Раздел 4. «Экономика. Общеобразовательные, социально-гуманитарные и фундаментальные дисциплины»

A.W. Fayez Wazani, Z.S. Gelmanova

Karaganda Industrial University, Temirtau, Kazakhstan
(E-mail: zoyakgiu@mail.ru)

Analysis and modeling of a photovoltaic system at a solar power plant in Surubi, Afghanistan

This technical and economic feasibility study for a solar power plant in Surobi aims to develop the renewable energy sector and promote low-carbon growth. The research's novelty lies in the project's phased division into intervals, each with its own indicators, dependent on the modeled impacts and conditions. The study evaluates the technical feasibility, economic viability, environmental and social impacts. The proposed technical solution includes crystalline modules, fixed-tilt structures, and central inverters. The technical and economic feasibility of constructing the Surobi solar power plant was examined using a specific example of this photovoltaic system. Financial modeling confirms the project's viability, showing an expected internal rate of return exceeding the discount rate. The project offers environmental benefits by investing in clean energy infrastructure and supporting the region's transition to sustainable and reliable energy production.

Keywords: solar power plant, photovoltaic system, technical feasibility, economic viability, renewable energy, environmental impact, social impact, crystalline modules, internal rate of return, sustainable energy.

Introduction

Due to the rapidly growing rates of electric energy consumption, energy supply comes to the forefront among the world's most important problems. Consequently, the issues of energy saving, development and implementation of renewable energy sources (RES) systems become very topical. In the last decade RES have a stable annual increase in capacity. Even during the economic downturn during the pandemic, the renewable energy segment continued to grow. According to the International Energy Agency (IRENA), capacity additions of alternative energy generation systems increased by almost 50% to 280 GW in 2020. This is a record annual jump over the last decade. In 2020, the major capacity additions amounted to - 127 GW of new solar installations [1]. Solar power has become one of several promising alternative energy sectors [2-5]. The decreasing cost of solar modules over the last few years and the rising prices of petrochemical fuels used to generate electricity have led to the increased use of photovoltaic systems.

We have presented an overview of articles reflecting topics related to general issues of renewable energy.

Methods and materials

In Child et al. [6], demonstrated that energy storage and grid interconnection technologies can facilitate the transition to a cost-optimal 100% renewable energy system for Europe by 2050. The paper compares scenarios in which specific countries and macro-regions in Europe are either energy independent or interconnected and analyzes how this would affect the cost of the energy system. Under the first scenario, in 2050, solar photovoltaic power plants will account for 45% of energy generation, wind power for 30% and 11% for hydroelectric power, 73% of energy sources will be included in the renewable energy exchange system, and 81% under the second scenario.

The main purpose of the publication [7] is to demonstrate the opportunities offered by combining different types of renewable energy, energy storage and advanced technologies to achieve the targets of energy transition realization. The authors have developed an algorithm to assess the impact of the introduction of wind and solar

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photovoltaic installations on the increasing share of renewable energy in electricity generation. The results of the work are applied to the data on renewable energy in Germany.

Results and discussion

In [8], a software platform for robust design of multi-component energy systems under limited input information is proposed. The optimal design of a decentralized system that includes renewable energy sources and energy storage systems is implemented. The problem is solved by a mixed integer linear programming method, which optimizes the system operation with respect to the needs of the final energy consumers, and minimizes the total annual cost and CO_2 emissions.

In [9], the authors analyze statistical information on the state of the energy system: electricity and heat demand, volumes of storage batteries and thermal reservoirs, and electricity prices.

In [10], the applicability of Danish experience in solar district heating (SDH) for China is analyzed. The applicability of the experience was assessed using PEST (politics, economy, social and technological aspects) and SWOT (strengths, weaknesses, opportunities and threats) analysis methods. In 2014, China accounted for 75.8% of the total solar collectors in the world and only less than 0.3% of solar collectors were used for space heating.

In the article [11], it is noted that nowadays there is an increasing need for alternative, economical, renewable and green energy sources such as hydrogen.

The overall objective of [12] is to investigate the scale of biomass demand in a fully renewable energy system. Extensive land use for biomass production threatens to exceed the permissible values, which, according to international experts, in 2050 will be about 10-30 GJ per person per year.

In [13], the causal relationship between carbon dioxide emissions, energy consumption, renewable energy, population growth and economic growth of countries in the region is investigated.

Topics reflecting the general issues of renewable energy are widely represented in scientific articles indexed in the Web of Science abstract database.

The European Photovoltaic Industry Association (EPIA) predicts that solar power will displace oil and nuclear power in the future. Today, solar photovoltaic systems are used intensively in Europe. The total capacity of solar power plants operating worldwide has grown by 31 GW, surpassing the 100 GW milestone. Today, they produce as much electricity as 16 large coal or nuclear power plants [14].

The use of RES and their combinations in the conditions of a particular region is economically, technically and socially justified [15]. At the same time, the use of RES is considered as an organic and necessary element of the program of sustainable development of the territory, determining the directions of development of engineering infrastructure of the region and indicating the ways of solving the set tasks [16-18].

This is more than relevant for Afghanistan, since its territory is home to a significant part of the population, which has no access to centralized power supply and backup energy sources. At the same time, these territories have a huge stock of natural renewable energy resources and the use of only the energy potential of solar energy is economical and realistic compared to other types of energy. With regard to the conditions of Afghanistan, the relevance of the work is to assess the potential of solar energy in order to create a RES-based energy complex that would ensure reliable and uninterrupted power supply to remote facilities and high-quality and efficient operation of solar power plants.

The Surobi solar power plant feasibility study utilized a multi-stage approach to assess the technical and economic viability of the proposed project. This methodology includes.

