`

SOLAR ENERGY RESOURCE MAPPING, SITE SUITABILITY AND TECHNOECONOMIC FEASIBILITY ANALYSIS FOR UTILITY SCALE PHOTOVOLTAIC POWER PLANT IN AFGHANISTAN

By

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DEDICATION

This study is dedicated to my humble and loving parents and family whose tireless efforts and sacrifice made possible to reach this goal.

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LIST OF ABBREIVATION

GHI	Global Horizontal Irradiance
LULC	Land Use and Land Cover
WSA	Water Stress Area
PA	Protected Area
MCDM	Multi Criteria Decision Making
AHP	Analytical Hierarchy Process
LCOE	Levelized Cost of Electricity
CF	Capacity Factor
IRR	Internal Rate of Return
NPV	Net Present Value
PBP	Pay Back Period
GHG	Green House Gas
IPPC	Intergovernmental Panel on Climate Change
T2	Temperature at two-meters height

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ABSTRACT

For deployment of solar power plant, it is essential to identify suitable and feasible location for plant installation. Suitability and economic feasibility analysis incorporating meteorological, land use, technoeconomic and environmental parameters. in this study at first viability of Global Horizontal Irradiance (GHI), temperature and wind speed datasets of Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2) are investigated at different location and timestamps across the study area, Global Horizontal Irradiance and temperature highly correlate >95% with ground data whereas wind speed show weak correlation, after the validation, annual Global Horizontal Irradiance map is generated for Afghanistan from MERRA-2 re-analysis monthly averaged data, its concluded that 100 % of land area has solar radiation greater than cut-off limit (1400 KWh/m2/year), high solar resource potential is available in south and south-eastern and south-western regions of the country.

The most suitable sites for photovoltaic (PV) power plants installation are determined in the country based on Multi Criteria Decision Making (MCDM), Analytical Hierarchy Process (AHP) method integrated with Geographic Information System (GIS) tool, incorporating levelized cost of electricity, land use and land cover, road network, transmission lines, protected area, and water stress area. Result map demonstrating that the high suitable sites are located near the transmission lines where solar radiation is high, and temperature is relatively low.

Techno-economic feasibility assessment is performed for 50MW power plant in selected point in the central province of Bamayan - Afghanistan constituting highly suitable site, different mounting systems including fixed tilt, single axis and dual axis and two types of panels materials poly crystalline silicon and mono crystalline silicon are investigated, the result is showing that all combination are economically feasible and deploying single axis polycrystalline silicon system is most financially acceptable and economically profitable option.

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CHAPTER 1

INTRODUCTION

1.1 Background

Rapid urbanization, intensive growth of population, and globalization of the economy have created the most critical challenges for human beings [1]. Energy either it's generated from (fossil fuel or renewable) is the primary and essential need for industries and life, electricity, as the core component of the energy is the most important requisite for the socioeconomic development of a country. The world population will reach by 7.9 to 13.1 billion people at the end of this century [1]. Due to growth of population and welfare increase would more intensify the amount of energy utilization, currently 771 million people are living without electricity in developing countries [2]. meanwhile critical growth of energy demand is the most critical problem of the world in recent decades [3].

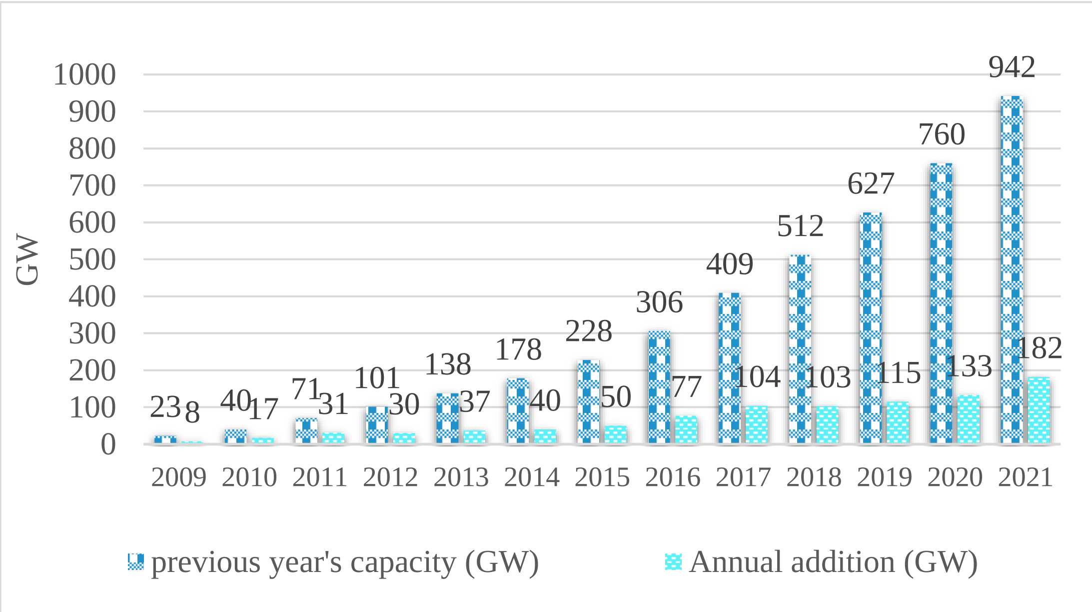
On the other hand, climate change and global warming, due to high utilization of fossil fuel, which emits tons of greenhouse gases into atmosphere and cause the warming of globe are the global problems, to mitigate the climate change crisis shift to Renewable energy (RE) technologies are the best solution for these worldwide challenges [4] [5]. That's why most of the countries fucus to generate energy from this environmentally friend resources to maintain their economic development and keep environment safe [5]. In the previous decades, solar energy development and utilization have been increased than other kinds of renewable energies technologies, including wind, biomass and geothermal [6]. Because solar energy serves a crucial function in the mitigation of global warming and reaching energy independence [5]. That's why it's necessary to identify the viable place for solar energy plants deployment [5]. To select the most viable location for solar power plant it needs some factors to be incorporated in site suitability study for sound location [5].

Afghanistan is considered as one of the high resource countries that has high capacity to generate solar energy in the world as it is located on the sun belt and has 300 sunny days in a year [7]. The production of power from solar resources makes good opportunity to bring off Afghanistan's long-term sustainability initiatives include increased geopolitical stability, a clean environment, and technological economic development[8]. The benefits of solar energy include improving energy security, scalability, no need for big infrastructure for panel and plant supporting, and it is availability in remote areas [8]. Photovoltaic (PV) system is one of the essential solar energy technologies as it does not include moving parts, that's why it requires less maintenance, has a long lifecycle, and does not cause water or air pollutions [8]. The energy production of PV technology depends on Global Horizontal Irradiance, these photovoltaic panels convert the solar radiation based on photoelectric effect directly into electricity [8]. Solar photovoltaic energy generation not only depends on level of solar radiations, but it is affected by PV cell heat tolerance capacity, cell conversion efficiency, temperature, relative humidity, and weather change [9], [10].

1.2. Global Photovoltaic installation capacity

In 2021 the amount of energy produced by solar photovoltaic has made 5% of total energy generation in the world and this percentage tends to reach 27% in 2032 [11]. In the previous decade, solar PV technology demand has been expanded and it became useful and a competitive option for electricity harnessing in some countries. Meanwhile, deployed capacity has risen remarkably due to the high availability of free solar resource potential and lowering prices of photovoltaic (PV) panels. 20% increase occurred in the solar PV market and generated amount of install capacity is still going upward in the world and reach 175 GW in 2021, and the total global solar PV deployed capacity became of around 942 GW [12], [13]. Table1 shows the evaluation of PV installed plant in the world from 2010 to 2021 [13].

Table 1. Evaluation of global PV installation from2009 to 2021



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1.3. Afghanistan energy scenario

A big challenge for feasible site selection of PV power plants is lacking accurate datasets, because station data is very restricted in the globe and very less stations are available in developing countries, like in Afghanistan where we had six meteorological stations in 2012 which had been installed by The RNED (Renewable Energy Department) and ACEP (Afghan Clean Energy Program) and in Parwan ,Balkh, Kabul, and Herat provinces after the evolution and regime change in the country these observed data are lost [14][15]. Solar PV power plant installation mainly depend upon GHI and affected by Temperature, wind speed and relative humidity, that the station data is not sufficient we use satellite and Reanalysis data sets which provide data for longer duration and cover all our study area, even its accuracy wouldn't be much high due to high spatial resolution. Meteorological data cover the whole world provided by Modern-Era Retrospective analysis for Research and Applications (MERRA-2) have been evaluated and used for PV site suitability assessment purposes worldwide were used this study [16],[17]. A detailed evaluation of the correctness and viability of MERRA-2 products is an essential and very important for their application in site suitability analysis for solar photovoltaic power plant [18] [19], [20]. Multiple studies have been conducted for the validation and investigation of MERRA-2 data sets in the world, but it still limited especially for our target study area, it need to be investigated further for a reasonable and sound result before utilizing.

Currently Afghanistan's energy is mostly dependent on imported electricity which make almost 1 GW amount from Uzbekistan, Tajikistan, Turkmenistan, and Iran shown in figure (b), and generated amount in the country make one quarter of total from renewable and nonrenewable sources [21]. Energy generation from fossil fuels and hazardous biomass like woods and coals which are the dominant sources for houses energy production in the country are deteriorating indoor and outdoor air qualities and have caused sever health problems, hence it's needed to utilize renewable technologies for harnessing of energy which are economically justifiable, sustainable and clean which can insure energy security, reduce the hazard impacts of nonrenewable energy and most important benefit of renewable technology utilization is reduces GHGs emission [21]. In Afghanistan the regulatory framework for energy is spread among different ministries and organizations, however some documents

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such as renewable energy laws and electrical energy services managing legislation has filed the gape of regulatory and legal framework of energy sector to be formed [1]. In Afghanistan the energy sector is remarkably being expanded, but still the national grid system is not existed in Afghanistan [14]. Afghanistan is among the lowest consumer of energy, its about 100 kilowatt hours (kWh) per year per capita consumption—and only 30 % of Afghanistan population has access to the grid connected electricity, which make the globally lowest rank. This grid connected electricity in the country has been insuring either by imported electricity or domestic generation (which makes only 20% of country electricity) [14]. the rate of electricity generation is much less as compared to imported electricity which makes the supply of electricity more insecure high shortage and losses in transmission line and more costly than internal generated electricity [14]. As per the new power system master plan the net electricity need will be increased six folds by 2032. The planed hydel and fossil fuel based; energy harnessing can not fulfill the the required load. Apart from the hydropower country has the high capacity of solar and wind electricity generation. However, there are only three operational on grid solar photovoltaic power facilities at utility scales in Afghanistan deployed in Kandahar province which have (15, 15 and 10) MW solar energy production capacity[22]. There are also some mini and microgrid roof top renewable energies system in rural areas supply electricity to fulfil household demand [23]. The significance increaseness in public awareness, about access to sustainable electricity generation resources, has significantly increased the demand for harnessing and utilizing sustainable and environmentally friendly renewable energies sectors [14]. It is also suggested by (ANDS) program to produce and utilize renewable energy in rural areas, in the response to this suggestion the 10% target of electricity production from renewable energy sources by (2030) has been set by National Renewable Energy Policy (NREP) [24].

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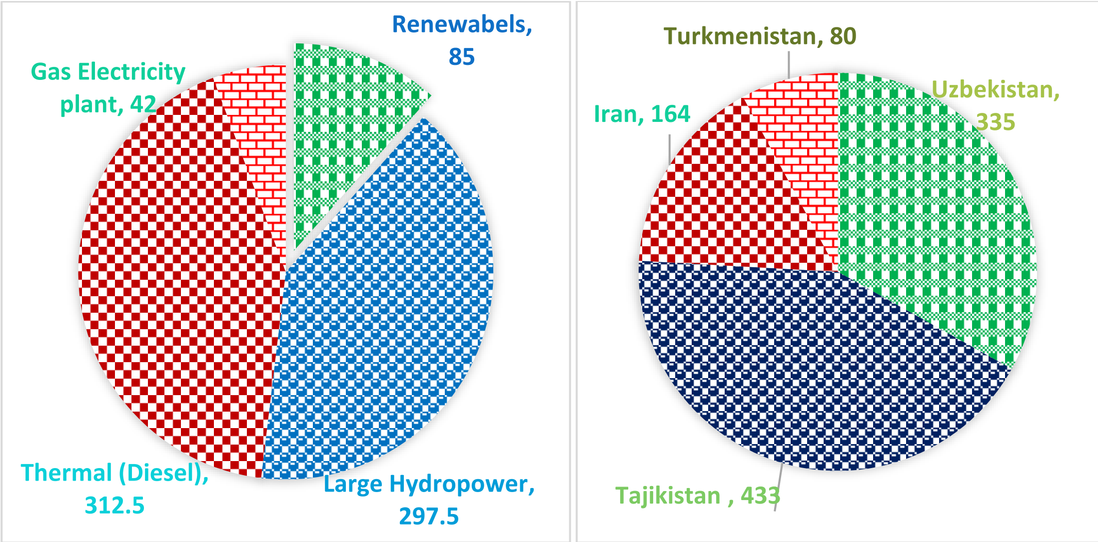

(a) Installed sources (b) imported sources

Figure 1. Total domestic installed and imported energy sources in Afghanistan

1.4. Problem statement

Afghanistan has been suffering from wars and instability for more than 40 years, due to country's volatile economic conditions, instability, and insecurity most of the previous infrastructures of energy have been demolished and currently due to population increase and economic development country needs high amount of energy to fulfill energy demands and stabilize economic development and improve life cycle of people [21]. Afghanistan economy is based on agriculture and livestock and more than 70% of population are involved in agriculture and livestock sectors to fulfil their needs, but in current it's evident that this sector is highly affected due to climate change and global warming, based on IPCC 5th report, Afghanistan is among the top 10 vulnerable country to climate change, consequently increased demand for environmentally friendly energy harnessing from local resources highly available in the country [25].

