Enhancing transboundary energy cooperation
through introduction of wind and solar energy into power systems
of the CIS countries to meet SDG7 for the implementation
of goal number 7 sustainable development of the UN

PROPOSITIONS

FOR
UNIFIED METHODOLOGY FOR ASSESSING GROSS AND TECHNICAL POTENTIALS FOR WIND AND SOLAR ENERGY IN THE CIS COUNTRIES, RECOMMENDED FORMAT FOR DATA REPRESENTATION, REGIONAL PROGRAMS OF WIND AND SOLAR ENERGY POTENTIALS UPTAKE METHODOLOGICAL BASES AND PRINCIPLES OF DEVELOPMENT

Content

Notation and abbreviations

ATE – administrative unit;
AS – aerological station;
CIS – Commonwealth of Independent States;
CSP – thermal power station;
DB – database;
GG – greenhouse gases;
EF – efficiency;
EPC CIS – Electric Power Council of the CIS;
IES – Isolated Energy System;
IRENA – International Renewable Energy Agency;
MS – meteorological station;
PS – polluting substance;
RES – renewable energy sources;
RES – regional energy systems;
SDG – Sustainable Development Goal;
FS – feasibility study;
TRF – ton of reference fuel;
UN – United Nations;
UES – United Energy System;
WTG – Wind Turbine.

Terms and definitions

- *Renewable energy sources* – energy sources, continuously renewable due to naturally occurring natural processes: solar radiation energy, wind energy, hydrodynamic energy of water; geothermal energy: heat of the soil, groundwater, rivers, reservoirs, as well as anthropogenic sources of primary energy resources: biomass, biogas and other fuels from organic waste used to produce electrical and (or) thermal energy, as well as other sources of energy determined as renewable, stipulated under legislation of the CIS member states.
- *Use of renewable energy* – process that includes procurement (extraction), transportation, storage, preparation for use, processing or other transformation of renewable energy, as well as the production of electrical, thermal and other types of energy from them.
- *Natural resource of a renewable energy source:* – the average daily amount of solar radiation falling on a unit of the horizontal surface, $kW \cdot h/m^2 \cdot day$; – average power of an air stream of a unit cross-sectional area, W/m^2.
- *Gross potential of renewable energy of the estimated territory* – average annual energy that can be fully converted into useful energy without taking into account geographical, legislative, economic, environmental, social and other restrictions on the possibility of placing power plants in this territory.
- *Technical potential of the renewable energy of the estimated territory* – part of the gross potential that can be realized on lands suitable for installing power equipment by modern power plants.
- *Fuel potential (effect) of renewable energy use* – the amount of unused fossil fuel in conventional and natural terms, while producing at the TPP a quantity of electricity equal to production using renewable energy.
- *Environmental potential (effect) of renewable energy use* – the amount of prevented emissions of greenhouse gases and pollutants into the atmosphere when burning fossil fuel.

Introduction

On January 1, 2016, the 17 Sustainable Development Goals (SDGs) set forth in the Agenda for Sustainable Development until 2030, which was adopted by the heads of 193 states, including the leaders of the countries of the Commonwealth of Independent States (CIS) in September 2015 at the historic United Nations (UN) summit[1]. The Sustainable Development Goals and related objectives are global in nature and universally applicable, while ensuring that different national conditions are taken into account in the levels of development potential and respect for national strategies and priorities. Since they are interrelated, efforts to achieve them must be comprehensive.

SDG 7 "Ensuring universal access to affordable, reliable, sustainable and modern energy sources for all"[2] is based on the fact that energy is central to almost every major problem and opportunity that the world is facing today. Whether it be jobs, security, climate change, food production, or increased incomes – access to energy for all is the determining factor. Sustainable energy is needed to strengthen the economy, protect ecosystems and achieve justice.

International cooperation is one of the tools for expanding the use of renewable energy, therefore one of the most important indicators of SDG 7 is to "strengthen international cooperation by 2030 to facilitate access to clean energy research and technologies, including renewable energy (RES), energy efficiency and advanced clean technologies for the use of fossil fuels, as well as promoting investments in energy infrastructure and environmental technologies stand energy"[3].

In 1981, at the UN Conference on New and Renewable Energy Sources in Nairobi, Kenya, the Decision on the establishment of the International Renewable Energy Agency (IRENA), which was officially founded in Bonn, Germany, on January 26, 2009, was adopted[4]. Today, with the active participation of more than 170 member states, including all CIS member states, IRENA promotes the use of renewable resources and technologies as a basis for transition to a sustainable future and helps countries use their potential in the field of renewable energy.

November 20, 2013 By the decision of the Council of CIS Heads of Government, the Concept of Cooperation of the CIS Member States in the Use of Renewable Energy Sources and the Plan of Priority Measures for its implementation were approved[5]. The concept represents a set of agreed views and approaches of the CIS member states to cooperate in the use of renewable energy sources and determines the goals, objectives, principles, mechanisms and main directions of such cooperation. Among the goals and main objectives of cooperation of the CIS member states in the use of renewable energy, the study and dissemination of international experience and experience of the CIS member states, ensuring the availability and unification of statistical data in the field and the unification of statistical data are considered to be necessary step of creating a favorable market environment for the development of renewable energy.

In 2015, within the framework of this Concept and the Plan of Priority Measures for its implementation, the CIS Electric Power Council began to form a "Roadmap" of renewable energy development in the CIS member states[6].

One of the principal results of the first stage of the development of the Road Map was the awareness of the need to create common approaches to strengthening cross-border cooperation in integrating renewable energy facilities in the power systems of the CIS countries, joint implementation of projects, attracting investment, transfer of innovative technologies. This circumstance was reflected in the recommendation "to continue work on the formation of a unified methodology for assessing the energy potential of renewable energy sources consistent with the global approach

[1] https://www.un.org/sustainabledevelopment/ru/about/development-agenda/
[2] https://www.un.org/sustainabledevelopment/ru/energy/
[3] https://www.unece.org/fileadmin/DAM/vision2030/BackgroundDocument_Rus.pdf
[4] http://renewnews.ru/irena/
[5] http://e-cis.info/page.php?id=23882
[6] http://energo-cis.ru/wyswyg/file/rgos/RGOS_20170516-18/Приложение_4.pdf

used by the International Renewable Energy Agency IRENA in the development of Global and Regional Atlases of Renewable Energy Sources".

Taking into account the largest scale of development of wind and solar energy, this work covers these renewable energy sectors and is dedicated to:

- elaboration of detailed proposals for a unified methodology for assessing natutal resources, the gross and technical potentials of wind and solar energy in the CIS countries;
- assessing the fuel and environmental effects of these potentials;
- developing recommendations for a unified data presentation format,
- analyzing positive experience in assessing the potentials of solar and wind energy in the CIS countries;
- analyzing and formulating proposals on the methodological foundations and principles for the development of regional programs for the implementation of wind and solar potentials.

The proposed recommendations are intended to harmonize and improve the general approaches to the formation of the information base of the energy potential of these types of renewable energy sources and to make technical and investment decisions on the selection and use of equipment based on renewable energy sources in centralized and distributed energy supply systems, taking into account economic, technical, environmental, logistic and other restrictions and factors.

1. Methodologies for assessing the potentials of solar and wind energy in the CIS countries: development of atlases, problems and suggestions

1.1. Web Atlas of the energy potential of renewable energy sources of the Republic of Kazakhstan

In 2017, an Australian company in collaboration with research centers of the Republic of Kazakhstan developed the Interactive System - Web-Atlas of the energy potential of renewable energy sources of the Republic of Kazakhstan. In the web-atlas of wind energy energy potential, there are maps of the distribution of average wind speeds and wind energy potential by seasons at heights of 10, 50 and 100 m above the ground over the territory of the Republic of Kazakhstan[7]. As the initial information, are used the results of measurements carried out on 13 wind-monitoring masts installed on the territory of Kazakhstan and presented on the map of Fig.1.

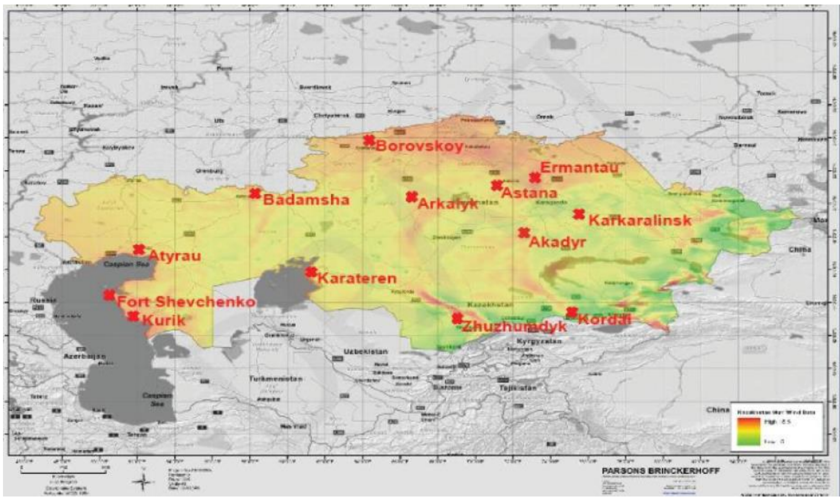

Fig.1. Map of wind measuring complexes location on the territory of the Republic of Kazakhstan

The mapping of the wind energy potential was carried out taking into account the fixed value of the of the wind turbines efficiency equal to k = 0.35. By Atlas, it is possible to make self calculations of wind energy potential at other values of efficiency using maps of average seasonal and annual wind speeds and air density for heights of 10, 50 and 100 m[8].

The assessment of the technical potential of solar energy over the territory of the Republic of Kazakhstan is based on the averaged technical characteristics of photovoltaic modules[9]. To construct maps of the total solar energy received on a horizontal surface, NASA satellite observations for the 22-year period (July 1983 – June 2005) were used, taking into account the number of cloudy days. The source data is represented by a table of insolation values at points in the grid nodes with a step of 1° in latitude and longitude.

Figure 2 shows the layout of meteorological stations, the data of which where used for the construction of the number of cloudy days interpolation map. Based on data from the meteorological stations of the Republic of Kazakhstan, the calculation results were visualized on the maps by interpolation.

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7 http://energy-atlas.kz
8 http://energy-atlas.kz/Content/documents/Ветровая%20энергия.pdf
9 http://energy-atlas.kz/Content/documents/Ветровая%20энергия.pdf

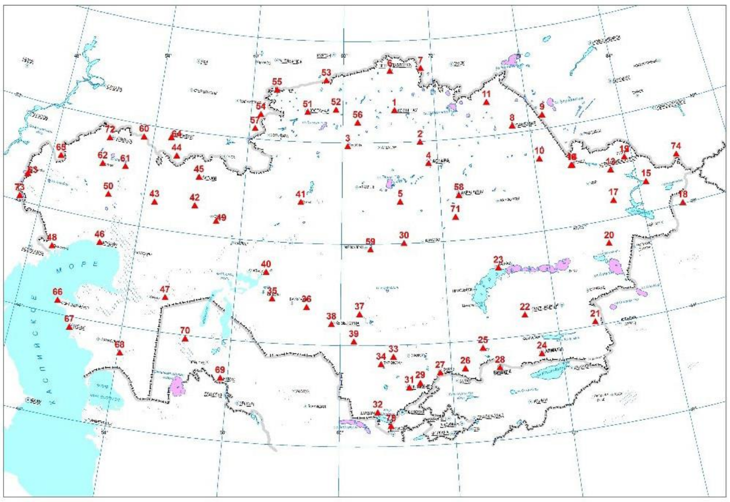


Fig.2. Map of meteorological stations in Kazakhstan, used to estimate the number of cloudy days.

