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Master of Science Program Energy and Nuclear Engineering

Master Thesis

Wind and solar photovoltaic power potential estimation method and application for the case of Uzbekistan

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Introduction

Technological developments made the energy of any form as important part of our life and its importance as resource is increasing with the time. Nowadays many factors are contributing to the increasing spreading of renewable energy sources: the increasing energy demand, the decreasing availability of the fossil fuels, the increasing problems related to pollution and an unsustainable lifestyle. Photovoltaic and wind turbine technologies represent alternatives with relatively high spreading and good development opportunities.

This work primarily treats method for renewable energy calculations and their financial and effect to environment. Formulations, data source and brief explanations of concepts have been collected in systematic way. This method is used for planning actions and then for separate projects. Secondly, this method is applied to the case of Uzbekistan by selecting test sites from different parts of the country. The main results are presented in figures and in tabular forms.

In addition, activity diagram which can help for transforming in perspective this method to the online source for renewable calculation is presented.

1 General theory

1.1 Words on renewable energy sources

During last decade renewable energy sources' share in power generation have increased to the level of full part of energy industry. Driving force for this growth is primarily policies to implement renewables which has been done on social pressure and scientific evidence of anthropological origin of global warming. Protection of environment and reduction of $CO_{2eq.}$ have been firmed by international laws and agreements. Incentives in different states have helped to development of this field of energy and now it has reached the level to be competitive with traditional electricity generation. For example, generation from wind power costs less as 5c$/kWh [II]. And from fossil fuel generation also has generation cost per kWh of electricity about this value. 85% of wind turbines are fully recyclable. These indicators allow reduction of incentives and sustainably continue to grow the renewables such as wind and solar power generation.

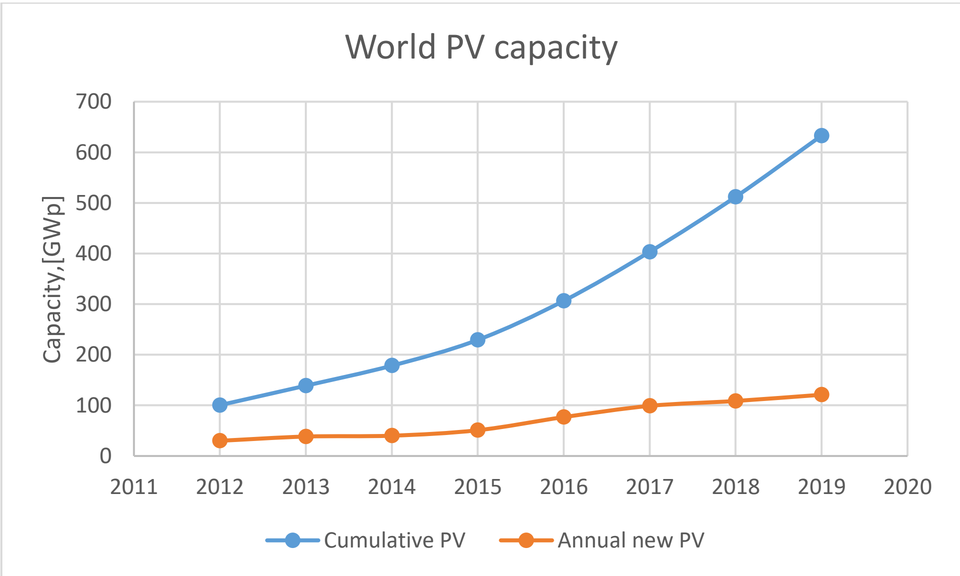

Figure 1-1: PV capacity of the world [II]

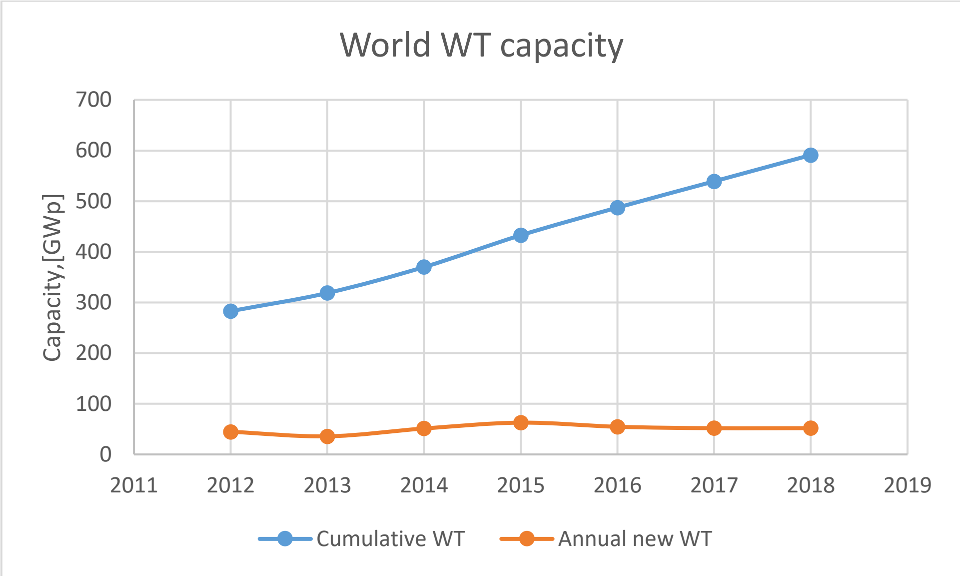

Figure 1-2: Wind power capacity of the world [II]

Together with all the progresses there are still problems to work on. Even if the generation cost was lowered the plant investment costs remain high compared to thermal power plants. At places where fossil resources are available the last one may be better option.

Capacity factors of renewables have increased over time but remains low and depends on location which means longer down times. To meet the grid load behaviour the storages must be integrated to the system.

Increase in the volume of renewable energy technology production has reduced their cost but the production power should be enough to supply the increased demand for installations. Especially, previous stage plants are finishing their exploitation periods like UK, France or Uzbekistan which is considered here. They should have not only capital for constructions of power plants but also resources for renewables.

Study of world renewable potential and make a map of plausible power plants locations may create opportunity for successful investments and beyond for high voltage international grid fed by renewable energy. With such considerations this work treats method of solar and wind power potential estimation for planning. Storage and optimisation of power plant size is not included into the scope of this work.

1.2 Description of RES calculation method

Method development for renewable source calculation is based on fundamentals of power generation from photovoltaic modules and wind turbines. All the technical information regarding the process of generation and financials can be found in the discipline of power generation from renewable resources and energy economics from Politecnico di Torino. These formulation in this work are brought to systematic order to calculate power generation, financial indicators and $CO_{2eq.}$ emissions. This method is applied only for onshore installations.

In section 2 theoretical part of the method is explained. The process begins with selection of location. the site must be valid for installation of power plant. GIS data or map of terrain is necessary to be observed for obstacles such as lake, river, forest rocks, mountains or desert dunes. Selected location is tested for productivity of PV modules and wind turbines. Primary inputs are meteorological data. These data can be considered for different time interval and time step of the data. In this work annual data are considered with hourly time step. Such qualities of data and related properties given in description of the data for every parameter where it is necessary. Data sources are indicated together with a link and an availability notice. Collected input parameters are used consecutively to calculation by formulas. Components in the formulas and outputs find short explanations.

In this work the concepts of power balance such as self-sufficiency, grid exchange and other are not considered. Being out of scope of this work these concepts will be used for definite power loads. In such case the power plants size can be checked for optimal value. This work assumes that all the power generated from power plants are sold to the grid.

Being part of bigger project, members of research group in Energy department of the Politecnico di Torino, have got share in this work. By effort of them this method is transferred into software on platform of excel. Excel tool's results are used in sections 3.4-3.6.

2 Theory for analysis of generation from photovoltaic power plant and from wind farm

In this section, the information regarding of renewable energy source calculation method is organised to make it easier to orient throughout the calculation process. This organisation allows to be clear with input data, calculation processes and output data. Systematized organisation helps to be in the relevant units of measurement, to have matching size of data and its temporal step. Information of the data which are necessary to be obtained from external datasets are grouped into data source, temporal step, spatial distribution, unit of measurement, symbol, file format of data retrieved from data source and size of imported data. And the information of calculation and output data are grouped into unit of measurement, symbol, formula and data inputs. And, additional groups where necessary to clarify the condition of the data such as data source for some constants, temporal and spatial distribution have been indicated. Concepts and formulations are provided with brief explanations.

2.1 Meteorological and geographical data

2.1.1 Global radiation

Global radiation is the main input to calculate the power and energy production of photovoltaic systems. It is the sum of direct normal radiation, diffuse radiation and albedo effect of surrounding on to a flat unit surface. For observations for definite period it can be given as average for time interval. For this work hourly average radiation during a year has been considered.

- **Data source:** Data are taken from the following external datasets:
  - SODA database, available at the following link: www.soda-pro.com/web-services/typical-years/normal-year-global-radiation-temperature
  - PVGIS database, available at the following link: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

- **Temporal step of the data**:
  - SODA: the dataset SODA refers to a period of time of 30 years, between 1961 and 1990. Data are given as hourly average values. Values referring to individual years are not available. 1990 is arbitrary year to indicate this is typical year.
  - PVGIS: the dataset PVGIS refers to a period of time of 10 years, between 2006 and 2016. Data are given as hourly average values. Data for each single year are available to perform deviation analysis for statistical purposes.
- **Spatial distribution of the data**:
  - SODA: the dataset SODA refers to the whole word
  - PVGIS: the dataset PVGIS refers to great part of the BRI. In particular, the eastern part of China is not included.

Actually, it is not possible to define the spatial granularity. It is supposed that data refer to a wide area (wider than 50x50km)

- **Unit of measurement**: kW/m^2
- **Symbol:** *G*
- **File format**: excel file with extension ".xls"
- **Data size after the import**: 8760*N_years

The data can be downloaded from the datasets only after the definition of tilt and azimuth of PV modules. The optimal values of tilt and azimuth depends on the latitude and earth morphology. The dataset PVGIS provides the optimal values of tilt and azimuth for every location in its database. This service also provides option of tracking of sun position during a year. By which the angle between direct radiation to surface and normal to the surface is minimized at every time interval.

2.1.2 Air temperature

Air temperature is an important input to calculate the power and energy production of photovoltaic systems. By it can be defined PV cell operating temperature. In practice by variation of air temperature varies also air density by Charles' law which affects the generation from wind turbines.

- **Data source:** Data are taken from the following external datasets:

  - SODA database, available at the following link: www.soda-pro.com/web-services/typical-years/normal-year-global-radiation-temperature
  - PVGIS database, available at the following link: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
- **Temporal step of the data**:
  - SODA: the dataset SODA refers to a period of time of 30 years, between 1961 and 1991. Data are given as hourly average values. Values referring to individual years are not available.
  - PVGIS: the dataset PVGIS refers to a period of time of 10 years, between 2006 and 2016. Data are given as hourly average values. Data for each single year are available to perform deviation analysis for statistical purposes.

The datasets presented above give air temperature measurement at 2 meters above the ground.

- **Spatial distribution of the data**:
  - SODA: the dataset SODA refers to the whole word
  - PVGIS: the dataset PVGIS refers to great part of the BRI. In particular, the eastern part of China is not included.

Actually, it is not possible to define the spatial granularity. It is supposed that data refer to a wide area (wider than 50x50km)

- **Unit of measurement**: °C
- **Symbol:** T_a
- **File format**: excel file with extension ".xls"
- **Data size after the import**: 8760*N_years

Variation of air temperature changes also air density. Air density is important component of energy which air flow conveys on to blades of wind turbines. As molar mass of air depends on its composition which varies in unpredictable manner, a dry air composition has been considered. The air density is calculated by Charles' law. The formulas are the following:

$$\rho(T_a) = \frac{\rho(T_0)*T_0}{T_a} \tag{2-1}$$

Components of formula (2-1) are air temperature (T_a), standard air temperature (T_0 =288.15 K) and an air density at reference T_0 ($\rho(T_0) = 1.225\frac{kg}{m^3}$).

Effect of variation of air density related to altitude from sea level (if it is required the barometric formula by altitude can be applied) and temperature for this work's perspective is considered to be negligible and input value of air density is assumed to be constant, which is equal to at standard conditions. By this we avoid complication to modify the power curve of wind turbines.

2.1.3 Wind speed

The wind speed is the speed of the wind measured by anemometers at a specific altitude. It is the main parameter for the calculation of power and energy production from wind turbines. It is also used to increase the accuracy of photovoltaic production models.

- **Data source:** Data are taken from the following external datasets:
  - Merra database, available at the following link: http://www.soda-pro.com/web-services/meteo-data/merra
  - PVGIS database, available at the following link: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
- **Temporal step of the data**:
  - MERRA: the dataset MERRA refers to time steps range from 1 min up to 1 month (original data are hourly). The data are available since Jan. 1980 and are regularly updated with approx.one month of delay
  - PVGIS: the dataset PVGIS refers to a period of time of 10 years, between 2006 and 2016. Data are given as hourly average values. Data for each single year are available to perform deviation analysis for statistical purposes.
- **Spatial distribution of the data**:
  - MERRA: the dataset MERRA refers to the whole word. Spatial resolution of approx. 50 km.
  - PVGIS: the dataset PVGIS refers to great part of the BRI. In particular, the eastern part of China is not included.

Actually, it is not possible to define the spatial granularity. It is supposed that data refer to a wide area (wider than approx.50 km)

- **Unit of measurement**: m/s
- **Symbol:** u_w
- **File format**: file with extension ".csv"
- **Data size after the import**: 8760*N_years

The wind speed is measured at 10 m of altitude with respect to the ground for above datasets.

2.1.4 Typology of surface

Qualitative grade of a given area for applicability of RES plant installations.

- **Data source:** Data are taken from the external datasets:
- **Temporal step of the data**: the data considered has no temporal variation for period less than RES plant lifetime.
- **Spatial distribution of the data**: the dataset refers to the whole word or to the scope of dataset.
- **Unit of measurement**:-dataset gives anwers to possibility of installation of PV modules or wind turbines.

From dataset we define the possibiltiy to install the plant at specified area. Location may be on water, mountain rocks or unstabile doons of desert. Evenmore the location should be reached easyly as possibly. For the test of location maps of location can be used in case absence of specified datasets.

Dedicated area is supposed for checking the typology of surface before specific project work.

2.1.5 Altitude

Altitude is elevation of terrain from level of reference sea. An average altitude and maximum altitude are considered in order to evaluate the shading effect due to mountains and hills.

- **Data source:** Data are taken from the following external datasets:
  Soda database, available at the following link: http://www.soda-pro.com/web-services/altitude/altitude-of-a-point
- **Temporal step of the data**: the data considered has no temporal distribution
- **Spatial distribution of the data**:
  SODA: the dataset SODA refers to the whole word. This Web service, provided by MINES ParisTech, returns the altitude value in meters from three different Digital Elevation Models:
  - SRTM: spatial coverage in degrees: [-56S;+60N] [-180W;+180E], spatial resolution 90 m, uncertainty 10 m.
  - GTOPO30": worldwide, 30" d'arc = 1 km.

- TB5': worldwide, 5' d'arc = 10 km.

- **Unit of measurement**: m.
- **Symbol:** h
- **File format**: excel file with extension “.xls”
- **Data size after the import**:2*N_sites

  As stated above effect of altitude to air density is considered to be negligeble.

2.1.6 Roughness of earth

Roughness of earth is height variation of terrain which affects wind speed

- **Data source:** Data are taken from the external datasets
- **Temporal step of the data**: the data considered has no temporal variation
- **Unit of measurement**: -m(meters)
- **Symbol:**-z_0

By logarithmic law the speed of wind cahnges by height. Roughness characterizes the change rate by height. It’s vaue depends on obejects present at the location. In general Technical data 0.1m value is applicable for open terrain. Smaller value of rugosity allows to install lower wind turbine tower and creation of force difference between higher blade and lower blades are smaller.

2.2 Energy calculation

2.2.1 PV power plant size

Installed capacity of the power plant. It is proportional to the number of modules and the nominal power of a single module.

- **Unit of measurement**: MW
- **Symbol**: P_r

Solar power plant size is calculated by this section based on the data inputs listed below. Number n on the index of $\boldsymbol{P_{r,n}}$ signifies alternative ways which a size can be defined. The preferred method is the first, in which the rated power ($P_{r,1}$) is calculated as a function of the available area. Thus, in this case, the calculated value expresses the potential of this RES in the selected area. The formula is the following:

$$P_{r,1} = \frac{S_{RES}}{PVOF} * \eta_{install} \quad (2\text{-}2)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - S_{RES}(km^2): Area considered for the installation the RES;
  - $PVOF$(km^2/MW): PV occupation factor
  - $\boldsymbol{\eta_{install}}$ is a ratio between the area suitable for installation of PV system. This is an empirical output of typology of surface, ground morphology and presence of obstacles

In the second case, the installed power is calculated as a function of the Intended investment cost (i.e., the quantity of money that can be invested in the project)

$$P_{r,2} = \frac{IIC}{IPVC} \quad (2\text{-}3)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - IIC($): Intended investment cost.
  - $IPVC$($/kWh): Installed PV plant cost.

For the cases where locality has got predefined portfolio for future energy generation, for the share of supply electric power from RES the rated power of the plant shall be calculated as in the following formula:

$$P_{r,3} = \frac{E_d}{Y_{PV}} \quad (2\text{-}4)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - E_d(kWh): Annual demanded production of electrical energy,
  - Y_{PV}(kWh/kW$_p$): Annual electrical energy yield at the test site.

While testing for optimal value of plant size nominal power of photovoltaic panels should be taken as size of step, then size of PV power plant is:

$$P_{r,4} = N_{pv} * \frac{P_{PV,r}}{1000} \quad (2\text{-}5)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $P_{PV,r}$(kW/unit): Nominal power of PV module specified by producer.
  - N_{PV}(unit): number of PV modules.

- **Data source:** Data are taken from the producers datasheets for product, e.g.:

  -https://www.jinkosolar.com

Operational characteristics of PV modules maybe different for every producer. In order to get yield of PV module at selected location one product is needed to get as reference.