Anwarzi et al., determined the utility-scale implementable potential of wind and solar energies for Afghanistan using GIS multi-criteria decision analysis, Naseri et al., have done Spatial modeling of solar photovoltaic power plant in Kabul, Afghanistan, the eastern portion of Kabul Province and the northern and southern portions of Kabul City were found to be acceptable regions, according to output maps. Literature has given that the studies on solar PV establishment in the study area is very limited, the feasibility needs to be systematically investigated, in terms of technical, economical,

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and environmental design and performance. Determined research gap, consulting literature is summarized as:

- Limited studies on frequently used satellite and reanalysis data validation globally and specifically in the country,
- Non-incorporation of meteorological variables' influence in feasibility assessment,
- Randomly selection of factors and sub-factors for site exclusion and site suitability analysis,
- Dependency on already produced annual average resource maps for establishment of generation potential without incorporation of social and technical constraints,
- Studies only focused on site suitability and electricity generation potential and lacking socio-economic and environmental viability indicators like net present value (NPV), Levelized Cost of Electricity (LCOE), internal rate of return (IRR) and greenhouse gas emission reduction analysis.
- Limitation of research for sustainable development of renewable energy technologies, especially on solar photovoltaic power in Afghanistan.

Contribution of this case study to the determined research gaps consist of:

- Validation of frequently utilized reanalysis datasets (available globally) over multiple timescales and discussion on influencing variables,
- Utilizing Validated, high spatial and temporal frequency datasets for energy resource mapping and concise simulation of PV systems energy generation potential,
- Area screening and site suitability importance is evaluated based on distinct social and techno-economic-environmental parameters,
- Use of meteorological variables as influencing factors in techno-economic and environmental feasibility assessment,

This study helps as first of it is kind, multi-objective feasibility assessment of PV power plants at different location in the study area, apart from this, generation of energy resource maps are done based on long term validated data. In addition, it can give supporting information for making plans and policies implementation to decision makers to attract and convince investors for solar energy establishment.

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1.5.Objectives

In order to select suitable sites for generation of environmentally friendly and chief electricity, we defined following objectives for our study:

1. To generate high resolution solar energy maps for Afghanistan
2. To assess techno-economic feasibility of utility scale solar grid connected PV power plant on selected location

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CHAPTER 2

LITERATURE REVIEW

2.1. Background

Photovoltaic (PV) system is one of the substantial solar energy technologies has been developing very rapidly due to it low material cost and its simplicity as it does not include moving parts, that's why it requires less maintenance, has a long lifecycle, and does not cause water or air pollutions [8]. The energy production of PV technology depends on Global Horizontal Irradiance, these photovoltaic panels convert the sunlight directly into electricity based on photoelectric effects [8]. In 2021 the amount of energy produced by solar photovoltaic has made 5% of total energy generation in the world and this percentage tends to reach 27% in 2032 [11]

Solar energy generation using PV panels is proportional with solar radiation capacity and dis proportional with temperature increase, suitable site determination considers multiple factors which include climatic, land use/land cover, topographic, environmental, and socioeconomic parameters. multiple studies have conducted research for suitable site determination recently based on MERRA-2 GHI reanalysis datasets with incorporating multiple other parameters in their studies.

2.2. Re-analysis data validation

Validated global horizontal irradiance data is important factor for identification of best sites of solar photovoltaic power plant in a region, GHI is validated against ground data over different countries and regions. Yunfi Du validated MERRA-2 GHI data against ground stations across the China, result shows high accuracy of MERRA-2 GHI over other datasets [17]. Khatibi and Krauter utilized daily average GHI data of 8 sites to assess the performance of MERRA-2 monthly GHI, the result demonstrated that the mean absolute error ranged from 140 Wh/m2/d to 872 Wh/m2/d, with the correlation coefficient between 0.95 and 0.99. [18]. The viability of the hourly average GHI of MERRA-2 is validated against ground stations from 57 Baseline Surface Radiation Network (BSRN) stations across the world [20], determining an overestimation of MERRA-2 in most locations of the globe, especially in Europe and North America. Tahir stated that the cloud fraction (CF) is one of the main reasons for the error in MERRA-2 GHI data [26]. Feng and Wang evaluated monthly GHI against meteorological stations over China, requested that the average MERRA-2

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overestimation is up to 43.86 W/ m2 in relation with underestimated capacity factor [27]. Zhang stated that the overestimation of MERRA-2 GHI hardly differs over the seasons [28]. The aforementioned studies typically evaluated the hourly, daily, and monthly GHI of MERRA-2. Studies stated that given clouds and aerosols are two substantial parameters have ability determining of uncertainty of the MERRA-2 GHI, it is important to find out the governing parameters, which is important for the further improvement and development of MERRA-2.

2.3. Multi Criteria Decision Making (MCDM)

The Geographic Information Systems has been utilized for numerous Studies coupled with multi-criteria decision making (MCDM) methods to determine the viable sites of PV parks establishment [29] – [32].

(MCDM) method to evaluate the viable sites of PV plants. MCDM has been utilised for energy management issues, long-term energy plans, choosing the best renewable technologies, and energy planning and decision-making at various levels and choosing of the viable location for solar parks establishment. There are distinct methods used for MCDM which can be coupled with the GIS environment such as rating method, trade-off analysis method, weighted sum method (WSM), Weighted Linear Combination (WLC), ranking method, analytic network process (ANP), Boolean overlay operation, and analytical hierarchy process (AHP)[8].

Currently Multi-Criteria Decision Making method combined with (AHP) utilizing Geographic Information System are utilized for selection of suitable location for Photovoltaic power plants in many countries and to provide sound information for decision makers regarding PV power plant deployment [16] [2]. AHP method has some advantages over other multicriteria decision making methods used in the studies. it is a competent method for managing decision consistency, which can decrease bias in the decision-making process. Table 2 depicts few of the studies have been published recently, which have utilized GIS based MCDM-AHP approach to analyze viable and suitable sites for PV power plants installation.

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Table 2. Literature review on site suitability analysis of solar PV power plants based on AHP coupled with GIS

Study area	Evaluated criteria	Applied method	Ref
Kabul, Afghanistan	Direct Duration radiation, Land use, Distance from roads, Precipitation, Distance from Fault, Slope, Aerosol Optical depth, Aspect	site suitability using GIS_AHP and GIS_ANP	[1]
Cyprus	land use and land cover, protected area, Land transportation, distance to airport and distance to water bodies,	AHP	[33]
The Regional Unit of Rethymno	GHI, DNI. Water bodies, power transmission network, land use and land cover, coastline, elevation, slope, aspect, road infrastructure, and most visited sites,	AHP	[34]
Malatya, Turkey	GHI, land use and land cover, human settlement area, aspect, power transmission network, roads, fault line, water bodies, substation, and natural gas lines,	AHP	[35]
Indonesia	GHI, land use and land cover, temperature, humidity, road infrastructure, elevation, slope, aspect, human settlements area, and electricity grid station.	AHP	[36]
India	Solar radiation, elevation, slope, aspect, coastline, water bodies, airport, protected area, land use/ land cover, transmission network, cities, roads, and power plants.	Fuzzy AHP	[37]
Chihuahua, USA	Land use and land cover, road network, solar radiation, temperature, wind speed, vapor pressure, soil texture, slope, aspect, and landforms.	The Ranking and AHP	[38]

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2.4. Analytical Hierarchy Process (AHP)

Analytical hierarch process is one of the widely used technique of MCDM, a developed technique for managing and analysing complex decisions via psychology and mathematics developed by Saaty in 1977. Neissi et al., in 2020 stated that AHP has numbers of benefits, including overspecification of judgment, built-in consistency tests, proper calculating scales, and implementation in the elicitation of utility functions. AHP technique make relative ratio scales of calculation, multiple criteria on a degree scale, obtain through the normalization process. The normalization and composition of weights of multiple criteria calculated on the same degree scale leads to meaningless numbers. This is due to the normalization of discrete sets of numbers, which ruin the linear link. To overcome the problem, at first, the weightages must be collected of multiple parameters and then normalization process should be done for AHP utilization.

Currently AHP is widely used model of MCDM method for site suitability analysis, recently Ibrahim used GIS integrated with AHP method to identified 369 suitable potential sites for establishing solar power plants in Erbil, Iraq [39]

H. Ebru. Colak conducted site suitability study for Malatya province of Turkey to identify suitable site for utility scale photovoltaic power plant utilizing MCDM, AHP method combined with GIS, this study criteria factors like land use, roads, transmission network and transformer center, slope, aspect, lakes, and dams are evaluated as AHP criteria for site suitability analysis.

Land use land cover, Roads, Transmission Network, Protected Area, water stress Area and LCOE and their sub criterion have been chosen as AHP parameters have been selected as AHP criteria in most studies.

2.5. Excluded Criteria

From aforementioned studies it’s cleared that the selection of criteria for exclusion and AHP processes depends on country specific policies for Land use and land cover for PV installation, however in Afghanistan there is not any policy enacted for Land use utilization PV power can be deployed even on crop land.

Many studies evaluated slope higher than 5% as exclusion criteria and to avoid biodiversity destruction human settlement, water bodies and snow have been evaluated as exclusion factors in many studies, Original spatial resolution is

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mentioned in above table, and all these data are resampled to 0.00277*0.00277 (300*300) m cell size in latitudinal and longitudinal directions for GIS weighted overlay processes to identify suitable locations for utility scale solar photovoltaic energy project installation in the country to meet the need of energy.

2.6. Weighted overlay process

Different GIS tools are used in studies for identifying of suitable classes, specially weighted sum and weighted overlay tools are very common [16].

2.7. Techno economic feasibility analysis using RET Screen

Government of Canada has developed and released RETScreen software which is an excel based renewable energy management tool in 1998 [40]and is kept with the support of Natural Resources Canada's CEDRL (CANMET Energy Diversification Research Laboratory). many administrations like United Nations Environment Program (UNEP), National Aeronautics and Space Administration (NASA), corporate with more than 307 experts from distinct academia, government, and industries to make this simulation software [40][41]. The cause and reason of developing this capacity building software was to increase the awareness about renewable energy harnessing, to provide such a software to the community utilizing which they can assess renewable energybased plant quickly. It is a validated tool package [42][43]that has many pages including two types of analysis methods sheets (method-1 and method-2) where method-1 is simple and incorporate less data for analysis where as method-2 is comprehensive [42]. This simulation software can be utilized for assessing the techno economic, GHGs emission reduction, and risk analysis of renewable energies projects, energy efficiency, and cogeneration plant[40]. in 2000 Thevenard et al., [43]suggested the first RET Screen tool to assess the potential of PV power project. After that, many researchers studied and assess solar PV technology utilizing the RET Screen tool to assess its techno economic, and environmental viability by focusing on distinct PV systems' aspects. Turcotte et al. [44] investigated the sizing and simulation ability of a hybrid PV system in RET Screen tool and done a comparative study to compare feasibility analyzing software like PVsyst HOMER, etc., and suggested these for future developments. Bakos and Soursos [45] evaluated the technical and economical feasibility of a off grid hybrid PV/diesel system for Greece's tourist resort. Then they examined the techno economic viability of grid-connected PV systems for Paros Island and developed in Greece [46][47]. Jaber et al.

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[48] evaluated the PV system's behaviour integrated with gas-turbine evaluating power conversion efficiency and economics of the plant. They demonstrated that this hybrid plant is been able to generate 140% more power per unit of the consumed fuel than a common gas turbine plant.

There is multiple open-source analysis software to evaluate techno-economic assessment of Photovoltaic technology like SAM, HOMER, RET Screen and…, in this case study RET-Screen expert clean energy management software version 8.1 is used to assess technical, economic, and environmental feasibility of solar Photovoltaic power plants in Afghanistan's highly suitable sites.

RET-Screen use climate database which includes both ground meteorological parameters datasets and NASA Surface Meteorology and Solar Energy (SSE) data Sets, but for our study area RET Screen doesn't have ground dataset and has only few NASA (SSE) points which are proper option to use these datasets because it can't represent the meteorological conditions of the whole country, Modern-Era Retrospective analysis for Research and Applications version-2 (MERRA-2) datasets which provide meteorological data in spatial resolution of (0.5*0.625) from 1980 to onward for multiple timestamps.

This study provides comprehensive maps for feasible sites in the whole country in different districts based on MCDA, AHP method utilization coupled with GIS, it's a kind of new study can serve as a helping tool for policy makers and to facilitate for investment on utility scale Photovoltaic power facilities in the country.

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CHAPTER 3

MATERIAL AND METHOD

3. Material

This section set out the input datasets incorporated in this study; rest of the section is specified for the framework of method used for considered data in this study.

3.1. Data sets

First part describes all the exclusion criteria and AHP parameters and their spatial and temporal resolution with their sources used in this study.

3.1.1. Land use and land cover data sets

Land use, environmental and socioeconomic parameters are shown in table 3.

Table 3. AHP datasets sources and description

Criteria	Data Format	Spatial Resolution	Time Period	Sources	References
Administrative Maps	.shp			Diva GIS	
Land use and Land Cover	. netcdf	300m	2020	European Space Agency-Climate Change Initiative	[49]
Water body	. netcdf	300m	2020	Derived from Land Cover	
human settlement	. netcdf	300m	2020	Derived from Land Cover	
Water stress area	. netcdf	SHP	2019	Aqueduct by Water Resources Institute	[50]
Transmission Network	.shp	SHP	2021	Energydata.info	[51]
Roads	.shp	SHP	2021	Humanitarian Open Street Map	
Elevation	.shp	90m		NREL (DEM)	
Slope	.shp	90m		derived from Elevation	
Protected Area	.shp	SHP	2021	United Nations Environment Program World Conservation Monitoring Centre	

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3.1.2. Global Horizontal Irradiance (GHI), Temperature and wind speed reanalysis data sets of MERRA-2

Short wave solar irradiances are firstly produced by station observation, satellite remote sensing and reanalysis data. stations observation or ground data are normally accepted as being the most accurate way for generating Global Horizontal Irradiance data [52]. however, observational sites are very limited [53]. Satellite retrievals and reanalysis datasets provide long term grided solar radiation data at large scale and can be used as beneficial substitute data for a region at the absence of ground measurements. Even, reanalysis and satellite data have bigger uncertainty than ground observations, MERRA-2 has been improved and validated over different regions and has been used as best GHI data sets for larger surface area and long-term data sets.