Of special note is that the Atlas of the energy potential of RES of the Republic of Kazakhstan is publicly available on the Internet.

1.2. The Wind Atlas of the Republic of Uzbekistan

In 2015, the German companies Geo-Net and Intec-Gopa developed the Wind Atlas in the form of an interactive information analytical system for the wind energy potential of Uzbekistan[10]. Based on the Atlas developed, Uzbekenergo identified two promising areas in the Navoi region and in the south of Karakalpakstan. In March 2015, meteorological masts 85 meters high were installed at each site. Atlas is developed by computer modeling. Information on basic data sources of wind speeds distributions is not available. Evaluation of average annual wind speeds was carried out at a height of 80 m (Fig.3).

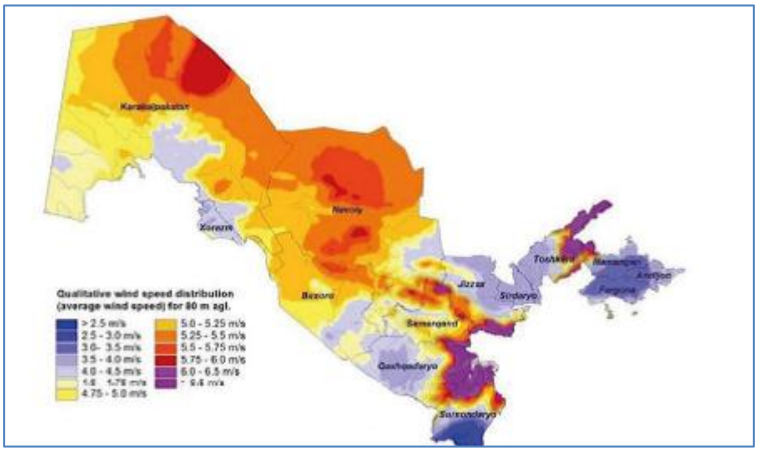


Fig.3. Map of average annual wind speeds of the Republic of Uzbekistan

In open sources of information access to the Atlas is missing.

[10] http://pubdocs.worldbank.org/en/615901492520591351/Uzbekistan-Wind-Power-ru.pdf

1.3. Atlases of renewable energy resources in Russia

In 2007, the first Handbook of renewable energy sources in Russia and local fuels was published, edited by Dr. P.P. Bezrukich[11]. In the Handbook with differentiation by regions of the federation and federal districts, three types of energy potential of renewable energy sources are estimated:

– gross (theoretical) resource (potential);
– technical resource (potential);
– economic potential.

A methodology for estimating gross and technical potential based on existing principles of utilizing wind and solar energy is given. In assessing the technical potential, the reletively constant power of the wind turbine is taken into account and the efficiency of solar batteries, which is used according to modern data. The value of the economic potential is defined based on expert estimates as the share of the technical.

The terminological definitions of potentials given in the Handbook are widely used in the professional environment.

In the period 2008-2011 Dr. V.G. Nikolayev published a number of monographs, including: “The National Cadastre of Wind Energy Resources of Russia and the methodological foundations of their assesment”[12]; “Prospects for the development of renewable energy sources in Russia”[13]; “Resource and feasibility study of the large-scale development of wind energy in Russia”[14]. The basic information for assessing wind energy potentials is based on long-term observation data at meteorological and upper-air stations of the USSR and Russia. The most representative and reliable are data obtained for the period 1950-1980. The methodological approach is based on the author's Model SANDWICH, which includes an empirical model, a spline approximation and a semi-empirical model describing the altitude profile of wind speed and taking into account the terrain and roughness of the underlying surface when modeling speeds in a given place.

Monograph contains estimates of characteristics and potential of wind energy, numerous charts and maps for the territory of Russia, CIS and Baltic countries.

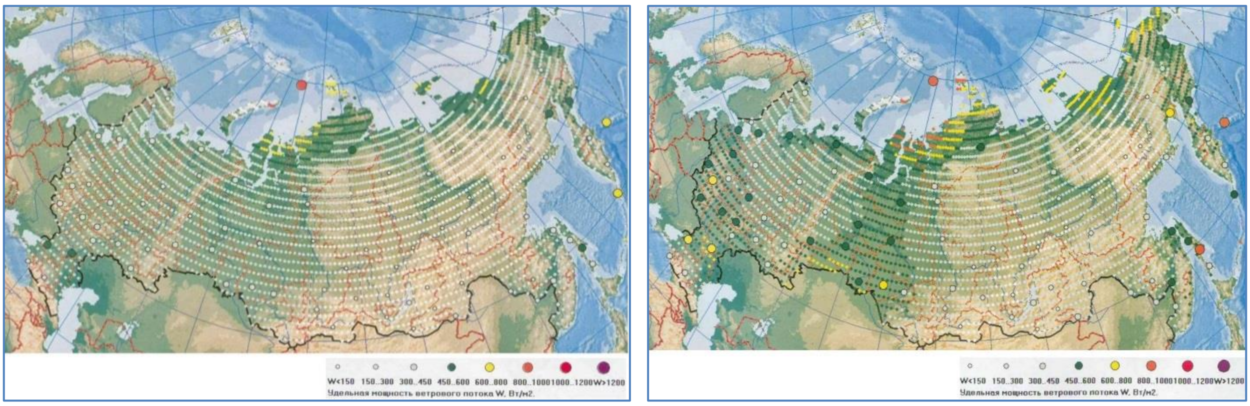


Fig.4. The map of the average annual specific power distribution of the wind flow at heights 50 and 100 m at the nodes of the coordinate grid

[11] https://www.c-o-k.ru/library/document/13071
[12] https://search.rsl.ru/ru/record/01004256320
[13] https://search.rsl.ru/ru/record/01005470302
[14] http://catalogv1.cntb-sa.ru/catalog_post/resursnoe-i-tehniko-ekonomicheskoe-obosnovanie-shirokomasshtabnogo-razvitiya-vetroenergetiki-v-rossii-v-g-nikolaev/

In 2015 experts of the Moscow State Lomonosov' University, Institute of Energy NRU HSE, Joint Institute for High Temperatures, Russian Academy of Sciences, developed an "Atlas of renewable energy resources in Russia"[15]. In the Atlas-Handbook, the assessment methods and results of calculations of solar and wind energy natural resources as well as of energy potentials are presented on the entire territory of the Russian Federation with the step 1° in latitude and longitude.

The source of the initial information was the NASA SSE database (July 1983 – June 2005): for calculating natural resources and wind energy potentials, the monthly mean wind speeds were used according to the gradations at a height of 50 m above the ground, for solar energy – the monthly average daily totals solar radiation falling on a unit of a horizontal surface.

Wind energy resources were estimated at altitudes of 30, 50, 100 and 120 m, solar energy resources – on a horizontally oriented surface. When calculating the technical potential of wind energy, the power curves of real wind turbines were taken into account, and solar energy – the average efficiency of photovoltaic modules (14%).

Maps of the distribution of the technical potential of wind and solar energy are shown in Fig.5.

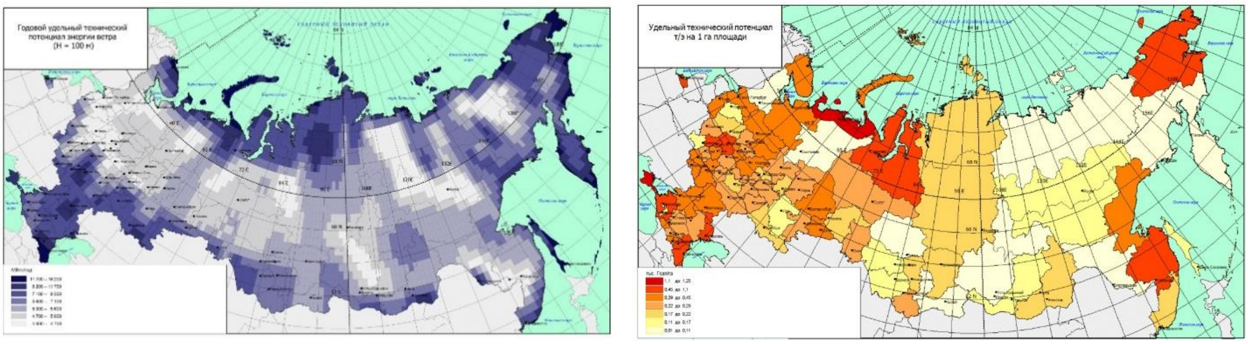


Fig.5. Maps of technical potential distribution of wind and solar energy in Russia

Atlas released in the form of printing edition, the Internet version does not exist.

1.4. Cadastre of renewable energy sources of the Republic of Belarus

In 2012, in the Republic of Belarus, a "State cadastre of renewable energy sources" was developed in which complete information was collected both on the installations already in operation and on the sites for the possible construction of new facilities, there is information about energy producers from renewable energy sources, etc[16]. Investigation of the wind energy potential of Belarus was carried out by the Belarusian Hydromet jointly with the RUP "Belenergosetproekt" and the NPGP "Vetromash". The results of the research contributed to the formation of guidelines fore use, creation, construction and operation of windturbines.

According to the data of the State Cadastre of Renewable Energy Sources of the Republic of Belarus, currently 640 operating plants with a total capacity of 1,161 MW are classified as renewable energy sources. Of these, 26 sites with 56 wind farms are situated in the Brest, Vitebsk, Grodno, Minsk and Mogilev regions with a total capacity of 43.3 MW. Table 1 shows information from the Cadastre for one of the wind turbines. It is noteworthy that for this installation information is provided on fuel economy (tons/year), as well as on prevented greenhouse gas emissions (tons/year) and pollutants (tons/year).

[15] https://istina.msu.ru/publications/book/11596712/

[16] https://www.belta.by/economics/view/kadastr-vozobnovljaemyh-istochnikov-energii-sformirovan-v-belarusi-71336-2012

Table 1 − NEG Micon NM 48-750 wind turbine near the village of Avgustovo

Organization name: **LLC "Windenergoprom"**	Type of energy used: **Wind energy**
The type of energy produced: **Electric**	Electric capacity: **0.75 MW**
Annual electricity generation, MW·h/year: **2316.60**	Annual electricity production, MWh / year: **2316.60**
Annual heat production, Gcal/year	Annual heat output, Gcal/year:
Number of hours of work per year: **3120**	Saving of standard fuel, tons of fuel equivalent per year: **284.56**
Reducing greenhouse gas emissions, t/year: **2340.00**	Decrease / increase of main pollutants emissions, t/year: **-8.17**

1.5. The results of a comparative analysis of the experience of assessing the energy potential of solar and wind energy by the CIS member states

Comparative analysis of the main provisions of the methodology for assessing the potential of renewable energy sources and their practical implementation in the CIS countries showed the following:

1. When developing the Atlases of Kazakhstan and Uzbekistan, the main contractors were foreign companies funded by international financial institutions. National research centers were trained on these projects. When developing the Atlas of Russia, domestic teams developed their own detailed methodologies that fully take into account world experience.
2. When developing all considered solar atlases, data from NASA SSE database with a 10x10 grid were used as initial information on the energy density of solar radiation.
3. When developing the Wind Atlas of Kazakhstan, measurement data for 13 wind measuring complexes were used as basic information. Estimates were made on the basis of average seasonal or annual speeds at 3 heights with a fixed value of wind turbine efficiency, in other words the power curves of real wind turbines were not considered in calculations and wind speed frequency was not taken into account. This fundamentally reduces the accuracy of calculations. The essential advantage of the Atlas is its interactivity and availability in the Internet.
4. When developing the Wind Atlas of Uzbekistan, satellite observations without reference to the source were used as basic information, only average annual wind speeds at an altitude of 80m were estimated, and the technical potential was not calculated. The declared Interactivity due to the lack of access to the Atlas on the Internet cannot be confirmed.
5. When developing the Wind Atlas of the of Russia, NASA SSE DB data with a 1^0x1^0 grid on wind speeds frequency at 50m altitude with hourly resolution was used as the basic information. Wind potential estimates were carried out at four heights, taking into account the power curves of real wind turbines. In the printed edition of the Atlas there are a lot of maps which clearly reflect the distribution of wind energy resources throughout the country. The lack of access to the atlas and the calculated databases via the Internet does not allow the interactive mode of working with Atlas.

