone PV solar system for Karachi, Islamabad, Lahore, Multan, Quetta and Peshawar. Modeled system viability is evaluated on the basis of economic determinants like NPV, IRR, equity payback period and simple payback period. Technical parameters like role of solar irradiance and resultant solar fraction are also observed. Software calculations also reveal that how much base case electric power load reduction is possible and how much GHG emissions can be reduced leading towards green growth of Pakistan?

III. MODELING METHODOLOGY

A. RETScreen Software

RETScreen international software is an excel based clean energy project analysis tool developed by Natural Resources Canada's CANMET Energy Diversification Research Laboratory (CEDRL)[15] known as Canadian Energy Center. It helps decision makers in evaluating the feasibility of certain energy project potential for implementation quickly and inexpensively. Software has incorporated all different type of energy especially renewable energy related details. Software algorithms can calculate technical, economic and environmental viability of different renewable energy, energy efficiency and cogeneration projects[15], [16] in terms of resultant solar fraction, NPV, IRR, payback periods, GHG emissions reduction and backup fuel savings[16].

B. Climatic Conditions of Selected Cities

RETScreen software developers embedded climatic and geographical conditions of almost all cities of world map reported by NASA. Solar irradiance is main attribute among climatic conditions of certain site that directly corresponds to life cycle performance of PV system.That's why selection of certain location for renewable energy system installation is an important consideration in terms of its climatic conditions and geographical information. Cities of Pakistan selected for current study are Karachi, Islamabad, Lahore, Multan, Quetta and Peshawar occupying different geographical locations and corresponding climatic conditions as shown on Pakistan map in Fig.3[17].Climatic and geological information of selected sites are mentioned in Table I.

Fig. 2. Standalone PV Model Locations Selected for Current Study[17]

TABLE.I
CLIMATE INFORMATION OF STANDALONE PV MODEL SITES IN PAKISTAN

Ambient data/ Location	**Climatic information of location**					
	Karachi	**Islamabad**	**Lahore**	Multan	**Quetta**	**Peshawar**
Latitude	24.9ºN	33.6ºN	31.5ºN	30.2ºN	30.3ºN	34.0ºN
Longitude	67.1ºE	73.1ºE	74.4ºE	71.4ºE	66.9ºE	71.5ºE
Ambient temperature (Annual)	26.1ºC	21.6ºC	24.4ºC	25.3ºC	18.0ºC	22.7ºC
Daily solar radiations- horizontal (Annual)	5.34 kWh/m^2/d	4.02 kWh/m^2/d	4.68 kWh/m^2/d	5.09 kWh/m^2/d	5.46 kWh/m^2/d	5.16 kWh/m^2/d
Wind Speed (Annual)	3.5 m/s	2.4 m/s	2.1 m/s	3.3 m/s	4.5 m/s	5.0 m/s
Heating Degree-Days	0ºC-d	659ºC-d	352ºC-d	358ºC-d	1,346ºC-d	555ºC-d
Cooling Degree-Days	5,861ºC-d	4,236ºC-d	5, 240ºC-d	5,571ºC-d	3,229ºC-d	4,644ºC-d

Purpose of current work is to study the viability of RETScreen modeled standalone PV system in different feasibleclimatic and geographical conditions. That's why cities pointed on Pakistan map in Fig.2 are selected as climatic conditions also show thatsolar irradiance value ranges from 4.02-5.46 kWh/m^2/d in these cities. Cooling degree-days also support these cities for standalone PV system application with respect to corresponding number of degree-days, not equally for all sites.

C. PV Array Technology

RETScreen software can simulate a PV system for different PV technologies like mono-Si, poly-Si, a-Si, CdTe, CIS and spherical-Si. A number of PV models fabricated by different manufacturers along with their characteristic parameters like optimum efficiency, nominal output temperature and solar collector area are integrated in software database. PV models represented in RETScreen software database are based on Evans [18] work, characterized by its optimum efficiency (η_p) parameter is calculated by (1);

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

And Evan's formula[18] relates module temperature (T_c) and mean monthly ambient temperature (T_a) as;

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

For current study, a mono-Si PV model is selected on the basis of its parametric characteristics and ease of availability. Characteristics features of selected model are mentioned in Table II.