MERRA reanalysis version 2 was revealed by NASA’s Global Modelling and Assimilation Office [54]. MERRA-2 is an updated version of MERRA and is also the first long-term global reanalysis datasets for different variables. space-observed aerosols are assimilated that are expected to show in better manner the interaction between physical processes and aerosols the climate system. Because of the upgrades to the prediction model, the implementation of a new atmospheric model (GEOS 5.12.4), and the data assimilation system tailored to observation data [55], brand-new microwave and hyperspectral infrared radiation tools are utilized for MERRA-2 to assimilate data. MERRA-2 consists various whether parameters, such as temperature, radiation, wind speed and relative humidity. This Re-analysis data mask the world with a cell size of $0.5^{\circ} \times 0.625^{\circ}$, a temporal resolution of 1 h, and a vertical layer with 72 layers. The surface incoming shortwave flux (SWGDN) from the MERRA-2 M2T1NXRAD dataset served as the GHI data for this study.

The MERRA-2 made by Global Model and Assimilation Office (GMAO) datasets provide meteorological data in NC formats from 1980 onward in 0.5 degree on latitude and 0.625 on longitudinal directions which cover the globe and the considered data in this study further been processed, MATLAB 2020a is used to extract the data from NC format to excel files. Global Horizontal Irradiance, temperature at 2m elevation (T2) and wind speed at 10 m elevation (Wind10) are considered as meteorological variable from 2007 to 2021 time periods in this study for PV site suitability analysis. Unfortunately Afghanistan has only one ground station measuring GHI data to get reasonable result of validation two stations are selected from neighbor

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country of Pakistan which has same climatic conditions bordering with Afghanistan and for other meteorological variables like Temperature and windspeed ground data from numbers of stations distributed in the country have been selected to validate Re analysis data of MERRA-2, all these data sets are validated and compared with ground stations data for different time scale like (hourly, daily and monthly), which have given reasonable results. Table 4 shows the meteorological parameters.

Table 4. Meteorological parameters used for feasibility analysis in this study

Parameter	**Data Format**	**Spatial Resolution (Degree)**		**Temporal Resolution**	**Time Period**	**Source**
		Lat	**Lon**			
GHI	. netcdf4	0.5	0.625	Hourly, Monthly	2007-2021	(MERRA-2)
Temperature	.csv	0.5	0.625	Hourly, Monthly	2007-2021	(MERRA-2)
Wind Speed	.csv	0.5	0.625	Hourly, Monthly	2007-2021	(MERRA-2)

3.1.3. Land use and land cover data

Spatial and temporal resolutions and its source mentioned in Table 3 and here it's classes will be further elaborated, land use land cover data in our case study consist of these 9 classes evaluated based on ICDR Land Cover from 2016 to 2020 Product User Guideline and Specification [25]. Agriculture, Sparse vegetation cover, Forest cover, grass land, baren land, settlement area, water bodies, snow cover and shrub land.

3.2. Applied methods

MERRA-2 meteorological data of GHI, temperature and wind speed for the country are used to perform solar resource mapping and feasibility analysis based on above mentioned data, firstly MERRA-2 data is validated against ground measurement to determine the viability of reanalysis data, then exclusion criteria are applied to screen

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out the area for feasible sites and then RETScreen software is utilized to generate Capacity Factor (C.F) and Levelized Cost of Electricity maps, then Analytical Hierarchy Process been applied which employed Land use land cover, LCOE, Transmission lines, Roads, Protected Area and Water stress Area and scores for main and sub criteria have been assigned based on literature and experts consultation and final weightages for main and sub criteria are developed by AHP, at the end weighted overlay process is caried out to determine feasible sites based on AHP weights. This whole process is highlighted in Fig 2.

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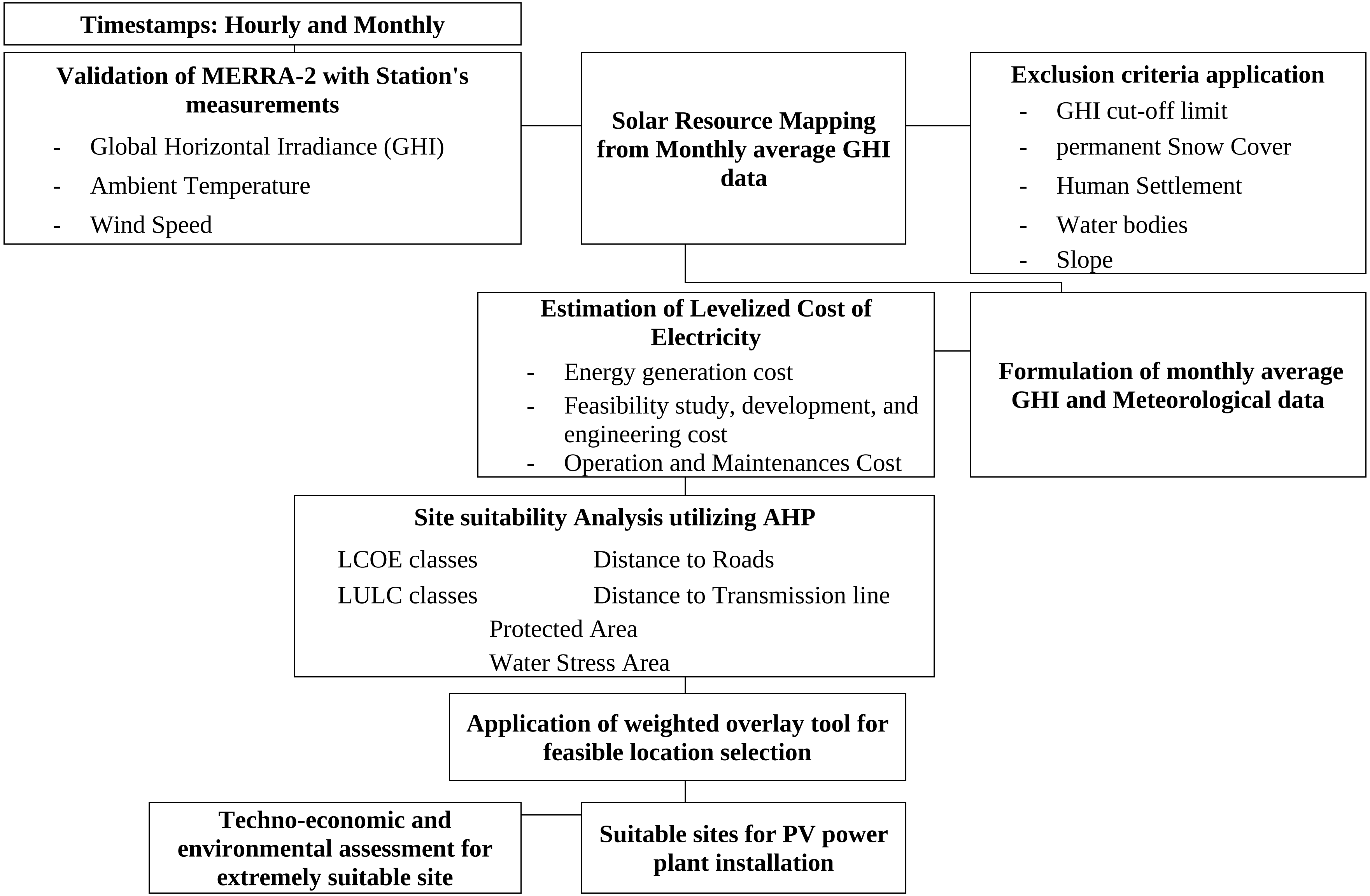

Figure 2. utilized framework for data validation, site suitability and techno-economic feasibility analysis for solar PV power plant

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3.2.1. Meteorological data validation

This section describes the validation processes of MERRA-2 Re analysis data with stations data, as RET Screen required for monthly averaged data of GHI, Temperature and wind speed for PV analysis, all these variables have been validated with ground stations, to achieve concise result we employ three statistical tests for validation, Root Mean Square Error test (RMSE), Mean Bias Error test (MBE) , regression tests of Pearson Correlation Coefficient test (R).

Pearson Correlation Coefficient test is carried out to Measure statistical relationship between the two variables data shown in equation 1.

$$R = \frac{\sum(G_i - \bar{G})(R_i - \bar{R})}{\sqrt{\sum(G_i - \bar{G})^2 \sum(R_i - \bar{R})^2}} \dots \dots \dots \dots 1$$

Mean Bias Error (MBE) test is conducted to find out possibility and level of overestimation and underestimation of re analysis data relative to station data shown in equation 2.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(G_i - R_i) \dots \dots \dots .2$$

Root Mean Square Error (RMSE) statistical test is performed to find out the difference between predicted values and actual measurement values is shown in equation 3.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(G_i - R_i)^2 \dots \dots \dots .3}$$

3.2.2. Solar resource mapping

Annual average GHI map produced from MERRA-2 monthly average data from 2007 to 2021 time period, monthly average data is downloaded and extracted using MATLAB 2020a from NC file for 198 points in the study area, then invers distance weighting (IDW) interpolation method is used using ArcMap 10.8.1 software map is reclassified to a specific cell size for homogenization.

3.2.3. Application of exclusion criteria

Four exclusion criteria based on consulting literature and experts and considering the Food security and economy issues, In this study (1400 Kwh/m2) threshold limit been

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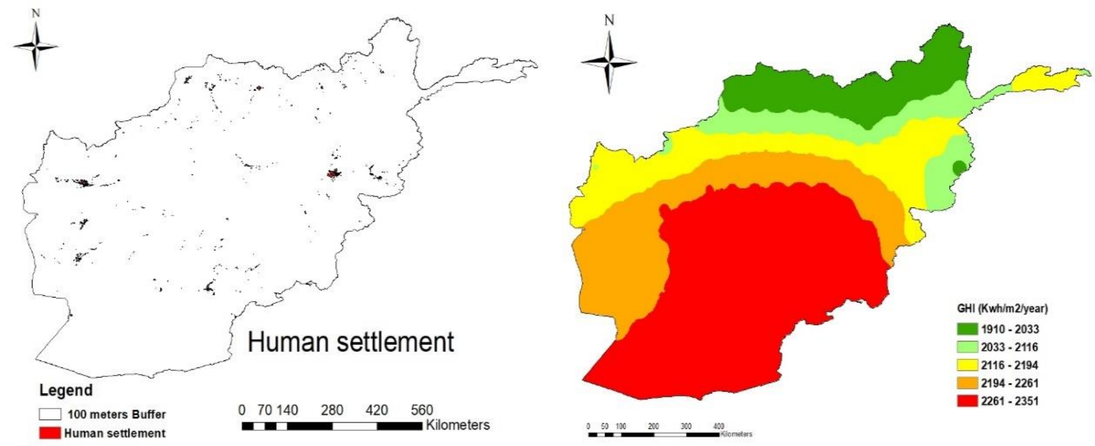
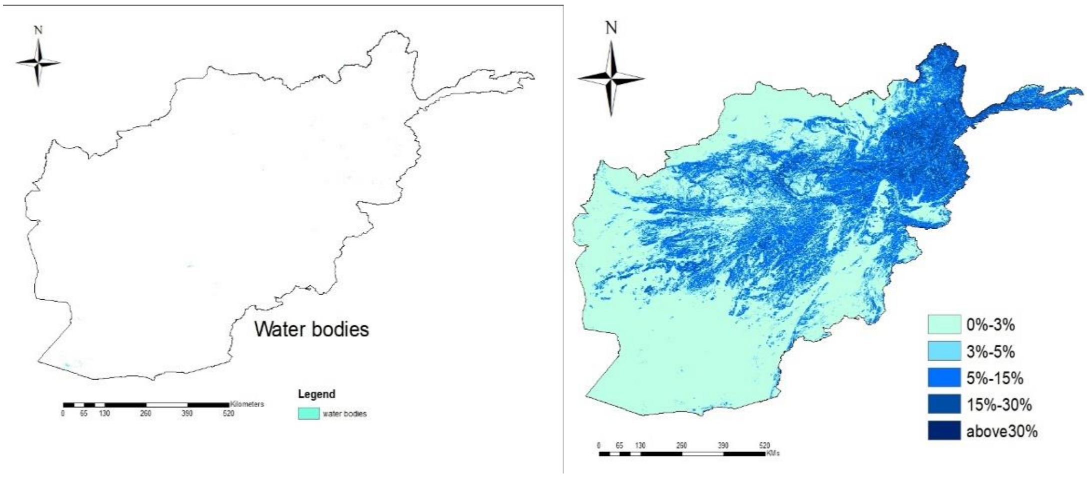
applied upon Annual GHI map, fortunately GHI minimum limit in our study area is more than 1900 Kwh/m2, Slope is derived from Elevation map using slop tool in ArcMap 10.8.1 as PV power generation plant need to be installed on flat area that's why slope higher than 5% is excluded then slope map applied on LCOE map, solar power plant deployment near Human settlement and its deployment on water bodies produce different environmental and socioeconomic problems, therefor it should be avoided to install near human settlement or on water bodies, 100 m buffer is applied for settlement for reducing noise and inconvenient conditions for residents. All the considered parameters' data sets are resampled to a specific resolution for further applications. GHI, Human Settlement, Water bodies and slope maps are shown in figures. 3 (a, b, c, and d) respectively.



(a) Human residential settlement (b) Global Horizontal Irradiance



(c) Water bodies (d) Slope

Figure 2. Input parameter utilized to Exclude sites of low potential

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3.2.4. Estimation of Levelized cost of electricity (LCOE)

LCOE is the ratio of the total cost of the project during its lifetime consisting of both initial costs and O&M cost of the electricity produced over its lifetime of the plant [41]. It's a robust calculation to compare distinct electricity harnessing technologies, and it's determined in terms of $/kWh or $/MWh. LCOE can be shown as follows:

$$\text{LCOE} = \frac{\text{Total cost during lifetime}}{\text{Total electricity produced during lifetime}} \dots\dots\dots 4$$

In this study technical analysis have been conducted for multiple tracking systems like fix tilted, single axis and dual axis tracking systems and for different panels materials like monocrystalline and polycrystalline for 109 points which are selected after the applying exclusion criteria in study area, RET Screen expert clean energy management software is utilized to evaluate the techno-economic potentials of each selected points, RET Screen expert are using meteorological and financial parameters along with panels materials cost, MERRA-2 reanalysis data of global horizonal irradiance, temperature and wind speed monthly averaged data of each point were used, financial parameters and cost data are got from recently published literature in the region, renewable energy repots and NREL guideline [25], [57]. The economically comparison result of these combinations are compared in terms of their economy and their profitability over each selected point. Single axis polycrystalline shows high profitability over other tracking systems, LCOE value of single axis polycrystalline system has been chosen for AHP process to identify suitable location for solar photovoltaic energy project all the financial parameters and cost data are shown table.5.