2.2.2 Electrical energy production from PV

The power and energy production from PV generators.[1]

- **Temporal step of the data**: data are available with hourly, monthly and yearly step. In the first step of the project, an annual basis is used
- **Spatial distribution of the data**: depending on the inputs (e.g. solar radiation, air temperature and wind speed)
- **Unit of measurement**: kWh/year, kWh/month, kWh/day, kWh/hour
- **Symbol**: E_{pv}
- **Data size after the calculation of annual production**: N_years

The power and energy production from PV generators are calculated by this section starting from the data inputs listed below. The formulas are the following:

$$E_{pv,i} = (1 - \beta * i) * E_{pv} \tag{2-6}$$

Annual expected energy generation from PV plant in the ith year. Because of PV modules ageing production reduces linearly since the start of generation.

- **Data inputs:** Data are obtained by using the following inputs:
  - E_{pv}(kWh/year): annual electricity production
  - β(%): ageing of PV cells. $\beta = 0.5\% \div 1\%$
  - i: Age of PV modules

$$E_{pv} = \eta_{pv} * \frac{1000 * P_r}{P_{PV,r}} * \int_{t=0}^{8760h} P_{PV} * dt \tag{2-7}$$

Energy production in one year by PV power plant in case hourly average power is calculated for one module.

$$E_{pv} = \eta_{pv} * \int_{t=0}^{8760h} P_{PV}(t) * dt \qquad (2\text{-}8)$$

Energy production in one year by PV power plant in case hourly average power is calculated for total power plant size.

- **Data inputs:** Data are obtained by using the following inputs:
  - η_{pv}: PV plant availability factor
  - P_r (MW): PV power plant size
  - $P_{PV,r}$ (kW/unit): PV module nominal power
  - P_{PV} (kW):average electric power generated in a hour instant

$$P_{PV} = P_{PV,r} * \frac{G - G_0}{G_{STC}} * \eta_{mix} * \eta_{therm} * \eta_{conv} \qquad (2\text{-}9)$$

Hourly average power generated from one PV module.

$$P_{PV} = 1000 * P_r * \frac{G - G_0}{G_{STC}} * \eta_{mix} * \eta_{therm} * \eta_{conv} \qquad (2\text{-}10)$$

Hourly average power generated from whole PV power plant.

- **Data inputs:** Data are obtained by using the following inputs:
  - G(kW/m^2): Solar radiation
  - G_0(kW/m^2): Radiation level trigger. G_0=0.0177 kW/m^2, which represents the minimum level of irradiance needed to turn on the inverter.
  - G_{stc}(kW/m^2): Irradition of PV module at standard test condition. G_{stc}=1kW/m^2
  - η_{mix}: Mixed losses.
  - η_{conv}: Converter losses
  - η_{therm}: Losses due reduction of electrical potential due to increase of cell temperture.

$$\eta_{mix} = \eta_{dirt} * \eta_{refle} * \eta_{MPPT} * \eta_{cable} * \eta_{shade} \qquad (2\text{-}11)$$

Mixed losses coefficient considers the power reduction in a year due to various effects. Components of this coefficient are average values encountered in utility scale PV power plants practice. For specific product it is necessary comply with producers' data for product.

- **Data inputs:** Components are following:
  - $\eta_{dirt} \approx$ 0.98-losses due to dirt covered PV panel surface.
  - $\eta_{refle} \approx$ 0.97-losses due to reflection from front glass.
  - $\eta_{MPPT} \approx$ 0.99-losses due to MPPT inaccuracy.
  - $\eta_{cable} \approx$ 0.99-losses due to Joule effect in cables.
  - $\eta_{shade} \approx$ 0.99-losses due to shading from objects.

$$\eta_{conv} = \frac{P_{ac}}{P_{ac}+P_0+C_L*P_{ac}+C_Q*P_{ac}^2} \quad (2\text{-}12)$$

Converter losses coefficient considers losses occurring in a DC/AC inverter during conversion of DC current to AC. Its value depends on instantaneous power which is loaded to converter.

- **Data inputs:** Components are following:
  - P_0≈0.385kW-no load power losses along the operation for 55kW power rack.
  - $C_L \approx 7.0 \cdot 10^{-3}$ kW^{-1}-linear losses coefficient.
  - $C_Q \approx 2.3 \cdot 10^{-6}$ kW^{-2}-quadratic losses coefficient

$$\eta_{therm} = \gamma_{therm} * (T_c - T_{stc}) \quad (2\text{-}13)$$

Thermal losses coefficient considers cell operating temperature effect to generation potential.

- **Data inputs:** Components are following:
  - γ_{therm}: Power loss coefficient with respect to STC condition. γ_{therm}=0.3÷0.5%/°C
  - T_{stc}(°C): Temperature standard test condition. T_{stc}=25°C
  - T_c(°C): Cell operating temperature.

$$\mathrm{T_c} = \mathrm{T_a} + \frac{(\mathrm{NOCT} - \mathrm{T_{aref}})}{\mathrm{G_{ref}}} * \mathrm{G} \quad (2\text{-}14)$$

PV cell operating temperature without consideration of convective PV module cooling by wind.

- **Data inputs:** Data are obtained by using the following inputs:
  - T_a(°C): Air temperature

- $NOCT$(°C): Normal operating cell temperature. Given by producer in product's datasheet.
- T_{aref}(°C): Reference temperature for normal operating cell temperature. $T_{aref} = 20°C$
- G_{ref}(kW/m^2): Reference radiation for normal operating cell temperature. G_{ref}=0.8 kW/m^2

$$T_c = 0.943 * T_a + 0.028 * G - 1.528 * u_w + 4.3 \quad (2\text{-}15)$$

Empirical cell temperature considering wind effect which reduces cell temperature by convective cooling. u_w is wind speed that comes from data obtained for wind turbine energy calculation.

Annual energy generation for the first years serves for benchmarking the location productivity with reference technology.

$$Y_{PV} = \frac{E_{pv}}{P_{PV,r}} \quad (2\text{-}16)$$

- **Unit of measurement**: kWh/ kW$_p$/year
- **Symbol**: Y_{PV} (Yield of PV)

This value helps to compare locations in terms of energetical performance.

2.2.3 Wind power plant size

Total capacity of wind turbines at specified area.

- **Unit of measurement**: MW
- **Symbol**: $P_{r,w}$

Wind power plant size calculated by this section is based on data inputs listed below. Number n on the index of $\boldsymbol{P_{r,w,n}}$ signifies alternative ways which a size can be defined. The preferred method is the first, in which the rated power ($P_{r,w,1}$) is calculated as a function of the available area. Thus, in this case, the calculated value expresses the potentiality of this RES in the selected area. The formula is the following:

$$P_{r,w,1} = \frac{S_{RES}}{WTOF} * \eta_{install} \quad (2\text{-}17)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - S_{RES}(km^2): Area considered for the installation the RES;
  - $WTOF$(km^2/MW): WP plant occupation factor
  - $\eta_{install}$ is a ratio between the area suitable for installation of WT system. This is an empirical output of typology of surface, ground morphology and presence of obstacles

In this second case, the installed power is calculated as a function of the Intended investment cost (i.e., the quantity of money that can be invested in the project)

$$P_{r,w,2} = \frac{IIC}{IWPC} \tag{2-18}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - IIC($): Intended investment cost.
  - IWPC($/kWh): Installed WP plant cost,

For the cases where locality has got predefined portfolio for future energy generation, for the share of supply electric power from RES the rated power of the plant shall be calculated as in the following formula:

$$P_{r,w,3} = \frac{E_d}{Y_{WT}} \tag{2-19}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - E_d(kWh): Annual demanded production of electrical energy by RES
  - Y_{WT}(kWh/kW$_p$): Annual electrical energy yield at the test site.

While testing for optimal value of plant size nominal power of wind turbines should be taken as size of step, then size of wind power plant is:

$$P_{r,w,4} = N_{wt} * \frac{P_{wt,r}}{1000} \tag{2-20}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $P_{wt,r}$(kW/unit): Nominal power of WT specified by producer.
  - N_{wt}(unit): number of PV modules.
- **Data source:** Data are taken from the producers datasheets for product, e.g.:

  -www.leitwind.com

Operational characteristics of WT are different for every producer. Yield of wind energy should be considered together with wind turbine model as the design and operational characteristics are different for every producer.

2.2.4 Electrical energy production from WT

The power and energy production from WT generators.[1]

- **Temporal step of the data**: an annual basis is used
- **Spatial distribution of the data**: number of sites
- **Unit of measurement**: kWh/year
- **Symbol**: E_{wp}

The power and energy production from WT generators is calculated by this section starts from the data inputs listed below. The formulas are the following:

$$E_{wp,i} = (1 - \beta_{wt} * i) * E_{wp} \tag{2-21}$$

Annual expected energy generation from wind power plant in the ith year because of WT ageing production reduces linearly since the start of generation.

- **Data inputs:** Data are obtained by using the following inputs:
  - $E_{wp}(kWh/year)$: Wind power plant annual electricity production
  - $\beta_{wt}(\%)$: Ageing of WT. $\beta_{wt} = 1.6\% \pm 0.2\%$
  - i: Age of WT

$$E_{wp} = \eta_{wp} * E_{WT} * \frac{P_{r,w}}{P_{wt,r}} \tag{2-22}$$

Wind farm energy generation in the first year of operation.

- **Data inputs:** Data are obtained by using the following inputs:
  - η_{wp}: WP plant availability factor.
  - $E_{WT}(kWh/year)$: Annual generated electrical energy by single wind turbine
  - $P_{r,w}(MW)$: WP plant size.
  - $P_{wt,r}(MW)$:Rated power of WT generators.

$$E_{WT} = \int_{h=0}^{8760h} dt * P_{WT}(u_2) \quad (2\text{-}23)$$

P_{WT} (kW) is wind turbine's power output derived from its power curve.

Energy generated from single wind turbine for one year. Power curve of wind turbines are data given by producer which specific to each turbine model. At standard air conditions the wind speed at height of wind turbine hub corresponds to predefined power. Intermediate values are interpolated to corresponding power generated. As the wind speed is average hourly data, corresponding power is also is hourly average power.

$$u_2 = u_1 * \frac{\ln\left(\frac{H_h}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \quad (2\text{-}24)$$

Data obtained from datasets have wind speed measurements for agreed heights. For exp. 10m, 50m or 100m heights. To calculate the wind speed at height of wind turbine hub the data should be interpolated by logarithmic law from height of initial measurements to the height of hub.

- **Data inputs:** Data are obtained by using the following inputs:
  - $u_2(\frac{m}{s})$: Wind speed at the level of wind turbine hub height
  - $u_1(\frac{m}{s})$: Average wind speed from datasets at defined height h_1(m),
  - z_0(m): Roughness length.
  - H_h(m): Hub height. Producer can provide available tower designs. The height selection depends on rugosity of terrain and effect of turbulence. Lower values of the last two allow to install lower tower height.

With selected test sample WT generator, production of annual electric power is used for benchmarking of the sites. Selected WT model brand is used only for technical purposes as technological reference productivity of WT generators at sites of analysis.

$$Y_{WT} = \frac{E_{WT}}{P_{wt,r}} \quad (2\text{-}25)$$

- **Unit of measurement**: kWh/ kW_p/year
- **Symbol**: Y_{WT} (Yield of WT)

- **Data inputs:** Data are obtained by using the following inputs:
  - E_{WT}(kWh): Annual electric energy output of one WT generator of preselected model
  - $P_{wt,r}$ (kW_p): Nominal power of a WT generator

2.3 Financial analysis

2.3.1 Investment and expenditures

2.3.1.1 Installed cost

Installed cost of the plant represents the cost of the initial investment, then the cost of turnkey. This value is referred to the nominal power of the plant.

- **Data source:** Data are taken from the following external datasets:
  - Publications: IRENA “Renewable power generation costs”
  - Record of local plants costs of the same type
- **Unit of measurement**: $/$kW_p$.
- **Symbol:** *IPVC and IWPC* (Installed PV plant cost and Installed wind power plant cost)

IRENA publications are free to use. Data refers worldwide specified areas in the materials. Due to change of the prices as possibly latest data should be used.

2.3.1.2 Investment cost

Investment cost is monetary resource for construction RES of predefined size.

- **Unit of measurement**: $(USD)
- **Symbol**: I_{PV} and I_{WP}

Investment costs are calculated starting from the data inputs listed below. The formula is the following one:

$$I_{PV} = P_r * IPVC * 1000 \tag{2-26}$$

$$I_{WP} = P_{r,w} * IWPC * 1000 \tag{2-27}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $P_r(MW)$: PV power plant rated power

- $P_{r,w}(MW)$: Wind power plant rated power
- $IPVC$($/kW): Installed PV plant cost
- $IWPC$($/kW): Installed WP plant cost

2.3.1.3 *Intended investment cost*

Monetary resource which shall be used for construction RES plants. At this stage, the project is made for appraisal purposes of sites. And so, the investment cost shall be called as intended investment cost in order to distinguish it from cost of working projects and the cost estimated by sizing first the plant rated power.

- **Unit of measurement**: $(USD)
- **Symbol:** IIC(Intended investment cost)

This value is used only if financial optimisation is necessary because of budget constraint

2.3.1.4 *Annual costs*

Includes cost of grid-connection charge from operator, operation and maintenance costs, insurance.

- **Data source:** Data are taken from the following external datasets:
  -IRENA: "Renewable Power Generation Costs"
- **Temporal step of the data**: year
- **Spatial distribution of the data**: Global, Specified Zones and countries.
- **Unit of measurement**: $/kW$_p$/year-fixed, $/kWh/year-variable.
- **Symbol:** AC_{PV} (annual costs for PV plant), AC_{WP}(annual costs for WP plant)

Annual costs depend on installation environment where inconvenient exposures increase maintenance costs such as sands in wind, moisture, high turbulence and etc.

2.3.1.5 *Taxes*

Tax policy of the country which is imposed on incomes of entities.

- **Data source:** Data are taken from the Ministry of finance, state taxation committees or databases collecting law documents
- **Spatial distribution of the data**: country

- **Unit of measurement**: % (percentage of income and property costs)
- **Symbol:** T

Taxation methods depends on policy of the country. It may differ from country to county. For example, it may be imposed as percentage of income or fixed quantity or other. Incentives and tax benefits to promote renewables vary from country to country and unique method for tax estimation cannot be applied.

2.3.2 Financial indicators

2.3.2.1 Net present value

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project.

- **Unit of measurement**: $ (any agreed currency for financial calcualtions)
- **Symbol**: NPV_{PV} (Photovoltaic Power Plant), NPV_{WP} (Wind Power Plant)

For solar power plants, the project life is taken equal to 25 years. Net present value is calculated as below. The formulas are the following:

$$NPV_{PV} = \sum_{t=1}^{N_{PV}} \frac{f_{net,t}}{(1+DF)^t} - I_{PV} \quad (2\text{-}28)$$

$$f_{net,t} = E_{PV} * EC - AC_{PV} * P_r - (E_{PV} * EC - AC_{PV} * P_r) * T \quad (2\text{-}29)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $f_{net,t}$($/year): Net value of cash flow for PV plant in the year t.
  - DF(%): Discount factor
  - I_{PV}($): Investment cost for solar power plant
  - E_{PV}(kWh/year): Annual electricity generation by PV plant.
  - EC($/kWh): electricity cost.
  - AC_{PV}($/kW$_p$/year): Annual costs related to PV plant operation and maintenance
  - P_r(kW$_p$): Rated power of power plant
  - T(%): Tax rate
  - N_{PV}(years): Plant useful lifetime, for PV plant equal to 25 years.

Similarly, NPV_{WP} is derived as written below considering that plant life is equal to 20 or 25 years:

$$NPV_{WP} = \sum_{t=1}^{N_{WP}} \frac{f_{net,t}}{(1+DF)^t} - I_{WP} \quad (2\text{-}30)$$

$$f_{net,t} = E_{WP} * EC - AC_{WP} * P_{r,w} - \left(E_{WP} * EC - AC_{WP} * P_{r,w}\right) * T \quad (2\text{-}31)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $f_{net,t}$(\$/year): Net value of cash flow in the year t.
  - *DF*(%): Discount factor
  - E_{WP}(kWh/year): Annual electricity generation.
  - *EC*(\$/kWh): electricity cost.
  - AC_{WP}(\$/kW_p/year): Annual costs
  - $P_{r,w}$: Rated power of power plant
  - *T* (%): Tax rate
  - N_{WP}(years): Plant useful lifetime, for PV plant equal to 25 years.

The discount rate expresses the time value of money and can make the difference between whether an investment project is financially viable or not. Relatively difficult parameter for determine its true value. Instead WACC can be used. Value of WACC depends on financial structure of the project. Sensitivity analysis can be performed on DF then input data size will be equal to number of variables DF.

The year at which NPV equals to 0 with discount rate defined by financial structure of the project is called payback time. The payback time is also indicator for financial assessment of the project.

2.3.2.2 *Internal rate of return*

Internal rate of return is equal to discount factor which gives NPV equal to 0 at the end of plant lifetime.

- **Unit of measurement**: %
- **Symbol**: IRR_{PV} (Photovoltaic Power Plant), IRR_{WP} (Wind Power Plant)

IRR is one of the parameters which can help to decide if the investment is profitable or not. Bigger value of IRR of the project than other analogous projects indicates that this project is more profitable. And also, value of WACC relative to IRR of the project must be lower in order previous statement to be true.

For solar power plants, the project life is taken equal to 25 years. Setting NPV equal to 0, by iterative convergence we derive the value of IRR for PV power plants. Internal rate of return is calculated as below. The formulas are the following:

$$0 = \sum_{t=1}^{N_{PV}} \frac{f_{net,t}}{(1+IRR_{PV})^t} - I_{PV} \rightarrow IRR_{PV} \quad (2\text{-}32)$$

$$f_{net,t} = E_{PV} * EC - AC_{PV} * P_r - (E_{PV} * EC - AC_{PV} * P_r) * T \quad (2\text{-}33)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $f_{net,t}$(\$/year): Net value of cash flow for PV plant in the year t.
  - I_{PV}(\$): Investment cost for solar power plant
  - E_{PV}(kWh/year): Annual electricity generation by PV plant.
  - EC(\$/kWh): electricity cost.
  - AC_{PV}(\$/kW$_p$/year): Annual costs related to PV plant operation and maintenance
  - P_r(kW$_p$): Rated power of power plant
  - T(%): Tax rate
  - N_{PV}(years): Plant useful lifetime, for PV plant equal to 25 years.