TABLE.II
PARAMETRIC CHARACTERISTICS OF SELECTED PV MODEL

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

D. Standalone PV Model

Standalone PV model represents off-grid system. In such a system, output energy of PV array can be utilized in two possible ways; either directly through charge controller/battery if connected load is DC or indirectly via battery-inverter setup in case of AC loads. Basic standalone PV system configuration is shown inFig.3.

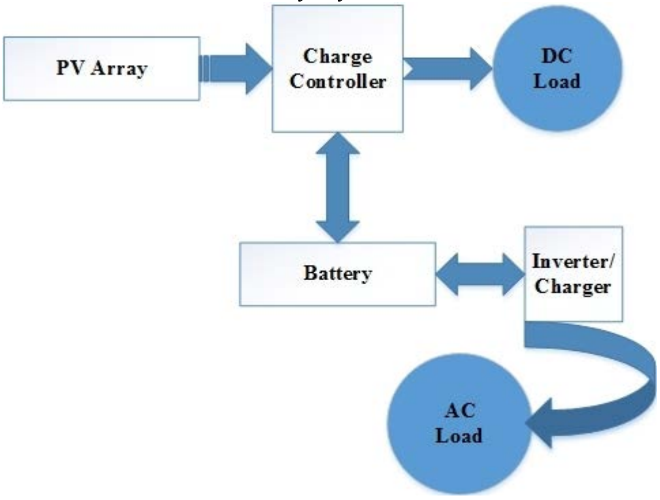

Fig. 3. Standalone PV Model Configuration

E. RETScreen Simulations

RETScreen software pays substantial attention to intermittent resource-load correlation. User specifies the load and its type either DC or AC, which is latter converted into total equivalent DC demand (D) by software algorithms using following formula[15];

$$D_{DC,equ} = D_{DC} + \frac{D_{AC}}{\eta_{inv}} \qquad (3)$$

This total equivalent DC demand is broken down into three parts[15] as;

$$D_{Dc,equ} = D_{match} + D_{cont.} + D_{bat} \qquad (4)$$

Among these three parts of total demand;

- D_{match} part of demand has positive intermittent resource-load correlation
- $D_{cont.}$ corresponds to steady load having zero intermittent resource-load correlation
- D_{bat} is part of demand having negative intermittent resource-load correlation

For current case study, load characteristics are estimated to shift the basic loads, which are part of almost every house, from grid connected electric power to standalone PV system. Load characteristics of current case study for which standalone PV system is modeled are shown in Fig.4.

For shifting load from grid connected to standalone PV system, 12V Ni-Cd battery bank with one day of autonomy is used to provide backup during non-sunny time with 80% maximum suggested depth of discharge. Among case study inputs, financial parameters like fuel cost escalation rate, inflation rate and discount rate are most important that play a significant role in making a certain system feasible or not. In Pakistan, fuel cost escalation rate is 4.10% [19], inflation rate has become 7.75% [19] while discount rate has been raised by State Bank of Pakistan up to 9.5% [19], [20]. Basic case study inputs used for modeling standalone PV system in RETScreen software are mentioned in Table III.

Description	AC/DC	Intermittent resource-load correlation	Base case load W	Hours of use per day h/d	Days of use per week d/w
4 Light	AC	Zero	160.00	10.00	7
2 Fan	AC	Zero	200.00	13.00	7
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

Fig. 4. Load Characteristics

TABLE III
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%

There are two main parameters assumed while modeling standalone PV system for domestic users;

- Base case power source is grid connected electricity
- Slope of PV module is assumed equal to absolute value of latitude of location for maximizing the solar irradiance value as system is modeled working year-round.

IV. RESULTS AND DISCUSSION

RETScreen software has been developed to figure out the viability of a system in terms of its technical parameters (like number of PV units used and correspondingpower delivered to load), economic determinants (i.e. NPV, IRR, equity and simple payback periods) and environmental constraints (like GHG emissions reduction). RETScreen outcomes are elaborated in three approaches;

- Technical Analysis
- Economic Analysis
- Emissions Analysis

A. Technical Analysis

In financial terms, technical analysis is a security analysis methodology of observing the changes in past prices with aim of forecasting future price and volume [21]. But in engineering terms, technical analysis deals with parameters of product upon which the efficiency and efficient utilization depends. For standalone PV system's technical analysis, number of PV units required for attaining 100% power capacity and resultant total power delivered to load are analyzed.