Table.6 summarizing the safety conditions, efficiency, and losses of Poly crystalline silicon and mono crystalline silicon panels materials and inverters for selected sites. Panels Miscellaneous losses consist to losses due to the existence of dust or snow on the modules, or losses due to mismatch and wiring, Usually, losses values fall between a few percent and 15%. This figure may reach 20% in some abnormal cases (such as in extremely severe environments). Based on U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, an inverter efficiency of 96% was chosen. [57].

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Table 5. Costs and financial parameters Structure for performing feasibility analysis

Parameter	Module	Tracking System	Value	Unit
Initial cost	Monocrystalline	Fixed tilt	651	$/KW
		Single axis	720	$/KW
		Dual axis	840	$/KW
	Polycrystalline	Fixed tilt	560	$/KW
		Single axis	630	$/KW
		Dual axis	750	$/KW
Operational & Maintenance cost		Fixed tilt	14.6	$/KW
		Single axis	16	$/KW
		Dual axis	17	$/KW
Periodic cost (inverter replacement)			40	$/KW/13y
Feasibility study cost			0.2	%Initial
Inflation rate			4.6	%
Discount rate			12.1	%
Electricity export rate (Tariff)			0.083	$/kWh
Project life			25	Year
Electricity export escalation rate			0	%

`

Table 6. Electrical specification of panels investigated in this study

Modules		Poly-Si JKM-250P-60	Mono-Si JKM-250M-60
Manufacturer		Jinko Solar	Jinko Solar
Model		Poly crystalline	Poly crystalline
Maximum Power	W	250	250
Number of units		200000	200000
PV Module Efficiency	%	15.27%	15.27%
Nominal operating cell temperature	ºC	45	45
Temperature coefficient	%/C	0.4	0.4
Solar collector area	m^2	327439.4237	327439.4237
Bifacial cell adjustment factor	%	0	0
Miscellaneous losses	%	5	5
Inverter			
Efficiency	%	96	96
Capacity	Kw	2500	2500
Miscellaneous losses	%	1	1

3.3. Site suitability analysis using Analytical hierarchy process (AHP)

Multiple criteria factors affecting sites selection for photo-voltaic power plant establishment, to conduct appropriate assessment for PV power plant site selection and resulted in highest degree of findings, data should be available at appropriate spatial and temporal resolution, the data affecting site suitability analysis consist of land use land cover, LCOE (generated based on GHI map), transmission lines, road network, protected area, and water stress area, these factors are decided based on consulting literature and expert's opinion for this specific area.

It is substantial to apply some methods to identify which parameter or criteria is more important over others, the highly prioritize criteria and the order of importance were identified utilizing AHP model. Thus, the factors considered in this study were not evaluated individually, consulting literature conducted in Afghanistan and in the region and experts' opinions in the filed were used to determine the weightages for criteria [1], [35], [57] – [59]. Then pairwise comparison matrix is applied to determine weights for each criterion, to check the coherence of the process, we calculated the consistency ratio (CR) for determination of the criteria weights, if the CR is less than 0.1 it shows that the process is accurate, if the CR value exceed from 0.1 it reveals that binary comparison is not accurate and the complete process should be repeated [61], [62].

For this study seven factor maps were ready for GIS tools application which LCOE (instead of GHI), slope map, Land use and land cover, transmission lines, road infrastructures, protected area, and water stress area. Among these factors some subfactors are evaluated as exclusion criteria like GHI less than 1400 Kwh/m2, slope higher than 5%, water bodies and human settlement with 100m buffer and permanent snow cover in land use land cover classes [57], [62] – [65].

3.3.1. Levelized cost of electricity

When the location is being chosen for solar photovoltaic power plants, the solar resource of the area where the solar energy generation project is planned to be established is first analyzed. establishment of solar energy project in the region where solar resources are low and receive low solar radiation of GHI make the project less efficient and costly. Therefore, it is essential to study the solar resources of the region and select the site with high solar radiation and high numbers of sunshine days which leads the project toward high efficiency and economically viable, in this study effects of temperature and wind also evaluated, instead of solar resource (GHI) map we incorporated levelized cost of electricity map which include the effects of temperature and wind speed on solar resources too. Temperature is an important factor influencing the generational potential of panels and affecting the efficiency of cells. Increase in temperature increases the module temperature, resulted in reduction of module efficiency. The operations of a PV panels increase at temperatures below 25C, but when temperature increases by every 1 C results in a 0.4% to 0.5% reduction in power generation from PV system [67], LCoE map is depicted in figure 4a.

3.3.2. Distance from transmission lines

Generated electricity in the solar power plant is transmitted to power substation via transmission network and then distributed to the consumers, the longer the distance

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between solar power plant and power substation the higher will be cost of new construction transmission line and higher will be the losses because losses are attributed with long transmission lines, and it leads the project less efficient and economically unviable. It necessary to select a location for solar power plant installation near the transmission network or transmission lines to reduce the cost and decrease the amount of energy losses and the project efficient and economically viable, transmission lines map is shown in figure 4b.

3.3.3. Land use land cover

Land use and land cover data is one of the highly substantial factors for photovoltaic power plant establishment, it necessary to avoid the installation of solar power plant in the region where less agriculture land is available, and risk of food security is dominant. Therefore, solar power plant should be installed as far as passible from scarce agriculture land, but in this case study, the county has not any specific regulation and rules for land use to be used for power plant installation that's why we give less weight to agriculture and forest cover to protect eco-system and avoid food insecurity conditions, LULC map is shown in figure 4c.

3.3.4. Distance from roads

Transportation is a substantial factor for deployment of solar power plant in a region. Deployment of PV electricity power plant may need a huge amount of transport to the selected area. Construction of new roads will generate much new costs in the region if there is no proper transport network. Therefore, it is essential to incorporate roads infrastructure in analysis of solar PV power plant establishment because it is an important factor which affect the cost of a new power project in a region, roads with multiple buffers map are shown in figure 4d.

3.3.5. Protected Area

Protected area is an important factor affecting solar power plant establishment, therefore, to protect environment, keep the ecosystem safe and protect the ancient assets from destruction and danger associated with power plant installation in a region, protected area designated based on united nation environment program or country environmental policies should be considered in solar PV power plant site suitability analysis, protected area map is depicted in figure 4e.

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3.3.6. Water Stress Area

Water stress area is an important factor in selecting suitable site for harnessing of solar energy in a region, solar power plant panels require water in installation stage and need water for panels washing on regular bass, that's why it is necessary to avoid installation of power plant in water stress area to passible extent, water stress area map is depicted in figure 4f.

To further demonstrate areas constituting high economic and environmental importance among sites of high technical and resource capacity, AHP is utilized. paired comparison method was made between main criteria as depicted in matrix table. As well same processes have been performed to each criteria sub-parameters, paired comparison method is shown in table 7.

Table 7. Pair-wise Comparison Matrix

Criteria	Water Stress Area	Protected Area	Distance to road	LULC	Distance to TL	LCOE
Water Stress Areas	1.00	0.33	0.20	0.20	0.14	0.11
Protected Area	3.00	1.00	0.33	0.20	0.20	0.14
Distance from Roads	5.00	3.00	1.00	1.00	0.33	0.20
LULC	5.00	5.00	1.00	1.00	0.33	0.20
Distance from Transmission lines	7.00	5.00	3.00	3.00	1.00	0.33
LCOE	9.00	7.00	5.00	5.00	3.00	1.00
column sums	30.00	21.33	10.53	10.40	5.01	1.99

Where LULC is used for land use land cover, TL to transmission lines, and LCOE to levelized cost of electricity.

Weights assigned to main and sub-parameters are shown bellow. LCoE was allotted highest weightage which consider GHI resources, Temperature and tracking system effects, lowest value is attributed with single axis tracking system which is furthermore considered as main factor for site suitability analysis. To minimize cost and losses of electricity, transmission network was given second highest weightage and to decrease potential clash between land use for powerplant establishment and other reasons like land of farming or groundwork establishment, and to avert social trouble and concern to ecosystems, land cover was given third high important criteria.

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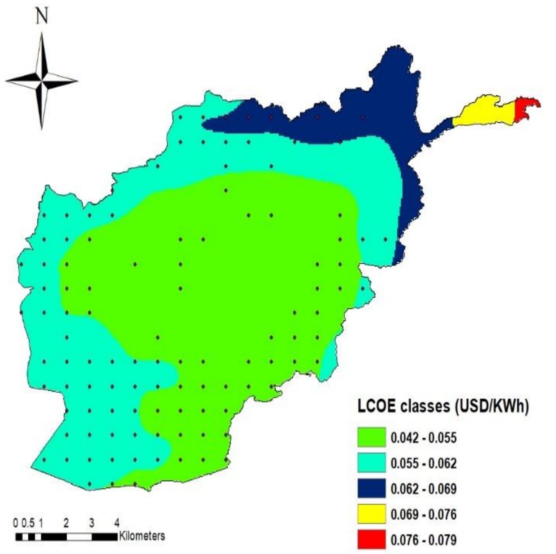
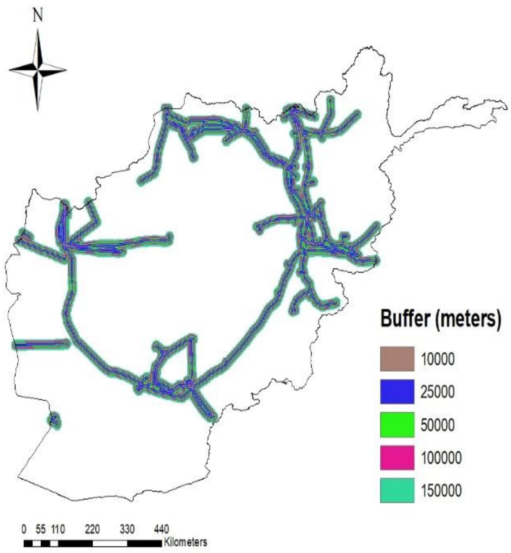
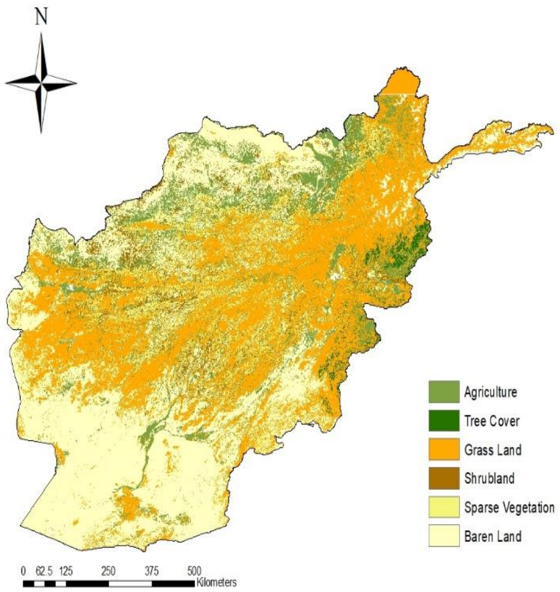
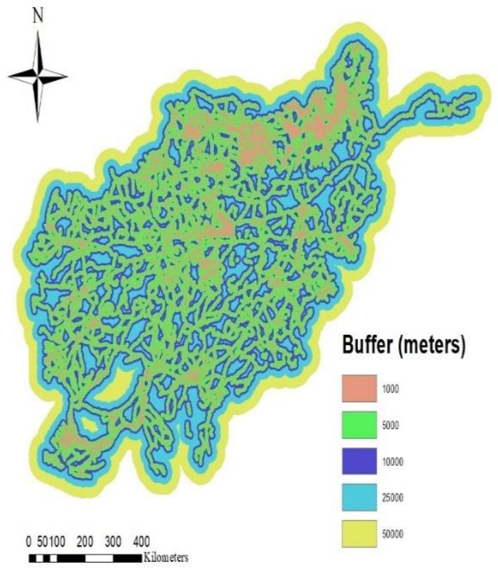
It was followed by distance from road infrastructure Protected areas were also evaluated in analysis to minimize damage and destruction of biodiversity and other area of environmental substance. Water would only be needed to clean the mirror once or in two weeks, minimum weight is allotted for water stress area then calculation of consistency ratios and indices was performed. Thematic maps of GIS input criteria are shown in Fig.4 (all resampled to 0.0027◦ cell size). The analysis was conducted utilizing weighted overlay tool in ArcGIS.





(a) Levelized cost of electricity (b) Distance from transmission lines





(c) Land use/land cover (d) Road's network

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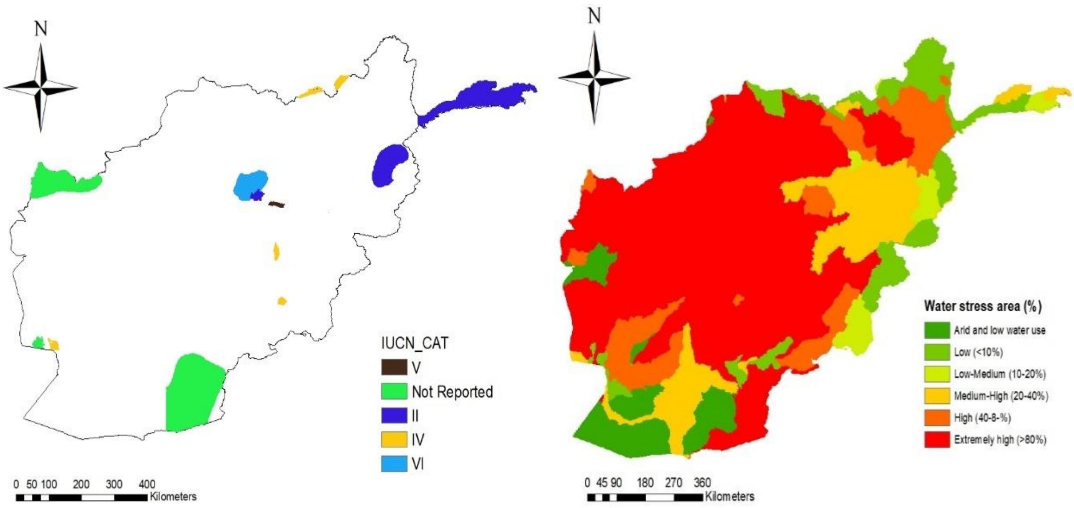

(e) Protected area (f) Water stress area

Figure 3. Input parameters utilized in PV site suitability analysis using AHP

3.4. Techno-economic feasibility analysis of grid-connected PV power plant

The on-grid PV technologies including PV modules for generating the required amount of electricity during daytime and is tied with local electrical sub station grid to obtain the electricity during the nighttime. The PV modules sometimes produce power more than the need during daytime and hence the excess amount of electricity is transferred to the substation. On the other side, when these modules are not capable to generate sufficient amount of electricity to fulfill the need, the shortage energy is compensated from the substation. Simply, the electricity moves forth and back to and from the grid asper to the availability of solar radiation and the real load demand in a on-grid PV power system. The grid connected PV systems are very common and simple and have comparatively lesser operational and maintenance costs. The on-grid PV technology directly give electricity to the grid that’s why there is no need for expensive power back-up batteries fig 5 depicts grid connected photovoltaic power plant configuration.