Similarly, IRR_{WP} is derived as written below considering that plant life is equal to 20-25 years:

$$0 = \sum_{t=1}^{N_{WP}} \frac{f_{net,t}}{(1+IRR_{WP})^t} - I_{WP} \rightarrow IRR_{WP} \quad (2\text{-}34)$$

$$f_{net,t} = E_{WP} * EC - AC_{WP} * P_{r,w} - \left(E_{WP} * EC - AC_{WP} * P_{r,w}\right) * T \quad (2\text{-}35)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - $f_{net,t}$(\$/year): Net value of cash flow in the year t.
  - I_{WP}(\$): Investment cost for wind power plant

- E_{WP}(kWh/year): Annual electricity generation.
- EC($/kWh): electricity cost.
- AC_{WP}($/kW$_p$/year): Annual costs
- $P_{r,w}$: Rated power of power plant
- T (%): Tax rate
- N_{WP}(years): Plant useful lifetime, for PV plant equal to 20-25 years.

2.3.2.3 Levelized cost of electricity

Levelized cost of electricity (LCOE) represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life.

- **Unit of measurement**: $/kWh
- **Symbol**: $LCOE_{PV}$ (Photovoltaic Power Plant), $LCOE_{WP}$ (Wind Power Plant)

For solar power plants, the project life is taken equal to 25 years. LCOE is calculated as below indicated below. The formulas are the following:

$$LCOE_{PV} = \frac{\sum_{t=1}^{N_{PV}} \frac{AC_{PV} * P_r}{(1+DF)^t} + I_{PV}}{\sum_{t=1}^{N_{PV}} \frac{E_{PV,t}}{(1+DF)^t}} \quad (2\text{-}36)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - AC_{PV} ($/kW$_p$/year): Annual costs
  - E_{PV}(kWh/year): Annual electricity generation by PV plant.
  - DF(%): Discount factor.
  - AC_{PV}($/kW$_p$/year): Annual costs related to PV plant operation and maintenance
  - P_r(kW$_p$): Rated power of power plant
  - I_{PV}($): Investment cost for solar power plant
  - N_{PV}(years): Plant useful lifetime, for PV plant equal to 25 years.

Similarly, $LCOE_{WP}$ is derived as written below considering that plant life is equal to 20-25 years:

$$LCOE_{WP} = \frac{\sum_{t=1}^{N_{WP}} \frac{AC_{WP}*P_{r,w}}{(1+DF)^t} + I_{WP}}{\sum_{t=1}^{N_{WP}} \frac{E_{WP,t}}{(1+DF)^t}} \tag{2-37}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - AC_{WP} (\$/kW$_p$/year): Annual costs
  - E_{WP}(kWh/year): Annual electricity generation.
  - DF(%): Discount factor.
  - AC_{WP}(\$/kW$_p$/year): Annual costs
  - $P_{r,w}$: Rated power of power plant
  - I_{WP}(\$): Investment cost for wind power plant
  - N_{WP}(years): Plant useful lifetime, for WP plant equal to 20 years.

2.3.2.4 Profitability index

The profitability index is an index that attempts to identify the relationship between the costs and benefits of a proposed project using a ratio

- **Unit of measurement**: dimensionless
- **Symbol**: PI_{PV} (Photovoltaic Power Plant), PI_{WP} (Wind Power Plant)

For solar power plants, the project life is taken equal to 25 years. In the formula written below, on numerator present value of future cash inflows and on denominator present value of future cash outflows are expressed. The formulas are the following:

$$PI_{PV} = \frac{\sum_{t=1}^{N_{PV}} \frac{EC*E_{PV,t}}{(1+DF)^t}}{\sum_{t=1}^{N_{PV}} \frac{AC_{PV}*P_r+(E_{PV}*EC-AC_{PV}*P_r)*T}{(1+DF)^t} + I_{PV}} \tag{2-38}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - AC_{PV} (\$/kW$_p$/year): Annual costs
  - P_r(kW$_p$): Rated power of power plant
  - DF(%): Discount factor.
  - E_{PV}(kWh/year): Annual electricity generation by PV plant.

- EC(\$/kWh): electricity cost.
- T(%): Tax rate
- I_{PV}(\$): Investment cost for solar power plant
- N_{PV}(years): Plant useful lifetime, for PV plant equal to 25 years.

Similarly, PI_{WP} is derived as written below considering that plant life is equal to 20-25years:

$$PI_{WP} = \frac{\sum_{t=1}^{N_{WP}} \frac{EC*E_{WP,t}}{(1+DF)^t}}{\sum_{t=1}^{N_{WP}} \frac{AC_{WP}*P_{r,w}+(E_{WP}*EC-AC_{WP}*P_{r,w})*T}{(1+DF)^t}+I_{WP}} \quad (2\text{-}39)$$

- **Data inputs:** Data are obtained by using the following inputs:
  - AC_{WP} (\$/kW$_p$/year): Annual costs
  - $P_{r,w}$(kW$_p$): Rated power of power plant
  - DF(%): Discount factor.
  - E_{WP}(kWh/year): Annual electricity generation by WP plant.
  - EC(\$/kWh): electricity cost.
  - T(%): Tax rate
  - I_{WP}(\$): Investment cost for wind power plant
  - N_{WP}(years): Plant useful lifetime, for WP plant equal to 20-25 years.

2.4 Environmental analysis

2.4.1 Share of Country Fossil Fuel Mix Generation

Fossil fuel deployment in the country of interest.

- **Data source:** IEA database, available at the following link: https://www.iea.org/statistics/?country=UZB&isISO=true
- **Temporal step of the data**:
  IEA: the dataset IEA refers to a period of time between 1990 and 2018. Data are given as yearly values. Values referring to individual years are available.

Values referring to electric energy production by each fossil fuel are available. The last year data are used for environmental analysis.

- **Spatial distribution of the data**:
  IEA: the dataset IEA refers to the whole word. It's possible to select the country of interest.
- **Unit of measurement**: % (percentage of electricity produced by source with respect to the country electricity production by fossil fuels)
- **Symbol:** W_i

2.4.2 CO2 weighted emission factor

GHG total emissions per unit of electricity produced, considering the actual share of energy mix, obtained by the Emission Factor (EF) for each fossil fuel and weighting it for their electricity production.

- **Temporal step of the data**: an annual basis is used
- **Spatial distribution of the data**: country
- **Unit of measurement**: kg_{CO2}/kWh_{el}
- **Symbol**: EF_{CO2}

The GHG emissions factor produced by the actual thermal power plants of the regions/countries are calculated starting from the data inputs listed below. The formulas are the following:

$$EF_{CO2} = \sum_{i=1}^{N} W_i * EF_{CO2,i} \tag{2-40}$$

- **Data inputs:** Data are obtained using the following inputs:
  - W_i(%): Electricity generation by i-th fossil fuel with respect the overall electricity production by fossil fuel (share of country fossil fuel mix)
  - $EF_{CO2,i}$(kg_{CO2}/kWh_{el}): GHG emission factor for kWh of electricity produced by i-th fossil fuel

2.4.3 Avoided CO2 emissions

Avoided CO_2 emissions are mass of GHG per year, assuming that the country will replace the existing fossil fuel mix generation with renewable electric energy generation.

- **Temporal step of the data**: data will be available with hourly, monthly and yearly step, according to the temporal step of the RES generation data. In this work an annual basis is used.
- **Spatial distribution of the data**: country
- **Unit of measurement**: Mt_{CO2}/year, Mt_{CO2}/month, Mt_{CO2}/day, Mt_{CO2}/hour
- **Symbol**: M_{CO2}

GHG avoided emissions are calculated starting from the data inputs listed below. The formula is the following one:

$$M_{CO2} = \frac{1}{1000} * \sum_{i=1}^{2} P_i * EF_{CO2} \tag{2-41}$$

- **Data inputs:** Data are obtained by using the following inputs:
  - P_i (kWh/year): Electricity Generation by RES per unit of time
  - EF_{CO2}(kg_{CO2}/kWh_{el}): Weighted GHG emission factor considering the actual share of country fossil fuel mix

3 Case study: Productivity of PV and WT in selected locations in Uzbekistan

3.1 Description of Uzbekistan and selection of sites

3.1.1 General information about country

Figure 3-1: Administrative map of Republic of Uzbekistan

Republic of Uzbekistan is in the centre of Asian continent. Being one of the Central Asian countries it has got borders with each of other Central Asian countries. From north and west it borders with Kazakhstan, from eastern side with Kyrgyzstan and Tajikistan, from south with Turkmenistan and smaller range of border with Afghanistan. Territory occupies 448,49 thousand square kilometres. The capital is Tashkent city. According to state statistics committee for situation of first January 2020, population reached 33.9 million. It is 1.95% more than at the beginning of the 2019. Before last year population growth rate was 1.83%. Share of urban population is 50.56% [III].

Code	Province	Area		Population(thousands)
		Thousand km²	Thousand mi²	01/10/2019
1	Tashkent city	0.34	0.131	2554.2
2	Andijan	4.3	1.66	3110.1
3	Bukhara	40.32	15.568	1916
4	Fergana	6.76	2.61	3733.1
5	Jizzakh	21.21	8.189	1374.5
6	Namangan	7.44	2.873	2795.7
7	Navoi	110.99	42.853	992.5
8	Kashkadarya	28.57	11.031	3261.4
9	Samarkand	16.77	6.475	3857
10	Syrdarya	4.28	1.653	841.8
11	Surkhandarya	20.1	7.761	2612.4
12	Tashkent region	15.25	5.888	2929.9
13	Khorezm	6.05	2.336	1856.4
14	Republic of Karakalpakistan	166.59	64.32	1889.9

Table 3-1: Administrative division of Uzbekistan and its population [III]

Most part of population live in eastern part of the country such in Fergana valley, Tashkent, Samarkand and others. This part includes western Tian Shan mountains. Reaming three fourth of land toward east territory becomes arid and semiarid lands passing through Kyzyl-Kum desert, Turan Plain and Ustyurt Plateau. Main rivers Syr Darya from north and from south Amu Darya partially pass through territory of the country and reach Aral Sea basin.

Climate is moderate continental. Most of rain falls area at nearby areas of mountains. Temperature falls below -20°C in coldest periods and usual temperature during summer days 40-42°C, at south desert area 43-45°C. 300 days are sunny during a year.

At the end of 2019, Uzbekistan's GDP grew by 5.5%. GDP growth rate was 5.1 percent in 2018, according to a review by the Ministry of Economy and Industry.

GDP growth was mainly driven by industrial growth of 6.4% (5.2%), construction - 11.8% (8.4%) and services - 6.1% (6.3%). The GDP per capita was $ 1,741 ($ 1,533 in 2018). Services contributed to GDP growth by 1.9%, industry by 1.5%, agriculture by 0.9%, construction by 0.6%, and private taxes by 0.6% [III].

Economy of Uzbekistan in last years has changed its policy. Actions taken for liberalization of economy have attracted foreign investments to every field industry and social life. In order to support business entities and attract foreign investments since the first January of 2019 new tax conception has been put into force. The new taxation simplifies tax system and reduces the load of tax. The conception would eliminate the income tax for legal entities (excluding commercial banks and insurance companies) and establish and apply the procedure for taxation of dividends payable exclusively at the rate of 25%. Abolition of all compulsory payments from the income of legal entities, that is, the proceeds of the income to the state trust funds [IV].

Also, the reduction of the value-added tax (VAT) from 20% to 12%, unification of the individuals' tax on income, single social payments and insurance contributions to the extra-budgetary Pension Fund under the Ministry of Finance at a flat rate of 25%, gradual reduction of the amount taxation of property tax of legal entities and exclusion from the taxation of buildings and constructions [IV].

3.1.2 Electricity production

Contemporary Uzbekistan is on the way of development in every socio-economic aspects of a country and also in the field of Energy industry. The government made priority to diversify energy system by modernization and reconstruction of existing power plants and energy system, construction of new ones implementing more efficient technologies, exploiting present energy sources wisely and also implementing renewable energy technologies. Increasing demand for electric power by population and also by industry make it urgent to double its installed capacity (27GW) until 2030. For this purpose, the government cooperates with international engineering organizations, initiating many investment projects to the field.

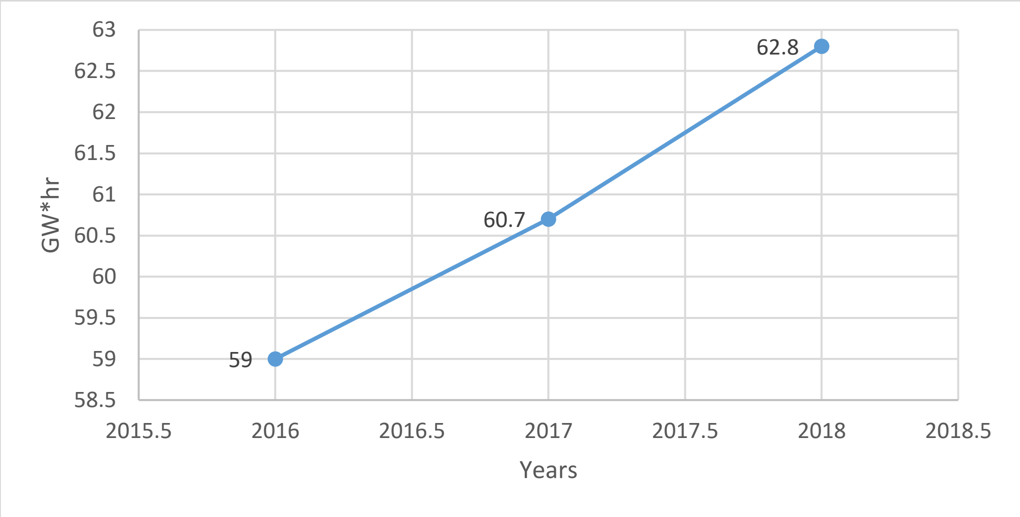

Figure 3-2: Electrical energy produced in the Uzbekistan [V]

Total electrical energy produced in 2018 was 62.8 GWh/year and out of this 58.9 GWh/year was produced by “Uzbekenergo” JSC. 88.52% of the last is the share of thermal power plants. 84% of thermal power plants have finished their service period. Remaining parts is the share of hydropower plants and minor production by other sources. By estimate in 2018 installed capacity is 14.1 GW and it strongly depends on fossil fuels [V].

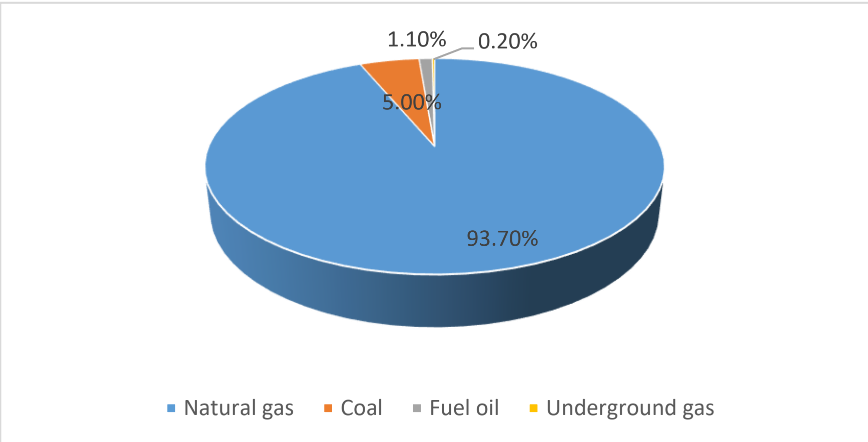

Figure 3-3: Fossil fuels share in Thermal Power Plants in 2018 [V]

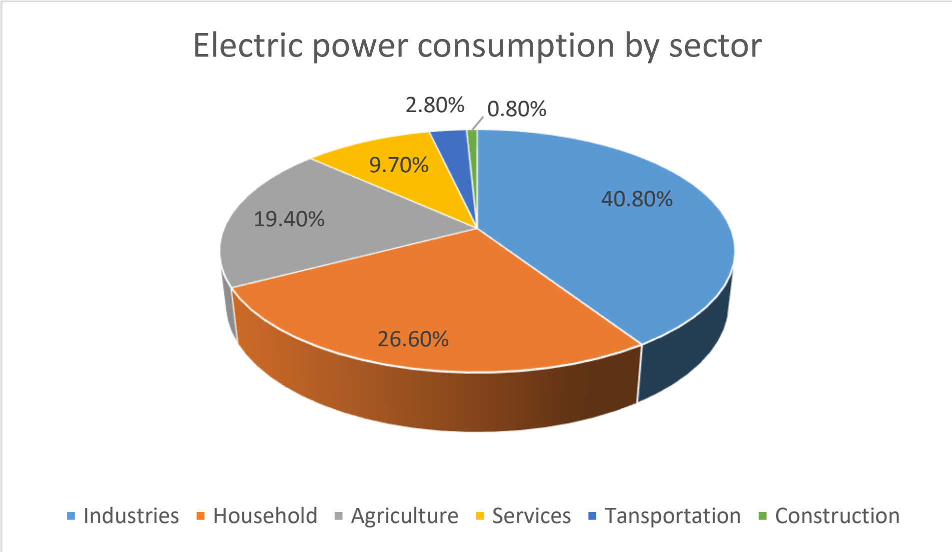

Figure 3-4: Electric energy consumption by sector [V]

Implementation of energy development and other tasks will allow increasing the deep processing of natural gas by 6 times by 2030.

Attraction of private capital to the Ministry of Energy in the electric power industry, as well as in the process of extraction and production of energy resources; A number of new tasks have also been set, such as the development of PPPs.

One of the main priorities for the development of the electric power industry in Uzbekistan is the development of such industrial facilities as thermal power plants (TPP), nuclear power, renewable energy sources (QTEM) through FDI.