Results show that two PV units provide more than required 100% power capacity but total power delivered to load is different for all cities as shown in Fig.5 becauseof difference in solar irradiance value. Thus Output power delivered to load is function of solar irradiance value in corresponding region. Results elaborated inFig.6 depict that higher the value of solar radiations falling on surface, greater the output power of PV system would be.

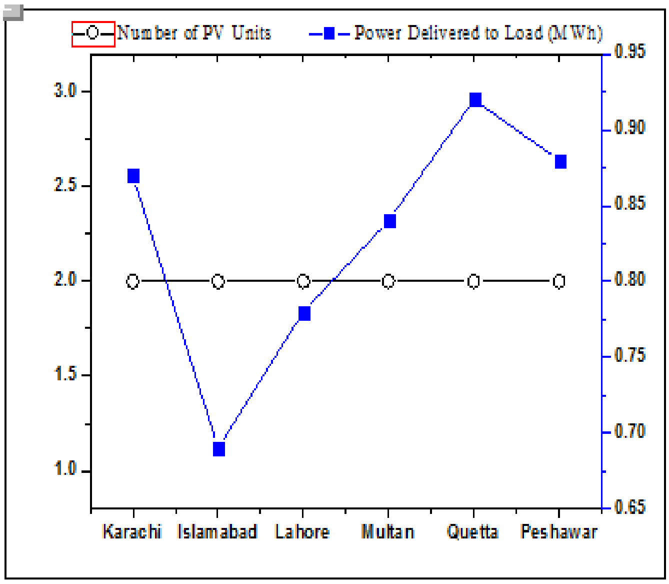

Fig. 5. Number of PV units vs Power Delivered to Load

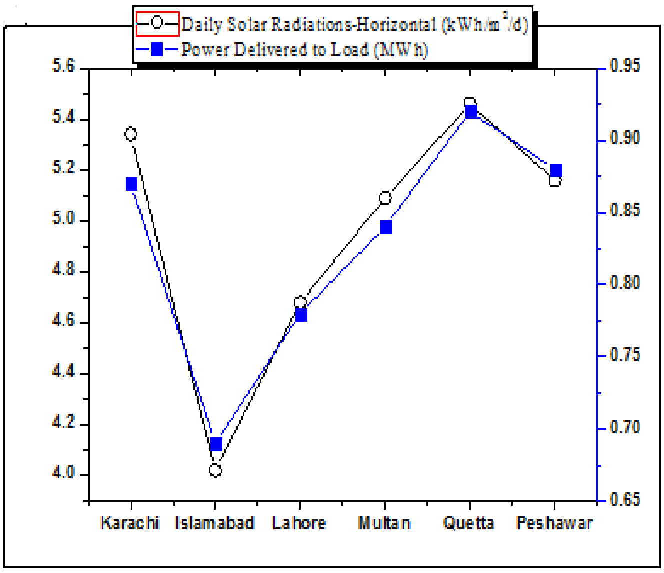

Fig. 6. Daily Solar Radiations-Horizontal vs Power Delivered to Load

B. *Economic Analysis*

Economics deals with production of goods, their distribution and consumer's response. Economics of a certain project can be evaluated on the basis of economic determinants like NPV, IRR, equity and simple payback periods.

NPV and IRR

Economic performance of a project can be visualized on the basis of its NPV and IRR. Among these two economic determinants NPV is preferable criteria accounts for time value of coming cash flows subsidized at certain discount rate[22], can be calculated using (5)[22].

$$-CF_0 + \Sigma_{i=1}^{t}[\frac{CF_i}{(1+r)^i}] = NPV \qquad (5)$$

IRR is form of return rate that makes NPV of project equal to zero, can be calculated by modifying (5) as [22];

$$-CF_0 + \Sigma_{i=1}^{t}[\frac{CF_i}{(1+r)^i}] = NPV = 0 \qquad (6)$$

Where; i= 1, 2, 3,….,t

Fig.7 showsNPV and IRR of standalone PV model. NPV and IRR show same trend for all cities selected for currentstudy. Both economic determinants favors the Quetta city the most while Islamabad least for standalone PV system application. If we see overall behavior of NPV and IRR for all cities, these curves are in accordance with daily solar radiations curve of Fig.6. This means that higher solar irradince value is causality engine behind larger NPV and IRR, making an energy project more feasible.