It seems appropriate to take into account all the advantages of the proposed approaches and eliminate the existing shortcomings to obtain a single common methodology for estimating wind and solar potential in the CIS countries.

2. General provisions of the proposed methodology

2.1. Main principles of the methodology for estimating the natural resources, gross and technical potentials of renewable energy sources

1. Using the experience of the CIS countries in assessing potentials and developing atlases of renewable energy;
2. Using IRENA's experience in developing a Global Atlas of Renewables;
3. Using of NASA DB and GWA DB as basic information about natural resources of renewable energy sources;
4. Using of representative data of long-term measurements of meteorological, upper-air and actinometric stations;
5. Using of official statistical data on the operation of the power systems of the CIS member states, including data on specific fuel consumption for electricity generation at thermal power plants, greenhouse gas emissions and pollutants in thermal power plants, losses in electrical networks, etc.;
6. Assesment of natural resources and gross potential of renewable energy;
7. Assessment of the technical potential of renewable energy sources taking into account the available areas for installation of generating equipment and its technical characteristics;
8. Assessment of natural resources and potentials of renewable energy at various levels of administrative-territorial division: national, regional, municipal;
9. Assessment of renewable energy natural resources and potentials at various levels of integration of electric power systems: UES, RES, IES, decentralized zone;
10. Assessment of fuel and environmental effects arising from the implementation of the technical potential of renewable energy.

2.2. The main stages of Natural Resource and RES Potentials assessment

The main stages of the proposed methodology for the assessment of natural resources, gross and technical potential of renewable energy sources are shown in the following flowchart (Fig. 6).

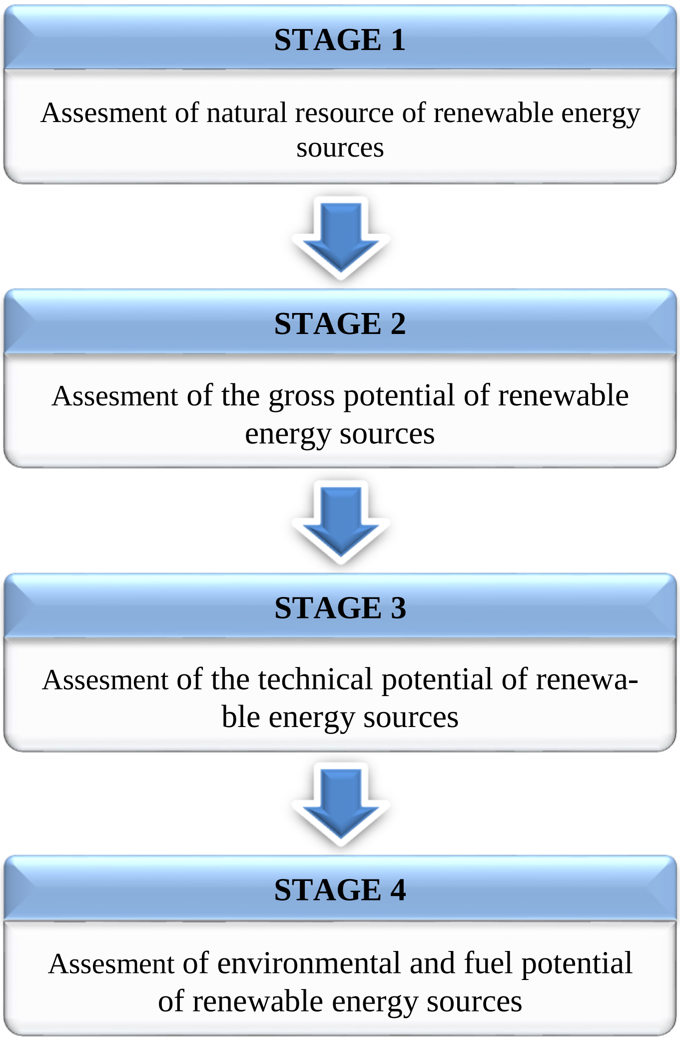


Fig.6. Flowchart of natural resources, gross and technical potentials of solar and wind energy assessment

3. Assesment of natural resources, gross and technical potentials of solar energy for photo-voltaic systems

3.1. Recommended data sources for assessing natural resources, gross and technical potentials of solar energy

The proposed methodology recommends using few sources of initial information on the distribution of solar energy resources.

The NASA POWER free database as a source of initial information on the distribution of solar energy resources [17] contains, among other things, the calculated values of the natural resources of solar energy - the average annual amount of total solar radiation falling on a horizontal

[17] NASA Surface meteorology and Solar Energy // Atmospheric science data center. [Электронный ресурс]. URL: https://eosweb.larc.nasa.gov/

surface unit (kWh / m2 day), obtained from the results of long-term observations of solar radiation for a grid of 0.5º × 0.5º covering the entire globe. Such a high spatial resolution significantly exceeds the spatial resolution of the existing terrestrial metorological, upper-air and actinometric networks. The database takes into account the characteristics of various climatic zones of the globe, including the nature of reflection of radiation from the earth's surface (albedo), the state of cloudiness, and atmospheric pollution with aerosols.

The database is accessible via the Internet[18]. In Fig.7. as an example, a map is presented with a window "POWER Single Point Data Access".

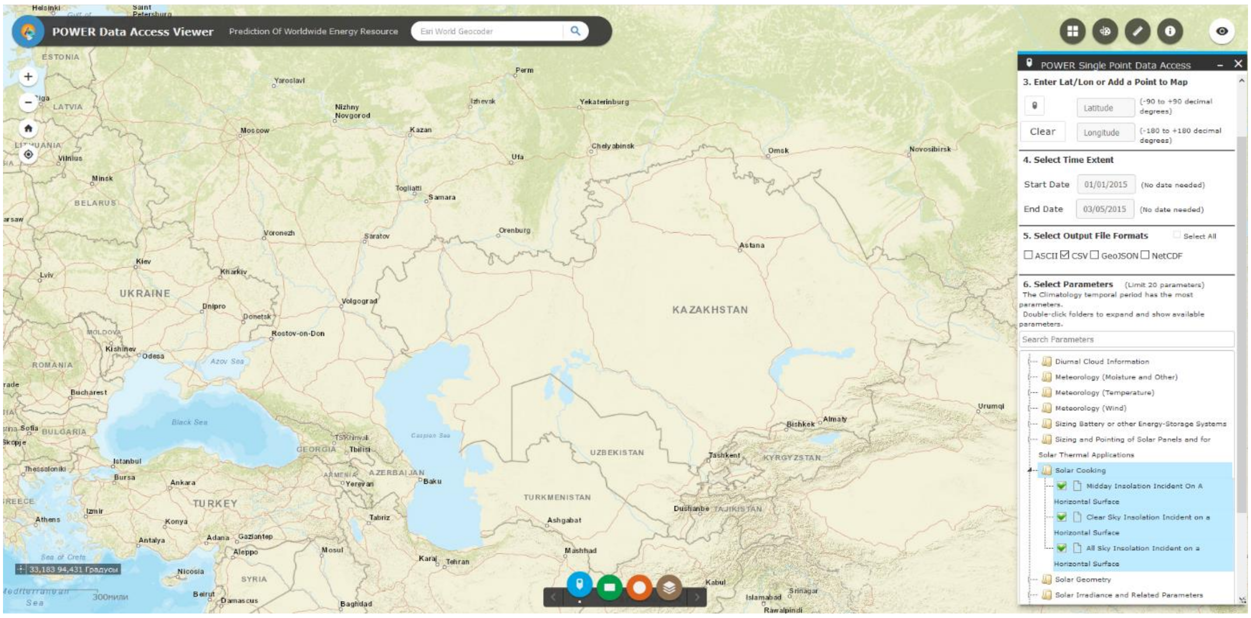
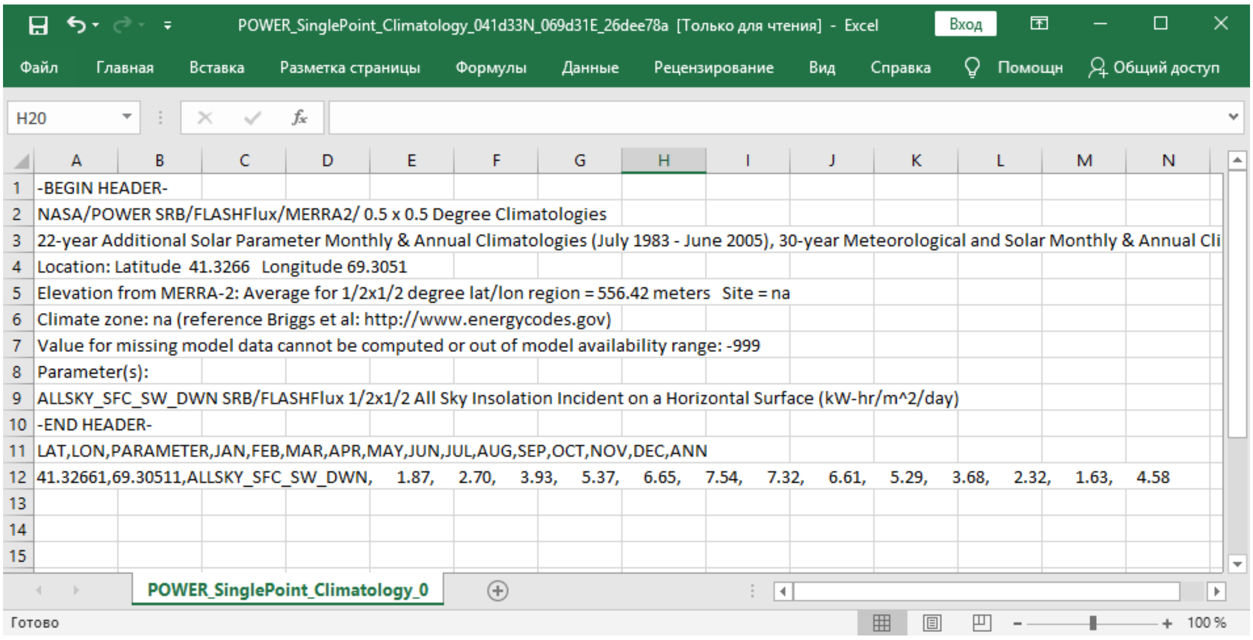


Fig.7. NASA map "POWER Data Access Viewer" - Prediction of a world energy resource.

Information about solar energy natural resources is located in the Solar Cooking folder, and for the selected coordinate is given in the form of a table, the element of which is shown in Fig.8.



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18 https://power.larc.nasa.gov/data-access-viewer/

Fig.8. The data table of the monthly average daily sums of total solar radiation falling on a horizontal surface, for the selected coordinates (for example, Tashkent)

The Global Solar Atlas (“Atlas")[19] (free axcess) supports solar power development in the phases of exploration, prospection, site selection and pre-feasibility evaluation. Photovoltaic (PV) technologies typically require an analysis on Global Horizontal Irradiation (GHI) and Global Tilted Irradiation (GTI, i.e. solar radiation received by the surface of photovoltaic modules).