Technical feasibility which is assessed based on the following factors:

- *Site Selection and Evaluation.* A comprehensive survey of potential sites was conducted to determine the most suitable location for the solar power plant. Factors such as resource availability, security, grid connection, land availability, topography and geology, and accessibility were considered. Based on the results of the site survey, a 70 hectare site in Surobi district was selected as the optimal location for the project. This site met all basic technical criteria and had advantages in terms of proximity to the Naglu hydropower plant and existing transmission networks,

- *Solar Resource Assessment.* The site selected for the project has excellent solar energy potential, averaging 5.4 kWh/m^2/day. Data from various sources including Meteonorm 7, NASA-SSE, local weather station measurements, and Vaisala Level 3 were analyzed to determine the availability of solar resources at

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the selected site. Vaisala 3tier Services developed and maintains a global, long-term, high resolution solar da taset, which was created using satellite observations from around the world. Satellite derived data have proven to be the most accurate method of estimating surface solar irradiance beyond 25 km of a ground station. Vaisala source of satellite observations is weather satellites in a geo-stationary orbit. These satellites have the same orbital period as the Earth's rotation and, as a result, their instruments can make multiple observations of the same area with identical viewing geometry each hour. Vaisala uses visible satellite imagery to calculate the level of cloudiness at the Earth's surface. The resulting time series of cloudiness (or cloud index) is then combined with other information to model the amount of solar radiation at the Earth's surface. The outcome is a 15+ year dataset that provides hourly estimates of surface irradiance (GHI, DNI, and DIFF) for all of the Earth's land mass at a spatial resolution of approximately 3 km. The general methodology is similar to other satellite derived solar datasets, but a majority of the algorithms are proprietary. Dataset also includes several key improvements such as higher spatial and temporal resolution, empirical fitting, and a monthly time series of turbidity esti mates. A cloud-index algorithm that produces consistent results when used with the large number of different satellites that must be combined to construct a global dataset has also been developed,

- *System Design.* The technical components of the solar power plant were determined. The project will utilize silicon PV - modules, fixed tilt structures and central inverters. Will have a capacity factor of 20%, which is in line with similar projects in the region. The project is expected to have a technical life of 25 years. The project will be connected to the national grid through a 20kV transmission line,

- *Energy Yield Estimation.* The PVsyst V 6.5.1 software package was used to model the expected energy production of the solar power plant. This included calculating incident energy, accounting for irradiation energy loss, accounting for contamination and module quality loss, estimating losses due to module mismatch, system performance, passive losses, and accounting for module degradation.

The economic feasibility of the project was assessed by the following factors:

- *Cost Estimation.* The capital cost of the solar power plant was estimated based on the cost of equipment, installation, acquisition of transmission lines, supporting infrastructure, and the first three years of operation and maintenance (O&M). The total project cost was estimated at US$46.68 million. The annual operating cost of the project will be US$0.56 million,

- *Financial Viability.* The financial viability of the project was analyzed by comparing scenarios with and without the project. The internal rate of return (IRR) at different end-user tariffs was estimated and the present value of electricity (LCOE) was calculated. The project has an internal rate of return (IRR) of 15% and expected to pay back in 7 years. The project is expected to generate US$7 million in annual revenue from the sale of electricity and is financially viable under different sensitivity options,

- *Environmental and Social Impacts.* The project is implemented based on the principles of sustainable development, taking into account environmental and social impacts.

Result 1. Technical feasibility of the project

Surobi is a district of Kabul province in Afghanistan. Its capital Surobi is located about 60 kilometers east of Kabul. However, much of the district is located northeast of Kabul. The main river in this district is the Kabul River.

There is not much suitable land in this region for the construction of solar PV system as the topography is hilly and steep. After extensive survey work, a 70 hectare plot of land was selected. The target site (named site 3) is located 5 km from Surobi village, on the bank of the Kabul River, 3 km downstream of the Naglu Dam and hydroelectric power plant.

The project area has transmission and distribution networks: 110 kV transmission lines connect the Naghlu hydropower plant to Kabul and Jalalabad, and a 20 kV distribution network is designed to electrify Surobi district. A brand new substation (20 MVA, 110/20 kV) located 2 km from the site towards the dam was proposed by DABS and commissioned in May 2018. This substation is part of DABS' plans to strengthen the distribution network in the area.

An additional 20 MVA transformer has been added to double the capacity of the Surobi substation to improve system reliability and ensure that all of the solar farm's generation is absorbed. Given the significantly low capacity of the solar power plant compared to the total NEPS generation, the integration of solar PV should not jeopardize grid stability. A load sharing analysis was performed for the 100 MW power plant in Naglu, which concluded that up to 50 MW of additional solar capacity can be absorbed by the NEPS grid, so it is assumed that 20 MW does not pose a risk to grid stability. The Google Earth image is marked with a yellow

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sign of the location where the new 110/20 kV substation will be built, which is the proposed grid connection point for the solar power plant « Figure 1» [19].

Figure 1 –The territory of the construction of a solar substation

Surobi area is located at an altitude of about 1000 meters above sea level. The land has a uniform slope to the south. Geotechnical investigations are required to characterize the soil for sizing the foundation of the solar structure.

Local steppe climate. Surobi Township receives little precipitation throughout the year. According to the Keppen-Geiger climate classification, this climate is considered BSk.

The average temperature in Surobi is 17.9 °C. The average annual rainfall is 348 mm according to Climate.org [20].

The driest month is September, with a rainfall of 2 mm. In April, precipitation reaches its peak with an average of 92 mm. July is the warmest month of the year. The average temperature in July is 29.9 °C. January, with an average temperature of 5.4 °C, is the coldest month of the year. The difference between rainfall in the driest and wettest months is 90 mm. The annual temperature fluctuation is about 24.5 °C.