Large investment projects are being developed to increase the power generation capacity by 2030. These include [VI]:

1) construction of effective heat power generating facilities with a total capacity of 15 GW;

2) construction of modern combined-cycle (steam-gas) power plants with total electricity generation capacity of about 9.5 GW (Syrdarya, Navoi, Tolimarjan, Takhiatash, Turakurgan thermal power stations, etc.);

3) construction of manoeuvrable production facilities on the basis of gas turbine units with a total capacity of about 3.2 GW, aviation gas turbines and modern power-saving systems (Syrdarya, Tashkent TPP, Mubarek TPP, etc.);

4) construction of solar, wind and hydroelectric power stations with a total capacity of over 8,400 MW and bringing them to 25% of total electricity generation. (Solar and wind power up to 7GW);

5) Construction of a nuclear power plant with a capacity of 2,400 MW

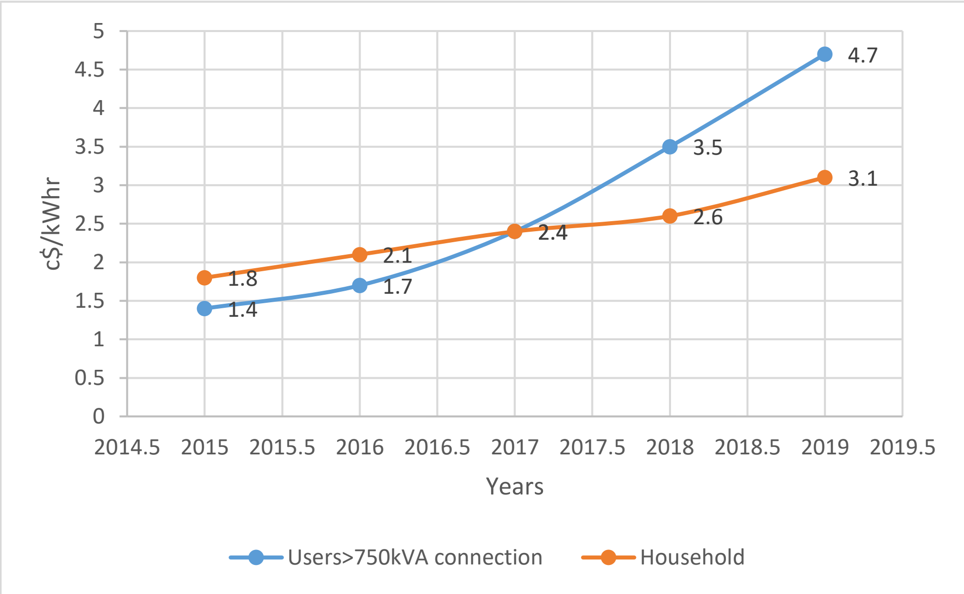

Figure 3-5: Electricity price [V]

Price of electricity comparatively low. State incentive aid to energy investment programs and construction of new power plants. During last years the price of electricity has considerably increased. This growth will continue and will increase investment attractiveness of the field.

3.1.3 Test sites

In this work five sites have been considered for estimation of energy productivity in the country, financial assessment of the project and environmental benefits from construction of solar and wind power plants.

For testing productivity of the sites in the country, points are selected considering firstly on presence of renewable energy source, then absence of obstacles, availability of wide area, closeness to logistic' means and population.

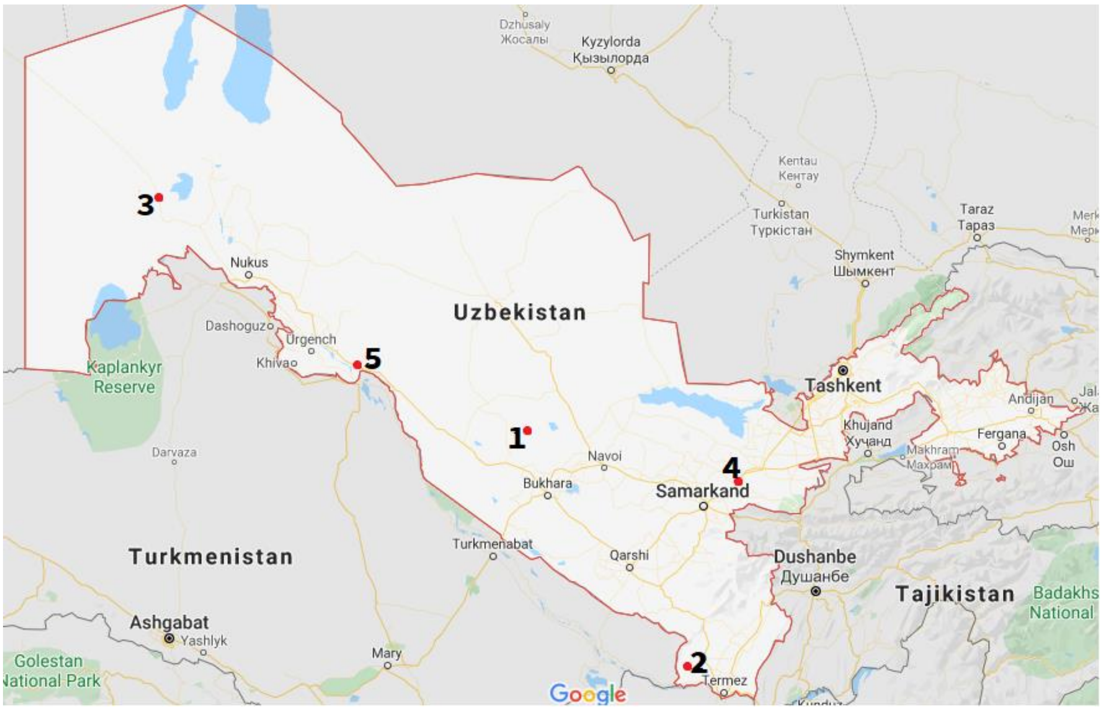

Figure 3-6: Test sites for RES appraisal

Code	Name	Region	Coordinate
1	Shofirkon	Bukhara	N40°33\`39\`\`, E64°04\`29\`\`
2	Sherobod	Surkhandarya	N37°35\`19\`\`, E66° 39\`41\`\`
3	Kongirot	Karakalpakistan Republic	N43°10\`56\`\`, E58° 12\`39\`\`
4	Bulungur	Samarkand	N39°48\`36.3\`\`, E67° 21\`54.3\`\`
5	Khazorasp	Khorezm	N41°22\`03.2\`\`, E61°18\`34.7\`\`

Table 3-2: Test sites

3.1.3.1 Shofirkon

The district Shofirkon is located at northern side of Bukhara region, close location to Bukhara city where most of the Bukhara population lives. It is a deserted area which has highly presence of wind resource. Open territory is placed in Kyzylkum desert and covered by sand and plants of desert. Toward north elevation goes higher and presence of wind increases. In this work the data are consider for this location because productivity for both technologies were satisfactory. For other location only results are presented.

3.1.3.2 Sherobod

Sherobod district is in Surkhandarya region and it is most southern part of the country. Area is located at the north-west from city of Termez. From this site the mountains at the east are placed at the farthest distance in this territory. And we can expect less shading by mornings. Toward north from this site there are hillside of mountains. Soil of the ground is comparatively stable and less dusty.

3.1.3.3 Kongirot

Kongirot is largest district of Karakalpakistan |Republic and it is located at most western part of the country, on Ustyurt plateau. Closest city to the site is Kyrkkyz town. Next to Amudarya valley, the area is shapen like wide canyon and it is narrowed toward south. Wind flow comes from north and north-east from the site. Toward north wind power density increases. One important aspect for consideration is, the site is located at vicinity of ecological catastrophe. On the place of dried Aral Sea, a desert of hazardous salty sands is situated. The wind blows these salts from dried Aral Sea basin to other places. State actions for growing forest as natural barrier can be aided by wind farms which can reduce the wind speed. If techno-ecosystem is considerably favourable it may help to soften the condition in the area.

3.1.3.4 Bulungur

Bulungur is the district of Samarkand region. it is located between Samarkand city and city of Jizzakh. Plane area has slightly less irradiation compared to southern part of the Samarkand region but better than Tashkent and Fergana valley. Considering that Tashkent and Fergana valley is located at farther north and at hills of mountains, obtained producibilities for Bulungur site can be as checking value. Going farther from Bulungur site to the above area we would get less promising producibilities for PV. And for wind turbine producibilities, the locations should be investigated at some formations of mountains. In this scale of work this location cannot be studied. Prospects described in section 4 can involve these areas too. The soil at Bulungur territory is stable and less dusty.

3.1.3.5 Khazorasp

Khazorasp is southern district of Khorezm region. It is located next to Turtkul district of Karakalpakistan. Central parts of the region, where there is more population is less windy and has less solar radiation. South-east part of the district together with Turtkul district have more presence of wind and solar radiation. But it is farther from logistics and from populated zones. Area is in the deserted and it is territory without obstacles.

3.2 Weather data obtaining for selected sites

External datasets dedicated for meteorological may suit at some level for application in this methodology, some extend may create difficulty. For purpose this work it is needed to get data of global irradiation, average air temperature, wind speed and rugosity of earth. Datasets presented in section 2.1 can be used for general researches or other sources considering specifics of the situation. This work considers hourly data as input and generation can be analysed by hourly profile.

Global irradiation is measurement of unit surface getting radiation energy and it depends on incidence angle of direct radiation. As much smaller is angle of incident ray with respect to surface normal, so the surface gets higher share of total radiation energy coming from sun. For fixed PV modules it is needed to define optimum tilt angle and azimuth. By tracking PV installation, we must consider sun path during a year and shades from mountains on horizon. Dataset of PVGIS solves most of the questions arising in situation of Uzbekistan. Data are available all part of the country on 4 surface positions. Dataset defines optimal position for fixed PV modules and tilt angle for one axis tracking PV modules. In this work we consider single inclined axis tracking PV modules for each location. At each location the optimal angle of inclinations is as recommended by PVGIS. PV modules track the sun during a day from east to west. Inclined axis is directed toward the north. As a typical year 2015 has been selected. Data inputs of weather can be used as typical year with range of variation or a selected one year. Last one can be checked with generation of other years if it can be accurate to predict average annual generation.

Name	Optimal tilt for inclined axis tracking, [degree]	Annual global irradiation, [kWh/m^2]
Shofirkon	37	2706
Sherobod	34	2605
Kongirot	38	2480
Bulungur	35	2577
Khazorasp	38	2657

Table 3-3: Annual irradiation of surface in case of inclined axis tracking PV [I]

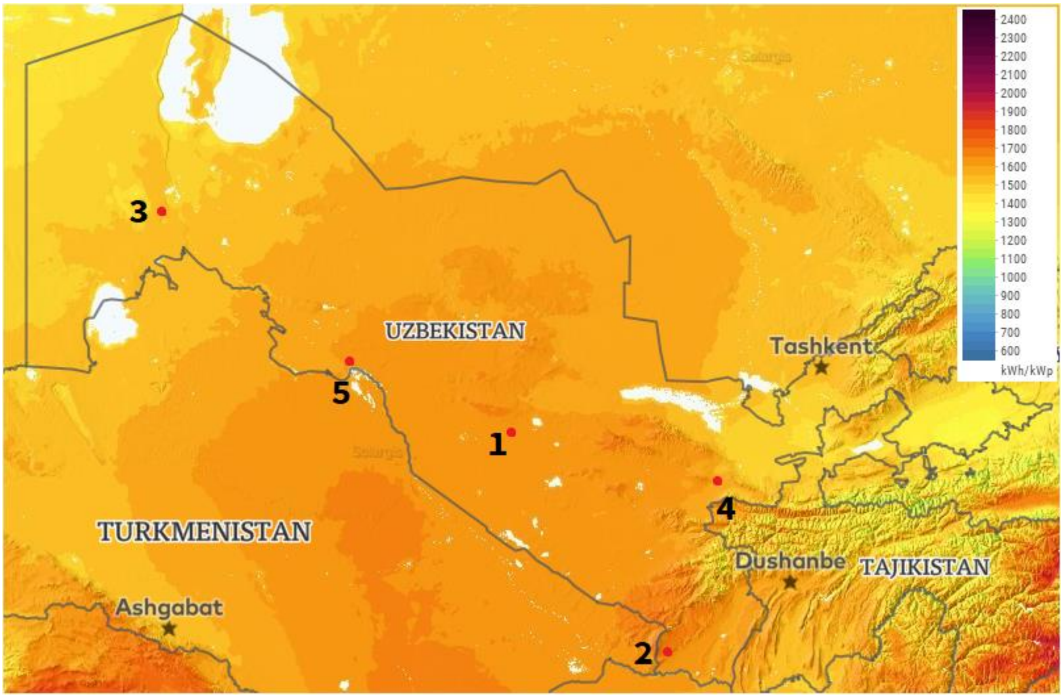

Figure 3-7: PV productivity by solar atlas [VII].

Air temperature can be taken from datasets indicated in section 2.1 or other dataset which can present hourly data. SoDa database give air temperature as typical year. In case of PVGIS we take the same year air temperature as of global radiation year. In this work data from PVGIS was used. Air temperature is measured at 2-meter height from the ground.

Wind speed data can be obtained from datasets given in section 2.1. MERRA-2 dataset has latest data with statistical correction. This work uses wind data from PVGIS dataset. Wind speed measurement given at height 10 meters from ground level. This data also is from the same year of global radiation and air temperature. By this way it is easier to estimate variation of productivity. If we consider variation of each input parameter analysis gets complicated.

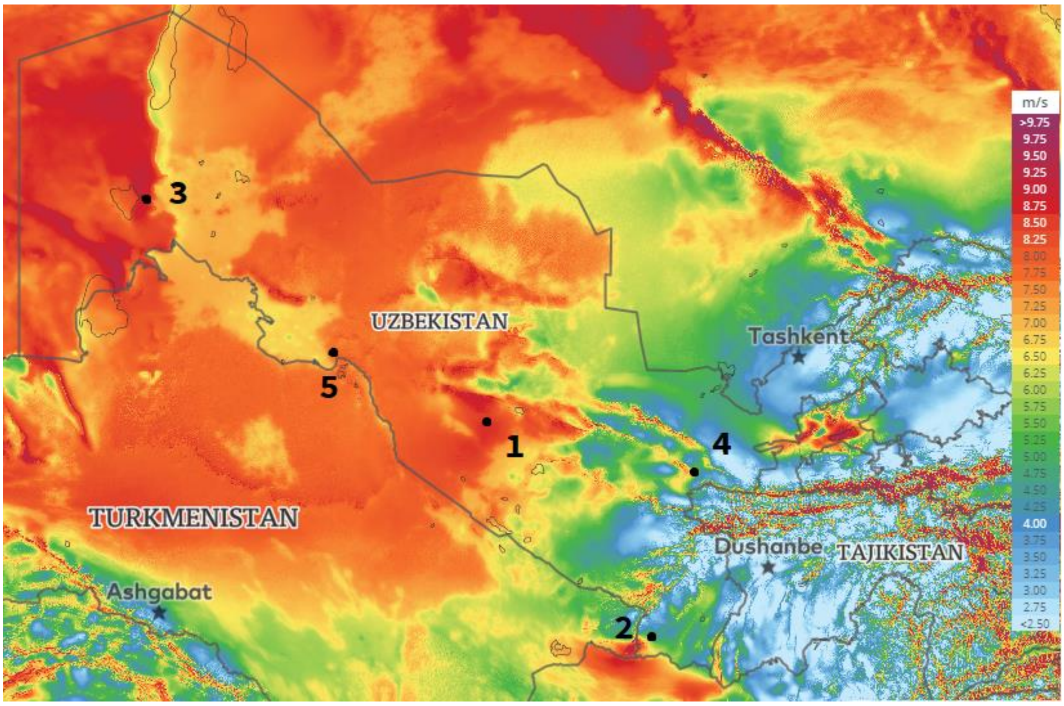

Figure 3-8: Wind speed map at 100m by wind atlas [VIII].

Another important input data are rugosity of the earth. This data must be done on assumption. In most of the cases rugosity equal to 0.1m is considered. But in desert areas this results to over estimation of wind speed at height of the wind turbine hub by logarithmic change. At sites where this work finds as suitable for wind farm the area is covered by desert sands only or covered by shrubs. It can be considered from other dataset such as https://globalwindatlas.info/ or from other GIS datasets. Here we assume 0.02m. this value corresponds to existing wind farms production. Lower value of rugosity allows to install lower tower height. But depends also on thermal driven turbulence.

In this work we assume 2015 as typical year and meteorological data corresponds to average annual production of renewable energy.

3.3 Selection of wind turbines, turbulence

Selection of suitable wind turbines is important for right functioning of the wind farm. Primary criteria are wind characteristics of the location, secondly energy harvesting performance and lastly initial cost and as well as maintenance cost.

By wind average annual wind speed and maximum gust in 50years, locations are classified in to 4 classes. I class wind turbine are considered to operate at average wind speed 10 m/s. such wind turbine structure should be sufficiently resistant to load. Smaller rotor diameter can be used comparatively to turbines of lower classes to get the same power. Wide area of Kongirot and falls to this class wind turbine application. Hill sides at north Shofirkon also can be fit for class turbines.

Second class of wind turbines are installed at areas where average annual wind speeds up to 8.5 m/s, called medium wind. In this work there are two location fitting to this class, but wind speeds are estimated at 100m height. By producer's design wind turbine tower vary from 80m to 120m. If shorter tower is enough to reach needed wind speed level the class may reduce to lover one. For example, as in case small rugosity of earth does not give much change of speed by elevation and in order to cost saving, we can take shorter tower. Most of the area of Shofirkon and adjacent districts have wind for this class turbines.

Most of the onshore wind turbines are of the III class which works at low wind areas. In order to get the necessary power, the rotor diameters of this class are bigger and produce more power per kilowatt installed. But structure does not require to withstand high loads of gust because it is rare very high wind speeds to occur. In case of gust or high turbulence structure may get damaged. Average annual wind speeds up to7.5 falls into this class. Khazorasp, Bulungur and Sherobod fall to this class.

Areas with average wind speed up to 6m/s may not be viable. These areas are classified as very low wind speed. Small size, special design wind turbines can be considered for application at such locations.

By turbulence level of the site the wind turbines are classified into subclasses A and B in each class. Considering that sites are in desert where summer periods thermal driven turbulence is certain A subclass for each class. Application of one or other model of wind turbines apart from classification can be site specific. The energy analysis has been performed for the same turbine model at each site. As test turbine most efficient turbine of class IIA/IIIA was considered. Power reduction due to turbulence must be considered by testing of turbine at the field and comparing it with theoretical production. By such empirical way it is possible to make direct method for energy calculation.

