Assessment of the wind and solar energy potential, and improved policy for their promotion

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Executive Summary

The EnviroGRIDS project brings together several 21st century information technologies for better understanding of the Black Sea watershed. The Group on Global Earth Observation Systems of Systems (GEOSS) is building a data-driven view of our planet that feeds into models and scenarios to explore our past, present and future. EnviroGRIDS aims at building the capacity of scientists to assemble such a system in the Black Sea Catchment, the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake. EnviroGRIDS will particularly target the needs of the Black Sea Commission (BSC) and the International Commission for the Protection of the Danube River (ICPDR) in order to help bridging the gap between science and policy.

One of the most important aims of the EnviroGRIDS project is to contribute Global Earth Observation Systems of Systems (GEOSS), which is being built by the Group on Earth Observations (GEO) on the basis of a 10-Year Implementation Plan running from 2005 to 2015, by providing data/information available at Black Sea Catchment. GEOSS is building a data-driven view of Earth that feeds into models and scenarios to explore past, present and future. The Fifth Work Package of the EnviroGRIDS Project mainly works on providing data/information to GEOSS system in terms of Societal Benefit Areas (SBAs) already considered by GEO. Partners contributing the Task 5.4 directly deal with Energy SBA. Task 5.4 does not only provide the results of the Renewable energy potential and forecasting in contributing countries as a report but it also contributes to GEOSS by providing maps of the result of the studies executed within this task.

This report is elaborated as an output within the implementation of Work package 5, and particularly Task 5.4 through the creation of The Deliverable D5.6. The main objective of D5.6 is to assess the wind and solar energy potential in Bulgaria; develop forecasts of the wind and solar energy potential in the country by 2050; compare the existing methods for measurement of the solar and wind energy potentials with the opportunities offered by GEOSS. Three institutions, Black Sea Regional Energy Centre (BSREC), Istanbul Technical University (ITU), and Ukrainian Scientific and Research Institute of Ecological Problems (USRIEP), contributed to this Task from Bulgaria, Turkey and Ukraine respectively.

This Deliverable includes one main summarizing report, which is a general overview of national studies executed within the Task 5.4 Energy, and four complementary reports covering the studies executed by each partner as annexes.

The Annex I, presented in this deliverable, covers the first national report entitled as “Assessment of the Wind and Solar Energy Potential in Bulgaria and Policy Recommendations for Their Promotion” and prepared by BSREC for Bulgaria. The approach that BSREC and the project team undertake is to estimate the renewable energy potential through integration and analysis of information in the environment of a GIS. The phenomena with relation to the topic of energy potential can by doing so be estimated for a chosen level of subdivision in the country, both administrative (regions, districts and municipalities) and geographic (watersheds, etc.). Detailed information on used methods, data and the entire workflow along with analyses of the results are provided below.

The analytical approach we undertake is to simultaneously assess the following conditions, which are a prerequisite for successful renewable energy projects implementation throughout the territory of Bulgaria:

- Physical, objectively existing environmental preconditions for the development of solar and wind projects
- Limitations for the actual implementation of renewable energy production, as consequence of:
  - Land-use and land cover, not permitting the creation of renewable energy facilities;
  - Administrative limitations for the creation of renewable energy facilities (Environmentally protected areas, territories with special regime of usage, etc.).

The Annex II, presented in this deliverable, covers the first national report entitled as “Assessment of the Wind and Solar Energy Potential in Turkey and Forecasts By 2050” and prepared by ITU in collaboration with BSREC for Turkey. In this context, BSREC, as the energy specialist in energy issues, took the responsibility of assessment of the wind and solar energy potential in Turkey together with the responsibility of preparing wind and solar energy forecasts for Turkey. ITU provided the main data that used in assessment and forecasting processes. Stated data includes meteorological data recorded at 41 meteorological monitoring stations, which are distributed in the study area, for the period of 2000-2009 and available literature data already published in

national reports and scientific studies on energy, official statistics official statistics and data provided by companies producing energy or services in the relevant areas. ITU is also responsible for preparing the parts related with "Evaluation of Meteorological Data Used Solar and Wind Power Potential Assessment Studies in Turkey" and general overview of "Legal Framework for Wind and Solar Energy in Turkey" together determination of the mapping methodology used in mapping the results of the study for Bulgaria and Turkey.