Surobi is located in western Afghanistan, between Kabul and Jalabab, and is connected to both cities by highway. The project site is 60 km from Kabul and 83 km from Jalabad and is accessible by road. Site coordinates:
- Latitude: 34.6127 °N,
- Longitude: 69.7180°E.

Electricity for site development works can be supplied from the existing grid as there are 20 kV overhead lines on the site, thus avoiding extensive use of diesel generators. This can be done by tapping a temporary connection to the overhead line passing the site. Local labor for construction and other development works could be from Surobi district and possibly from neighboring districts.

Solar Resource Assessment. The following databases were evaluated as sources of solar radiation, temperature and other relevant climate data:- Meteonorm 7- NASA-CCE- Local measurements from weather station (MEW)- 3-level Vaisala number «Figure 2».

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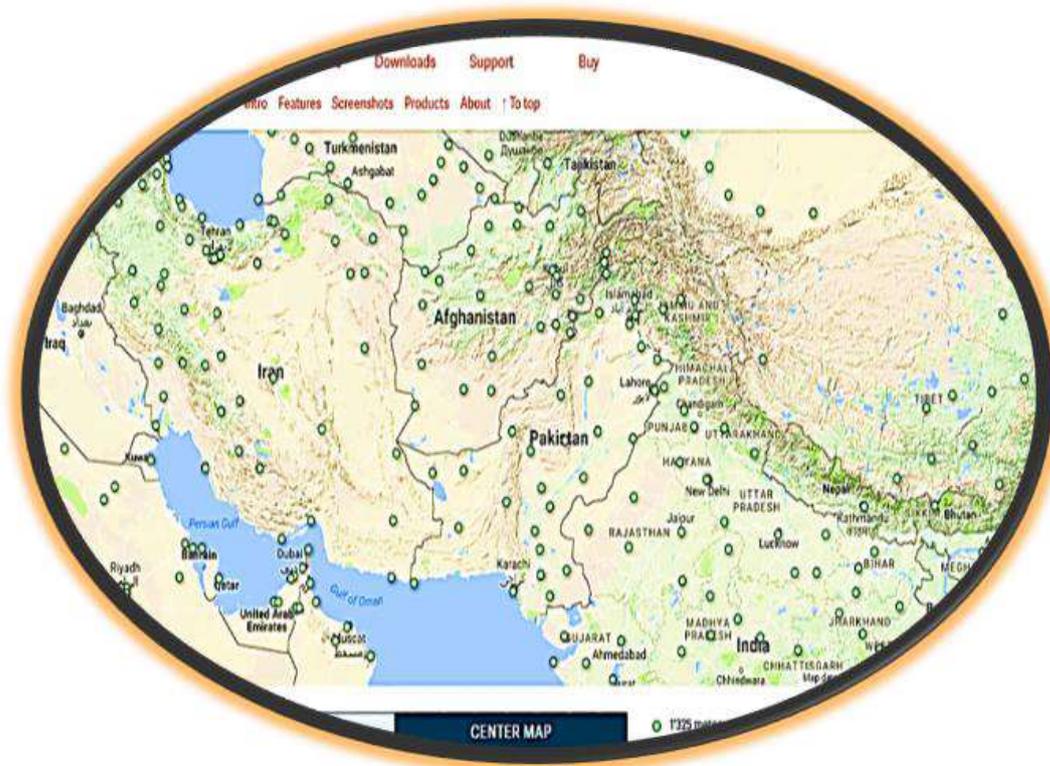

Figure 2 – Databases for the assessment of solar resources.

Although data from all of them are shown for comparison, only Vaisala Level 3 should be used for performance evaluation «Figure 3» [21].
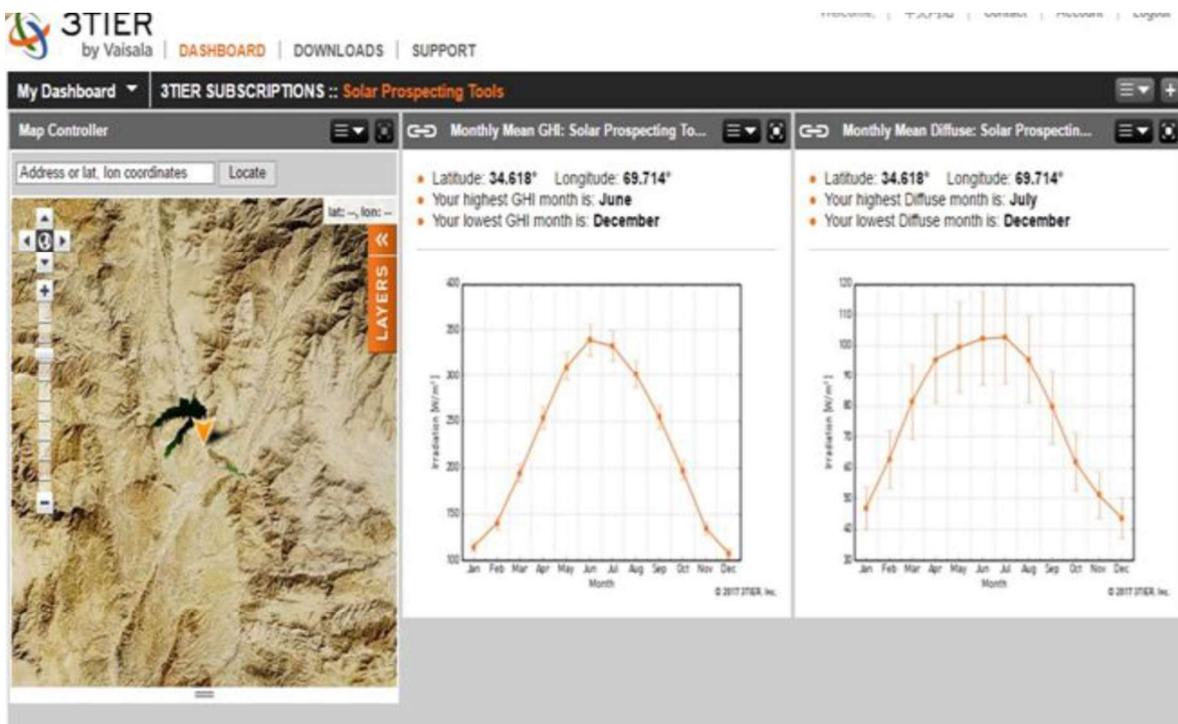

Figure 3 – Vaisala 3 tier data for energy efficiency assessment.