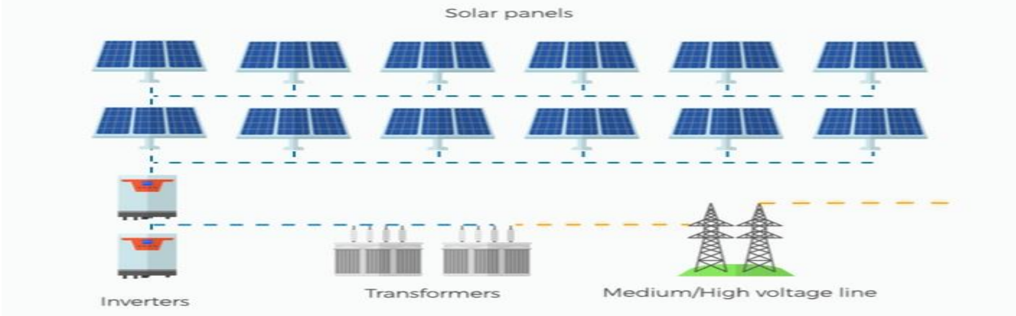

Figure 4. grid connected photovoltaic power plant configuration

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3.4.1. Grid-connected PV system performance indicators

Performance indicators of on-grid PV power plant are utilized to assess the PV power projects and substantial to evaluate their economic feasibility and profitability over their lifetime, which is conventionally 25 to 30 years. These indicators are assessed to perform the comparison process of different PV panels and mounting systems.

Capacity factor (CF)

The capacity factor (CF) of a photovoltaic power project is determined as the ratio of the output over a year and the output if it had functional at nominal power that whole year.

3.4.2. Economic assessment indicators of solar photovoltaic (PV) system

Solar PV systems have high initial cost and low operation and maintenance (O&M) cost. following is a discussion of important economic indicators for solar PV investments assessment to determine whether the project is economically and financially viable or not in that selected place.

Levelized cost of electricity

LCOE is the ratio of the total cost of the project during its lifetime consisting of both initial costs and O&M cost to the electricity produced over its lifetime of the plant. It's a robust calculation to compare distinct electricity harnessing technologies, and it's determined in terms of $/kWh or $/MWh. LCOE can be shown as follows:

$$\text{LCOE} = \frac{\text{Total cost during lifetime}}{\text{Total electricity produced during lifetime}}$$

Payback period (PBP)

Payback period is an important indicators of economic feasibility analysis of solar PV power project, which is determined as the time required for investment to achieve it is initial cost, this recovering is not including the periodic and O&M costs only consists to initial investment. If the PBP is less than useful life of the project, it shows that the project is economical viable.

Net present value (NPV)

NPV is the discounted sum of the income from selling the produced electricity net of all costs affiliated with the electricity transmission system. This parameter considering the time value of money and the entire life cycle of the power plant. All expected costs are discounted to the currentt time and are determined as the present

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worth of the cost. A positive NPV specify that the project is financially viable while a negative NPV represent that the project is financially infeasible

Internal rate of return (IRR)

It is an important economic indicator for feasibility analysis of PV power project, if the project IRR is higher than discounted rate or net interest rate, it shows that the project is economically profitable.

3.4.3. Greenhouse gases emission reduction analysis

As stated earlier, climate change and global warming has become one of the greatest consequential crises facing the human being in this century in different aspect especially agriculture which is highly affected sector due to climate change and most of the people relay on this sector to fulfil their basic life needs, thereby conducting studies on GHG emissions reduction analysis is essential for each kind of electricity generation project. An emissions analysis page is available in RET-Screen expert to help investigation on the GHG emissions reduction capability of renewable energy electricity plant. Water vapours, CO2, methane (CH4), nitrous oxide (N2O), ozone (O3), and fluorinated gases are the primary GHGs. In RET-Screen expert software GHGs that are incorporated for energy power plant analysis are CO2, CH4, and N2O. Results from the GHG equivalency tool in the RET Screen expert are demonstrated in terms of the annual quantity of CO2 that, regardless of the actual gases, would be equivalent to the overall emission reduction. and it is accomplished by translating CH4 and N2O emissions to the comparable CO2 emissions considering their capability for heating capacity. [68].

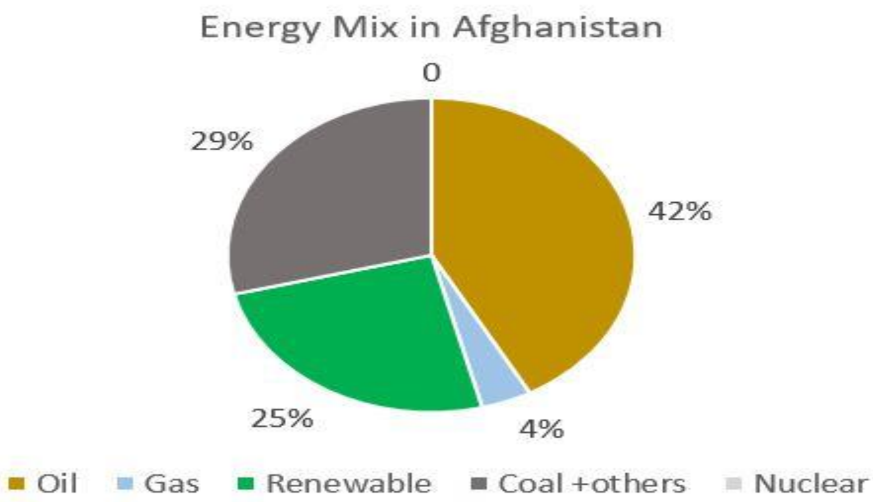

Figure 5. Afghanistan Energy Mix used for GHG emission analysis

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Currently due to utilization of fossil fuel high amount of greenhouse gases are emitted to atmosphere where it can remain for decades, these greenhouse gasses absorb energy radiation in the form of infrared emitting from earth surface back to atmosphere, some amount from these absorbed radiations are reemitted to earth surface which is cause earth surface warming and affect human life and many other sectors which affects indirectly on human, animals, and ecosystems. using of clean power sources for energy production resulted in the minimization of greenhouse gases emissions into the air. The most important greenhouse gases are CO_2, CH_4 and N_2O. This analysis is conducted based on Afghanistan Energy Mix and Fuel wise emission factors which are derived from IPPC report and used by RETScreen expert software for this analysis, shown in table 8.

Table 8. Fuel-wise emission factors utilized for GHGs emission analysis

	Emission Factors (kg/GJ)		
	CO_2	**CH_4**	**N_2O**
Hydroelectric	0	0	0
Nuclear	0	0	0
Oil	74.1	0.0029	0.0019
Natural Gas	49.6	0.001	0.0009
Coal	92.7	0.0145	0.0029
Solar	0	0	0
Wind	0	0	0

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CHAPTER 4

RESULTS AND DISCUSSIONS

The generated results and conclusion are demonstrated, evaluated, and discussed in this part.

4.1. Re-analysis data validation

In this part based on statistical analysis viability and precision of MERRA-2 re-analysis dataset is demonstrated along with reasons behind the calculated correlation and calculated errors.

4.1.1. Global Horizontal Irradiance

MERRA-2 GHI strongly correlates with ground GHI data, Overall underestimation due to overestimation of aerosols factorization in retrieval algorithm.

High bias is measured for GHI due its high potential to be influenced by cloudiness, humidity, and aerosols in Atmosphere. Huge error (RMSE) assigned to each data source and timescales may be because of distinct cell size of reanalysis datasets, and in what followed, them being validated to data of a single point source since irradiation is almost never geospatially similar. Correlations, MBE and RMSE are shown in table. 8.

4.1.2. Ambient temperature

MERRA-2 daily Temperature strongly correlates with ground Temperature due to diminish of fixed surface temperature in MERRA-2 Algorithm.Almost all location shows high correlation with observational data shown in (Table 9). The 'R' value is determined to be higher than 0.9 for all selected location. Studies have claimed that this may possibly be due to elimination of fixed sub-surface temperature and rendering of power conduction via the surface in MERRA-2 algorithm.

4.1.3. Wind speed

'R' value ranges from 0.21 to 0.9 for all sites at monthly timescale shown in (Table 9). The large differences can be attributed to surface specification for all location, as sites with simple topography depict strong correlation. With a few deviations, sites at lower altitude depict highest correlation because of terrain surface feature utilized in retrieval algorithm. further, the wind speed dynamics highly rely on the altitude at the boundary level of the atmosphere, resulting in inability to serve events of critical wind speeds. commonly, the dataset underestimates wind speed, but RMSE values shows sporadic underestimation and overestimation. This might be because of the sites' rough topography, which constantly impacts the drag coefficient, and the coarse resolution of the dataset makes it unable to account for changes in it.

Table 9. Results of Pearson Correlation Coefficient (R) Root Mean Squared Error (RMSE) and Mean Bias Error (MBE) for meteorological variables at different timestamps

Variables	Time stamps	Kabul			Jalalabad			Kandahar		
		R	MBE (%)	RMSE (%)	R	MBE (%)	RMSE (%)	R	MBE (%)	RMSE (%)
Ambient Temperature	Hourly	0.95	5.62					0.97	1.02	2.50
	Monthly	0.97	-3.64	4.40	0.98	6.21	6.53	0.95	1.48	3.44
GHI	Hourly							0.95	-11.64	1.13
	Monthly									
Wind Speed	Hourly	0.21	-0.04	2.38				0.47	0.39	1.88
	Monthly									

Variables	Time stamps	Mazar e sharif			Peshawar			Quetta		
		R	MBE (%)	RMSE (%)	R	MBE (%)	RMSE (%)	R	MBE (%)	RMSE (%)
Ambient Temperature	Hourly				1	10.3	16.1	1	10.5	17
	Monthly	0.96	3.66	2.78	1	10.3	13.1	1	10.5	12.7
GHI	Hourly				0.95	44.68	0.86	0.97	16.69	0.83
	Monthly									
Wind Speed	Hourly				0.8	-30.8	90.9	0.9	-5.3	58.7
	Monthly				0.7	-30.8	50.7	0.9	-5.3	34.2

`

4.2. Solar resource mapping

Annual average GHI map for Afghanistan is depicted in (fig 8), 100 % of land area has solar radiation greater than cut-off limit (1400 KWh/m2) even whole study area has solar radiation higher than 1800 kWh/m^{2,} High resource in south and south-eastern and south-western regions → Huge deployment capacity of solar energy in global form is possible in Afghanistan, Temporally June receive highest solar radiation due to high solar incidence whereas November receives minimum solar radiation. Annual average GHI map for the country is generated for the year 2007-2021.

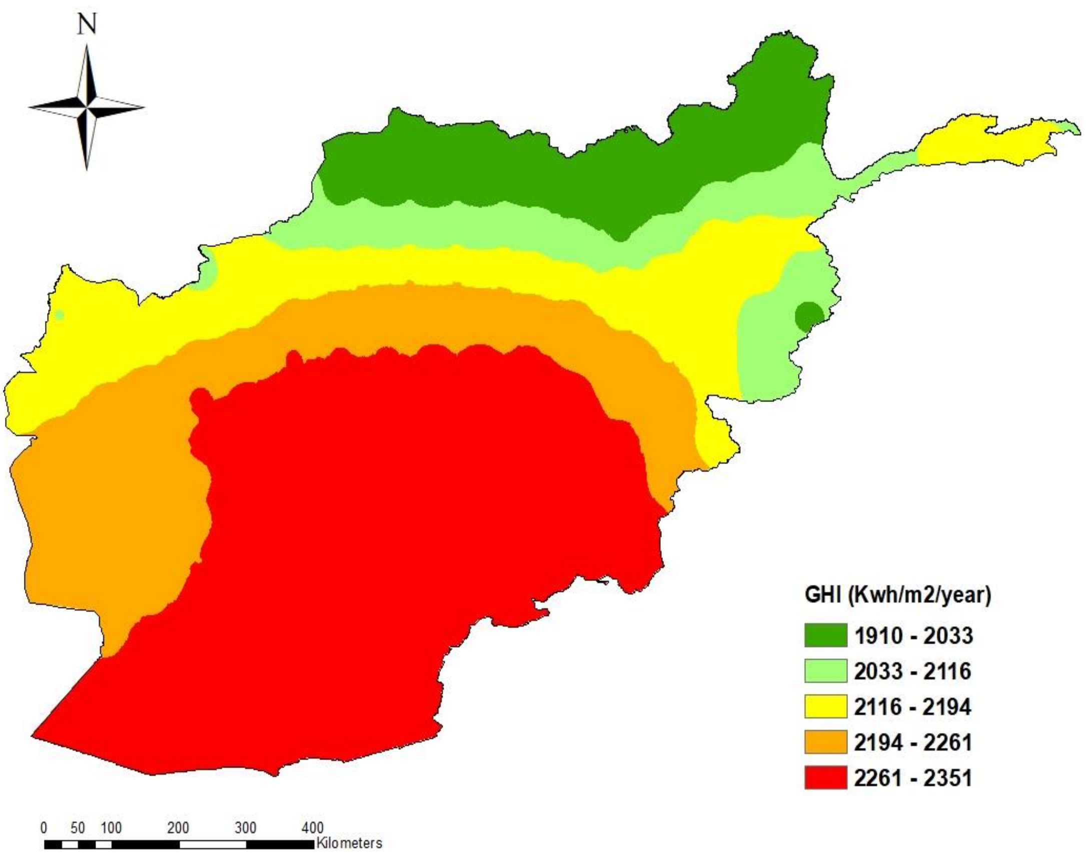

Figure 6. Afghanistan annual Global Horizonal Irradiance map

4.3. Site suitability analysis

4.3.1. Criteria excluded, capacity factor mapping

Many areas in central, north, northeast, and northwest parts are excluded due to high slope higher than 5% and permanent snow cover area. High-capacity factor attributed with high solar radiations and low temperature's areas, Highest Capacity factor is attributed with dual axis tracking system and has disproportionally relation with