According to this task allocation, BSREC prepared a report on the assessment of the wind and solar power energy and forecasting wind and solar energy potential by the year of 2050. In this national study, the same methodology, which was also applied for assessment and forecasting wind and solar energy in Bulgaria, was mainly used. BSREC developed two main scenarios – maximum and minimum development of RES (solar and wind).

The Annex III, presented in this deliverable, covers the first national report entitled as "Wind and Solar Energy Potential Assessment of Ukraine" and prepared by USRIEP for Ukraine. For this period in accordance with work plan, USRIEP team has assessed an existent wind and solar energy potential of Ukrainian part of Black Sea Catchment region. Pursuant to the objectives of Task 5.4 "Energy", the results of wind and solar energy potential of Ukraine were analyzed and mapped in GIS environment. Based on the problem introduced by Task 5.4 "Energy", the models suitable for wind and solar power potential assessment of Ukrainian part of Black Sea Catchment region had been selected and tested for assessing the current state of RES potential in Ukraine. Such models are based on identical and available data for all project partners. Annex III covers a detailed report of the studies executed by USRIEP for assessing the current state of wind and solar energy potential.

The Annex IV, presented in this deliverable, covers the first national report entitled as "Analysing Spatial Interpolation Methods for Mapping Meteorological Data in Bulgaria and Turkey" and prepared by ITU both Bulgaria and Turkey. This report includes a case study for determining the efficiency of the spatial interpolation methods used for presenting the point source data as raster surfaces in terms of accuracy. Some of the maps produced within this Task were prepared by using spatial interpolation method determined as a result of the studies presented in this Annex.

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1 Background

One of the most important aims of the EnviroGRIDS project is to contribute to the Global Earth Observation Systems of Systems (GEOSS), which is being built by the Group on Earth Observations (GEO) on the basis of a 10-Year Implementation Plan running from 2005 to 2015, by providing data/information available at the Black Sea Catchment.[1] GEOSS is building a data-driven view of the Earth, that feeds into models and scenarios to explore past, present and future. The Fifth Work Package of the EnviroGRIDS Project mainly works on providing data/information to GEOSS system in terms of Societal Benefit Areas (SBAs), already considered by GEO.

The EnviroGRIDS project brings together several 21st century information technologies for the better understanding of the Black Sea watershed. EnviroGRIDS aims at building the capacity: of scientists to assemble such a system in the Black Sea Catchment; of decision-makers to use it, and of the general public to understand the important environmental, social and economic issues at stake. EnviroGRIDS particularly targets the needs of the Black Sea Commission (BSC) and the International Commission for the Protection of the Danube River (ICPDR), in order to help bridging the gap between science and policy.

This report is elaborated as an output of Work package 5, and particularly of Task 5.4, throughout the creation of deliverable D5.6. The main objective of D5.6 is to assess the wind and solar energy potential; to develop forecasts of the wind and solar energy potential by 2050; to compare the existing methods for measurement of the solar and wind energy potentials with the opportunities, offered by GEOSS. It comprises three appendixes – national reports for the countries, participating in the project: Bulgaria, Turkey and Ukraine.

The approach, that the project team undertook, is to estimate the renewable energy potential through integration and analysis of information in the environment of a GIS. The phenomena, with relation to the topic of energy potential, is being estimated for a chosen level of subdivision in the country - administrative units (regions, districts and municipalities) as well as geographic ones (elevations, watersheds, etc.). Detailed information about the used methods, data and the entire workflow, along with analyses of the results, is provided in the studies.

A separate report entitled "Analyzing spatial interpolation methods for mapping of meteorological data in Bulgaria and Turkey" is attached. Its results are used in the national report of Turkey. In Bulgarian report an alternative approach is used, which take into considerations the geographical relief of the country as well.

[1] http://www.earthobservations.org, official web site of the Group on Earth Observation.

2 Existing Methods for Measurement of Solar and Wind Energy Potentials and the Opportunities Offered by GEOSS

2.1 Wind and Solar Potential Estimation

A necessary precondition for the technologies development is the information availability and the common efforts of researchers, designers, executives, governments, investors, grids operators and the vast society.

The dashing development of wind energy in the last years faces difficulties in three aspects:

- Lack of information on the primary sources;
- Imperfection of the technologies for transforming primary energy into electricity;
- Management of the electricity obtained from these renewable resources.