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NASA. GEOS-4 satellite data are used to calculate temperature averages for the period 1983 through 2006. The data are compared with ground-based measurements from the Globalsod database. The temperature values have the same resolution as the irradiance values (grid cells of 1° latitude and 1° longitude) [22].

Meteonorm. Temperature values are taken from the Globalsod database. Out of the available 8000 stations around the world, about 5000 are used. The density of the station network depends on the respective regions with the densest distribution in Europe. The period of record reflected in the database includes the years 2015 - 2024.

Vaisala-3 Levels. Temperature data were collected for the Surobi site using the Vaisala 2.1 algorithm and will be used for yield estimation.

Table 1

Summary of all temperature data from different sources

Monthly average temperature (°C)			
Source	Meteonorm 7	NASA	Vaisala 3tier
January	7,9	-3,4	-0,6
February	10,7	-1,7	0,0
March	16,2	3,3	6,6
April	21,0	9,0	12,7
May	26,1	14,0	17,5
June	28,0	19,1	23,2
July	28,2	21,2	23,9
August	27,2	20,1	22,7
September	24,2	15,7	18,2
October	19,7	9,4	13,0
November	13,1	4,3	6,9
December	9,2	-0,6	3,5
Average	19,3	9,2	12,3

The base case of the plant is designed based on standard 72-element 325 W STC multicrystalline silicon modules, chosen for their high performance as well as advanced specifications.

Modern grid-connected central inverters are considered as a basic option, but string inverters can also be a suitable option to convert DC power to AC power, provide reactive power compensation as per grid requirements, synchronize the solar power plant with the grid, protects the system from internal and external electrical disturbances and faults, optimizes the operating point of the solar panels maximizing power generation, it also controls the key parameters of the generation system along with other secondary functions.

The expected yield estimation is based on climate modeling and simulation tools used to represent the behavior of the PV power plant system in a specific environment. The energy production modeling performed with the PVsyst V 6.5.1 software package provides two main results:
- Annual total electricity production (kWh/year),
- Annual specific power generation (kWh/kW/year).
The main steps of the modeling process are the following parameters.

Incident Energy. Global and diffuse irradiance data in the horizontal plane are used to calculate the irradiance in the inclined plane of the photovoltaic array (PVA). The transposition of diffuse solar irradiance is carried out in the simulation process using specific models. Two models are usually available for this purpose: the Perez model and the Hay model. The Perez model was chosen after recent results of a comparative analysis, which indicate a closer agreement for radiation transposed to the lattice plane [23].

Irradiation Energy Losses. Losses are calculated using specific models reflecting optical, transmittance and/or surface effects to transfer the energy available for the irradiation-electrical conversion process.

Contamination. For the local environment, reduced contamination losses are considered, assuming that cleaning of the PV module will be performed regularly during the operation and maintenance phase. For less frequent cleaning (e.g., once every 4-6 months), the contamination losses will be higher.

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Module Quality. Because of the special conventions inherent in the modeling software used, it will be necessary to distinguish between "plus/minus" and "positive only" tolerance cases. "Positive tolerance only" modules are those with an effective power slightly higher than the nominal value specified in the data sheet. Positive tolerance only modules are represented by negative values of the module quality loss parameter. The average module quality was calculated at 0.4 % of the rated power based on the data sheet provided by the module manufacturer. This value is set in the software as a negative value representing the gain and reflecting the specific installation configuration.

Losses due to module mismatch. This parameter is used to account for the fact that the power tolerance specified by the manufacturer in the product specifications or quantified by flash test measurements will result in additional performance degradation resulting from interconnecting modules with different current and voltage levels. For crystalline silicon modules, the loss due to module mismatch is estimated to be 0.7% on average.

System Performance. It is based on the properties and characteristics of PV modules (output power, partial shading effects, temperature characteristics, etc.) and inverters (conversion efficiency, partial load, etc.).

Passive Losses. These losses occur in electrical cables and are estimated by the PVsyst software using the cable dimensions specified in the system configuration to finally correct the energy delivered at the system output. Ohmic losses include DC cable losses from the solar modules to the inverters and AC losses from the inverters to the transformers and from the inverter output to the power meter located at the point of supply. These losses are based on the electrical configuration depicted in the single line diagram.

Module Degradation. For this type of crystal module, an average initial degradation of 1.1% was considered for modeling purposes, since typical guaranteed light-induced degradation values are 2.5%. For annual degradation, a value of 0.5% is considered appropriate for predictions, which is half of the expected generation loss for calculating the P50 value in the first year.

Own Energy Consumption. Since not much power will be required for the security systems and most of the inverters are expected to be installed outside, the own consumption of the power plant is expected to be small. Thus, the value of the plant's own consumption is estimated to be 0.4% per year.

Plant Availability. Plant availability is expected to be 99% within one year. This value is representative of PV plants using a stationary plant.