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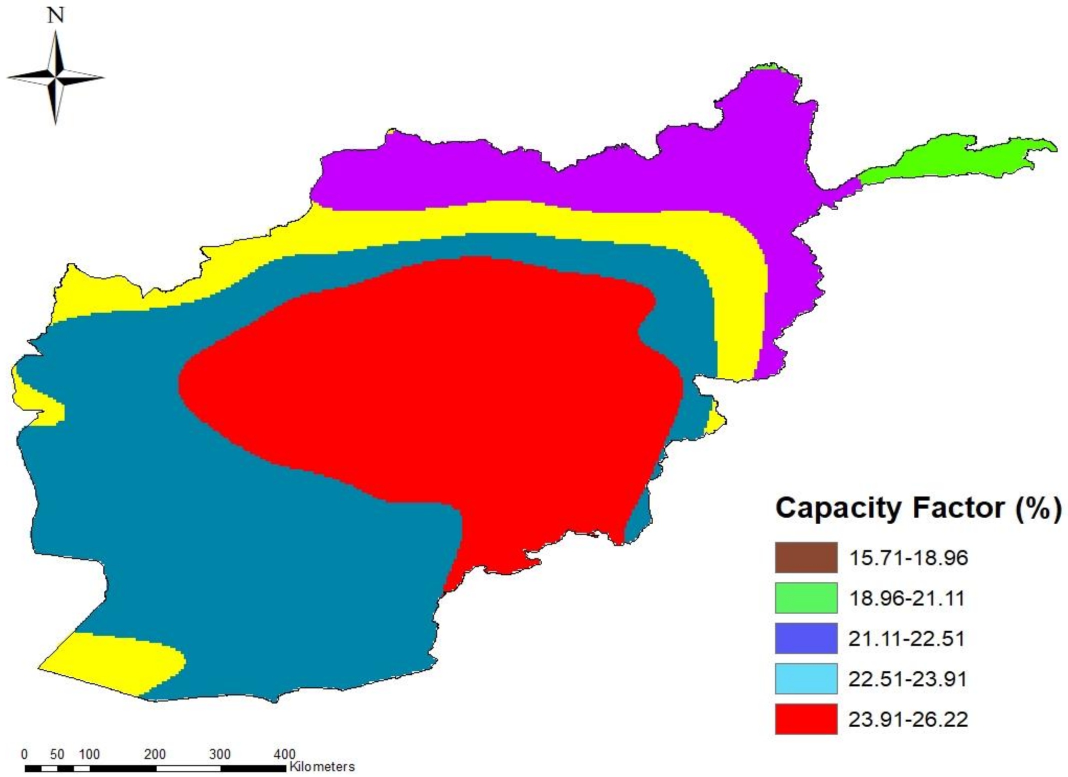
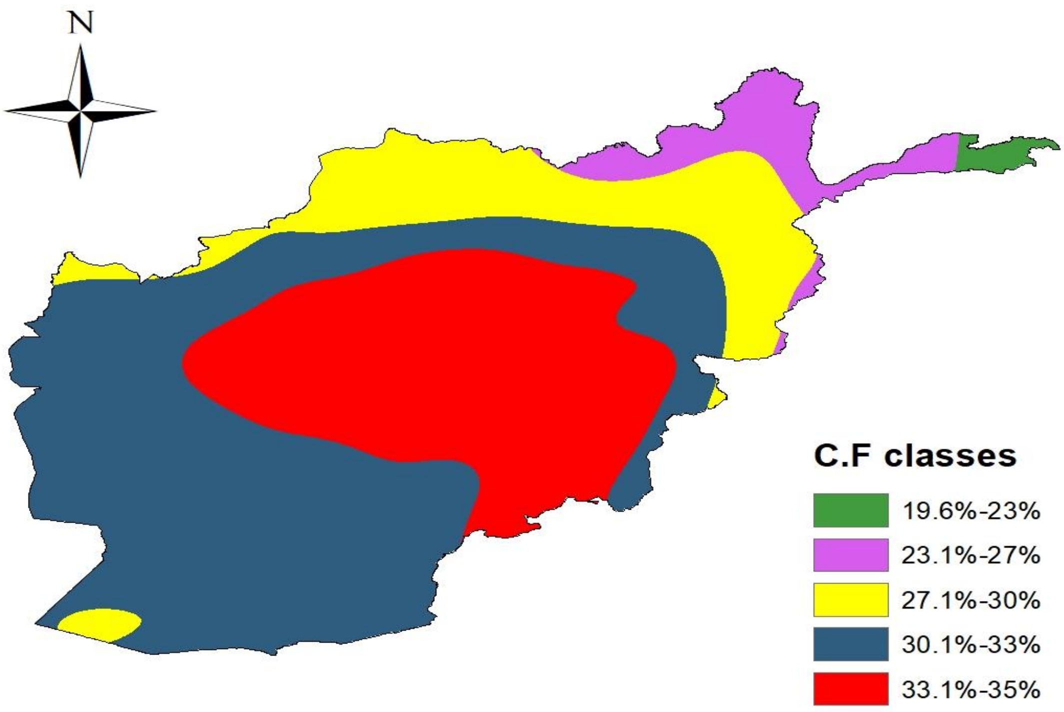
Levelized cost of electricity, capacity factor maps are depicted in figure.8 (a, b, and c) respectively depicts fix tilted, single axis, and dual axis mounting systems.



(a) Fixed tilt



(b) Single axis

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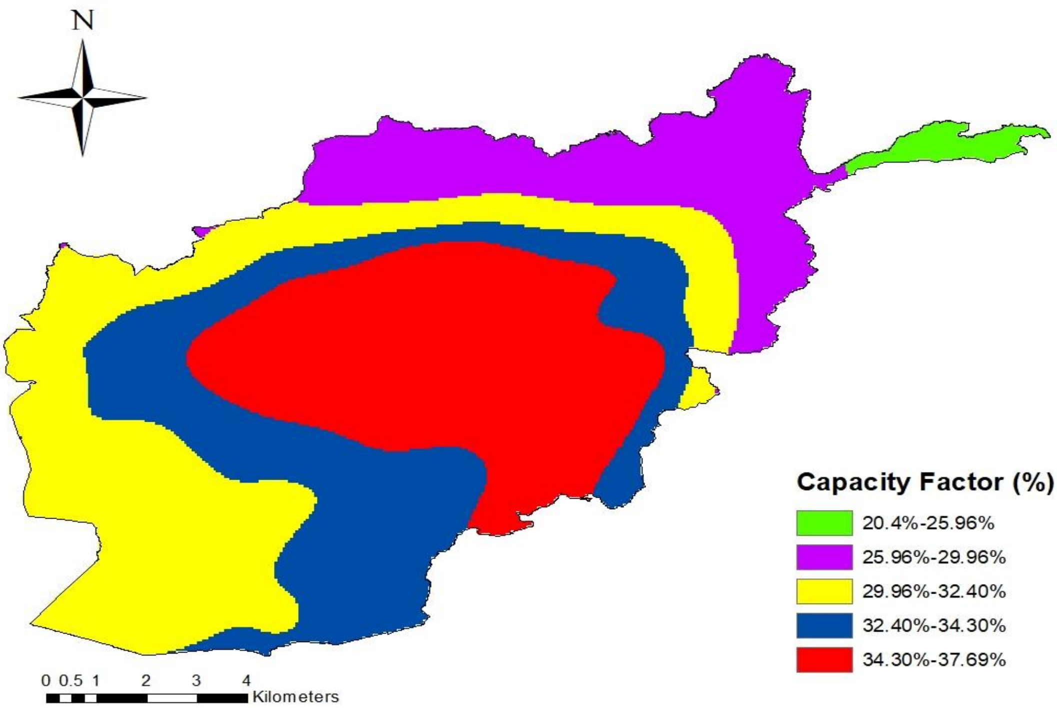

(C) dual axis tracking system

Figure 7. Capacity Factor maps

4.3.2. Levelized Cost of Electricity

LCOE is the ratio of the total cost of the project during its lifetime consisting of both initial costs and O&M cost to the electricity produced over its lifetime of the plant. It's a robust calculation to compare distinct electricity harnessing technologies, and it's determined in terms of $/kWh or $/MWh. LCOE can be shown as follows:

$$\text{LCOE} = \frac{\text{Total cost during lifetime}}{\text{Total electricity produced during lifetime}}$$

Almost all kind of tracking system present low value for central region of the country. Lowest value is attributed with single axis tracking mode among all three systems, based on this high technical potential we selected single axis LCOE map as main criteria for sit suitability analysis, more than 65% of study area found to have LCOE lower than global average. Global average of LCOE is 0.057$/KWh.

LCOE maps are shown in figure 9 (a, b, and c) show fix tilted, single axis and dual axis mounting systems respectively.

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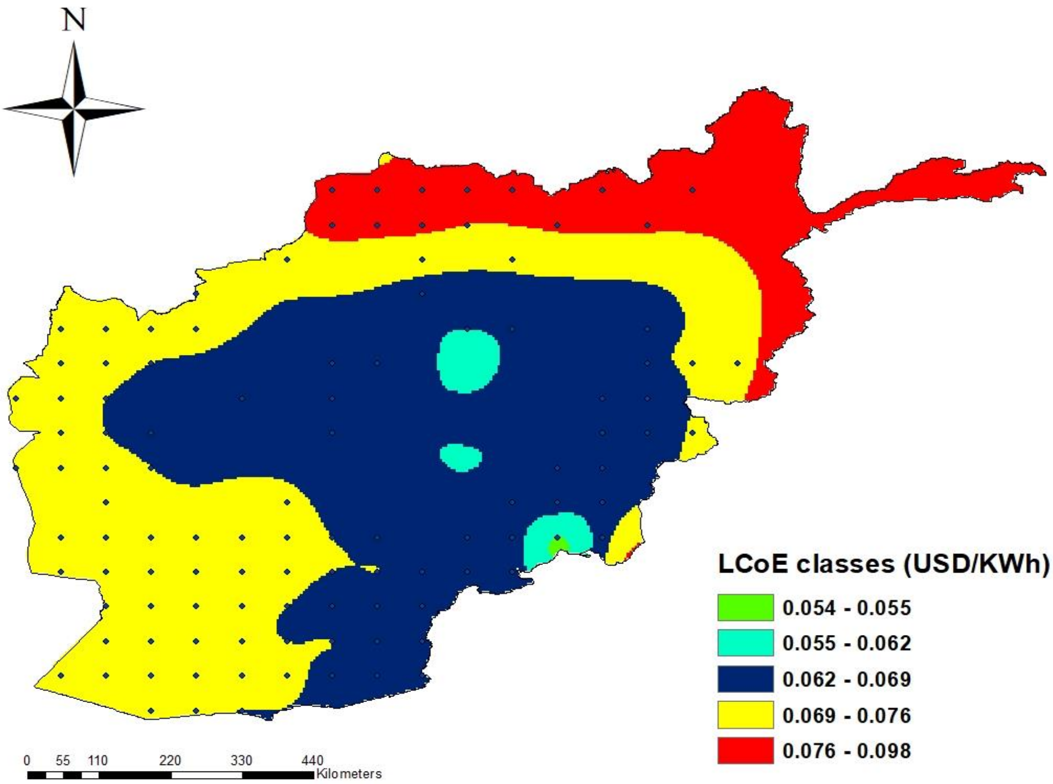
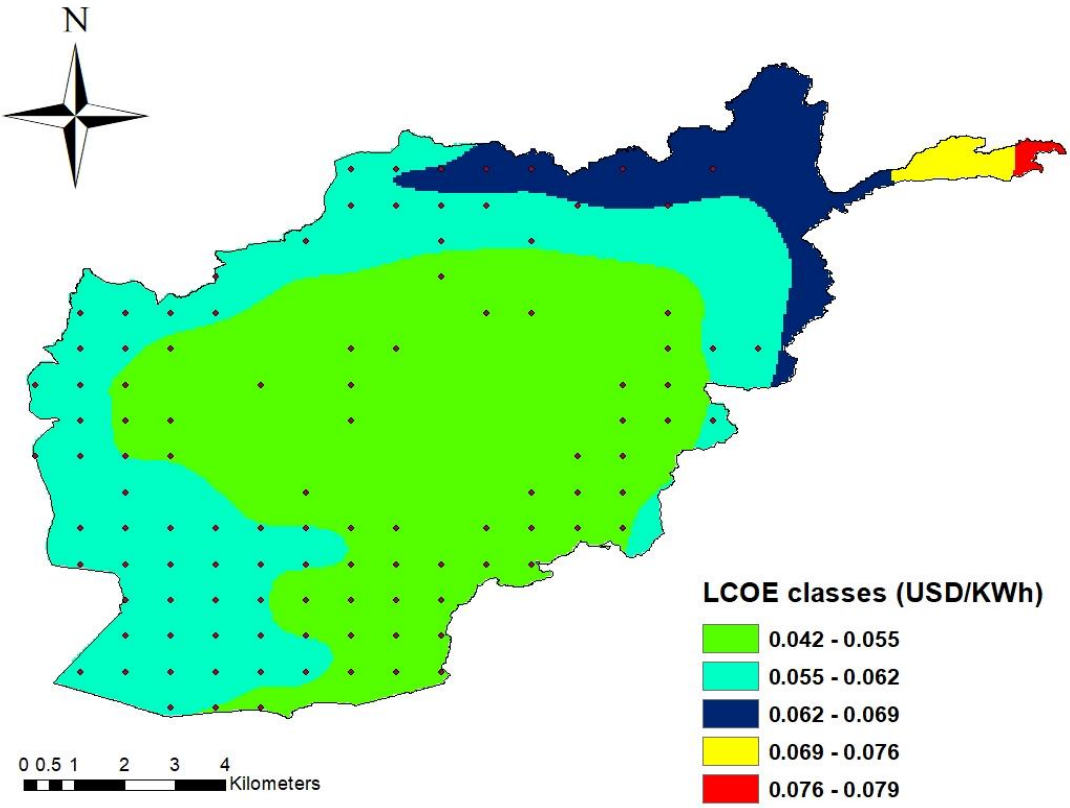