2.1.1 Random Character of Solar Radiation and Wind

Solar radiation and wind are variable in time and space, dependent on multiple factors, and due to these reasons they are difficult to predict. This applies especially to wind. In order to obtain relatively reliable information about the wind parameters, long years of observation are needed at specific spots, where good perspectives for use appear. In the last years the meteorological stations measurements, enriched with data from meteorological, military, geographical and other satellites, observation airplanes and probes, provide an important amount of data, but its reliability decreases substantially because of the wind random character and its strong dependence on the terrain.

Solar radiation is much easier to predict, but random factors and mostly clouds make the forecasts uncertain as well.

2.1.2 Efficiency of Generators

The industrial development of converting technologies - wind turbines, and especially of photoelectric panels - began essentially in the last two-three decades. The abundance of natural resources in the past – fossil fuels like coal, oil, gas, uranium – was giving no ground to humanity to worry about the future over 100 years horizon, especially having in view the perspective of the nuclear synthesis unlimited resource.

For wind energy capture relatively simple machines are used and the technology improvement is not quite difficult. Trends are to implement units of larger scale, better technical solutions of different components and control. Up-to-date turbines with several megawatts capacity are not too far from concurrent participation at the electricity market without additional stimulation. Of course, this could only happen if the electrical system has control means and reserve capacity for integration of intermittent generators.

Solar irradiation conversion to electricity is a new technology, which first technical applications were performed in the last century fifties. Despite the big successes in its improvement and the decrease of costs, an important technological breakthrough is indispensable, in order to bring them closer to commercialization. Hopefully, it will be realized in the next decade, however, further research, applied science activities and implementation are needed.

Even today, after decades of research studies, demonstration projects and support by the promotional energy policy, the solar panel captures less than 10% of the energy of the falling over its surface electro-magnetic wave.

Low efficiency and high investments impose the use of non-commercial means through political intervention, with the goal to deploy solar technology in the electrical power generation, as a precondition for their further improvement. Such process requires of course enormous public costs, which is the price of the natural environment preservation.

2.1.3 Electricity System Control

The operating electricity systems are built in conformity with the existing technologies – mainly fossil fuels, hydro resources and nuclear fission - in the same time endeavouring for rational use of energy resources. The size of units is an important characteristic of contemporary power plants, as normally larger units are more efficient.

Solar irradiation and wind are unsteadily distributed in space. Especially the solar panels are limited in capacity, being convenient for generation at the consumption location. It is important, that generated power can not be subject to regulation without primary resource losses.

Therefore, in order to master these technologies, refurbishment of the electrical systems with new control technologies would be necessary: electricity accumulation and storage, systems for control, interconnection, information and communication, automation.

The wind and solar irradiation potential for electricity generation shall be estimated, both for planning the energy policy and for evaluating investments projects in electrical power generation, transmission and distribution.

2.1.4 Information Basis

Pressure on the environment, resulting from human activities, imposes the need of quick replacement of technologies based on fossil fuels by clean, low emissions technologies. This act requires, in addition to the important costs imposed to the society, coordinated efforts by the entire energy and researchers' community.

Such efforts shall be based on data, not only for the climate and geography, but also on information for the technologies achievements, possibilities and perspectives. The necessity for database availability is obvious - to collect information from the possible sources, to offer access and processing, analysis and synthesis options, in order to overcome the boundedness of individual, institutional and national observations.

The establishment of a database will facilitate investigations, planning and investments to reach the sustainable development goals.

The GEOSS is intended to play such role. Energy conversion and consumption - the overwhelming polluters of environment – are considerable components of GEOSS.

One of the main areas of GEOSS with regard to energy is *Improving management of energy resources.* GEOSS 10 Years Implementation Plan defines the goals of the system in the energy field, as follows:

"GEOSS outcomes in the energy area will support:

- environmentally responsible and equitable energy management;
- better matching of energy supply and demand;
- reduction of energy infrastructure risks;
- more accurate inventories of greenhouse gases and pollutants; and
- a better understanding of renewable energy potential"

GEOSS represents exactly what researchers, explorers, designers, investors, managers, planners, all energy sector participants are missing now, in order to coordinate their communities actions in all countries - a portal to collect information, to organize it in databases accessible to all the participants, a portal directing to information sources, estimation methods and models, analytic software etc.