Grid Availability. Since the solar plant will have a dedicated feeder at Surobi substation that is connected to the NEPS 110 kV grid, grid availability is considered high and a 98% daytime uptime percentage (solar generation hours) should be considered.

Performance Ratio. The performance ratio (PR) is considered as the ratio of (annualized values of) total AC energy to theoretically available energy and gives an indication of the quality of the installation. PR can be seen as the ratio between the effective and theoretical electricity production of the PV system measured at the AC metering point.

Result 2. Economic feasibility

The specific output and performance factor were calculated using the internal algorithms of PVsyst modeling software based on the performance and components.

The resulting energy yield and performance prediction results are shown in the following Table 2, which includes AC losses and medium voltage transformer losses. The transformer losses are typical of standard high efficiency transformers used in solar PV installations. Moreover, the results take into account $\cos \varphi = 1$ (power factor of the inverters), which means that no reactive power enters the grid (hence, no additional inverter losses need to be considered in this respect).

Table 2

Main simulation results for the evaluated PV plant

Output Power	20 MW
Installed DC capacity	24.336 MWp
Performance Ratio	80.5%
Specific yield	1,796 kWh/kWp
Annual energy generation	43,705 MWh
Plant Factor	20.5%

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Equivalent hours at full load	2,185 h

The capital cost of a 20 MW solar PV system consisting of a 24 MW solar array, site preparation and evacuation infrastructure was estimated based on capital expenditure (CAPEX) for equipment (solar PV system, inverters, other equipment, cables, structures.), transmission line, etc.), transportation costs, labor costs, and other costs. The distribution of all project costs (in millions of dollars) is shown in table 3.

Table 3

Distribution of all project costs (millions of dollars)

No.	Cost Element	General
A	Investment costs:	
	Turnkey contract for construction	24.5
	Solar photovoltaic systems	2.10
	Purchase and installation of power lines	3.93
	Supporting infrastructure	1.68
	First three years of operation and	4.30
	maintenance	36.51
	Taxes and duties	
	Total A	
B	Current expenses:	
	Project management	1.0
	Capacity development	1.2
	External audit	0.1
	Total B	2.3
C	Unforeseen circumstances	6.05
D	Financing costs during implementation	1.82
Total project cost (A + B + C + D)		46.68

Operating costs (OPEX) for the three-year period have been estimated and are included in the cost summary. This cost includes operation and maintenance of the solar power plant as well as security services.

Capital costs considered for the financial analysis consist of: equipment supply and installation costs for the solar power plant infrastructure; site preparation and civil works; grid connection costs; security and clearance; supporting infrastructure such as roads, water treatment and control systems; taxes and duties; ongoing project management costs; and budgeted physical contingencies. The financial analysis excludes commitment costs, interest during construction, and unanticipated price changes. The project will also incur annual incremental O&M costs consisting of labor, spare parts, and other operating costs (e.g., water and telecommunications charges). The analysis assumes that O&M costs remain constant over the life of the model. The total cost of the project is estimated at US$46.68 million, which includes investment costs, operating costs, contingencies, and financing costs during implementation.

The project will have a number of positive environmental and social impacts, including:

Greenhouse Gas Emissions Reduction: will reduce greenhouse gas emissions by 20,000 tons per year.

Job Creation: 200 jobs during construction and 100 jobs during operation will be created.

Stimulating the Local Economy: The project will stimulate the local economy by creating new business opportunities and increasing tax revenues.

The project will have a number of positive social impacts, including:

Improving Access to Clean Energy: The Project will provide clean, renewable energy to the community, which will improve their quality of life.

Promoting Education and Training: The Project will provide education and training in the field of renewable energy.

The PVsyst V 6.5.1 software package is used to simulate the expected energy production by a solar power plant. «Figure 4-8» show the implementation of solar power plant model in the Surobi of Afghanistan.

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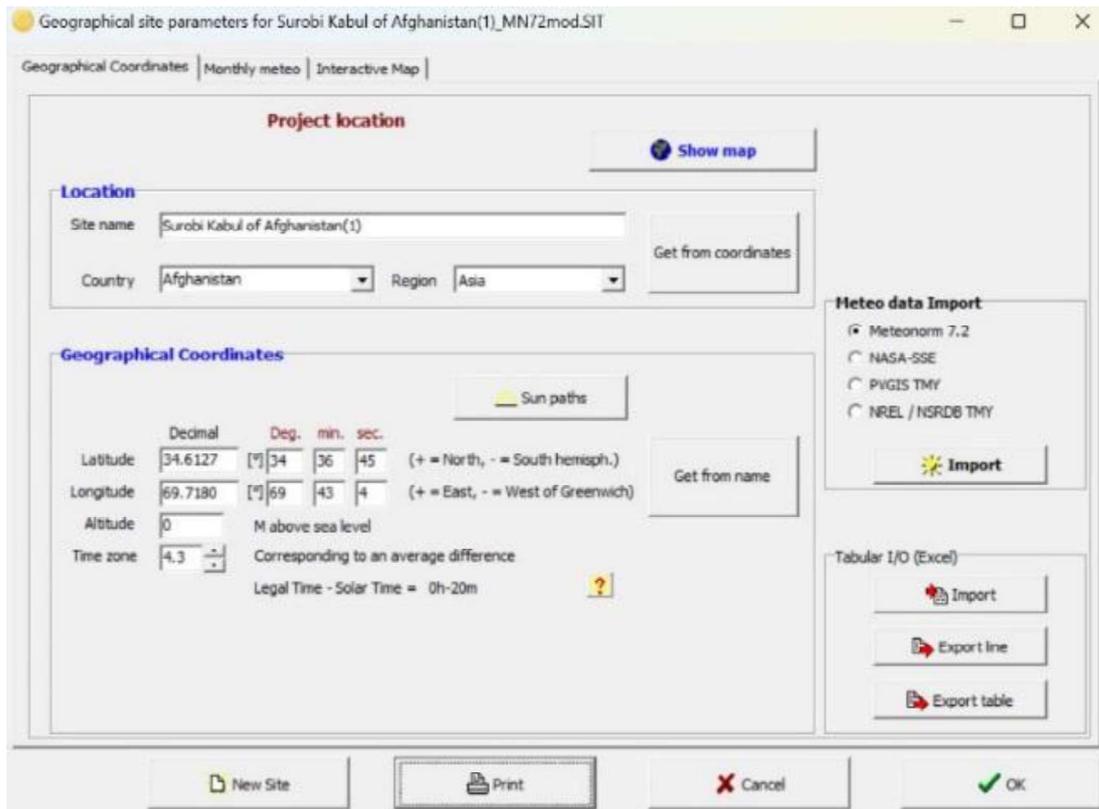