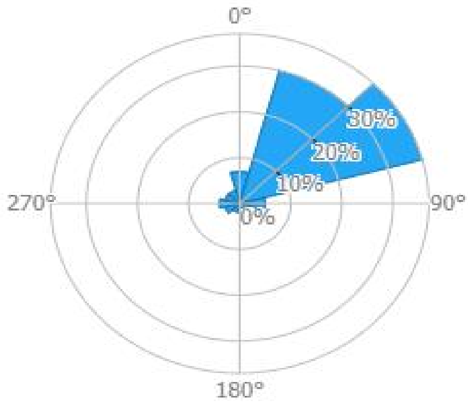

Figure 3-9: Wind rose diagram at Shofirkon by wind atlas [VIII]

Name	Annual average wind speed at 100m, [m/s]	Wind class
Shofirkon	8.6	I-II
Sherobod	6.5	III
Kongirot	9.1	I
Bulungur	7.3	III
Khazorasp	7.8	II-III

Table 3-4: Wind speed classes of sites

N.	Model	Rated power, [kW]	Producer	Wind class	Wing blade length, [m]	Hub height, [m]	Cut-in, [m/s]	Cut-out, [m/s]
1	LTW77	800	Leitwind	IIA/IIIA+	38.3	61.5	3	25
2	LTW80	800	Leitwind	IA/IIA	40.15	65	3	25
3	LTW77	850	Leitwind	IIA/IIIA+	38.3	65	3	25
4	LTW80	850	Leitwind	IA/IIA	40.15	65	3	25
5	LTW77	1000	Leitwind	IIA/IIIA+	38.3	80	3	25
6	LTW80	1000	Leitwind	IA/IIA	40.15	80	3	25
7	LTW86	1000	Leitwind	IIIA/IIIB	43.15	80	3	25
8	LTW80	1500	Leitwind	IA/IIA	40.15	60	3	25
9	LTW86	1500	Leitwind	IIIA/IIIB	43.15	80	3	25
10	LTW80	1650	Leitwind	IA/IIA	40.15	65	3	25
11	LTW80	1800	Leitwind	IA/IIA	40.15	80	3	25
12	LTW101	2000	Leitwind	IIIA+	50.5	80	3	25
13	Vestas V90	2000	Vestas	IIA	45	80	4	25
14	ENERCON E-82 E-2	2000	Enercon	IIA	41	78	2	28
15	W2E 100/2	2000	wind to energy	IIIA	55	70	3.5	25
16	Gamesa G114-2	2000	Gamesa	IIA/IIIA	57	93	3	25
17	Nordex N117 gamma	2400	Nordex	IIIA	58.4	91	3	20
18	LTW101	2500	Leitwind	IIIA+	50.5	80	3	25
19	LTW101	3000	Leitwind	IIIA+	50.5	93.5	3	25

Table 3-5: Wind turbine samples

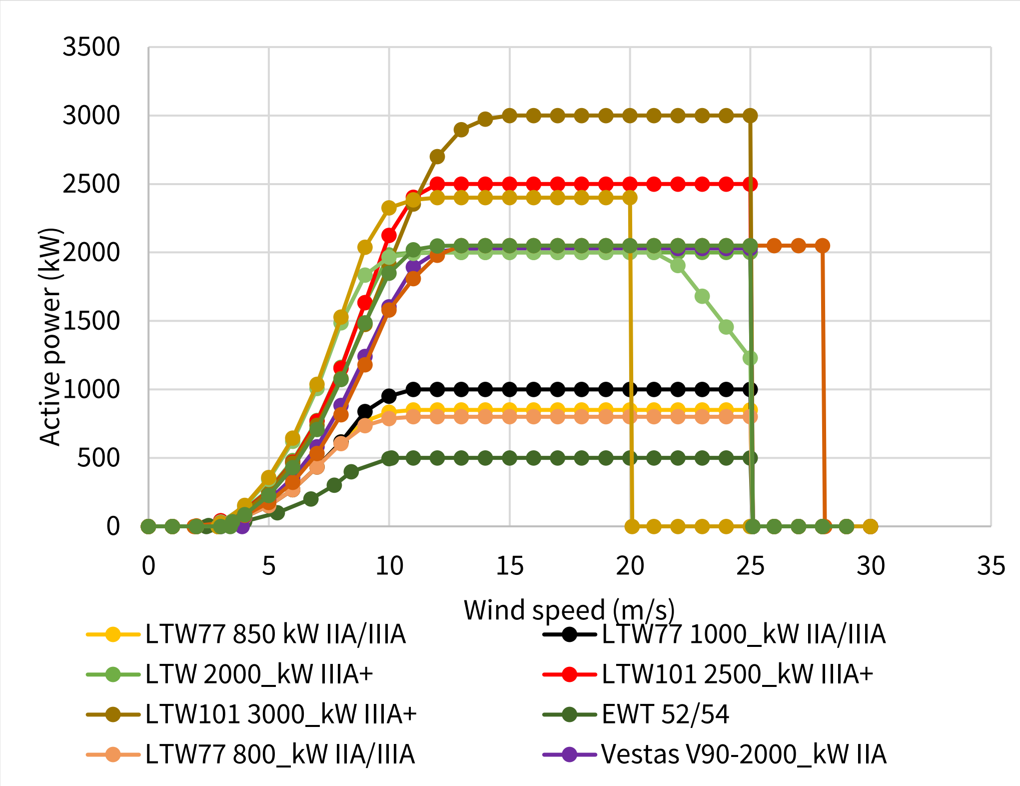

Figure 3-10: Wind turbine power curves

SELECTABLE TURBINES	Specific annual production (kWh/kW)
LTW77 850 kW IIA/IIIA	3318
LTW77 1000_kW IIA/IIIA	3164
LTW 2000_kW IIIA+	3034
LTW101 2500_kW IIIA+	2575
LTW101 3000_kW IIIA+	2173
EWT 52/54	3023
LTW77 800_kW IIA/IIIA	3382
Vestas V90-2000_kW IIA	2416
Gamesa G114-2000kW IIA/IIIA	3575
ENERCON E-82 E-2 IIA	2280
Nordex N117 Gamma IIIA	3264
W2E 100/2MW IIIA	2660

Table 3-6: Productivity of different wind turbines at Shofirkon site

3.4 Energy generation analysis of test sites

3.4.1 Shofirkon-energy generation profile

On location of Shofirkon the profile of generation shows for both technologies annual variation. PV modules reaching the peak of generation in a month of July, 100MW PV plant would produce 34.7% of its monthly capacity. And wind farms also reach in July the highest production, that is 74.7% of monthly generation capacity. Lowest month for both technologies were January. PV modules at this month would generate 12.9% of its monthly capacity and wind farms would 22.7% of monthly capacity. In July PV modules in everyday (figure 3-13) work with regular generation profile. In January (figure 3-12) this kind of regularity is absent. Wind turbines in July would work at full capacity (figure 3-13) at most of the time and in January they would work at low capacity or stop the generation (figure 3-12).

The periodicities of PV and wind turbine generation are contemporary by monthly production. Observing the graphs of other months by hourly generation we see that in very low wind hours generation from PV modules were present. Especially from March to May and from September to November.

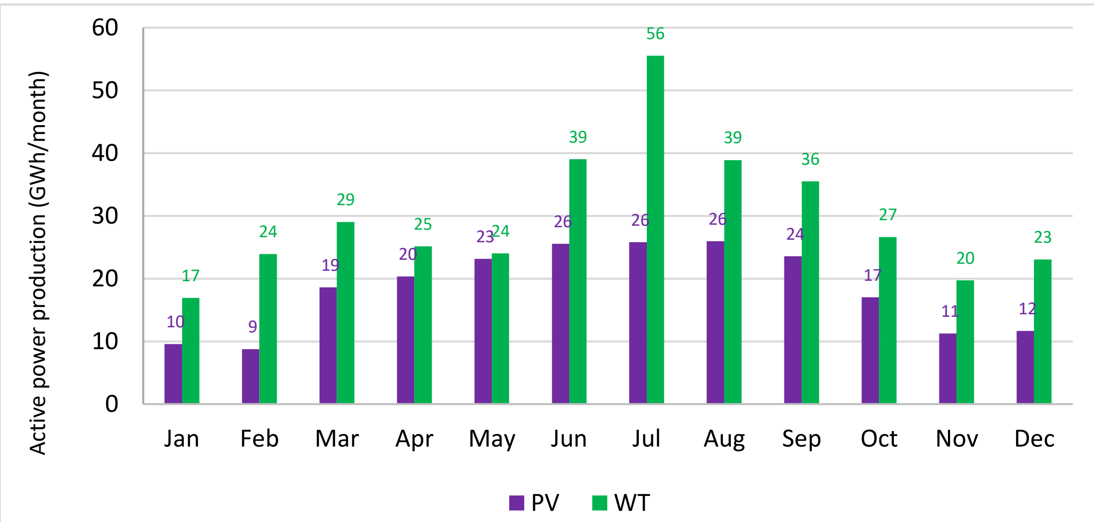

Figure 3-11: Generation by technology at Shofirkon

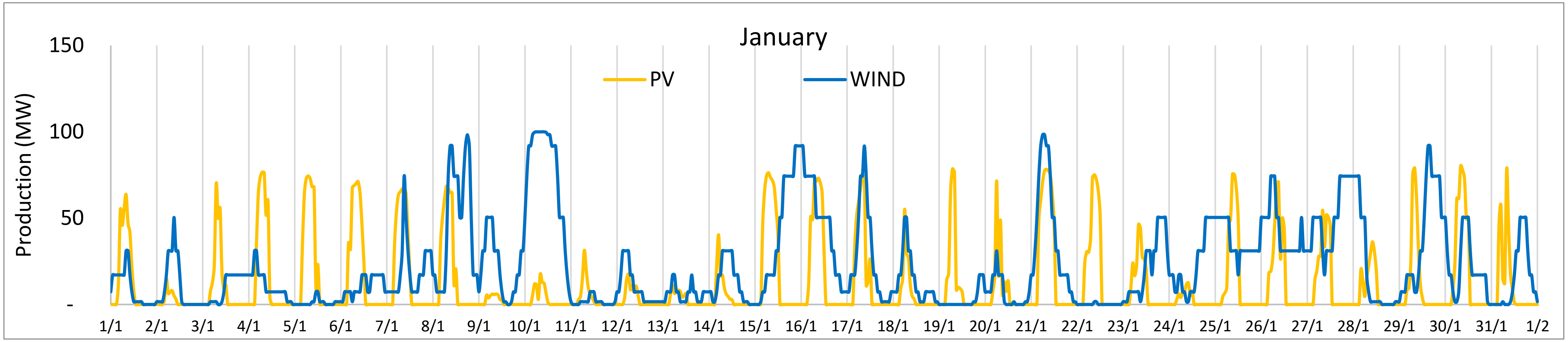

Figure 3-12: Generation profile during low production month at Shofirkon

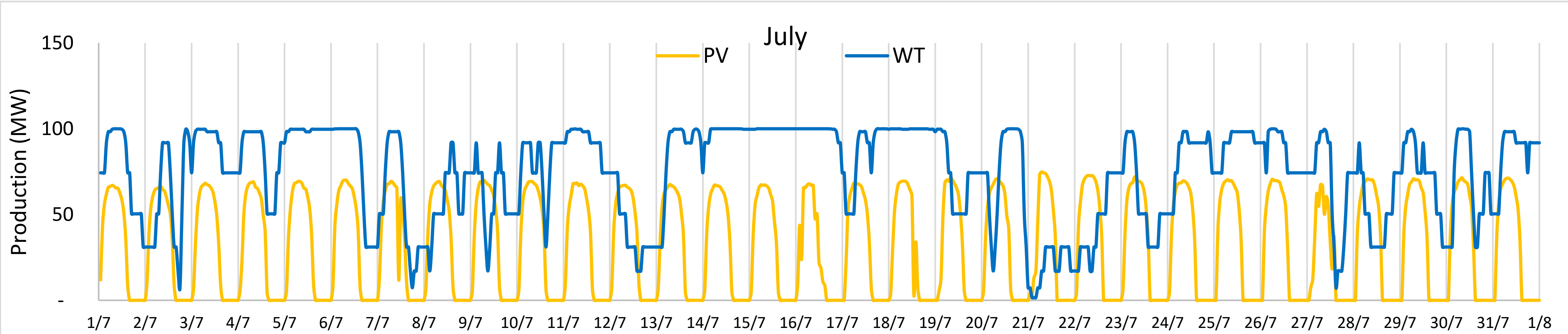

Figure 3-13: Generation profile during high production month at Shofirkon

3.4.2 Sherobod-energy generation profile

On location of Sherobod the profile of generation shows for both technologies annual variation, but in different manner. PV modules reaching the peak of generation in a month of July, 100MW PV plant would produce 32.8% of its monthly capacity. In July PV modules in everyday (figure 3-17) work with regular generation profile. Such kind of regular generation also present in months of June, August and September. Lowest month for PV modules were January (figure 3-15). PV modules at this month would generate 13.5% of its monthly capacity. In months of April, May and October daily generation profiles have some irregularities at few days. In other months generation from PV modules are not smooth but still capacity factor remains higher than of wind turbines. Wind farms reach the highest production in January and in February, that is 16.8% and 20.7% of monthly capacities accordingly. Wind turbines in July would work at 5.1% of monthly capacity. In intermediate seasons production capacity varies from low to high and vice versa. Most of the generation from wind turbines correspond to sunset hours. And at remaining hours wind turbines would remain down.

The periodicities of PV and wind turbine generation are not contemporary by monthly production. Even though, for optimisation power plants size for two technologies would not be reasonable because the wind presence at this location is very low.

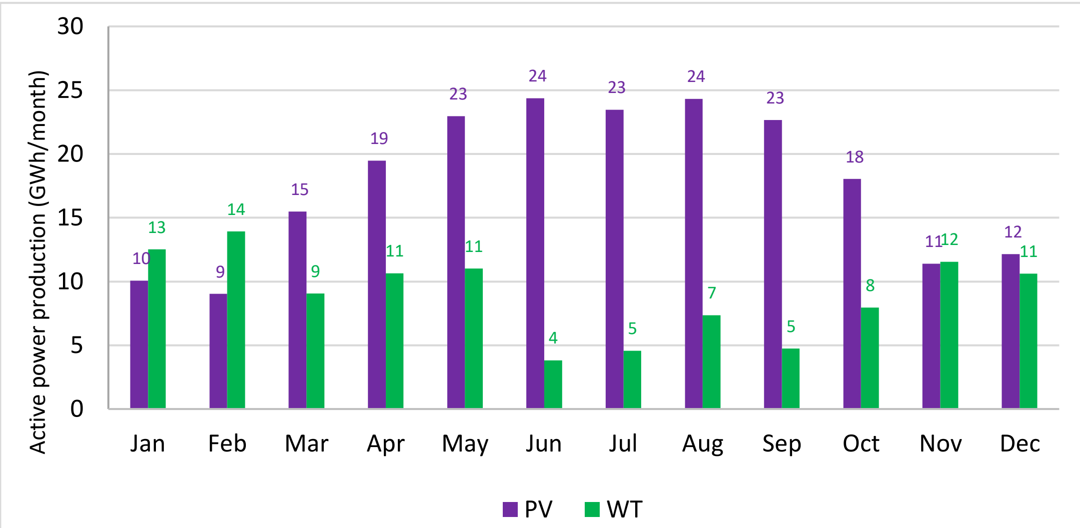

Figure 3-14: Generation by technology at Sherobod

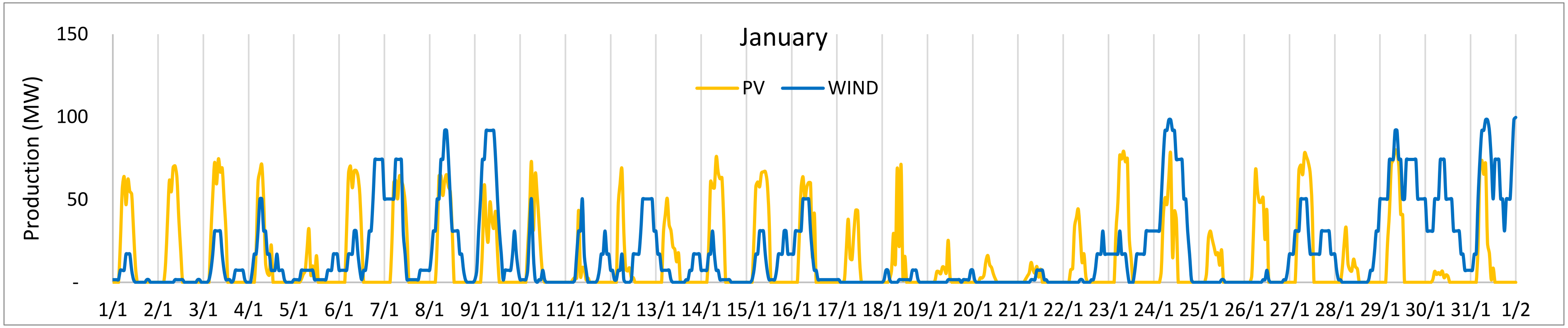

Figure 3-15: Generation profile during low production month at Sherobod

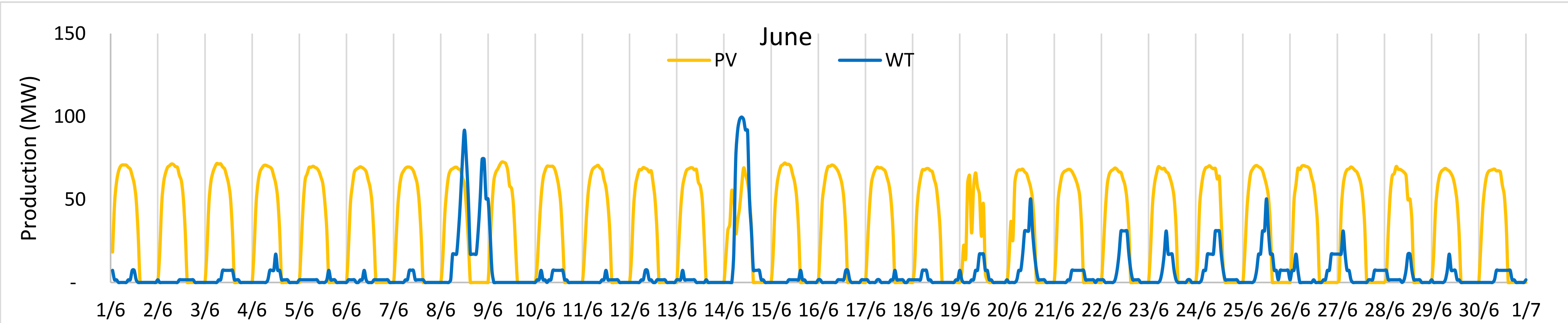

Figure 3-16: Generation profile during high production month at Sherobod

3.4.3 Kongirot-energy generation profile

At Kongirot site PV generation reached the peak in June and it is 34.1 % of monthly generation capacity. Generation profiles are similar from June to September I hourly basis. During these months there are irregular generation hours during some days. And, during these months generation from wind were lower. Especially in most of the daylight hours wind turbines are off. Generation from wind turbines correspond to night and morning hours. Lowest production from PV modules in a month of January and 12.5% of monthly generation capacity. Generation from PV modules in remaining months are not smooth during daylight hours. Wind farms would reach highest production month in April with 45.9% monthly capacity and lowest in August with 20.2% monthly capacity. These periods do not match with PV modules' low and high generation periods. In January wind farm produce 32.6% of monthly generation capacity and in June it is 34.6%.