From individual city point of view, installation of modeled standalone PV system is feasible for all cities as NPV is positive and IRR is greater than discount rate for all selected cities.

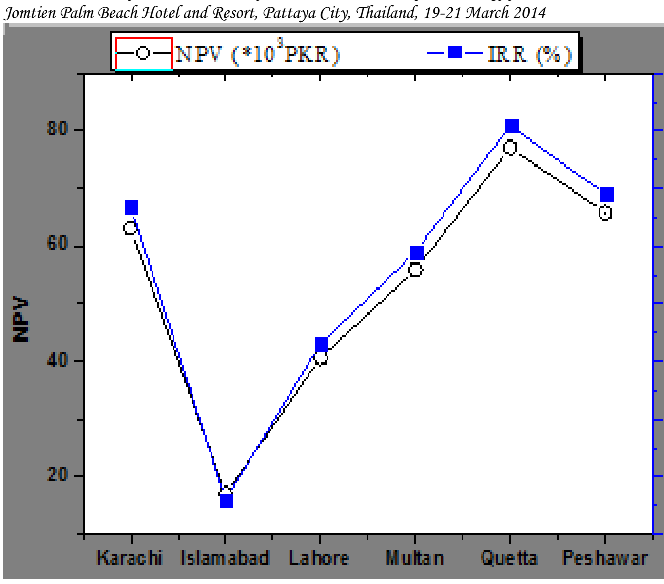

Fig. 7. NPV and IRR Interpretation

<u>*Payback Period*</u>

Payback period is an important economic determinant with investor's point of view. Payback period of any project can be calculated by using a simple mathematical relation [23];

Payback Period= Cost of Project / Annual Cash flows (7)

Fig.8 depicts the equity payback and simple back period values for modelled standalone PV system application. Analysis favours Quetta city the most while Islamabad least. As a whole, both parameters show same comparative feasibility trend as NPV and IRR show for selected cites of Pakistan. Software outcomes also reveal that greater the value of daily solar radiations falling on surface, lesser the payback period is. From individual city perspective, payback period values for all cities are much smaller, even less the half of suggested project life that is 25 years.

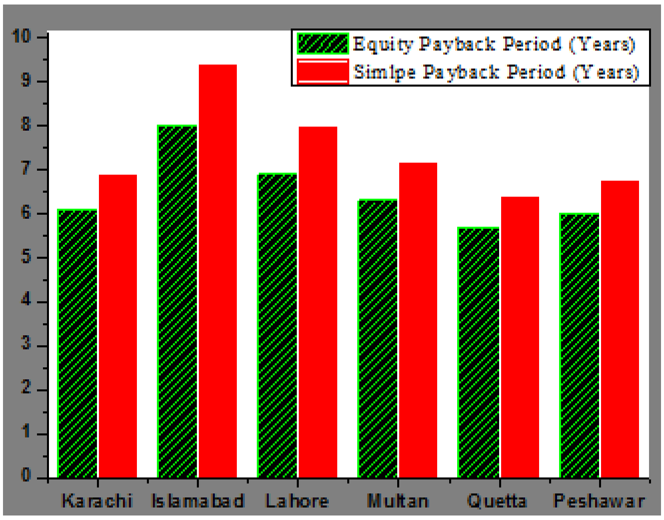

Fig. 8. Payback Periods Interpretation of Standalone PV Model

C. *Emissions Analysis:*

GHG emissions are main drive of global warming effect that is causing serious health issues and even deaths of thousands of people every year. Main source behind GHG emissions is incomplete combustion of high carbon content fossil fuels. That's why the whole world is searching for clean and environment friendly energy sources and in this perspective many protocols have also been set to control emissions.