Figure 4 – Geographical site parameters for Surobi Kabul of Afghanistan (Geographical Coordinates)
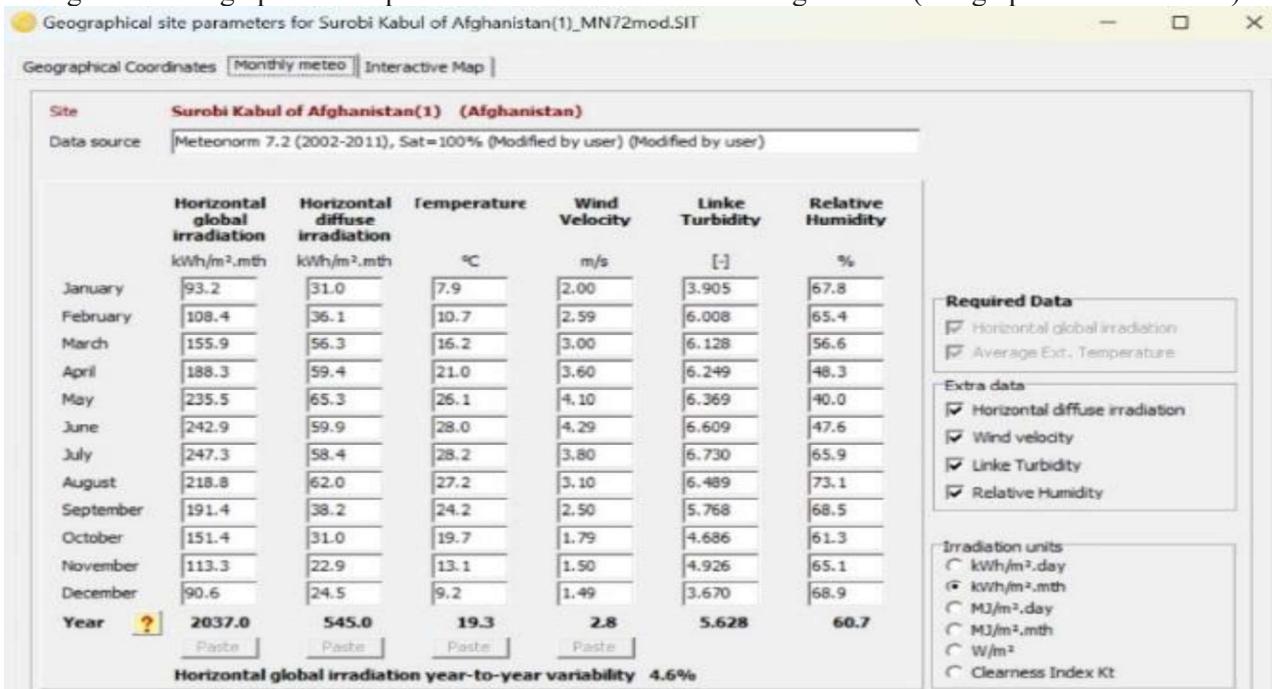

Figure 5 – Geographical site parameters for Surobi Kabul of Afghanistan (Monthly meteo)

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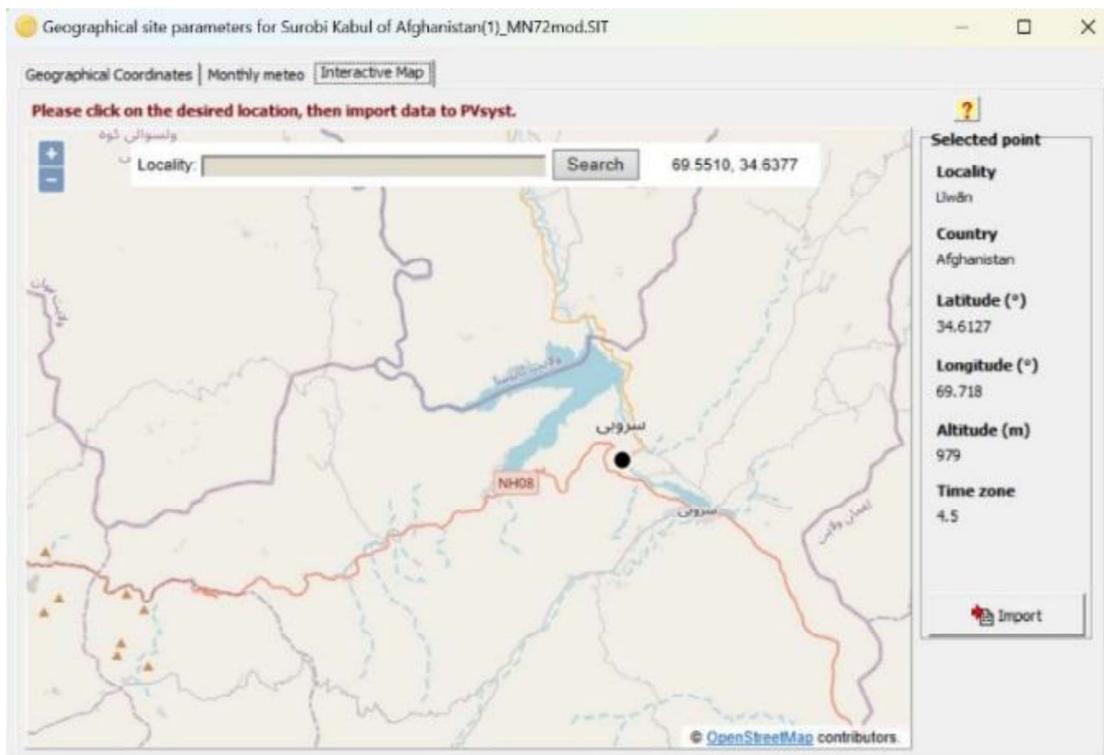