The Atlas provides long-term averages of **solar resource** (global, diffuse and direct normal), the principal climate phenomena that determines solar power generation. This Atlas supports only the first stage of a solar energy project lifecycle: prospection and preliminary assessment.

The Atlas covers areas between latitudes 60°N to 45°S. Areas north and south of these coordinates are not covered because the incline of the satellite imagery prohibits an accurate assessment of cloud cover. The primary grid resolution of solar resource data is approximately 3 to 7 km (depending on the latitude), which is enhanced by downscaling to a nominal resolution of approximately 1 km. The spatial resolution of other data parameters has been also harmonized to 1 km.

The solar resource and PV power potential represent a time period from January 1994/1999/2007 till December 2015, depending on the satellite data coverage (see Figure below). Temporal resolution (time step) of solar resource depends on the satellite region, and this ranges between 10/15/30 minutes.

This Atlas provides long-term yearly averaged solar resource and PV power potential values, described alternatively as yearly and daily summaries. The air temperature is represented as a long-term yearly average.

GTI (Global Tilted Irradiation): Sum of direct and diffuse solar radiation falling on a tilted surface of fixed-mounted PV modules [kWh/m^2]. Compared to the horizontal surface, the tilted surface also receives a small amount of ground-reflected solar radiation.

PVOUT (PV Electricity output): Amount of energy, converted by a PV system into electricity [kWh/kWp] that is expected to be generated according to the geographical conditions of a site and a configuration of the PV system. Three configurations of a PV system are considered: (i) Small residential; (ii) Medium-size commercial; and (iii) Ground-mounted large scale.

OPTA (Optimum angle): Optimum inclination [º] of an inclined and fixed PV modules for a specific azimuth (orientation), for which the PV modules receive the highest amount of solar radiation per year. As default azimuth values towards the Equator are considered, i.e. South (180º) for Northern hemisphere and North (0º) for the Southern hemisphere.

Definition of user inputs

Location (site): Site of interest can be located by latitude and longitude values, by typing the address of directly browsing and clicking on the map.

Type of PV system: Three type of a PV system are predefined: (i) small residential; (ii) medium-size commercial; and (iii) ground-mounted large scale.

[19] https://globalsolaratlas.info

System size: Total DC capacity (installed power) of a PV system is considered. It represents the sum of the nominal power of the PV modules installed and connected at the site (ground, roof or facade). The system capacity (or nominal power given by the module under standard test conditions) is given in kWp (kilowatt peak).

Azimuth: Orientation of the PV modules. A value between 0º and 360º is expected, where North is represented by 0º or 360º, East by 90º, South by 180º and West by 270º.

Inclination: Tilt of PV modules measured from a horizontal surface as a reference. A value between 0º and 90º, where 0º represents a horizontal surface and 90º a vertical surface.

The GEOMODEL SOLAR[20] supports planning, financing, and operation of photovoltaic, concentrated photovoltaic and concentrated solar power energy systems. GEOMODEL SOLAR provides reliable and accurate solar, weather and solar electricity data that are used in the whole lifecycle of solar power plants, from prospection to development and operation. Since 2010 GEOMODEL SOLAR develops and operates a platform for fast access to historical, recent, and forecast data for almost any location on the Earth. The GEOMODEL SOLAR could be used on commercial basis.

In connection with the fact that this work is devoted to unified methodology for assessing gross and technical potentials for wind and solar energy not going into details of specific projects development and is the first attempt to introduce it in the CIS countries to reach comparability of national statistical data the results presented below are based on NASA POWER database. At he next stages of methodology elaboration more ssofisticated data bases should be used.

3.2. Assesment of natural resources and gross energy potential of solar energy

Since the NASA POWER database for each grid cell of 0.5º×0.5º already contains the calculated values of the natural resources of solar energy, to assess the natural resources of solar energy of considered territory, you should use the formula:

$$H_{ter.}^{All} = \sum_{j=1}^{m} \left(H_j^{All} \cdot S_j / S_{tot.ter.} \right) \quad (1)$$

where

$H_{ter.}^{All}$ – the average annual amount of total solar radiation falling on a unit of the horizontal surface of Considered territory, *kWh/m² day*;

H_j^{All} – the average annual amount of total solar radiation, falling on a unit of the horizontal surface in the *j*-th cell, *kWh/m² day*;

S_j – area of the territory under consideration, falling into the *j*-th cell, *km²*;

$S_{tot.ter.}$ – total area of the territory under consideration, *km²*.

The gross potential of the solar energy of Considered territory is calculated by the formula:

[20] https://solargis.com

$$P_{gr.ter.} = 10^{-6} \cdot H_{ter.}^{All} \cdot S_{tot.ter.} \cdot D_{year} \quad (2)$$

where

$P_{gr.ter.}$ – gross potential of solar energy of the territory under consideration, *mln. kWh/year;*
$D_{year} = 365$ – number of days per year, *day*.

3.3. The recommended format of data on natural resources and the gross potential of solar energy

The formats of the database of natural resources and the gross solar energy potential of the territories under consideration are given in Tables 2 and 3, respectively.

Table 2 − Format of the database of natural resources of solar energy

Considered territory	**Natural resources of solar energy, *kWh/m²·day***
Municipality	
Region (region, province, etc.)	
Country	
Power supply zone, *including*:	
UES	
RES	
IES	
Decentralized	

Table 3 − Format of the database of gross potential of solar energy

Considered territory	**Total area, *km²***	**Gross potential of solar energy, *mln. KWh/year***
Municipality		
Region (region, province, etc.)		
Country		
Power supply zone, *including*:		
UES		
RES		
IES		
Decentralized		

3.4. Assesment of technical potential of solar energy

The technical potential of converting solar energy into electrical energy for Considered territory is calculated by the formula:

$$P_{tec\square.ter.} = P_{gr.ter.} \cdot (Eff_{mod} \cdot N \cdot Eff_{inv} \cdot Eff_{tr} \cdot K_{ter}) \quad (3)$$

where:

$P_{tec\square.ter.}$ – technical potential of solar energy of the territory under consideration, mln. kWh/year;

Eff_{mod} – Efficiency of the solar module. The average efficiency of modern solar modules is about 20-22% under standard conditions (AM spectrum 1.5, 1000 W/m^2, 25°C);

N- number of installed modules;

Eff_{inv} – Inverter efficiency (97-98%);

Eff_{tr} – Efficiency of step-up transformer up to 10-110 kV (96-99%);

K_{ter} – the territorial coefficient reflecting the share of the total area of the territory in which it is possible to install solar panels.

3.5. Recommended format for presenting data on the technical potential of solar energy

The format of the database of the technical potential of solar energy in the territories under consideration is given in Table 4.

Table 4 − Format of the database of technical potential of solar energy

Considered territory	K_{ter}	**Technical potential of solar energy, *mln. KWh/year***
Municipality		
Region (region, province, etc.)		
Country		
Power supply zone, *including*:		
UES		
RES		
IES		
Decentralized		

4. Assesment of natural resources, gross and technical energy potential of wind energy

4.1. Recommended data sources for assessing natural resources, gross and technical potentials of solar energy

In the proposed methodology, it is recommended to use the NASA POWER USA database and the Global Wind Atlas (GWA 2.0) database as sources of the initial information on the distribution (repeatability) of wind speeds over gradations.

4.1.1. NASA POWER Database

The NASA POWER DB[21] was developed as part of the World Energy Resource Forecasting Project (POWER). All the characteristics of the wind in the submitted database are given both as climatic values, which are obtained on the basis of data taken from the MERRA-2 assimilation model for the period 1.01.1984-31.12.2013 (30 years), and in the format of time series of average daily values, constructed using data of assimilation models MERRA-2 and GEOS 5.12.4.

The MERRA-2 data spans the time period from January 1, 1981 to within several months of real time; the GEOS 5.12.4 data span the time period from the end of the MERRA-2 data stream to within several days of real time. Values from MERRA-2 and GEOS 5.12.4 models are initially produced on a 1/2-degree by 2/3-degree global grid and then bi-linearly interpolated by the POWER project to a global 0.5° grid.

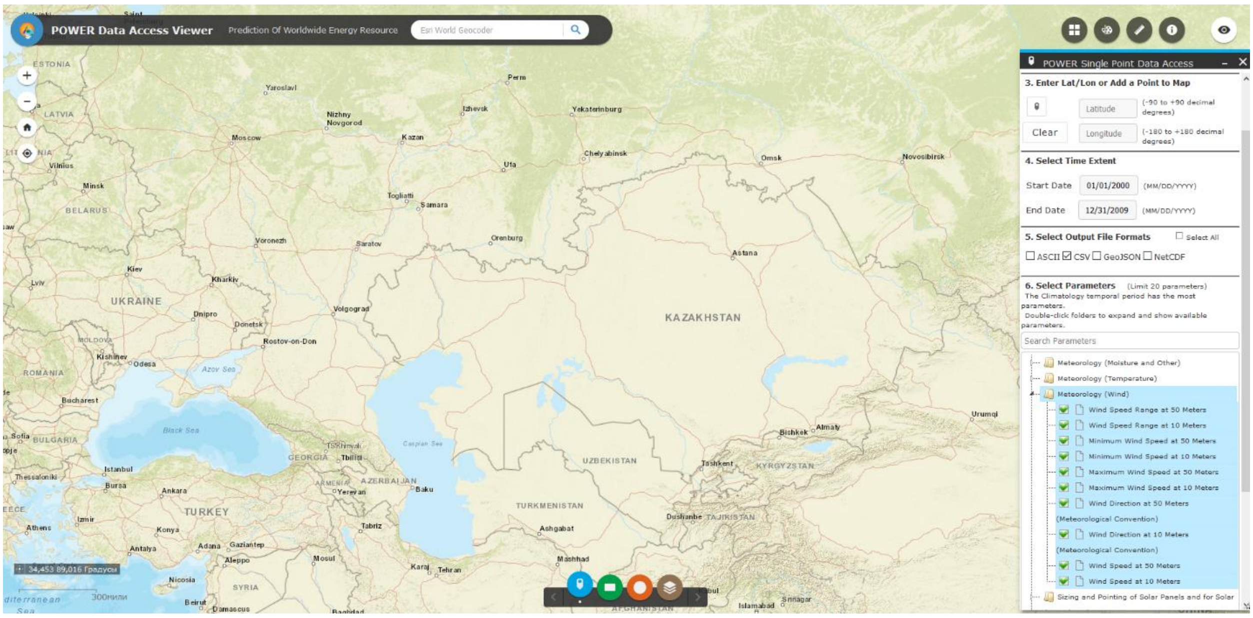

Fig.9. The "POWER Data Access Viewer" map with the "POWER Single Point Data Access" window for entering the coordinates of the point and the evaluation period

Currently, NASA POWER DB contains no data on the repetition of wind speeds by gradations, although the documentation provided[22] implies the presence of this indicator. Perhaps, work is underway to form this data set, and in the future it will be available to the user.

If necessary, the repeatability can be calculated independently using a time series of average daily wind speed values. To do this, we recommend using the following algorithm:

1. For a given point, download average daily wind speeds at a height of 50 m for a period of at least 10 years (Fig. 9-10).

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[21] https://power.larc.nasa.gov/data-access-viewer/

[22] https://power.larc.nasa.gov/documents/POWER_Data_v9_methodology.pdf

2. All values of wind speeds should be spread by ranges (gradations), for example: from 0 to 2 m/s inclusively, from 2.1 to 6 m/s inclusively, etc. To improve the accuracy of calculations, one can select smaller ranges, for example: 0-1, 1-2 m/s, etc.