(a) Fixed tilt



(b) Single axis

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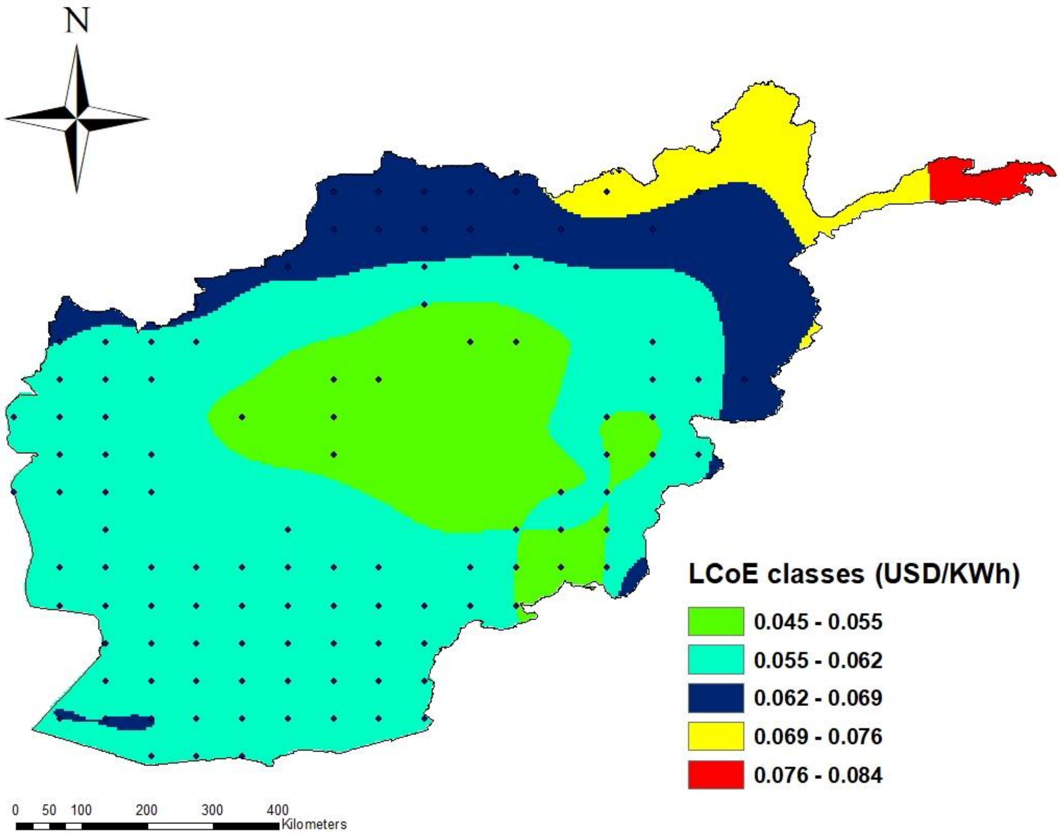

(c) Dual axis

Figure 8. Levelized Cost of Electricity (LCOE)

4.3.3. Suitable sites for PV power plants

The final weightages of AHP factors and sub parameters are illustrated in table 9.

Site suitability map shows different suitability classes which are shown in the (figure 10) by different colors from not suitable sites to extremely suitable site.

Southern and South-western parts of the country have high Solar radiations capacities, but their suitability is decreased due to distance from transmission network and high Temperature.

Extremely suitable site for photovoltaic power plant installation located in the central Bamyan province of the country, which has extremely high potential for deployment. It's depicted in figure 11.

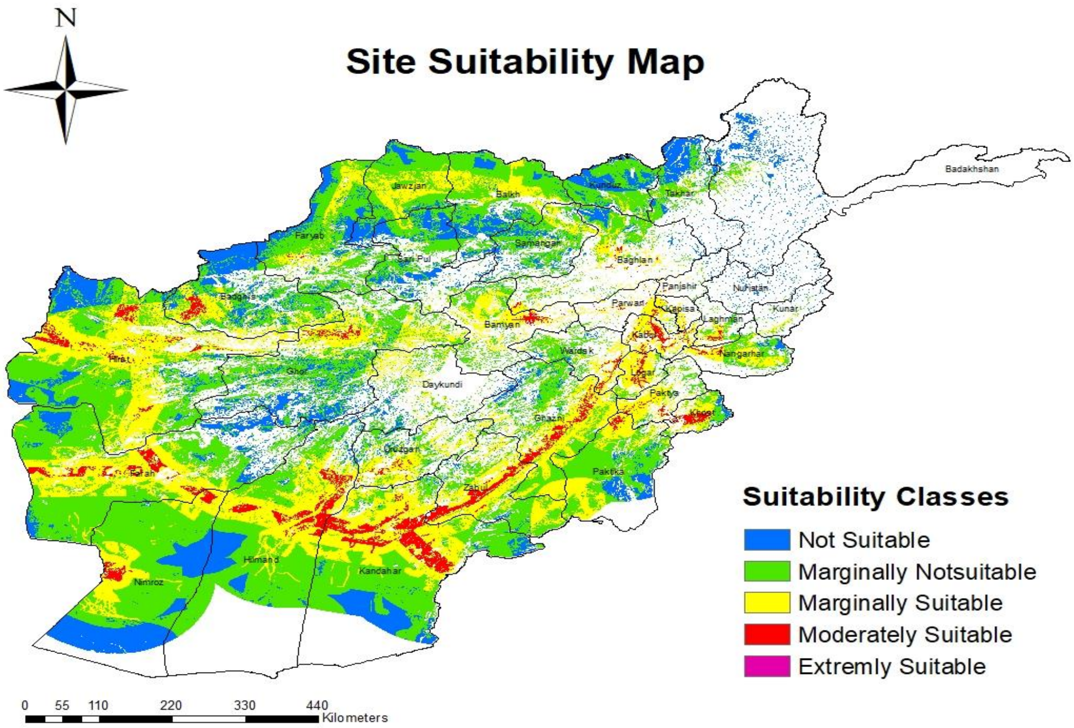

Figure 9. Site suitability Map

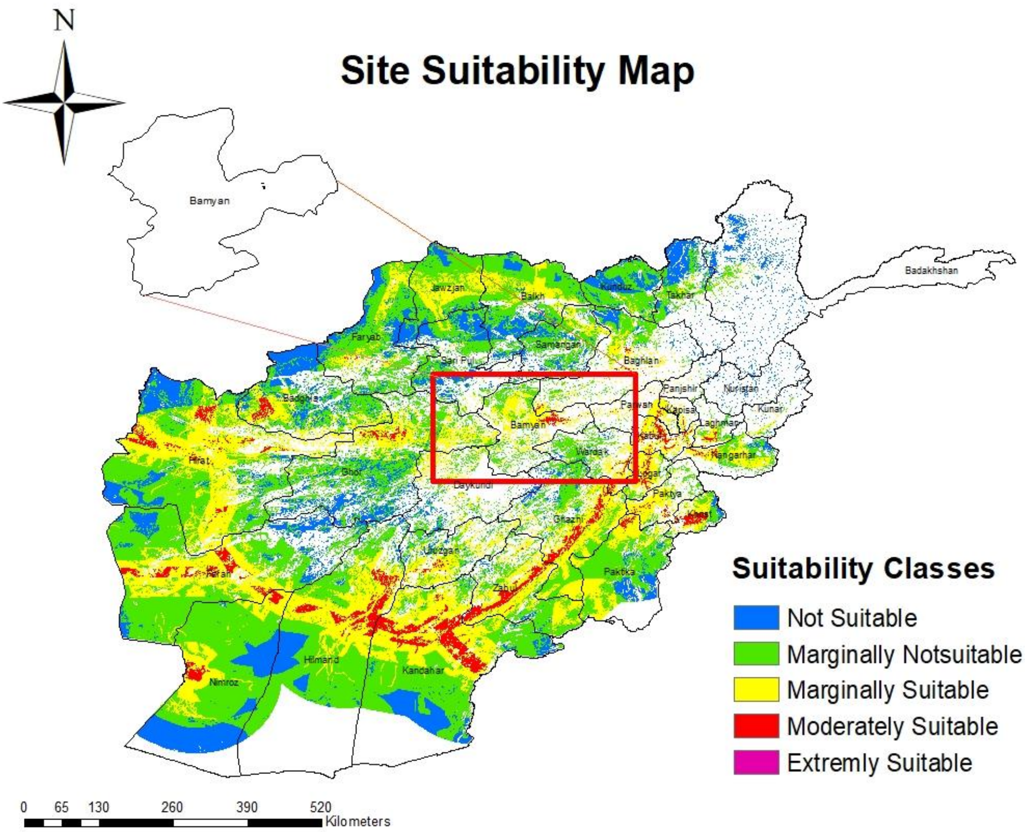

Figure 10. Extremely suitable site

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Table 9. Final weights for main and sub criteria used in AHP

Criteria	Unit	Final Weights	Sub-Criteria	final Weights
LCOE	$/kWh	0.4476	0.042088568 -0.049504557	0.5028
			0.049504558 -0.056920546	0.2602
			0.056920547 -0.064336535	0.1344
			0.064336536 -0.071752524	0.0678
			0.071752525 -0.079168513	0.0348
Distance from road	km	0.1109	0.1 to 1	0.5028
			1 to 5	0.2602
			5 to 10	0.1344
			10 to 50	0.0678
			>50	0.0348
LULC		0.1266	Barren Land	0.3710
			Sparse Vegetation	0.2788
			Grassland	0.1995
			Cropland	0.0819
			Tree Cover	0.0439
			Shrubland	0.0249
Distance from TN	km	0.2347	0 to 10	0.5028
			10 to 25	0.2602
			25 to 50	0.1344
			50 to 100	0.0678
			100-150	0.0348
Water Stress Areas	%	0.0286	Low (<10%)	0.5028
			Low-Medium (10-20%)	0.2602
			Medium-High (20-40%)	0.1344
			High (40-80%)	0.0678
			Extremely High (>80%)	0.0348

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Protected Area	0.0516	Not reported	0.4825
		VI: PA with sustainable use of natural resources	0.2358
		V: Protected Landscape	0.1523
		IV: Habitat Management	0.0868
		II: National Park	0.0426

4.4. Technoeconomic-environmental feasibility analysis for utility scale PV power plant

In the study area the proposed 50MW PV power plant is examined from technical, economical, and environmental perspective. For the mentioned 50MW PV power plant 60 cell Polycrystalline and monocrystalline 200000 panels having 250W capacity and 25 inverters of 2MW capacity have been selected from Jinko solar manufacturer, technoeconomic feasibility analysis are conducted for evaluation of fixed tilt, single axis and dual axis mounting systems in terms of electricity generation, net present value, levelized cost of electricity, internal rate of return, payback period and greenhouse gas emission reduction analysis in the selected site.

4.4.1. Electricity generation

It’s shown that highest electricity generation potential (162942 MWH) is attributed with dual axis tracking system for both poly crystalline silicon and mono crystalline silicon modules graph 12.

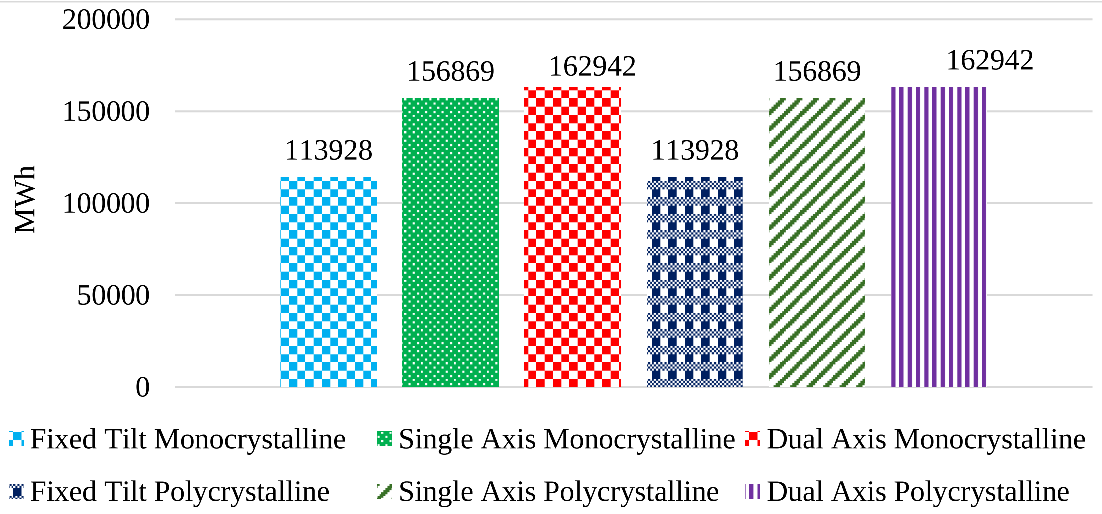

Figure 12. Electricity generation values of selected modules and different tracking sys

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4.4.2. Net Present Value

NPV present contrast between the present value of cash inflows and cash outflows. A positive NPV specify that the project is financially viable while a negative NPV represent that the project is financially infeasible, high economically feasibility is attributed with Dual axis Poly crystalline silicon module plant figure 13.