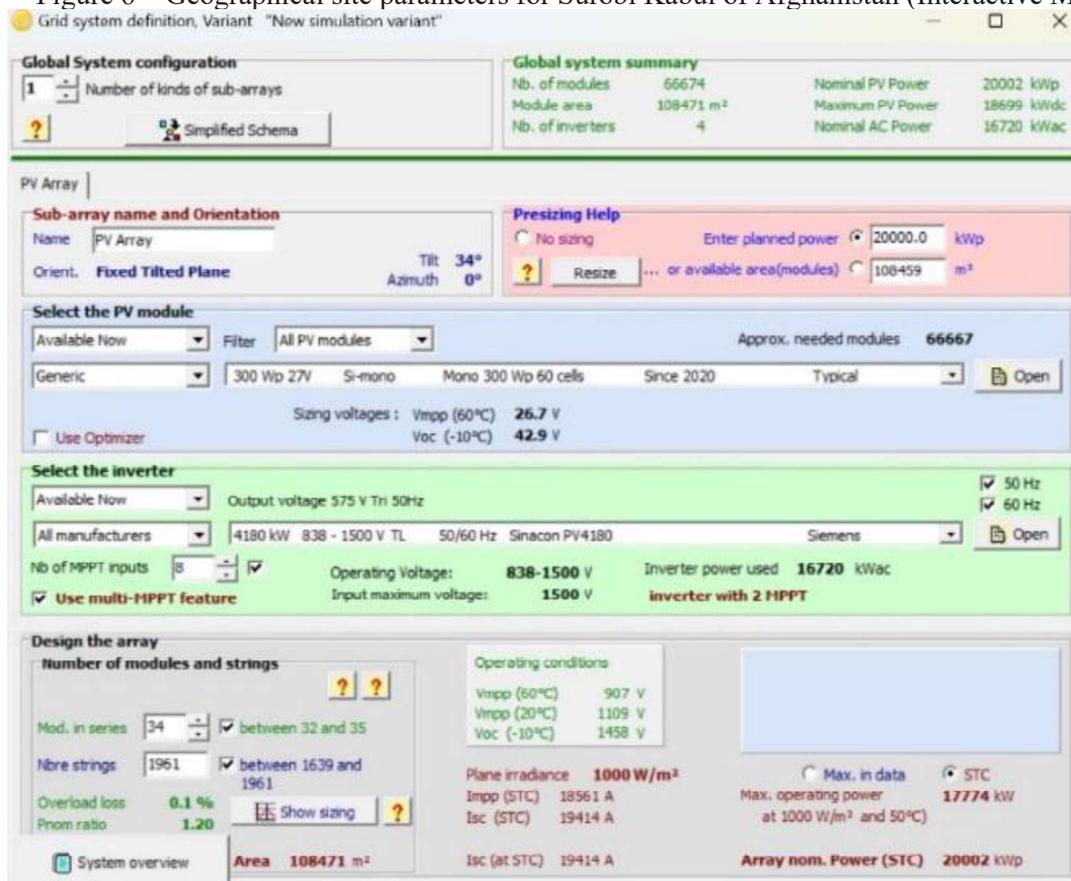Figure 6 – Geographical site parameters for Surobi Kabul of Afghanistan (Interactive Map)

Figure 7 – Main parameters «System»

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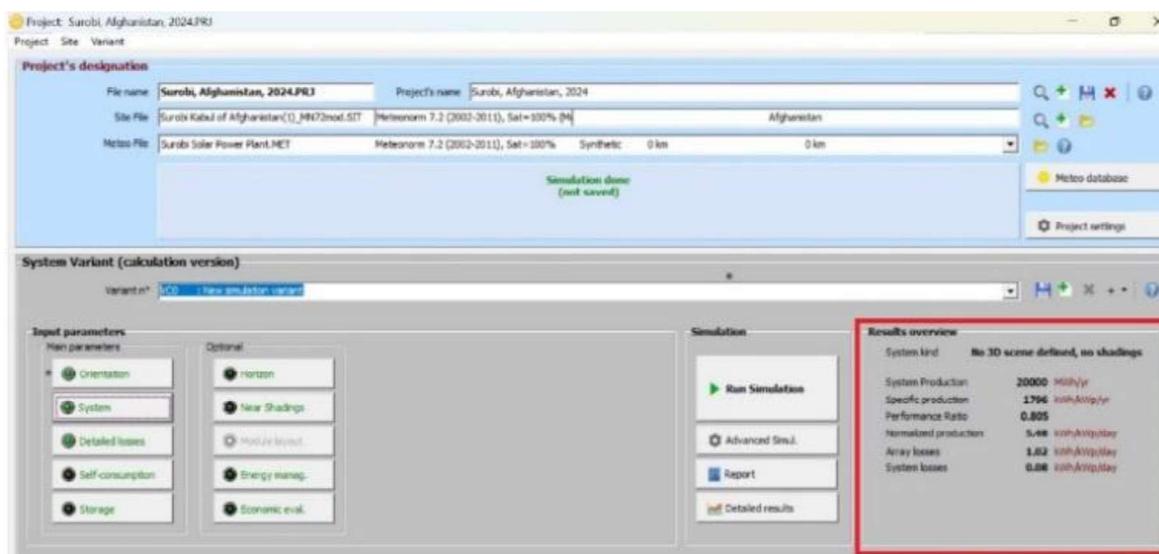

Figure 8 – Main simulation results for the evaluated PV plant.