3. Calculate the number of cases when the wind speed falls into each range, and divide it by the total number of days of the selected period. The repeatability is determined in % or fractions of a unit.

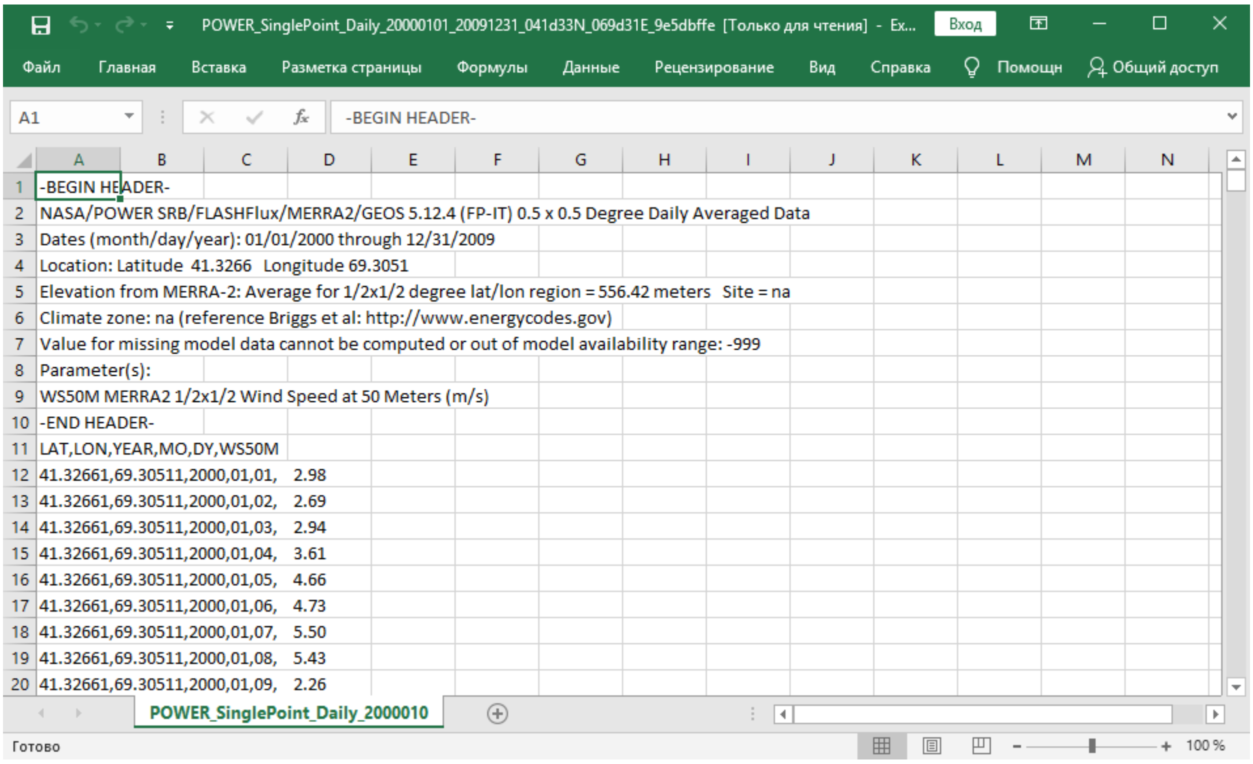

-BEGIN HEADER-
NASA/POWER SRB/FLASHFlux/MERRA2/GEOS 5.12.4 (FP-IT) 0.5 x 0.5 Degree Daily Averaged Data
Dates (month/day/year): 01/01/2000 through 12/31/2009
Location: Latitude 41.3266 Longitude 69.3051
Elevation from MERRA-2: Average for 1/2x1/2 degree lat/lon region = 556.42 meters Site = na
Climate zone: na (reference Briggs et al: http://www.energycodes.gov)
Value for missing model data cannot be computed or out of model availability range: -999
Parameter(s):
WS50M MERRA2 1/2x1/2 Wind Speed at 50 Meters (m/s)
-END HEADER-
LAT,LON,YEAR,MO,DY,WS50M
41.32661,69.30511,2000,01,01, 2.98
41.32661,69.30511,2000,01,02, 2.69
41.32661,69.30511,2000,01,03, 2.94
41.32661,69.30511,2000,01,04, 3.61
41.32661,69.30511,2000,01,05, 4.66
41.32661,69.30511,2000,01,06, 4.73
41.32661,69.30511,2000,01,07, 5.50
41.32661,69.30511,2000,01,08, 5.43
41.32661,69.30511,2000,01,09, 2.26

Fig.10. The table of data for the characteristics of the wind for the selected coordinates (for example, Tashkent) in the period from 01.01.2000 to 31.12.2009

To simplify the acquisition of basic data of wind speeds frequency by gradations during the period of refinement in the NASA POWER database of this information array, it is proposed to use the NASA SSE DB (NASA Surface meteorology and Solar Energy), which is the prototype of the NASA POWER database.

The NASE SSE DB provides for the 1°×1° grid covering the entire globe, information on the average monthly / year frequency of wind speeds according to the gradations at a height of 50 m above the ground, which is obtained from data taken from the GEOS-1 assimilation model for the period 07.01.1983-30.06.1993 (10 years).

The NASA SSE database with information on wind speeds frequences at a height of 50 m is attached to this report on electronic media.

4.1.2. Global Wind Atlas (GWA 2.0)

The Global Atlas of the Wind (GWA 2.0)[23] is a free electronic resource developed by the Department of Wind Energy of the Danish Technical University (DTU Wind Energy) in partnership with the World Bank Group. GWA 2.0 provides the ability to work with a global database that contains information about the so-called “generalized” or “regional” wind climate for a grid covering the entire earth's surface and part of the waters (up to 30 km from the coast) with 9 km spatial resolution.

[23] https://globalwindatlas.info/

The presented array was obtained by DTU Wind Energy as a result of the process of "generalization" of mesoscale modeling data conducted by Vortex SL using its own technology based on the Weather Study and Prediction Model (WRF). The ERA-Interim[24] reanalysis database, covering the observation period since 1979, was used as a source of initial data.

The concept of a "generalized" wind climate is a key element of the Atlas methodology developed by DTU Wind Energy, which is fully set out in the Euro-Atlas of the Winds[25].

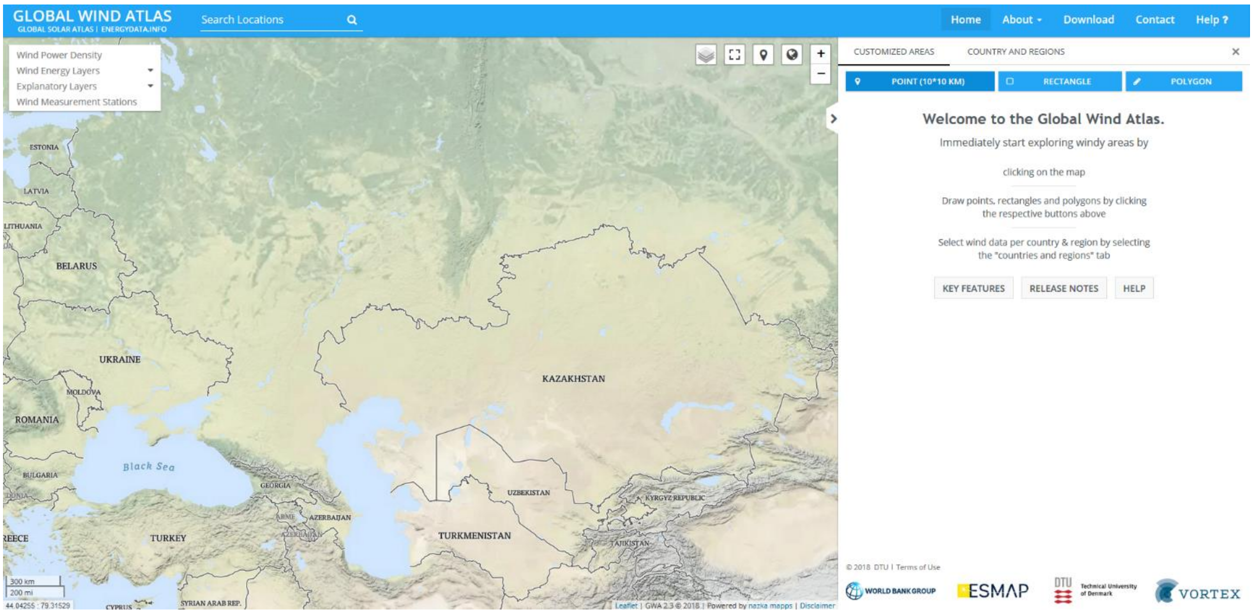


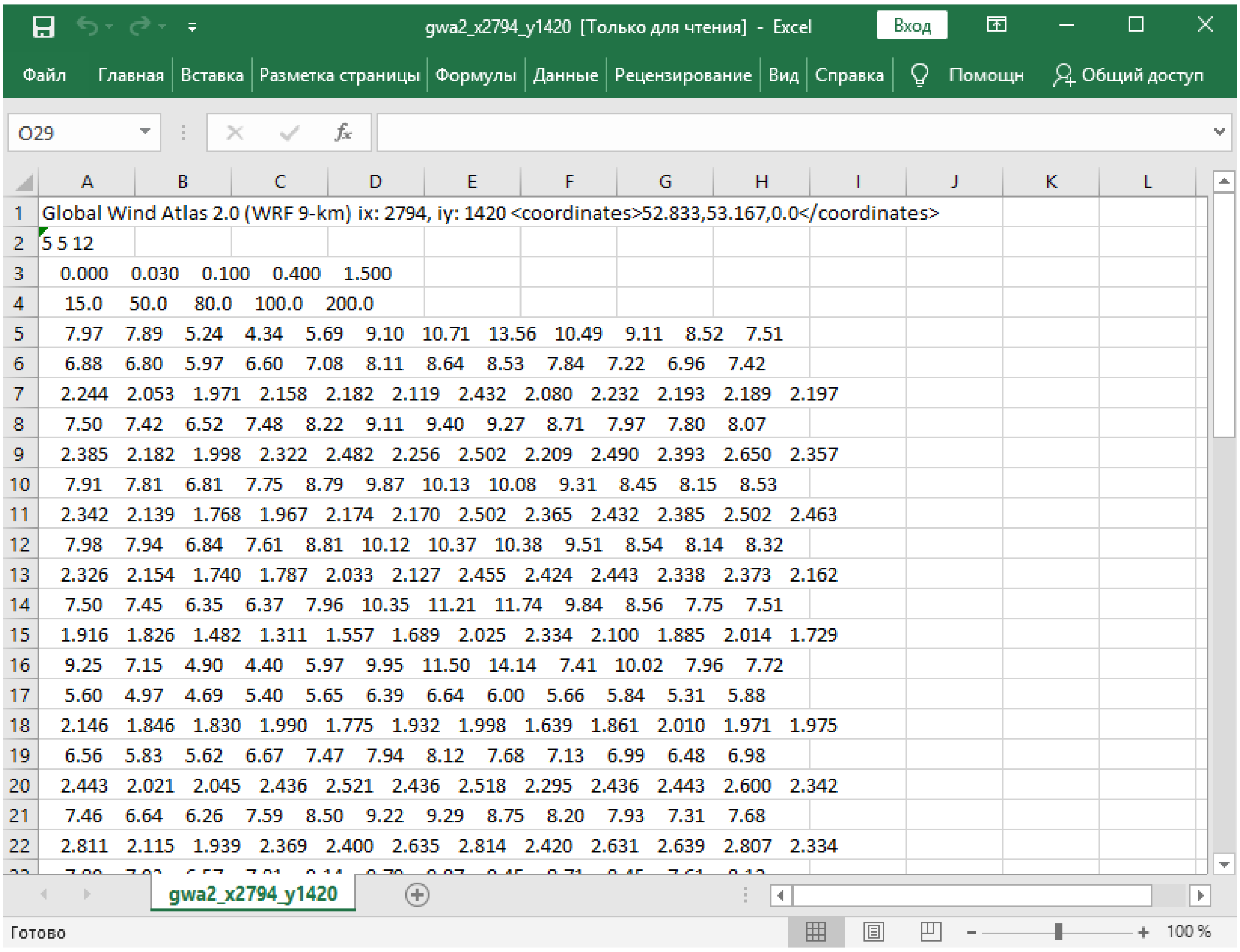
Fig.11. Global Wind Atlas Map (GWA 2.0)

Information on wind-climatic conditions is provided in a separate GWC file for each grid cell. The general format of the GWC file and its example are shown in Table 5 and Figure 12, respectively.