As the generation hours and months are not contemporary, the site is suitable for both technologies to be optimised for load profile of consumers.

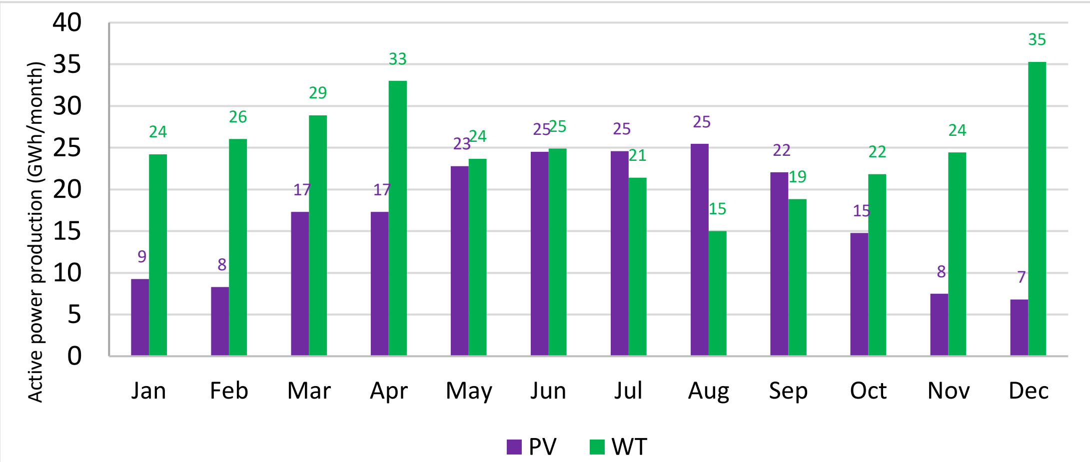

Figure 3-17: Generation by technology at Kongirot

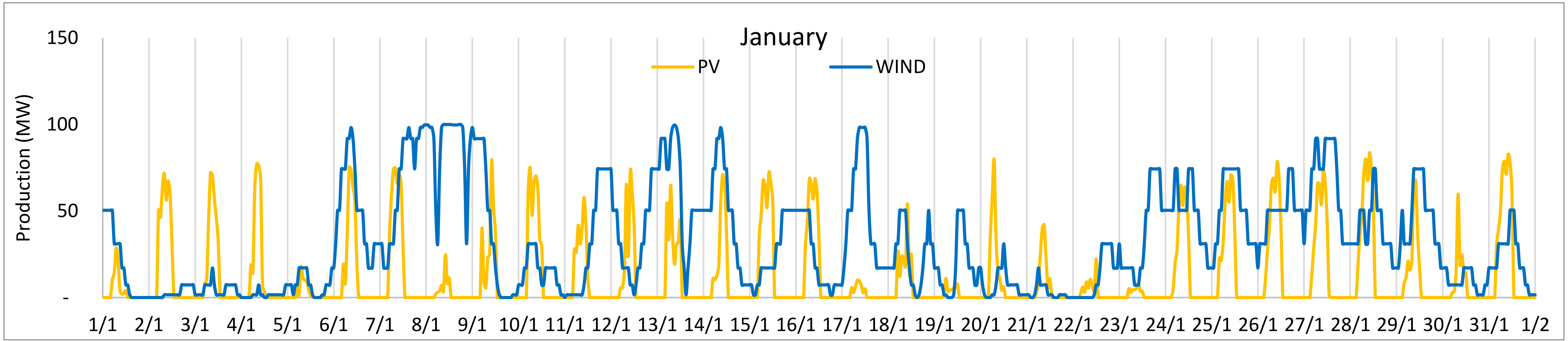

Figure 3-18: Generation profile during low production month at Kongirot

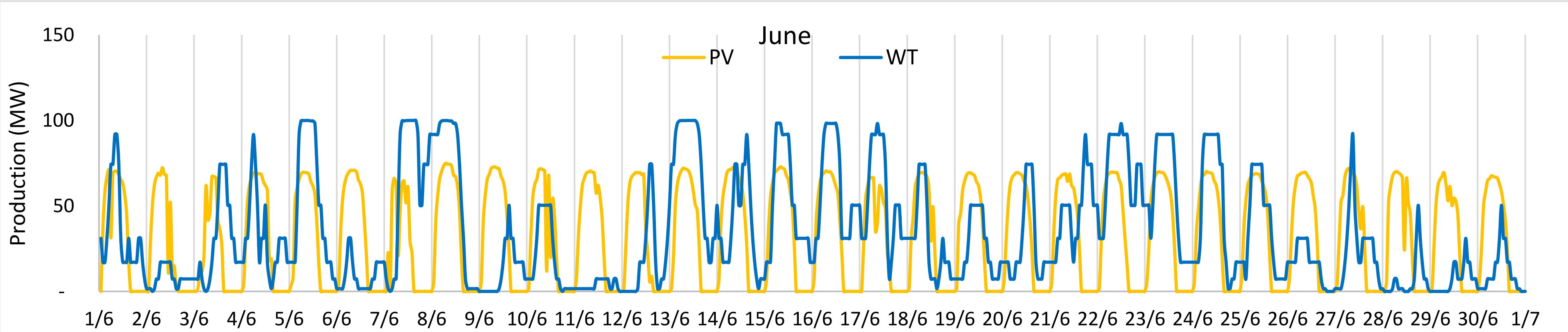

Figure 3-19: Generation profile during high production month at Kongirot

3.4.4 Bulungur-energy generation profile

At Bulungur site the PV modules would reach highest generation in July. In the figure 3-20 the July months is lower than two adjacent months constituting 32.8% of monthly capacity. With more years' data consideration, it would be July the pick generation month by PV modules. It is seen in generation profile with data of 2014. In January it is lowest months and it is 9% of monthly capacities. Wind turbines at this location would reach the pick power generation and it is highest by data of 2015, but with bigger difference from two adjacent months. It is 28.2% of monthly capacity. Most of the hours wind turbines in still condition. In functioning hours, it is contemporary with daylight hours and moreover performance also not high. From May to September PV modules operate in regular period. In spring and autumn period generation profile becomes irregular.

Contemporary periods of PV and wind turbine generations and very low wind speed do not allow to install both types of technologies. Area from energy generation point of view is more suitable for Solar power plants installation.

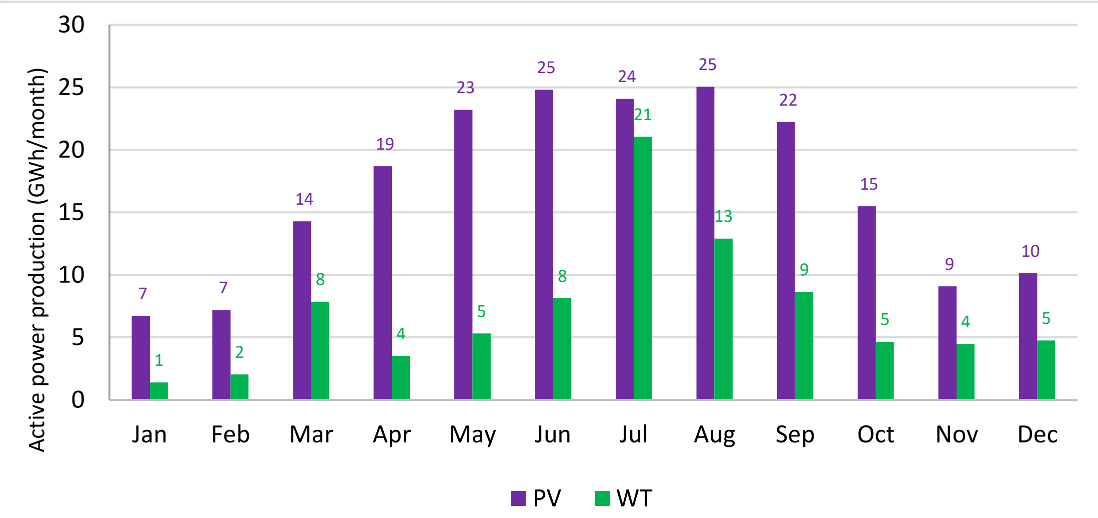

Figure 3-20: Generation by technology at Bulungur

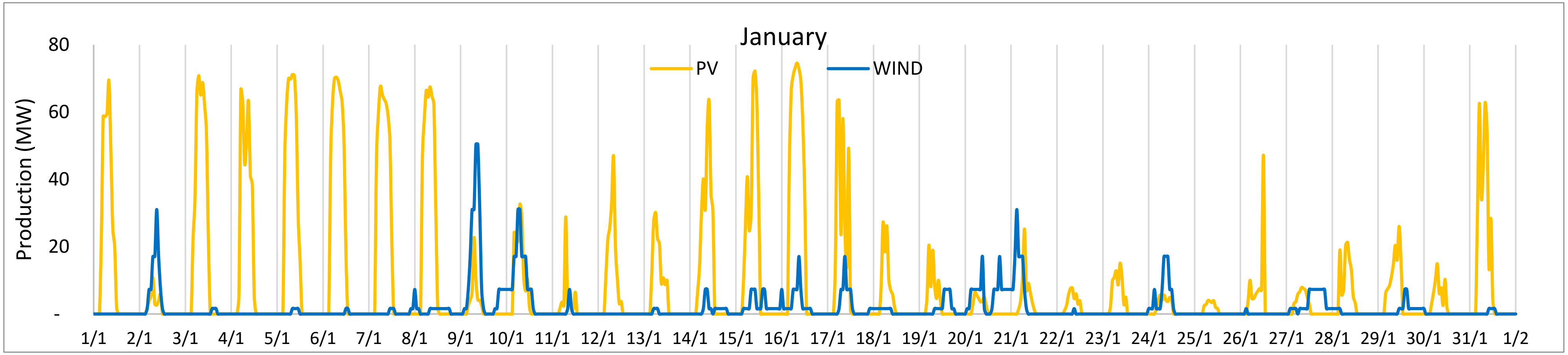

Figure 3-21: Generation profile during low production month at Bulungur

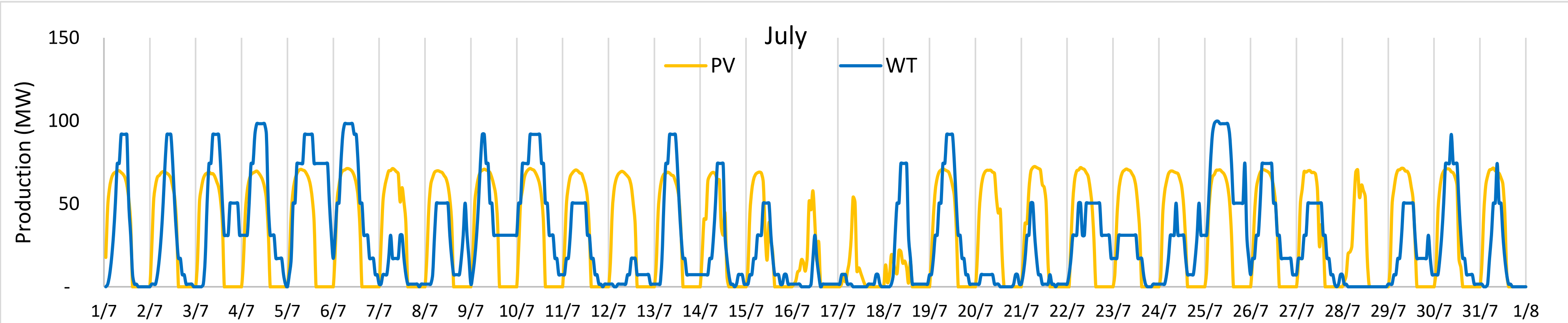

Figure 3-22: Generation profile during high production month at Bulungur

3.4.5 Khazorasp-energy generation profile

On location of Khazorasp the profile of generation shows for both technologies annual variation. PV modules reaching the peak of generation in June, 100MW PV plant would produce 35.7% of its monthly capacity. And wind farms also reach in June the highest production, that is 42.8% of monthly capacity. Lowest month for both technologies was January. PV modules at this month would generate 12.8% of its monthly capacity and wind farms would 19.9% of monthly capacity. In June PV modules in everyday work with regular generation profile. In January PV generation profile varies during daylight hours in unpredictable manner. Wind turbines in July would work at higher capacity but time period varies a lot. In January they would work at low capacity or stop the generation.

The periodicities of PV and wind turbine generation are contemporary by monthly production. Observing the graphs of other months by hourly generation we see that in very low wind hours generation from PV modules were good in April, May, august and September. In hours of sunlight absence wind turbines in observable times were generating in February, March, November and December.

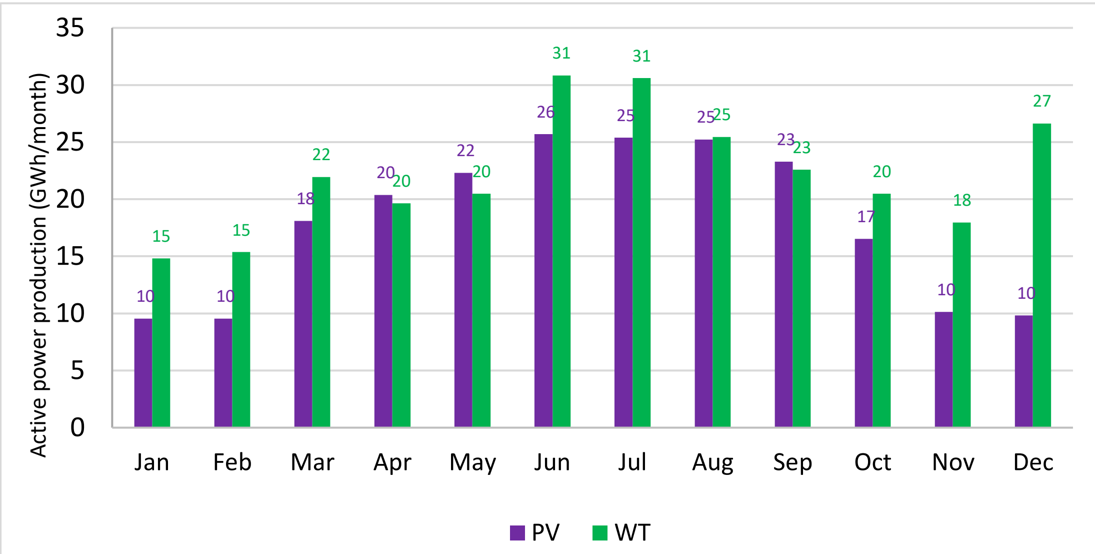

Figure 3-23: Generation by technology at Khazorasp

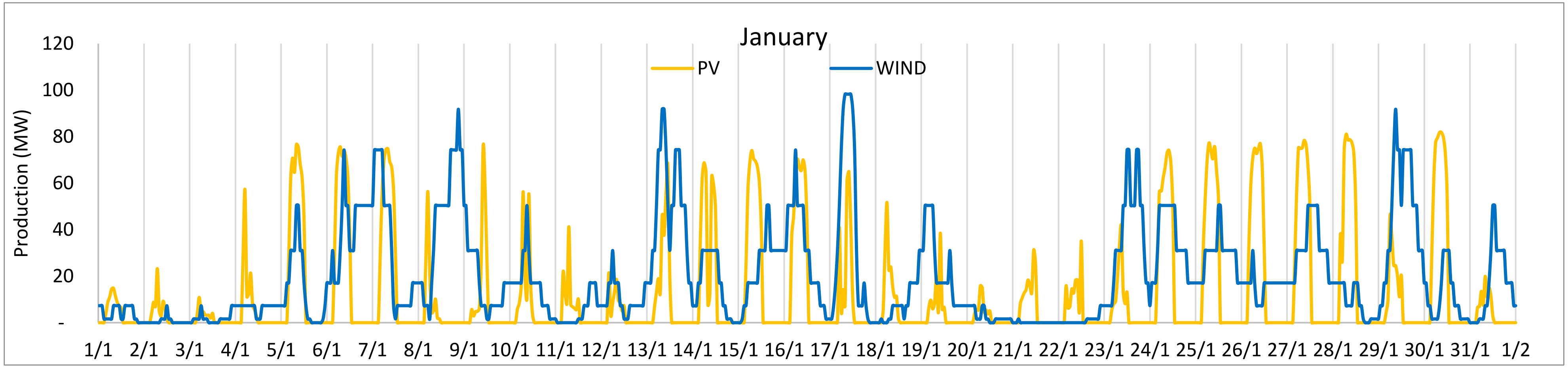

Figure 3-24: Generation profile during low production month at Khazorasp

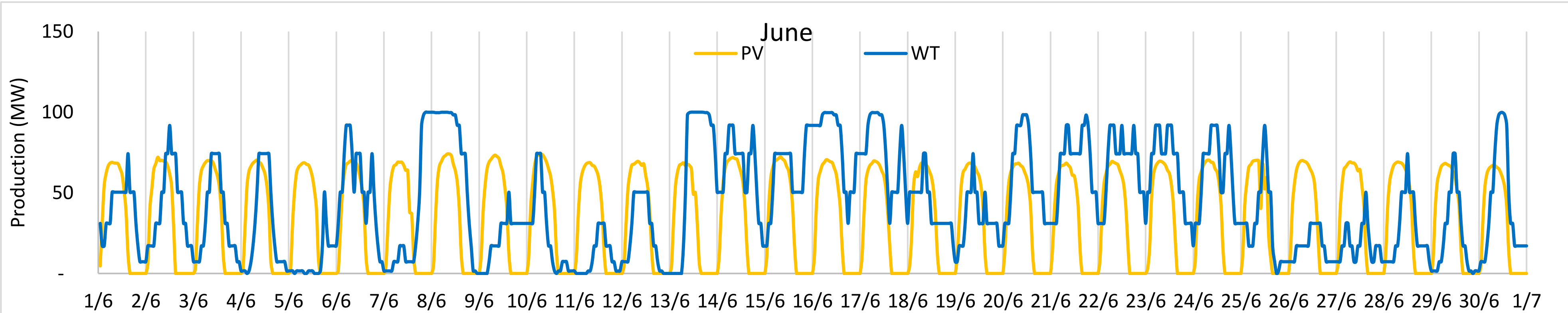

Figure 3-25: Generation profile during high production month at Khazorasp

3.4.6 Productivity comparison

Table 3-7 presents data of productivity from radiation record of three years. Energy analysis financial analysis and avoided emissions are calculated based on data from 2015. Productivity from this year is lower than average, by this assumption it is less probable to overestimate production.