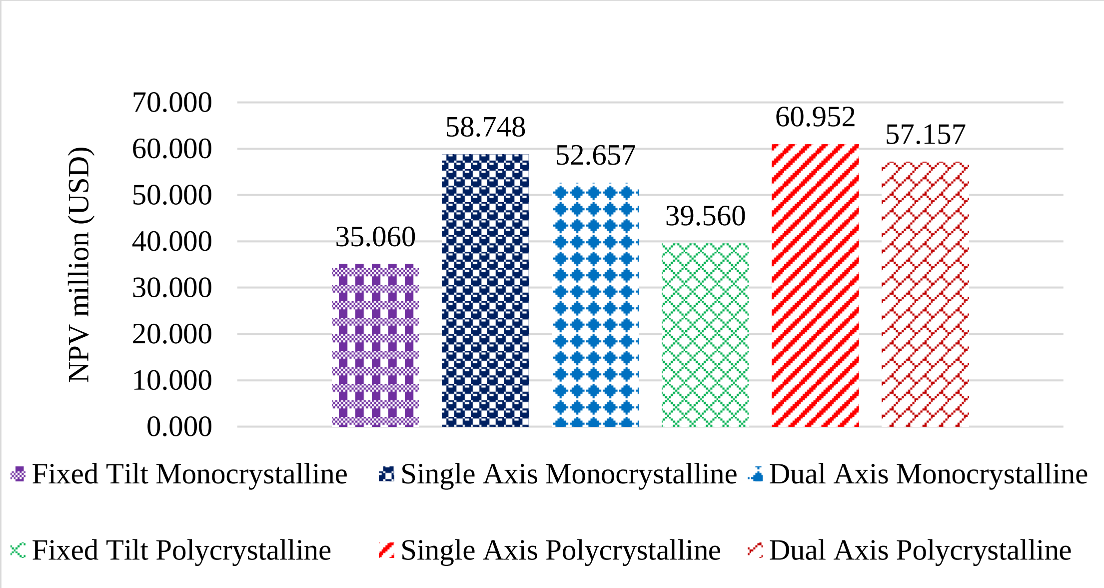

Figure13. Net Present Value of selected modules and different tracking system

4.4.3 Internal rate of return

IRR values for all combinations are higher than the threshold value, which is discount rate (12.1), highest internal rate of return value is attributed with single axis polycrystalline, shows high profitability it's depicted in figure 14.

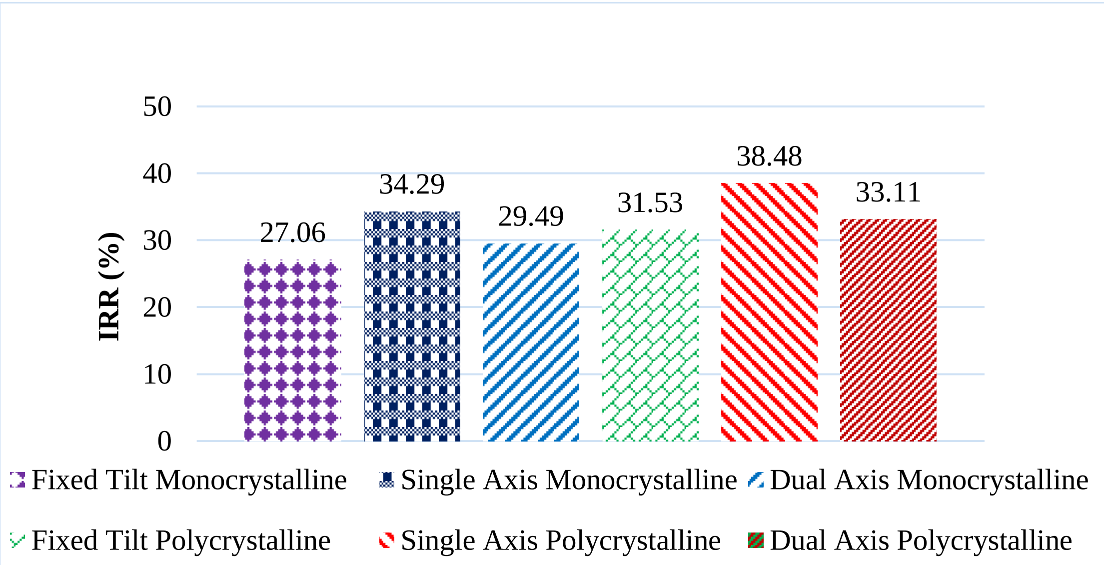

Figure 14. Internal Rate of Return of selected modules and tracking systems

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4.4.4 Levelized cost of electricity

LCOE is the ratio of total cost of project during its lifetime including initial cost, O&M cost and periodic cost to energy produced during the lifetime of the project. Single axis polycrystalline shows high profitability over others Tracking systems LCOE values for all combinations are less than the global average, shown in (fig 15).

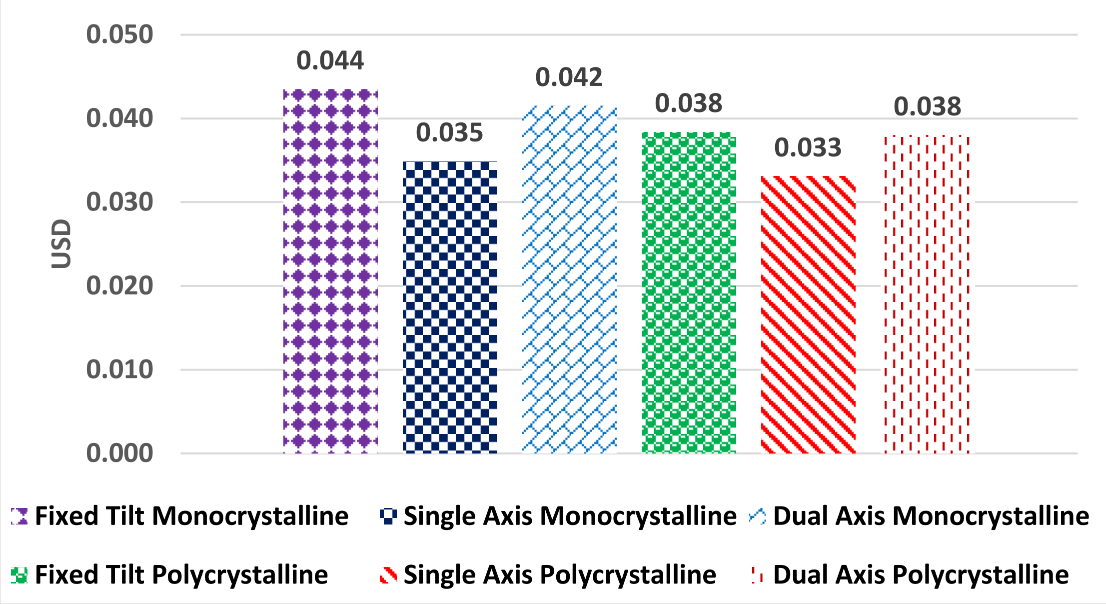

Figure 15. Levelized Cost of Electricity of selected modules and tracking systems

4.4.5. Pay Back Period

PBP is defined as the time needed to recover the initial cost of the plant. An economic comparison between different mounting system and different modules demonstrated that use of single axis mounting system of Poly crystalline silicon panels is the most economical option for selected point. Single axis poly crystalline silicon shows high profitability over others Tracking systems shown in figure 16.

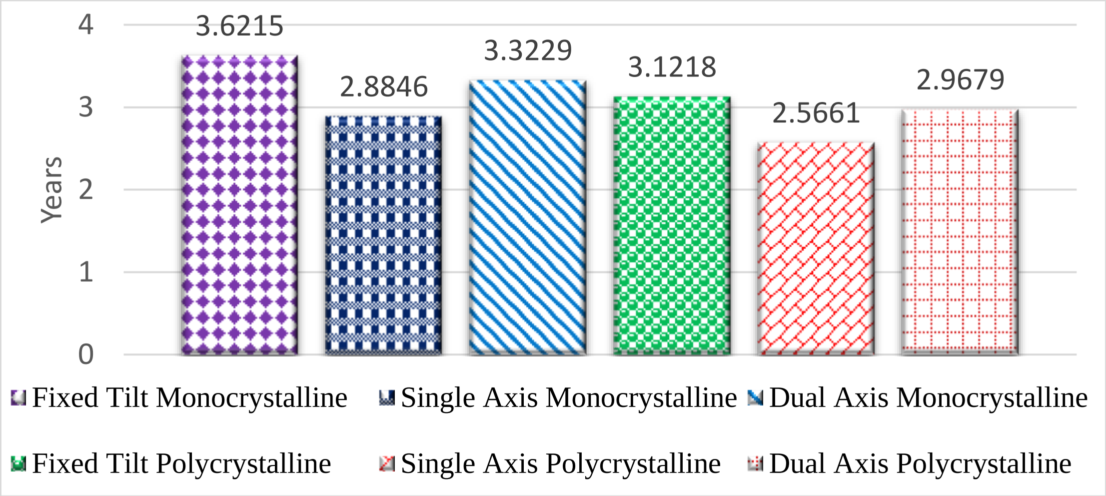

Figure 16. Pay Back Period of selected modules and tracking systems

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4.5. Greenhouse gas emission

GHG emission analysis is performed to measure the yearly net GHG reduction in ktons of CO2 per year (ktCO2/year) because of the deployment of the new PV plants in place of the baseline fossil fuel electricity plant is shown in figure 21 and it also shows GHGs emission reduction.

The high reduction of GHG emission is attributed with dual axis system, the estimated value is 123 KtCO2e.

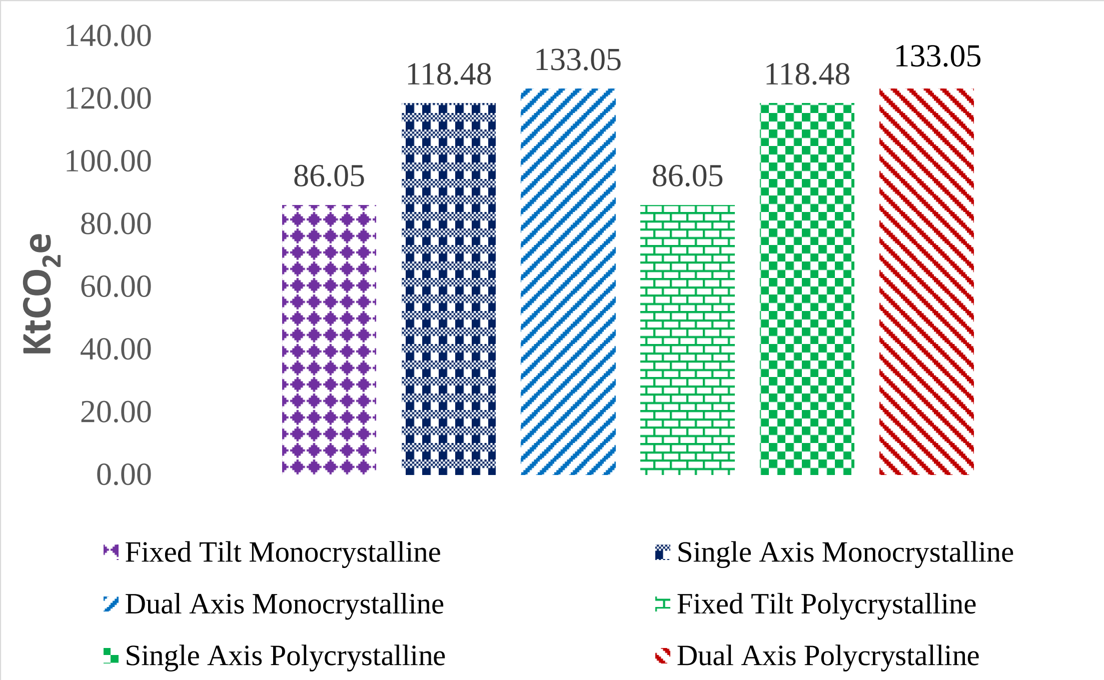

Figure 17. Proposed PV power plant expected GHGs emission reduction of selected modules and different tracking systems

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CHAPTER 5

Conclusions and recommendations

In this study, MERRA-2 re-analysis datasets of Global Horizonal Irradiance and other meteorological variables (temperature and wind speed) were validated against observed data at different timescales and multiple locations in the study area. Annual average Global Horizonal Irradiance resource map from compared dataset was produced. In order to undertake a concise technical resource assessment of photovoltaic power plants over Afghanistan. Then study area is screen out based on solar resource capacity, topography, and land use classes. Additionally, a multi-criterion based Analytic Hierarchy Process incorporating socio-techno-economic elements were used to examine the suitability of a site for future decision-making. From the study, the following findings can be drawn:

- MERRA-2 Global Horizonal Irradiance strongly correlates with ground Global Horizonal Irradiance data, Overall underestimation due to overestimation of aerosols factorization in retrieval algorithm.
- High bias is measured for Global Horizonal Irradiance due its high potential to be influenced by cloudiness, humidity, and aerosols in Atmosphere. Huge error (RMSE) assigned to each data source and timescales may be because of distinct cell size of reanalysis datasets and in what followed, them being validated to data of a single point source since irradiation is almost never geospatially similar.
- Ambient temperature. MERRA-2 daily Temperature strongly correlates with ground Temperature because of diminishing of fixed surface temperature in MERRA-2 Algorithm.Almost all location shows high correlation with observational data shown in (Table 9). The 'R' value is determined to be higher than 0.9 for all selected location. Studies have claimed that this may possibly be due to elimination of fixed sub-surface temperature and rendering of power conduction via the surface in MERRA-2 algorithm.
- 100% of land area of Afghanistan has solar radiation greater than cutoff limit 1400 kWh/m2/day

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- South, Southwestern, and southeastern parts of the country have high Solar radiations capacities, but their suitability is decreased due to distance from transmission network and high Temperature.
- Extremely suitable site located in places where high solar resources, relatively low temperature are available and have less distance from transmission networks, access to transmission network and temperature in proximity eliminates many high potential sites for solar development.
- Energy Generation Potential of 162.9 GW from dual axis photovoltaic deployment at selected site can be achieved.
- All selected combinations of photovoltaic models are found to be profitable with IRR greater than 12.1%, economically comparison between all type of tracking system show that the single axis polycrystalline silicon is the highest profitable among them
- High Reductions in annual greenhouse gases emissions up to 133 $ktCO_2e$ can be expected from dual axis PV deployment.

Low certainty data can straightly affect power plant profitability and bankability in terms of predicting technical and financial associated risk, not only for PV power plant facilities but for any other sustainable power technologies. Current study demonstrates the importance of ahead of time data validation performance, and reciprocal influence of technical, economic, topographic, and environmental factors on PV facilities execution modelling and upcoming installation likelihood.

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