Conclusions

Presented in the aspect of deciding on the profitability of continuing with the project.

In the aspect of providing the enterprise with resources. The SES project is modern and high-tech, the whole installed SES complex has a high degree of automation of working processes. The complex completely provides itself with electricity, which allows to solve the issue of heating, lighting and power supply of the main technological processes without attracting this resource from outside.

In the aspect of social effect - it creates jobs and has high indicators of tax profitability for the budget.

In the aspect of production indicators - significantly improves electricity generation in the region and gives a powerful innovative effect for the production and infrastructure industry. The proposed solar PV project uses standard 72-cell multicrystalline silicon modules with high performance characteristics. Advanced grid-connected central inverters are considered along with fixed-tilt mounting structures optimized for maximum solar energy harvesting throughout the year.The paper also discusses solar resource assessment using various databases, with Vaisala 3tier data recommended for yield estimation purposes. The modeling process using PVsyst software provides insights into energy production, specific yield and capacity factor projections. The estimated annual energy production is 43,705 MWh, a specific yield of 1,796 kWh/kW peak and an efficiency of 80.5%.

In the financial analysis aspect, the project demonstrates viability: the internal rate of return (IRR) exceeds the discount rate and the normalized cost of electricity (LCOE) is below 8 US cents per unit. The implementation of this solar photovoltaic power plant will not only contribute to Afghanistan's renewable energy goals, but will also address low per capita electricity consumption, reduce dependence on imported fuel, and provide employment opportunities.

Overall conclusion, the project is cost-effective and should be implemented in accordance with all of the above, taking into account all outcomes in the form of implementation as defined by the study methodology. Specific energy projects affect the economic, social and environmental aspects of sustainable development of a country or region.

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Раздел 4. «Экономика. Общеобразовательные, социально-гуманитарные и фундаментальные дисциплины»

А. В. Файез Вазани, З.С. Гельманова

Ауғанстанның Суруби қаласындағы күн электр станциясындағы фотоэлектрлік жүйені талдау және модельдеу

Бұл Суроби қаласындағы күн электр станциясының техникалық және экономикалық мақсатқа сәйкестік зерттеуі жаңартылатын энергия көздерін дамыту мен төмен көміртекті өсуін қолдауды мақсат етеді. Зерттеудің жаңалығы жобаның кезеңдерге бөлініп, әр кезеңнің өз көрсеткіштерімен және модельденген әсерлер мен жағдайларға байланысты болуы. Зерттеу техникалық іске асуы, экономикалық мүмкіндігі, экологиялық және әлеуметтік әсерлерді бағалайды. Ұсынылған техникалық шешім кристалды модульдер, тұрақты еңкейтілген құрылымдар және орталық инверторларды қамтиды. Суроби күн электр станциясын салудың техникалық және экономикалық мүмкіндіктері осы фотоэлектрлік жүйенің нақты мысалы арқылы қарастырылды. Қаржылық модельдеу жобаның өміршеңдігін растап, ішкі кірістілік мөлшерлемесінің дисконттау мөлшерлемесінен жоғары болатынын көрсетті. Жоба экологиялық пайда ұсынады, таза энергия инфрақұрылымына инвестиция салып, аймақтың тұрақты және сенімді энергия өндіруге көшуін қолдайды.

Түйінді сөздер:: күн электр станциясы, фотоэлектрлік жүйе, техникалық іске асуы, экономикалық мүмкіндігі, жаңартылатын энергия, экологиялық әсер, әлеуметтік әсер, кристалды модульдер, ішкі кірістілік мөлшерлемесі, тұрақты энергия.

А. В. Файез Вазани, З.С. Гельманова

Анализ и моделирование фотоэлектрической системы на солнечной электростанции в Суруби, Афганистан

Этот технический и экономический анализ солнечной электростанции в Суроби направлен на развитие сектора возобновляемой энергетики и стимулирование низкоуглеродного роста. Новизна исследования заключается в фазированном разделении проекта на интервалы, каждый из которых имеет свои показатели, зависящие от моделируемых воздействий и условий. Исследование оценивает техническую осуществимость, экономическую жизнеспособность, а также экологические и социальные воздействия. Предложенное техническое решение включает кристаллические модули, фиксированные наклонные конструкции и центральные инверторы. Техническая и экономическая осуществимость строительства солнечной электростанции в Суроби была проанализирована на основе конкретного примера данной фотоэлектрической системы. Финансовое моделирование подтверждает жизнеспособность проекта, показывая ожидаемую внутреннюю норму доходности, превышающую ставку дисконтирования. Проект предоставляет экологические выгоды, инвестируя в инфраструктуру чистой энергии и поддерживая переход региона к устойчивому и надежному производству энергии.

Ключевые слова: солнечная электростанция, фотоэлектрическая система, техническая осуществимость, экономическая жизнеспособность, возобновляемая энергия, экологическое воздействие, социальное воздействие, кристаллические модули, внутренняя норма доходности, устойчивая энергия.

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