By considering the data table 3-7 we see that each location has got potential to install one or both type of renewable energy power plants. Average world power capacity factor wind turbines is 35% (varies from 25% to 45%). For wind power, the locations Shofirkon Kongirot and Khazorasp are suitable in terms of productivity. From data presented above generation profiles we see that wind power generation from winter to summer increases. Southern deserts get hot and light air mass elevates. Heavier air mass from north moves to the place of lower pressure area. From wind rose above (figure 3-9) we see most of the wind blows from north-east which is compatible to the origination of the wind at these sites.

Average capacity factor for photovoltaic power plants is 20% (varies from 10% to 30%). Sites at desert farther from mountains and as much possibly close to south must show higher productivity by general understanding the PV generation. And we see it in case of Shofirkon and Khazorasp. Sherobod, Kongirot and Bulungur comes next accordingly. Better side of Sherobod and Bulungur sites is, these areas not desert as other location. Solar panels subjected to effect of sand and dust may get degraded faster or require more often cleaning actions.

Below, power generation from each source with rated power 100MW plants are apprised for their generation profile. It is assumed that all the energy generated is delivered to the electricity grid all over the year.

Shofirkon						
	2013	2014	2015	Average	Deviation	Average capacity factor
PV productivity, [kWh/kWp/year]	2261	2324	2212	2266	46	25.9%
Wind productivity, [kWh/kWp/year]	3768	4338	3575	3907	324	44.6%
Sherobod						
	2013	2014	2015	Average	Deviation	Average capacity factor
PV productivity, [kWh/kWp/year]	2220	2201	2134	2185	37	24.9%
Wind productivity, [kWh/kWp/year]	1195	917	1078	1069	114	12.2%
Kongirot						
	2013	2014	2015	Average	Deviation	Average capacity factor
PV productivity, [kWh/kWp/year]	2083	2131	2006	2074	51	23.7%
Wind productivity, [kWh/kWp/year]	3076	3029	2978	3028	40	34.6%
Bulungur						
	2013	2014	2015	Average	Deviation	Average capacity factor
PV productivity, [kWh/kWp/year]	2076	2013	2009	2033	30	22.9%
Wind productivity, [kWh/kWp/year]	709	592	847	724	105	8.3%
Khazorasp						
	2013	2014	2015	Average	Deviation	Average capacity factor
PV productivity, [kWh/kWp/year]	2227	2339	2159	2243	74	25.6%
Wind productivity, [kWh/kWp/year]	2505	2809	2668	2664	124	30.4%

Table 3-7: Productivity comparison of sites

3.5 Financial and economic analysis

3.5.1 Financial inputs

Uzbekistan just recently has begun its experience in the field of utility scale solar power plants and wind farms. For situation of 2019 only small size pilot installations are in function. In common considerations there is no evidencing plants to get orientation for financial indications. IRENA report on costs of renewables does not have data for this country.

First contracted project for construction of Solar photovoltaic power plant in 2020 in territory of Navoi region, between “Masdar energy” and “Ministry of Investment and foreign trade” consider as investment cost as 1000$/kW$_p$. In next calculations investment cost of solar power plants are assumed to be 1000$/kW$_p$. Similarly, China's “Lioaning Lide” company in territory of Gijduvan district in Bukhara has contracted building wind farms with investment cost 1200/kW$_p$. In next calculations investment cost of wind power plants are assumed to be 1200$/kW$_p$.

Operation and maintenance costs for solar power plant by indications of IRENA has been assumed to be equal to 10$/kW$_p$/year by fixed cost and for wind power plant equal to 0.02$/kWh/year. By the same reasoning discount rate 10% and lifetime of plant 25 years for both type power plants have been used as financial input [2].

Ageing of technologies as percentual reduction of producibilities have been taken from evidenced numbers in functioning of these kind of power plants. Solar power plants get degraded from 0.5% to 1% annually. Onshore wind farms show degradation 1.6%±0.2% annually. In analysis, they are taken equal to 0.5% for solar and 1.4% for wind power plants.

Selling price of electricity in domestic market is low than project to be feasible. On average it is 3.5c$/kWh. But over time the price of electricity going to be close to international electricity prices. In current situation state incentive programmes have not been made public. In neighbouring Kazakhstan having slightly higher price of electricity, the functioning solar power plant sells electricity at the price 9.11c$/kWh. Based on similarities of conditions and in order the projects to be feasible in the analysis the selling price of electricity to the grid from both type of power plants is assumed to be equal to 9c$/kWh during all the life of the plants.

3.5.2 Financial indicators

Results of financial appraisal gives us understanding potential location for renewable energy sources in Uzbekistan. Under more precise planning of financing the projects, plants at those sites can be successful.

At the site of Shofirkon financial indicators show both type of can be feasible. PV and Wind power plants relatively have better performance technically and financially than other sites. Related to safety of front cover of PV modules, the area is more suitable for Wind farms. But still productivity of solar panel at this location is highest between these five test sites.

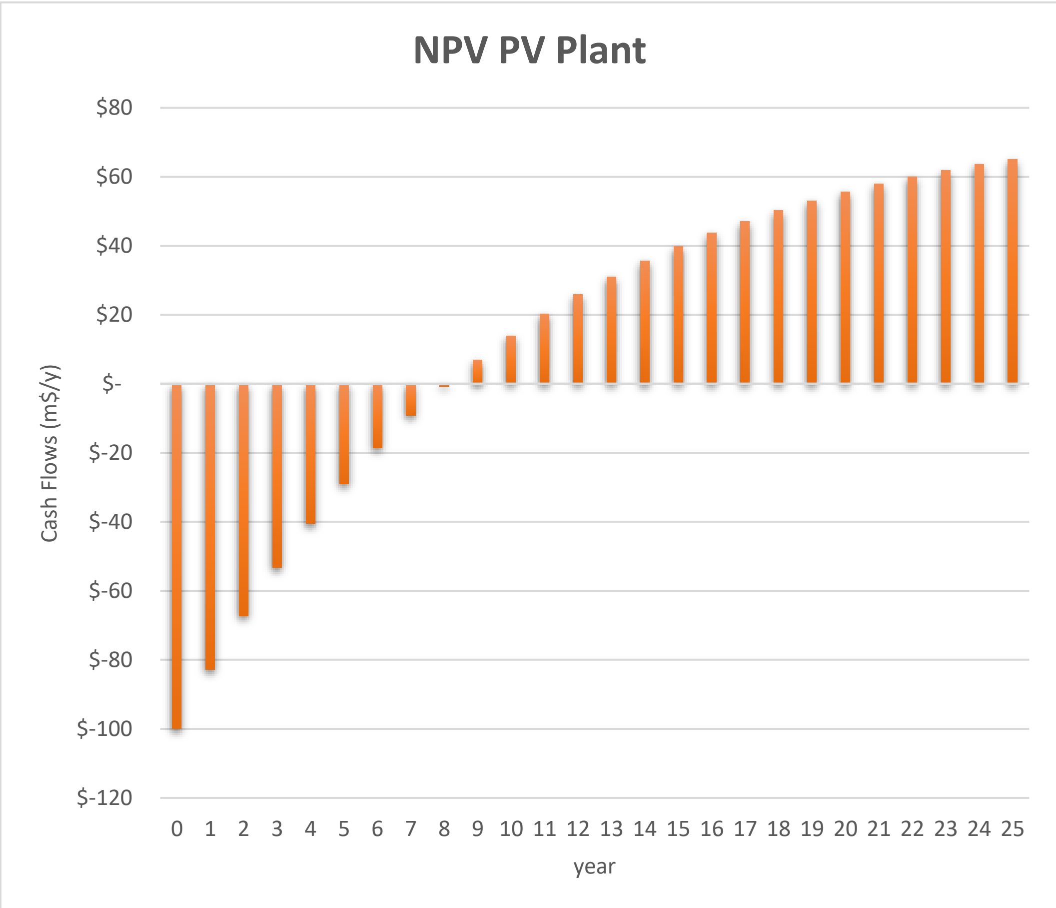

Figure 3-26: Net Present value of PV plant at Shofirkon

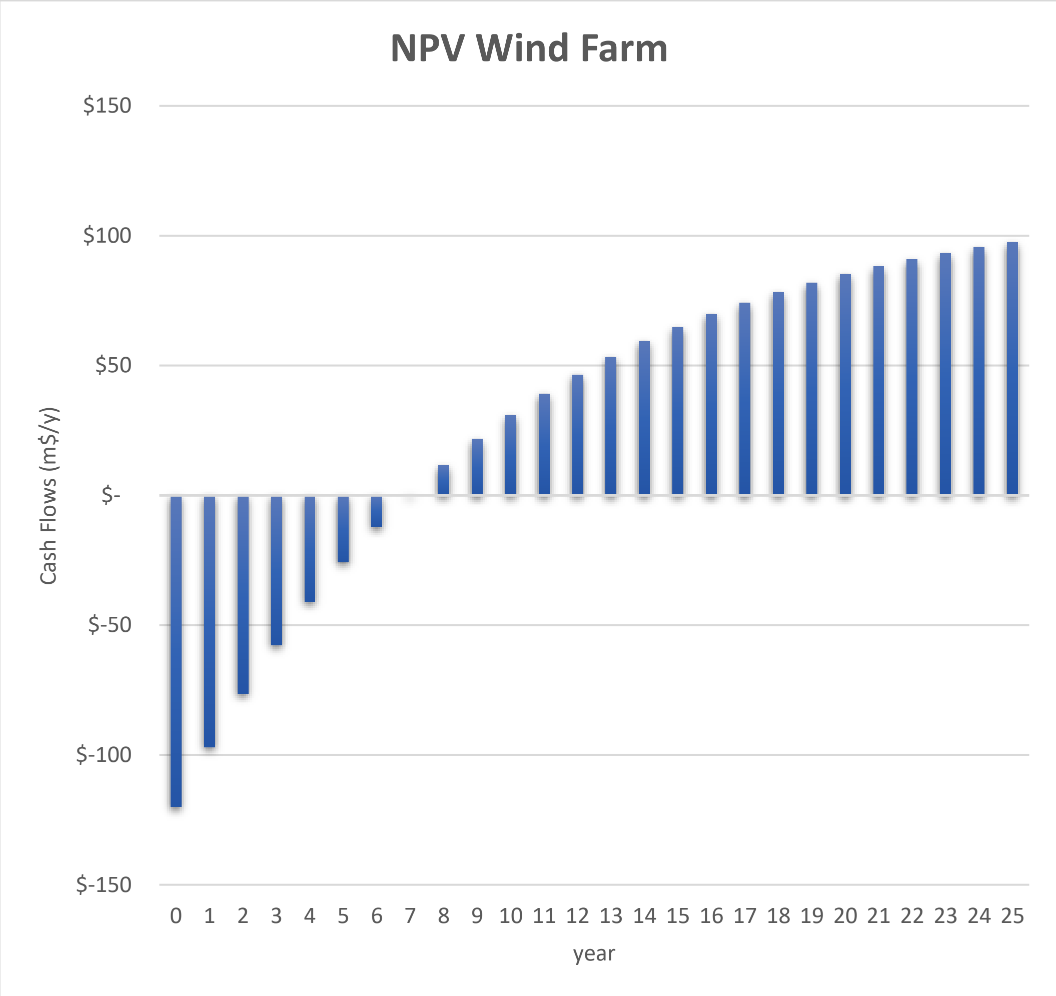

Figure 3-27: Net Present value of Wind farm at Shofirkon

Sherobod site shows that are is suitable only for solar power plants. It has enough productivity and less subjected to particles coming with wind. And Wind farms at this area has no perspective in utility scale as at this coordinate the amount of wind is not enough.

Kongirot site has got potential for solar and wind power plants at the same level. Feasibility of the power plants depends on more favourable financial structure of the projects.

Bulungur site as the site of Sherobod is not suitable for wind power plants with same reasons. The area has got potential for solar power plants with condition that discount rate can be lower than 10%.

Khazorasp territory shows little less potential for wind power to be feasible at the area. But toward the east and bordering district the productivity of the wind power increases. Solar power at this location can be source of energy as the indicators are similar to in Shofirkon and in Sherobod.

		Shofirkon	Sherobod	Kongirot	Bulungur	Khazorasp
Investment, [M$]	PV (100MW)	100	100	100	100	100
	WT (100MW)	120	120	120	120	120
NPV, [M$]	PV (100MW)	65.11	58.93	48.9	49.12	60.92
	WT (100MW)	97.39	-54.5	60.97	-68.47	42.24
PBT, [years]	PV (100MW)	9	9	10	10	9
	WT (100MW)	7	26	10	26	12
LCOE, [c$/kWh]	PV (100MW)	5.64	5.84	6.21	6.21	5.77
	WT (100MW)	5.96	14.93	6.74	18.41	7.28
IRR, [%]	PV (100MW)	7	7	6	6	7
	WT (100MW)	9	-6	6	-8	4

Table 3-8: Financial indicators for RES plants

3.6 Avoided $CO_{2eq.}$ emissions

At this stage the analysis concerns the reduction of CO_2 emissions. This analysis is performed on the level of country. If the country decides to install renewable energy source instead of conventional technologies, then it will avoid emissions which would be emitted. Analysis can be done for future possible portfolio of energy mix that is different than operating or for existing portfolio by weighting the emissions.

Primary inputs as indicated in section 2.4 are energy mix of the country, emission factors and annual energy generation from none emitting technology which was calculated in previous sections.

In section 2.4 as data source for energy mix the International Energy Agency (IEA) data are indicated. We can use these data or refer to section 3.1.2. taken from "Uzbekenergo" JSC web site.

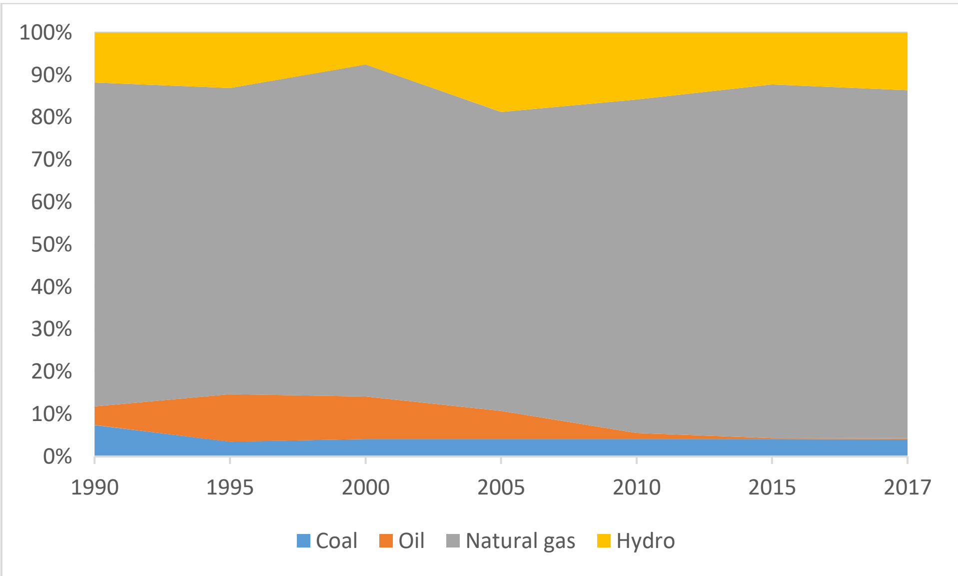

Figure 3-28: Energy mix of Uzbekistan (IEA) [IX]

SOURCE	Emission factor (g_{CO2}/kWh)	Energy Share
Coal peat and oil shale	1000.0	4%
Oil	1349.6	0.30%
Natural Gas	500.2	82.10%
Solar	0.0	0.00%
Wind	0.0	0.00%
Hydro	0.0	13.60%
other	0.0	0.00%

Table 3-9: Energy mix of Uzbekistan for 2018 [V].

Weighted emission factor for the country then equals to 454.71 gCO2/kWh. Then for every kWh electrical energy generated from solar or wind power plants we would avoid 454.71 gCO2. 100MW each power plants at the test sites would avoid emissions as in the next table.

	Shofirkon	Sherobod	Kongirot	Bulungur	Khazorasp
Generation from PV, [GWh/year]	221.23	213.38	200.65	200.93	215.9
Avoided for PV, [tCO2/year]	100598	97028	91237	91364	98175
Generation from WT, [GWh/year]	357.49	107.71	297.59	84.74	266.8
Avoided for WT, [tCO2/year]	162556	48979	135320	38531	121319

Table 3-10: Avoiding CO2 emissions by generation from 100MW power plant.

4 Toward creation of online software for renewable energy source estimation

XXI century is presented as a period for taking actions to reduce the ecological changes of anthropological origin. Amongst several ecological problems the reduction of CO2 and other greenhouse gases emission without compromising energy needs of people must be done. In many countries power plants are constructed in second half of last century. They are mostly powered by fuels of fossil origin and part of nuclear power plants. On both cases they are going to be replaced by new ones. In order to compete with traditional power generation technologies, the renewables such as solar and wind power must be planned and shown the opportunities faster. Model accepted for calculation in this work can be applied for other places as planning methodology. By testing for many places, the map of renewable potentials can be built including their financial and environmental indications.

By the idea above the model written software platform can be moved to online software based on RES calculation tool on excel. The online software may contain all the calculation steps and internal databases for input and records of analysis of other locations. Input parameters have time and spatial granularity. Depending on inputs step size maps also will have granularity considering GIS data which shows terrains that allow installation of power plant units. The software taking order from user makes queries to datasets indicated in section 2.1, performs all the calculations and returns to web interface the calculation results. Figures 4-2 and 4-3 depicts activity diagrams by rules of unified modelling language (UML) which should be performed during analysis of scenarios for RES. By algorithms the user interacts with system and systems taking instructions and data from datasets performs the RES analysis.

Unified modelling language (UML) helps interaction between developers of the online software and database of RES potentials. UML in general is a graphical tool which helps the interaction and expressing the ideas between designers, developers, businesspeople, engineers and other fields of different specialties. It is a form of advanced pictorial diagrams and with respect to flowchart, hierarchy and relation diagrams, it has got more rules and tools which more complex. This becomes handy when algorithms are not only flow of action or data, but also more specific conditions of action, interest and role of entities involved in project, unfamiliar concepts between specialities of different disciplines etc. Rules of UML are in constant improvement. It is updated annually to meet the required simplicity of communication of ideas of the complex projects.