Table 5 – General GWC File Format

Line	Contents
1	Global Wind Atlas 2.0 (WRF 9-km) ix: XXX, iy: YYY <coordinates>lat,lon,height</coordinates>
2	Number of roughness classes, heights and sectors in data set Values are: 5, 5 and 12
3	Reference roughness lengths [m] Values are: 0.00, 0.03, 0.10, 0.40, 1.50 m
4	Reference heights above ground level [m] Values are: 15, 50, 80, 100 and 200 m a.g.l.
5	Frequencies of occurrence for reference roughness #1 (0 m)
6	Weibull A-parameters for reference height #1 (15 m) in [m/s]
7	Weibull k-parameters for reference height #1 (15 m)
8-9	Weibull A- and k-parameters for reference height #2 (50 m)
10-11	Weibull A- and k-parameters for reference height #3 (80 m)
12-13	Weibull A- and k-parameters for reference height #4 (100 m)
14-15	Weibull A- and k-parameters for reference height #5 (200 m)
16-26	As lines 5-15, but for reference roughness #2 (0.03 m)
27-37	As lines 5-15, but for reference roughness #3 (0.10 m)
38-48	As lines 5-15, but for reference roughness #4 (0.40 m)
49-59	As lines 5-15, but for reference roughness #5 (1.50 m)

[24] https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim
[25] http://orbit.dtu.dk/files/112135732/European_Wind_Atlas.pdf



Global Wind Atlas 2.0 (WRF 9-km) ix: 2794, iy: 1420 <coordinates>52.833,53.167,0.0</coordinates>

5 5 12

0.000	0.030	0.100	0.400	1.500							
15.0	50.0	80.0	100.0	200.0							
7.97	7.89	5.24	4.34	5.69	9.10	10.71	13.56	10.49	9.11	8.52	7.51
6.88	6.80	5.97	6.60	7.08	8.11	8.64	8.53	7.84	7.22	6.96	7.42
2.244	2.053	1.971	2.158	2.182	2.119	2.432	2.080	2.232	2.193	2.189	2.197
7.50	7.42	6.52	7.48	8.22	9.11	9.40	9.27	8.71	7.97	7.80	8.07
2.385	2.182	1.998	2.322	2.482	2.256	2.502	2.209	2.490	2.393	2.650	2.357
7.91	7.81	6.81	7.75	8.79	9.87	10.13	10.08	9.31	8.45	8.15	8.53
2.342	2.139	1.768	1.967	2.174	2.170	2.502	2.365	2.432	2.385	2.502	2.463
7.98	7.94	6.84	7.61	8.81	10.12	10.37	10.38	9.51	8.54	8.14	8.32
2.326	2.154	1.740	1.787	2.033	2.127	2.455	2.424	2.443	2.338	2.373	2.162
7.50	7.45	6.35	6.37	7.96	10.35	11.21	11.74	9.84	8.56	7.75	7.51
1.916	1.826	1.482	1.311	1.557	1.689	2.025	2.334	2.100	1.885	2.014	1.729
9.25	7.15	4.90	4.40	5.97	9.95	11.50	14.14	7.41	10.02	7.96	7.72
5.60	4.97	4.69	5.40	5.65	6.39	6.64	6.00	5.66	5.84	5.31	5.88
2.146	1.846	1.830	1.990	1.775	1.932	1.998	1.639	1.861	2.010	1.971	1.975
6.56	5.83	5.62	6.67	7.47	7.94	8.12	7.68	7.13	6.99	6.48	6.98
2.443	2.021	2.045	2.436	2.521	2.436	2.518	2.295	2.436	2.443	2.600	2.342
7.46	6.64	6.26	7.59	8.50	9.22	9.29	8.75	8.20	7.93	7.31	7.68
2.811	2.115	1.939	2.369	2.400	2.635	2.814	2.420	2.631	2.639	2.807	2.334

Fig.12. Weibull distribution parameters table for various wind directions, heights above the ground and surface roughness classes

In the Global Atlas on Renewable Energy IRENA[26] a special platform for presenting GWA data is created. Currently, the old version of the Atlas GWA 1.0 is posted on the IRENA website and work is underway to update it.

It should be noted here that, despite the release of a new product, GWA 1.0[27] still deserves attention and can also be used for resource assessment, since it contains all the necessary data for a "generalized" wind climat for this, almost similar to GWA 2.0 (except for heights of 15 and 80 m). Information is provided for each grid cell covering the entire surface of the Earth in increments of 1/2° latitude and 2/3° longitude. When working out GWA 1.0, CFDDA, CFSR and MERRA reanalyses were involved.

[26] https://irena.masdar.ac.ae/gallery/#tool/38
[27] http://science.globalwindatlas.info/map.html

Fig.13. Global Wind Atlas Map (GWA 1.0)

Summarizing the above, we can conclude that the GWA 2.0 database allows, without additional tools, to carry out wind energy calculations at several heights and significantly higher resolution than NASA databases, but the complexity of the analysis also increases at the same time. The inconvenience is added by the fact that in the GWA 2.0 database it is possible to download GWC files only one at a time, separately for each grid node. The GWA 1.0 DB in this regard is more convenient for use, since allows you to upload the archive of files for all the part of the terrain highlighted on the map at a time.

Currently, work is underway to create a new version of the Atlas GWA 3.0, the spatial resolution of which will be already 3 km and include water areas adjacent to the coast at distances up to 200 m. The ERA5[28] reanalysis database is used as a data source.

4.2. Assessment of natural wind energy resources

Assessment of natural wind energy resources is carried out using such an index as wind flow energy density, by which is meant the average power of the air stream flowing per unit time through the cross section area of one square meter:

$$N_{ed} = \frac{1}{2}\rho \cdot \sum_{i=1}^{n}(u_i^3 \cdot t_i) \tag{4}$$

where

N_{ed} – energy density (power density) of wind flow, *W/m²*;

ρ – air density, *kg/m³*;

u_i– average wind speed on the *i*-th interval of wind speeds, *m/s*;

t_i – part of the time during which the wind speed is in the *i*-th speed range.

For the calculation of the weighted average over the territory of the N_{ed} value, the considered territory should be represented as a set of zones, in each of which wind-climatic conditions can be considered conditionally homogeneous:

[28] https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

$$N_{ed.ter.} = \sum_{j=1}^{m} \left(N_{edj} \cdot S_j / S_{tot.ter.} \right) \quad (5)$$

where

$N_{ed.ter.}$ – energy density of the wind flow in the territory under consideration, *W/m²*;
N_{edj} – energy density of the wind flow in the *j*-th zone, *W/m²*;
S_j – area of the territory under consideration that falls into the *j*-th zone, *km²*;
$S_{tot.ter.}$ – total area of the territory under consideration, *km²*.

When working with a NASA database, a 1/2°×1/2° cell (NASA POWER) or 1°×1° (NASA SSE) is taken as such a "conditionally homogeneous" zone, when working with the GWA database, the cell is 9×9 km (GWA 2.0) or 1/2°×2/3° (GWA 1.0).

4.3. The recommended format of data on the natural resources of wind energy

The format of natural resources database for wind energy of the territories under consideration is given in Table 6.

Table 6 – Format of the database of wind energy natural resources database

Considered territory	**Energy density of wind flow, *W/m²***
Municipality	
Region (region, province, etc.)	
Country	
Power supply zone, *including*:	
UES	
RES	
IES	
Decentralized	

The developed database format allows to systematize information on wind energy resources (wind flow energy density) in the whole country, detailed by UES and ATE with the allocation of decentralized power supply zones.

4.4. Assesment of gross potential of wind energy

Methodical approaches to the assessment of the gross potential of wind energy are based on the tenets of the classical theory of an ideal wind turbine, reflecting the fundamental features of the aerodynamic interaction of the air flow and the wind wheel. In accordance with this theory, the installation of even the most perfect construction can only convert a part of the kinetic energy of the wind flow that comes to it, which is characterized by 0.593- wind energy utilization factor, into useful work. Since this value was derived independently from each other by the German physicist Albert Betz (1919) and the Russian professor N.E. Zhukovsky (1920), quite often it is also called the Zhukovsky-Betz coefficient.

The gross potential of the wind energy of the territory under consideration is a part of the average long-term total energy of the wind flow, which can be maximally used throughout the year by ideal wind turbines when they are placed over the entire area of the territory under consideration:

$$P_{gr.ter.} = 10^{-9} \cdot N_{ed.ter.} \cdot S_{sw} \cdot k_{Z-B} \cdot T_{year} \cdot N_{WT\,tot.} \quad (6)$$

$$S_{sa.} = \pi \cdot D_{WW}^2 / 4 \quad (7)$$

where

$P_{gr.ter.}$ – gross potential of wind energy of the considered territory, *mln. kWh/year*;

S_{sw} – surface area swept by the wind wheel, *m²*;

$k_{Z-B} = 0{,}593$ – he Zhukovsky-Betz coefficient (the wind energy utilization factor of an ideal wind turbine);

$T_{year} = 8760$ – the number of hours per year, *hour*;

D_{WW} – diameter of the wind turvine wheel, *m*;

$N_{WT\ tot.}$ – the number of wind turbines that can be placed on the entire territory under consideration, *pcs*.

The total number of wind turbines $N_{WT\ tot.}$ is determined by their layout, which is chosen in such a way as to minimize wind screening of wind turbines. In addition, it is necessary to take into account land use opportunities, distances to residential buildings and the power grid, elevation differences on the ground, etc. But since this is an integrated assessment of wind energy resources and not designing wind farms in a specific area, to calculate the value of $N_{WT\ tot.}$ it is recommended use the widely used scheme for the layout of wind turbines in nodes of a square grid with a side of the square $10D_{WW}$:

$$N_{WT\ tot.} = \left(1000/(10 \cdot D_{WW})\right)^2 \cdot S_{tot.ter.} \qquad (8)$$

4.5. The recommended format of data on the gross wind energy potential

The database formats for the total area and number of wind turbines and for assesment of the gross potential at the territories under consideration are given in Tables 7 and 8, respectively.