Fig. 9 depicts net GHG emissions reduction possible through installation of single modeled standalone PV system in selected cities of Pakistan. Fig.10 elaborates detail emissions analysis and reveals CO_2, CH_4, N_2O emissions reduction factor in net GHG emissions reduced. Analysis shows that installation of standalone PV system,one in each of six selected cities of Pakistan, will lead to 3.8 tCO_2 emissionsreduction. Detailed emissions analysis curves in Fig.10 also depict that installation of standalone PV system in a region with higher solar irradiance value would result in larger emissions reduction value.

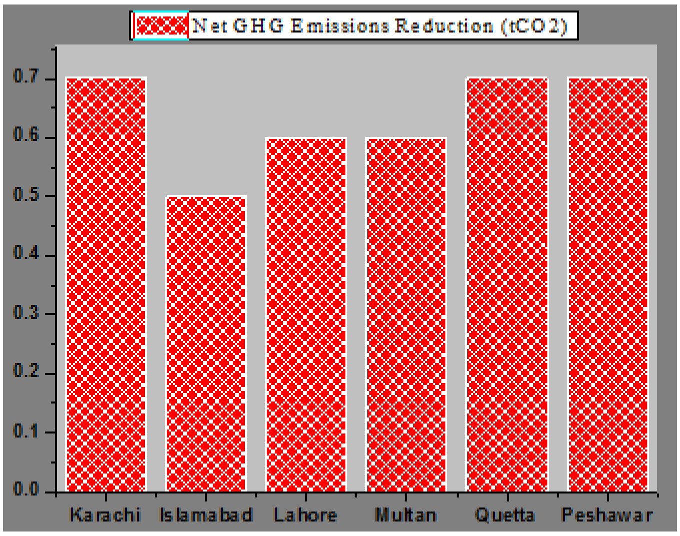

Fig. 9. Net GHG Emissions Reduction

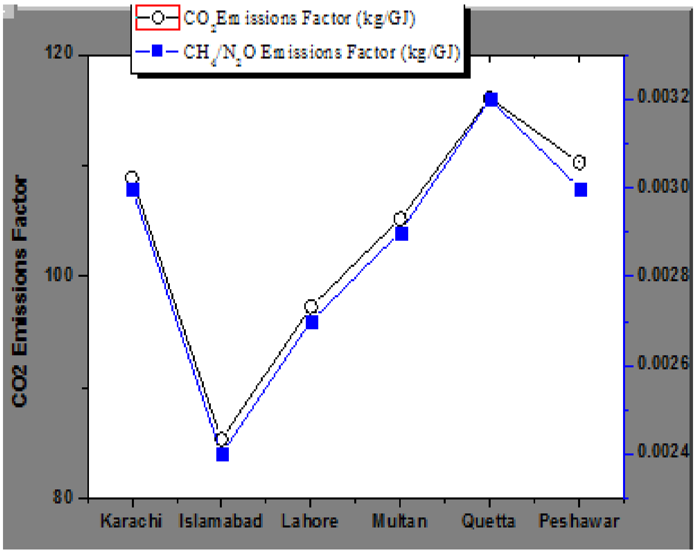

Fig. 10. Detail Emissions Analysis

V. CONCLUSION

A standalone PV system is analyzed using RETScreen software for six major cities of Pakistan having different climatic conditions and geographical location. Techno-economic evaluation of modeled system is performedin terms of project resultant solar fraction, power delivered to load, NPV, IRR, equity and simple payback periods. Emissionsanalysis is also carried out. Analysis shows that installation of standalone PV system is feasible for all selected cities. But on comparative basis, Quetta city is most feasible location while Islamabad capital is least one.

Results also reveal that feasibility of PV technology for a certain region is function of solar irradiance value. Higher the value of solar radiations falling on surface is, larger the potential of PV technology implementation would be. Replacement of fossil fuels with PV technology will also lead towards GHG emissions reduction. So, PV system application will be helpful in tackling the energy crisis of country and will provide great relief to domestic users from power load-shedding problem. On other hand, PV technology will also be helpful in green growth of Pakistan.

VI. RECOMMENDATIONS

PV technology utilization for various purposes can be made more efficient by using maximum power point tracker (MPPT). MPPT will be helpful in increasing the solar fraction value of system and will also provide economic benefit in terms of reducing number of PV units required to fulfill energy needs.

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