During the process of development this UML “Astah UML” software is used. This software is free to use. To complete the UML of the project it should be developed Structure diagrams, Behaviour diagrams and Interaction diagrams. Activity diagram presented in this work is one part of the project and depending on stage of the project it will change further.

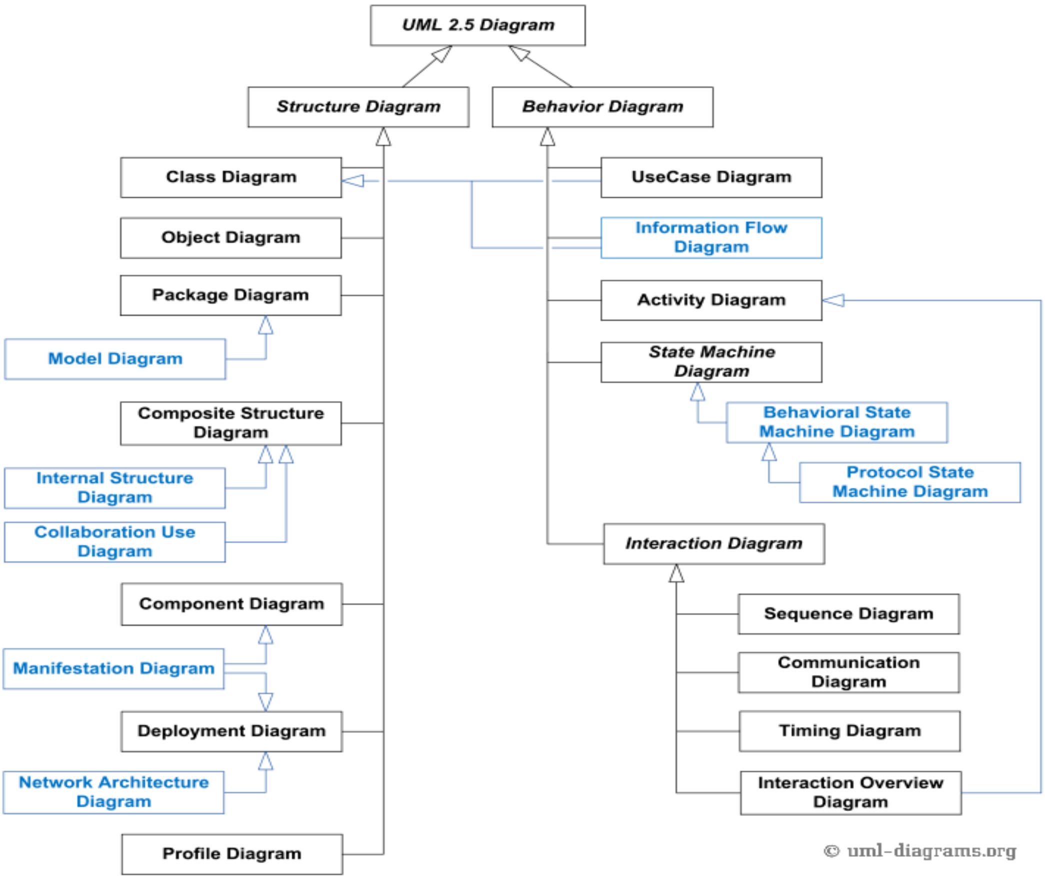

Figure 4-1: UML diagrams

Activity diagram presented in figure 4-2 represents algorithms and data flow between 6 entities. User, system, general database scenario database, datasets and web interface are entities which perform actions in corresponding part of activity flow. The user is person performing the analysis of scenario. He or she selects the process initiations at the site of interest, makes decisions about technical parameters and typology of scenario, makes modifications to these parameters and concludes the result of scenario analysis. All the processes of data collection from databases and external datasets, calculation of energy, financial and environmental outputs, presenting and saving results or parameters, checking for correctness of data inputs is performed by the system. The system interacts with all other entities. Web interface makes the task of medium for interaction with the user. It should depict the data to the user in proper way to be understandable to human and collect the decisions of the user and return it to the system. General database is the collection of all the parameters and constants used for calculation. It is created by developers of the engineering tool. External datasets are sources of meteorological, financial and environmental data which is described in section 2. And, scenario database is a collection of results of analysis. Finished scenarios and unfinished result of energy calculation are kept in this database. The last one is used to subsequent analysis as input data.

Activities are performed in the scope of entities or between entities. Activities for energy calculation is in orange colour, financial calculations activities are in violet and environmental calculation activities in green. Activities performed by user is in white colour. The user initiates the analysis and selects to new scenario analysis or upload existing scenario. In case new scenario, the system sends query to general database for available geographical areas. The user selects location from these presented geographical areas. Then system make a query to PVGIS database for initial parameters to make assessment about continuation of the analysis. Characteristics of these parameters are described in “astah.UML”. If the user wants to change the location, he may select other location or he can start energy analysis. Energy analysis process begins by sending queries to external datasets for meteorological data and to general database for other parameters which are necessary to perform calculations. External datasets (MERRA, GIS) upload requested data and send back to the system. Meanwhile general database returns options of parameters to web interface. The user selects these parameters and after these parameters go to the system. Depending on selected parameters the system makes another query to external dataset. System can perform the calculation only if all the required data inputs have been collected. After correctly collecting all the input data the system can start to calculate the energy generation. Steps of energy calculation and other calculations are depicted in calculation activity diagrams (figure 4-3). Output of calculation is sent to the web interface and to the scenario database. From scenario database, in relevant form the energy generation results are used for next calculations. The user from web interface can observe the results of energy in graphical figures. If he does not want to change, he can go to next step of analysis.

Financial and environmental analysis also are performed in similar logics. By query of the system external datasets, general and scenario databases return the parameters. Optional parameters are selected by the user. After all inputs are collected, the system calculates the output. Calculation activity for financial and environmental calculations are depicted in figure 4-3. The user can change the parameters for recalculation or can continue with obtained results. After the end of scenario analysis user can save or discard the results. By confirming his choice user finishes scenario analysis.

In case user uploads the existing scenario from previously saved event he/she may have option to modify all the analysis steps. If he/she modifies the energy calculation the he must repeat the financial and environmental calculations part.

The activities described above are fundamental part of RES analysis process. But it is not restricted to above scheme. In progress of work there can be added other entities and functions. Such as a results comparison or optimisation considering load and financial constraints.

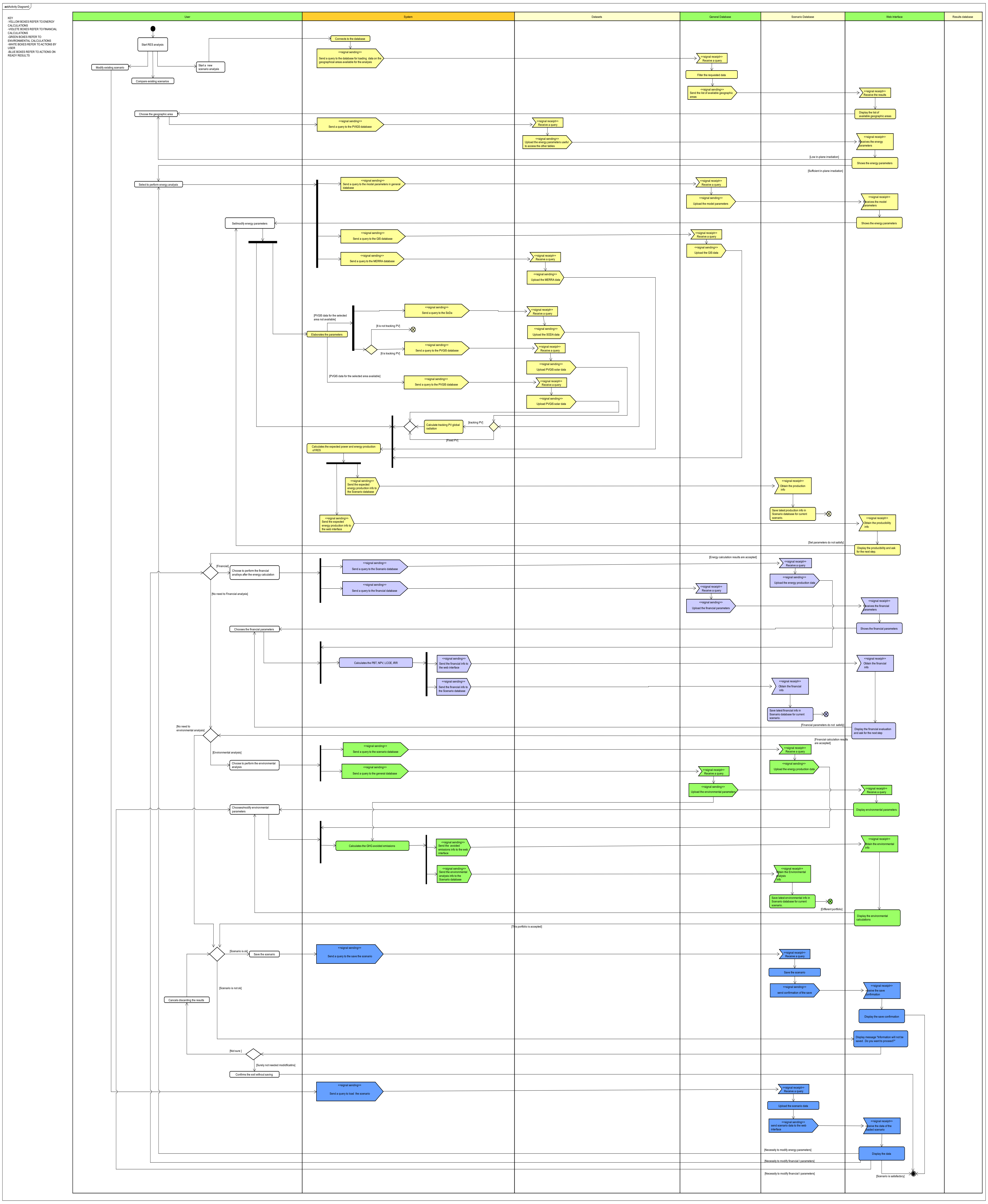

Figure 4-2: General activity diagram

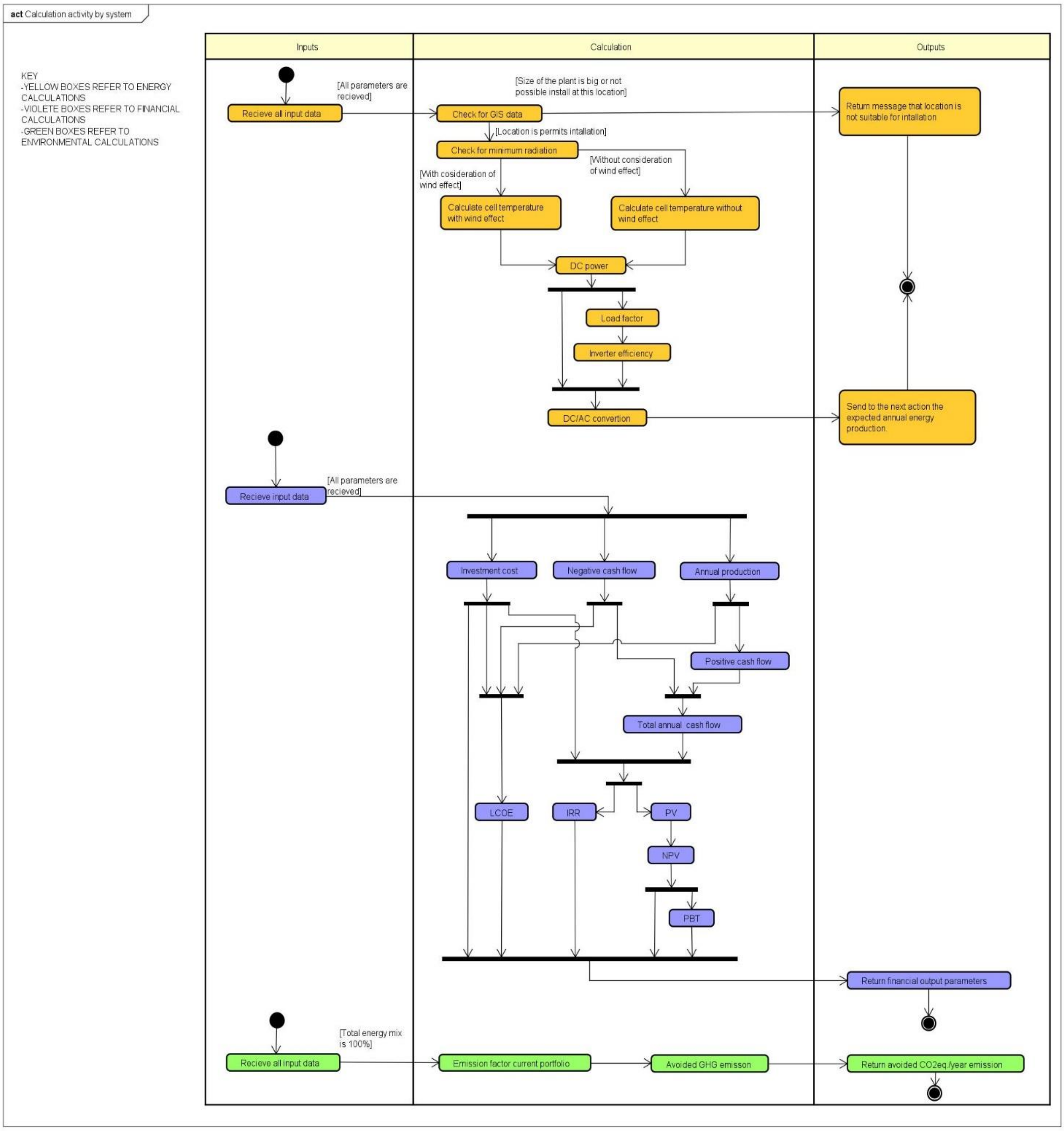

Figure 4-3: Calculation activities by system

5 Conclusion

By applying the wind and solar power potential estimation method described in this document, the results of energy analysis, financial analysis and environmental impact have been obtained for Uzbekistan. Results are discussed for feasibility of power plants and prospects in this field. Based on these results following conclusions have been drawn.

Analysis of energy production at sites reveals that wind and solar power would not be evenly distributed. Some locations have got better performance but concerning drawbacks. Some locations are perfect for one type of technology. The analysis of financial issues made it clearer that do the drawbacks affect the power plants feasibility. By indications of producibilities of PV generation, all the test sites have got potential to good electricity generation. And it can be assumed that the areas close to these sites also have got similar productivities. Questions arise by observing other graphs and qualities of sites. Central and western territories of the country have got wide area for low, medium and high wind power potential. High potential areas depend on terrain morphologies.

Shofirkon site is the most productive between test sites by considering PV generation. But it is also showing the highest wind potential. Wind may cause high pressure to structure of PV and by gust may damage the modules. For installation PV power plant areas at south from Shofirkon, where wind speed is lower can be considered. For wind power generation area showing high potential among test sites. And can be considered as a source of wind power.

At Sherobod site the PV energy generation is acceptable. LCOE is 5.84c$/kWh which is 0.2c$ more than the best performing site. What is more important is the area is not very windy and terrain is not a desert. PV modules would not have damaging influences. The area can be considered as solar energy source. Energy profiles show that winter generations in the mornings and evenings are steeper. By location of the site we may conclude it is the effect of shading from mountains as this site is located after the mountains. Situation can be improved by moving to the north where are is elevated or to the south, farther from mountains. Wind power at this area is very poor.

At Kongirot site the financial indicators are almost the same for PV and wind power plants. And at this location it is possible to make optimal combination to match the load profile. Considering that wind may cause pressure to PV modules, the plant location can be moved to the south or south-east of the district where wind speed is lower. Also, for wind power plants the area at northern parts can be more productive. This area can be renewable energy source if lower investment cost and expenditures were possible.

At Bulungur site the productions of both sources are lower. This site is the closest location to Tashkent vicinity and Fergana valley. It can be expected similar or more unfavourable conditions at these areas. PV generation is on average better than wind power. By improved financial constraints such as investment cost or discount rate the area can be source of PV energy. Most of the losses of radiation occurs during spring and autumn rain fall periods. As it was mentioned in above sections, most of the rain is at the eastern part of the country. Areas toward south-east from this test site may have reduced shading from cloudiness. Wind power at this site is very poor.

At the site of Khazorasp production from PV modules is good and the site can be source of PV power. Considering that coordinate of site is taken from northern point of the district, toward the south productivity can increase. But may face with the difficulty of logistics. Wind power at this area must be reconsidered by testing pilot wind turbine. Wind turbine generation profile depict sharp changes in generation. In practice these data may indicate higher turbulence at the area. Wind power may be higher at the north and north-east from the test point. Assuming the data estimated here it can be assumed that with better financial planning the area can be source of wind power.

By test sites analysis we can conclude that in the country there are a lot of places to be source of renewable energy. By confronting the price of electricity in the country, the costs of renewable power plants are still higher. Support from the side of government to the energy sector specifically to renewables and gradual increase of the energy cost may aid the investment projects.

6 References

Documents

1. Alessandro Ciocia-"Optimal Power Sharing between Photovoltaic Generators, Wind Turbines, Storage and Grid to Feed Tertiary Sector Users" - PhD thesis in Electronic Engineering. Politecnico di Torino, 2017.
2. F. Spertino-"Power generation from renewable sources" - Educational documents for MSc course in Energy and Nuclear Engineering. Politecnico di Torino, 2018.
3. IRENA-"RENEWABLE POWER GENERATION COSTS IN 2018"
4. IRENA-"RENEWABLE POWER GENERATION COSTS IN 2017"
5. IRENA-" Session 2a: Wind power spatial planning techniques"
6. I. Staffell,R. Green-"How does wind farm performance decline with age?" -Imperial College Business School, Imperial College London, London SW7 2AZ, UK.

Websites

I. https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
II. https://globalsolaratlas.info/map
III. https://globalwindatlas.info/
IV. https://www.iea.org/data-and-statistics
V. https://en.wind-turbine.com/
VI. https://www.investopedia.com/
VII. UML-diagrams.org
VIII. https://stat.uz/en/
IX. http://www.uzbekenergo.uz/uz
X. https://minenergy.uz/en
XI. https://lex.uz/ru/
XII. https://www.gazeta.uz/oz/
XIII. Wikipedia.com