Table 7 – Format of the database of total area and number of wind turbines

Considered territory	**Total area, km²**	**Number of wind turbines, pcs.**
Municipality		
Region (region, province, etc.)		
Country		
Power supply zone, *including*:		
UES		
RES		
IES		
Decentralized		

Table 8 – Format of the database of gross wind energy potential

Considered territory	**Gross wind power potential, *mln. kWh/year***
Municipality	
Region (region, province, etc.)	
Country	
Power supply zone, *including*:	
UES	
RES	
IES	
Decentralized	

4.6. Assesment of technical potential of wind energy

The technical potential of the wind energy of the territory under consideration is a part of the average long-term total energy of the wind flow, which can be converted into electrical energy at the current level of technology development during the year in the potentially accessible area of the territory under consideration:

$$P_{tec\square.ter.} = 10^{-6} \cdot T_{year} \cdot N_{WT\ av.} \cdot \sum_{i=1}^{n} \sum_{j=1}^{m} \left(P_i \cdot t_{ij} \cdot S_j / S_{tot.ter.}\right) \qquad (9)$$

where

$P_{tec\square.ter.}$ – technical potential of wind energy of the territory under consideration, *mln. KWh/year*;

P_i – technical parameter of a specific model of wind turbines, issued by the manufacturer and characterizing the amount of electrical energy that the installation produces at wind speed u_i, *kW*;

t_{ij} – part of the time during which the wind speed in the *j*-th zone is in the *i*-th speed interval;

$N_{WT\ av.}$ – the number of wind turbines that can be placed on the potentially available area of considered territory, *pcs*.

To determine the value of $N_{WT\ av.}$ it is recommended to adopt a similar layout and model for calculating the number of wind turbines, as in the assessment of the gross potential:

$$N_{WT\ av.} = \left(1000/(10 \cdot D_{WW})\right)^2 \cdot S_{av.ter.} \qquad (10)$$

where

$S_{av.ter.}$ – potentially available area of the territory under consideration, km^2.

4.7. The recommended format of the data on the technical potential of wind energy

The format of the technical potential potential of wind energy is presented in Table 9.

Table 9 − Format of the database of technical potential of wind energy

Considered territory	**Technical wind power potential, *mln. kWh/year***
Municipality	
Region (region, province, etc.)	
Country	
Power supply zone, *including*:	
UES	
RES	
IES	
Decentralized	

In the existing databases, unfortunately, there are no comprehensive data on the vertical profile of the frequency of wind speeds, which leads to the impossibility of assessing wind energy resources throughout the entire range of heights of the wind wheel axis. Therefore, for full-fledged work with the submitted databases, it is necessary to develop additional methodological approaches, with the help of which, based on the available data at the base height (or a set of base heights), one can determine the distribution of wind speeds at any other height.

One of these techniques, which is in good agreement with the NASA SSE database, is given in the Appendix.

5. Asessment (accounting) of fuel and environmental potentials (effects) of renewable energy

5.1. Assesment (accounting) of the fuel potential (effect) of renewable energy sources

The fuel potential of renewable energy is calculated by the formula:

$$F = P_{tec\square.ter.} \cdot b_e \quad (11)$$

where

F – fuel potential of renewable energy sources, *tons of fuel equivalent per year*;

$P_{tec\square.ter.}$ – technical potential of RES, *mln KWh / year*;

b_e – the specific fuel consumption for the generation of electricity at TPPs, in *grams of fuel equivalent/kWh*.

The basic information on the actual values of the SFC in GRF/ kWh for the assessment of fuel potential of renewable energy sources are official reporting data on specific fuel consumption at TPPs, published in the documents of the Executive Committee of the EES of the CIS, including:

- Annual report "Electric Power Engineering of the Commonwealth of Independent States"
- consolidated monitoring reports of the “Roadmap on key environmental issues of the integration of the electricity markets of the EU and the CIS”.

Таблица 10 − Dynamics of specific fuel consumption for electricity supply at power plants of the CIS member states[29] for the period from 2000 to 2016, GRF / kWh·h

CIS member states	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016
The Republic of Azerbaijan	411.3	378.8	327.9	317.6	313.5	314.2	303.6	293.55	291.96	285.73
Republic of Armenia	373	390.7	384.1	304.0	285.0	299.4	289.2	298.0	285.3	283.1
Republic of Belarus	274.8	274.6	267.7	268.9	264.3	254.6	256.1	246.8	235.5	230.4
The Republic of Kazakhstan	385.0	362.2	350.8	352.2	355.0	360.1	361.9	378.2	382.1	382.5
Kyrgyzstan	262,5	252,4	409,9	403,0	405,7	407,0	401,1	411,8	417,1*	424,7*
The Republic of Moldova	346,0	no data	no data	279,4	249,5	254,5	250,2	238,6	299,4	227,9
Russian Federation	341.2	334.3	333.1	334.4	330.6	334.0	328.7	325.5	322.8	319.3
The Republic of Tajikistan	326,6	269.9	341.8	440.7	405.2	388.4	360.2	441.8	219.7	364.4
Turkmenistan	371,0	439.6	452.2	461.6	444.8	no data	no data	no data	no data	no data
The Republic of Uzbekistan	379,5	381.0	383.6	379.9	378.9	379.8	374.1	375.56	374.89	375.81

[29] Consolidated Report for 2015-2016

5.2. Assessment of the environmental potential of renewable energy

5.2.1. Estimated prevented greenhouse gas emissions

Since at TPPs more than 99% of GHG emissions are CO_2 emissions, it is recommended to estimate the prevented emissions of greenhouse gases only for this greenhouse gas.

Gross CO_2 emissions are recommended to be determined by the formula:

$$M_{CO_2} = K_G \cdot B_G + K_C \cdot B_C + K_{FO} \cdot B_{FO} \quad (12)$$

where

B_G, B_C, B_{FO} – respectively, the consumption of natural gas, coal and fuel oil in tons of reference fuel (*trf*) substituted by the corresponding fuel potential of renewable energy sources;

K_G, K_C, K_{FO} – emission factors emission factors (specific CO_2 emissions) from the combustion, respectively, of natural gas, coal and fuel oil in *tCO_2/trf*.

The quantitative values of emission factors are recommended to be taken as equal, respectively: $K_G = 1.62$; $K_C = 2.76$; $K_{FO} = 2.28$. The values of these factors were obtained on the basis of the Inventory of greenhouse gas emissions of CHPs of RAO UES of Russia, take into account almost all types of solid fuel burned in the CIS countries and are confirmed by an international independent expert evaluation.

5.2.2. Assesment of prevented emissions of pollutants

The ecological potential of RES is calculated by the formula:

$$M = 10^{-3} \cdot F \cdot K \quad (13)$$

где

M – volume (mass) of prevented emissions of pollutants, *tons/year*;

F – fuel potential of renewable energy sources, *tons of fuel equivalent per year*;

K_{NO_x} – specific emission of nitrogen oxides when burning natural gas, coal, fuel oil, *kg/tons of fuel equivalent*;

K_{SO_2} – specific emission of sulfur dioxide when burning coal, fuel oil, *kg/tons of fuel equivalent*;

K_{SP} – specific emission of solid particles (ash) when burning coal, *kg/tons of fuel equivalent*.

Quantitative values of specific emissions of pollutants PS - (K_{NO_x}, K_{SO_2}, K_{SP}), must be taken taking into account the organic fuel burned in the territory under consideration. For this purpose, it is recommended to use the standard values of emission coefficients for newly commissioned and reconstructed boilers installed in GOST R 50831-95 and TP “Requirements for emissions into the environment when burning different types of fuel in boilers of TPPs” (Table 11-16).

Table 11 − Standards of specific emissions of ash into the atmosphere for newly commissioned and reconstructed boiler installations

Thermal power of boilers Q, MW (steam capacity of the boiler D, t/h)	The present ash content, A_{pr}, % kg/MJ	Emission of solid particles kg/trf
Up to 299 (up to 420)	less than 0.6 0.6-2.5 more than 2.5	1.76 1.76-2.93 2.93
300 and more (420 and more)	less than 0.6 0.6-2.5 more than 2.5	0.59 0.59-1.76 1.76

Table 12 − Standards for specific emissions of SO_2 into the atmosphere for newly commissioned and reconstructed boiler installations

Thermal power of boilers Q, MW (steam capacity of the boiler D, t/h)	Reduced sulfur content Spr, % kg/MJ	SO2 emission, kg/trf
up to 199 (up to 320)	0.045 and less more than 0.045	14.7 17.6
200-249 (320-400)	0.045 and less more than 0.045	11.7 13.1
250- and more	0.045 and less more than 0.045	8.8 8.8

Table 13 − Standards for specific emissions of NOx for the newly commissioned and reconstructed boiler plants

Thermal power of boilers Q, MW (steam capacity of the boiler D, t/h)	Type of fuel	NO_x emission, kg/trf
Up to 299 (up to 420)	Gas	1.26
	Mazut	2.52
	Brown coal	3.20
	Coal:	
	solid slag removal	4.98
	liquid slag removal	6.75
300 and more (420 and more)	Gas	1.26
	Mazut	2.52
	Brown coal	3.20
	Coal:	
	solid slag removal	3.81
	liquid slag removal	6.16

The technical regulation “Requirements for emissions into the environment when burning various types of fuel in boiler plants of thermal power plants” was approved by the Government of the Republic of Kazakhstan on December 14, 2007 No. 1232, as amended by the Government of the Republic of Kazakhstan dated July 21, 2010 No. 747.

Table 14 − Technical specific standards for emissions of solid particles to the atmosphere for all types of solid fuels

Thermal power of boilers Q, MW (steam capacity of the boiler D, t/h)	The reduced ash content A_{re}, % kg/MJ	Mass particulate emissions, kg/trf.		
		operational boiler plants of thermal power plants before reconstruction	reconstructed and newly commissioned boiler plants at operating CHPs from January 1, 2013	newly commissioned boiler plants at operating TPPs from January 1, 2013
Up to 299 (up to 420)	less than 0.6	8.21	1.76	1.76
	0.6-2.5	8.21-10.56	1.76-5.86	1.76-2.93
	more than 2.5	10.56	5.86	2.93
300 and more (420 and more)	less than.6	7.04	1.18	0.59
	0.6-2.5	7.04-14.08	1.18-4.70	0.89-1.76
	more than 2.5	14.08	4.70	1.76
1180 and more (1650 and more)	0.6-2.5	14.08-18.77	1.18-4.70	1.18-2.36

Table 15 − Technical specific standards of emissions of sulfur oxides for solid and liquid fuels

Thermal power of boilers Q, MW (steam capacity of the boiler D, t/h)	The reduced ash content A_{re}, % kg/MJ	Mass particulate emissions, kg/trf.		
		operational boiler plants of thermal power plants before reconstruction	reconstructed and newly commissioned boiler plants at operating CHPs from January 1, 2013	newly commissioned boiler plants at operating TPPs from January 1, 2013
Up to 199 (up to 320)	0.045 and less	25.7	25.7	14.7
	more than 0.045	44.0	44.0	17.6
200-249 (320-400)	0.045 and less	25.7	25.7	11.7
	more than 0,045	44.0	44.0	13.1
250-299 (400-420)	0.045 and less	25.7	25.7	8.8
	more than 0,045	44.0	44.0	8.8
300 and more (420 and more)	0.045 and less	25.7	25.7	8.8
	more than 0.045	38.0	38.0	8.8

Table 16 − Technical specific standards for emissions of nitrogen oxides for solid, liquid and gaseous fuels

Thermal power of boilers Q, MW (steam capacity of the boiler D, t/h)	Type of fuel	Mass emission of NOx, kg/trf		
		operational boiler plants of thermal power plants before reconstruction	reconstructed and newly commissioned boiler plants at operating CHPs from January 1, 2013	newly commissioned boiler plants at operating TPPs from January 1, 2013
Up to 299 (up to 420)	Gas	3.54	2.58	1.26
	Mazut	4.16	3.02	2.52
	Brown coal:			
	solid ash removal	6.60	5.47	3.20
	liquid slag removal	7.15	6.05	3.20
	Coal:			
	solid ash removal	7.28	6.10	4.98
	liquid slag removal	9.10	7.49	6.75
300 and more (420 and more)	Gas	4.05	2.93	1.26
	Mazut	5.21	3.64	2.52
	Brown coal:			
	solid ash removal	6.60	6.27	.20
	liquid slag removal	–	–	–
	Coal:			
	solid ash removal	9.10	6.96	3.81
	liquid slag removal	11.24	8.56	6.16

6. Methodological bases and principles for the development of regional programs for uptake of wind and solar energy potentials

6.1. Principles for the development and implementation of regional programs

Regional programs and projects for the implementation of wind and solar energy are an effective tool for the sound development of this type of energy supply and contribute to the involvement of stakeholders making decisions at the regional and higher levels. Although methods and approaches may differ depending on the scope of the project and regional differences, a number of key success factors can be generalized to determine sequental steps aimed at successful implementation of projects.

The basic methodological principles for the development and implementation of regional programs in modern conditions are:

- reasonable and realistic goal setting;
- the complexity and synchronicity of the goals and objectives of the program at each stage of its implementation;
- target orientation and systematicity of program activities;
- variant development of program activities taking into account alternative conditions for its implementation;
- resource availability for the program;
- targeting of program tasks (performers, deadlines, benchmarks, etc.);
- ensuring the manageability of the program (creating the necessary legal, organizational and financial mechanisms).

6.2. Program structure

The draft program should include:

- goals and objectives of the program, specified qualitatively and quantitatively;
- stages and terms of the program;
- justification of financial and other costs;
- calculations of socio-economic efficiency and assessment of environmental consequences;
- description of the mechanisms for implementing the program (necessary regulatory and institutional changes, system for stimulating and attracting financial resources, organizing program management and monitoring its implementation);
- information on government customers and program implementers.

6.3. The main stages of the development and implementation of the program

It is conditionally possible to distinguish 5 stages of program development, including:

1. Comprehensive analysis of source data and concept development;
2. Assessment of renewable energy potentials;
3. Assessment of the environmental and fuel effects of the realization of the potentials of wind and solar energy;
4. Description of measures that can be used to realize the potentials of wind and solar energy.
5. Monitoring the implementation of the program.

Successful implementation of wind and solar energy programs and projects largely depends on the reasonable setting of common goals and objectives. In the process of preparing a program using a variety of analytical methods, a concept is developed containing various scenarios and forecasts of potential energy demand in the region.

The stage of the program "comprehensive analysis of source data and concept development" is based on the results of a reliable database being created for conducting technical analysis and developing scenarios. Analysis of the energy potential of wind and solar energy, the current situation and potential of regional energy and economy are central elements of the overall technical analysis. The results of the analysis provide a good idea of the scenarios and variants of the program evaluation, including technically untrained stakeholders and decision makers. Based on the analysis of the situation, potential opportunities and development scenarios, a specific implementation program is developed.

After completion of the draft program, the customer organizes the coordination of the measures and financing sources provided for it with the ministries and departments, local authorities, business structures - the program implementors. Examination of the program is conducted, and according to its results the corresponding refinement is done.

At the monitoring stage, the economic aspects of the program, quality assurance are reviewed and monitored, and, if necessary, adjustment and optimization of processes during program implementation is carried out.

Conclusion

The UNECE Committee on Sustainable Energy is charged with implementing results-oriented measures, including "II. Spheres of activity: (c) Renewable energy sources". In line with the UN Secretary-General's Sustainable Energy for All initiative, the UNECE has focused on activities that will help increase the uptake of renewable energy sources in the region and achieve the goal of "energy accessibility for all" in the ECE region (ECE / EX / 2013 / L.15).

Analytical materials presented in this paper and propositions on a unified methodology for assessing natural resources, gross and technical potentials of wind and solar energy in the CIS countries, recommended formats for providing data, methodological foundations and principles for the development of regional programs for implementing the potentials of wind and solar energy may be useful framework for strengthening cross-border cooperation in this energy sector.

Appendix

The main source of information for assessing wind energy potential is the data on the distribution (repeatability) of wind speeds over gradations, which are obtained by statistical processing of observations from meteorological (MS) and upper-air stations (AE), as well as using satellite methods sounding of the atmosphere.

For a number of objective reasons, measurements of wind parameters are performed for a very limited set of heights. Thus, in the case of the most developed and extensive MS network, measurements are made only at the level of the weather vane (10–20 m). The lack of comprehensive data on the vertical profile of the wind speeds when there is a wide range of wind power plants with different technical characteristics on the world market makes it impossible to analyze the probabilistic characteristics of wind speeds over the entire height range of the wind wheel axis and, as a result, effective equipment selection during design centralized or distributed power supply system in a specific locality.

It was this similar mismatch between "demand and supply" for such information that gave rise to the need to develop this methodology. Its key idea is to determine the parameters of the probability density function of wind speeds at various heights above the earth's surface based on the following measurement data at the q_{th} point of the territory:

– *repeatability* $p_{jh_{bas.q}}$*wind speeds at a base height* $h_{bas.q}$ *for gradation intervals from the set* J^{int};

– *average wind speed* $u_{av.\square_{bas.q}}$ *at this height;*

– *roughness coefficient of the underlying surface* α_q.

To this end, the Weibull two-parameter distribution was chosen as the law of distribution of a random variable, which is widely used in domestic and foreign practice to approximate the actual repeatability of wind speeds.

Weibull probability density function is:

$$f(u) = \frac{K}{A}\left(\frac{u}{A}\right)^{K-1} e^{-\left(\frac{u}{A}\right)^K},$$

where u – wind speed, *m/s*; A – scale parameter (speed), *m/s*; K – dimensionless shape parameter of the curve.

It is easy to show that the Weibull integral distribution function can be written as

$$F(u) == \int_0^u \frac{K}{A}\left(\frac{v}{A}\right)^{K-1} e^{-\left(\frac{v}{A}\right)^K} dv = 1 - e^{-\left(\frac{u}{A}\right)^K},$$

where v – variable defining the wind speed.

There is an experimentally obtained information on the repeatability of wind speeds $p_j = p_{jh_{bas.q}}$ on set $J^{int} = \{1,\ 2,\ \dots\ j,\ \dots\ n\}$ intervals of gradations of wind speeds at base altitude $h_{bas.q}$ above the ground in a geographic point q with concrete coordinates and upper boundaries $u_j = u_{jh_{bas.q}}$ each j_{th} gradation interval.

The task is to determine the parameters $A = A_{bas.q}$ and $K = K_{bas.q}$ of the Weibull function at the base height.

To find a solution, a function is introduced

$$\phi(u) = 1 - F(u) = e^{-\left(\frac{u}{A}\right)^K},$$

which is then twice logarithmic:

$$ln(-ln\,\phi\,(u)) = ln(-ln(1 - F(u)) = K\,ln\,u - K\,ln\,A$$

Using the results of the experiment $F(u_j) = \sum_{i=1}^{i=j} p_i$ (for $\forall j \in J^{int}$) This expression can be represented as follows:

$$ln(-ln(1-\sum_{i=1}^{i=j} p_i)) = K\,ln\,u_j - K\,ln\,A,$$

and after entering the notation:

$$y_j = ln(-ln(1-\sum_{i=1}^{i=j} p_i)),\ x_j = ln\,u_j,\ a = K,\ b = -K \cdot ln\,A$$

so $y_j = a \cdot x_j + b$

It makes sense to look for unknown coefficients a and b, and through them, the parameters of the Weibull function, using the criterion of the minimum of the standard deviation of the values predicted by the ratio $y = a \cdot x + b$ from the experimental results, i.e. by minimizing the function

$$\Phi(a,b) = \sum_{j=1}^{n} \left[y_j - (a \cdot x_j + b)\right]^2$$

Using the least squares method (LSM) allows to determine the values of the parameters of the Weibull probability density function

$$K = K_{bas,q} = \frac{c_1 c_{22} - c_2 c_{12}}{c_{11} c_{22} - c_{21} c_{12}}$$

$$A = A_{h_{bas.q}} = e^{\frac{c_{11}c_2 - c_{21}c_1}{c_1 c_{22} - c_2 c_{12}}}$$

where $c_{11} = \sum_{j=1}^{n} x_j^2$, $c_{12} = \sum_{j=1}^{n} x_j$, $c_1 = \sum_{j=1}^{n} y_j x_j$, $c_{21} = \sum_{j=1}^{n} x_j$, $c_{22} = n$, $c_2 = \sum_{j=1}^{n} y_j$.

The use of the LSM to determine the parameters of a linear regression equation, and then the parameters of the Weibull function, in contrast to the graphic methods used, allows a statistical evaluation of the results of approximation of the empirical histogram by the Weibull formula. The mathematical expectation $M(U)$ of a random wind speed U is the initial moment of the first order ν_1, corresponds to the average value of the speed $u_{av.}$ and is written as the following integral

$$M(U) = \nu_1 = \int_0^{+\infty} u \frac{K}{A}\left(\frac{u}{A}\right)^{K-1} e^{-\left(\frac{u}{A}\right)^K} du.$$

By transforming the original integral expression, the initial moment of the first order was represented as a simpler and more convenient for further use of the integral:

$$\nu_1 = \int_0^{+\infty} e^{-\left(\frac{u}{A}\right)^K} du = A \int_0^{+\infty} e^{-w^K} dw,$$

where $w = u/A$, or its equivalent ratio using gamma function Γ

$$\nu_1 = A \frac{1}{K} \Gamma\left(\frac{1}{K}\right)$$

Analysis of available statistical information allowed to conclude that the statistical significance of a low height of the air jet impact on the value of shape parameter curve K in the fixed point area when there are significant errors in the original data.

In this regard, when performing most estimates, an assumption can be made about the constancy of the value of the curve shape parameter at different heights from the surface of the earth at a fixed point in the territory, i.e. $K_{h_{bas.q}} = K_{hq} = K_q = const$. It follows that for the initial moments of the 1st order $\nu_1(U_1) = M(U_1)$ and $\nu_1(U_2) = M(U_2)$ any two random variables U_1 and U_2, having a Weibull probability distribution with the same values of the shape parameter, the ratio of these moments is equal to the ratio of the speed parameters A_1 и A_2 функции Вейбулла, i.e.

$$\frac{\nu_1(U_1)}{\nu_1(U_2)} = \frac{M(U_1)}{M(U_2)} = \frac{A_1}{A_2},$$

and with a known value of the parameter A_1 first random variable value parameter A_2 second random variable can be defined as

$$A_2 = \frac{M(U_2)}{M(U_1)} A_1 \text{ и } A_2 = \frac{u_{av.2}}{u_{av.1}} A_1$$

or

$$A_h = \frac{u_{av.h}}{u_{av.h_{bas}}} A_{h_{bas}}$$

If the dependence of the average wind speed $u_{av.h_q}$ is given at the heigt h_q in *q_{th}* point of the territory from the average wind speed $u_{av.h_{bas.q}}$ at the heigt $h_{bas.q}$ at the same point, then at the known value of $A_{h_{bas.q}}$ at the base height it becomes possible to determine A_{h_q} at the height h_q. One of the fairly common dependencies of this kind is a power function of the form

$$u_{av.h_q} = \left(\frac{h_q}{h_{bas.q}}\right)^{\alpha_q} u_{av.h_{bas.q}}$$

with the exponent α_q, characterizing the level of surface roughness at the measuring point.

Focusing on the results obtained, it can be shown that large-scale high-speed parameters of the Weibull function for different heights above the ground in the q_{th} point of the territory are related as follows

$$A_{h_q} = \left(\frac{h_q}{h_{bas.q}}\right)^{\alpha_q} A_{h_{bas.q}}$$

Thus, knowing the parameters of the probability distribution function of wind speeds at the base height $h_{bas.q}$ one can determine the values of these parameters at any given height h_q.