2.2 The Role of GEOSS

The system idea is to concentrate the information and to make it available to the experts, institutions and technical systems operators, according to some Data Sharing Principles (The Global Earth Observation System of Systems):

- There will be full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation;
- All shared data, metadata, and products will be made available with minimum time delay and at minimum cost;
- All shared data, metadata, and products, being free of charge or no more than cost of reproduction, will be encouraged for research and education.

The system will provide statistic information on the random RES parameters, on the characteristics of the up-to-date technologies for wind energy transformation, on control systems etc. That is how enormous costs in time and funds will be spared and forecasted statistical evaluations with admissible confidence intervals will be possible to elaborate. The more accurate evaluation of the generators capacity credit will make possible to save investments in reserve capacities, accumulating installations and control tools. Planning will be based on more reliable information and will, therefore, increase the stable operation of the electrical systems.

Quite naturally, not only power systems will use GEOSS, but also all energy systems – heating, cooling, transportation – all of them are expected to use more and more renewable energy.

3 Summary of the Performed Work and Results

Each national report is developed in three stages:

- Data collection;
- Processing and modelling;
- Analyses of the regulatory framework.

3.1 Data Collection

As already stated, the input data has a role of upmost importance. In the target countries the information is gathered mainly through the registered by the meteorological stations data flows. Although these data have a certain level of reliability, they should be used tentatively, because, especially in the case of wind, the stations are localized in places not very suitable for building of proper energy generating equipment. As a result of this fact, the teams prepared their estimations, related to the project, together with the collection of information from all other available sources.

Even after that, the information, presented as an average or calculated values, cannot be used directly for investment estimations, but as an approximation of the energy potential – total and regional.

The information about the geographical conditions is much more reliable and can be found in the information databases at the country level, as well as at the European level.

The team partners used the following sources:

Bulgaria

The following data have been included in the analysis process:

- PVGIS solar data from CM-SAF
- Wind parameters data from 39 meteorological stations for the period 1995 - 2005
- Wind speed data for Bulgaria, produced by 3TIER Inc. USA
- Environmentally protected territories
- CORINE Land-cover
- Administrative breakdown
- Data for settlements
- Data on elevations

It can be seen, that in addition to the meteorological data, the Bulgarian partner used data, obtained on commercial basis from 3TIER Company, which are considered better from an energy point of view. The statistical comparison of both sets of data – local and 3TIER - show little correlation in between, which can be related to the reasons described above.

Turkey

The data, used within the context of Task 5.4, were compiled from different data sources. The main data, used for assessing the renewable energy potential in Turkey, were obtained from Turkish State Meteorological Service. Stated data were daily recorded at 10 meters height (10 year period including the years 2000 and 2009) at 41 meteorological observation stations, separately located in 41 provinces, covered by the study area. These data include:

- maximum wind speed,
- average wind speed,
- maximum temperature,
- minimum temperature,
- solar intensity,
- total precipitation, and
- global solar radiation

In addition to the above stated records, some data and information on economic, social and demographic trends in Turkey were first collected from existing archives, published by related authorities or scientific reports at international and national level, and then used for both assessing the current renewable energy potential, and for forecasting the future demands and potential. In this context current energy prices, gross domestic product, information stated in the national ten year growth outlook, 60 year demographic trend of population (for 1990-2050 period), information on the main components of Turkish electricity industry (such as the overall generation market, installed wind and solar technical potential in Turkey, supply and demand trends, installed capacities of different generation units), declared by national authorities, were compiled and used in this study. Additionally, the forecast considered for the period up to year 2018 is based on the "Turkish Electrical Energy 10-Year Generation Capacity Projection Plan (2009 – 2018)"[2].

Ukraine

In order to assess wind potential of Ukraine, USRIEP team has obtained an averaged climatic data from the State Hydrometeorological Service of Ukraine, measured at 187 meteorological stations in Ukraine. Meteorological stations are uniformly distributed all over the country and the distance between them does not exceed 50-100 km. Observation period covers 30 years.

Obtained data includes:

Averaged wind speed values for 30 years (m/s), measured at 10 meters above ground level;

- Wind speed frequency (%) for the following wind speed ranges:
    - 0 – 1 m/s;
    - 2 – 5 m/s;
    - 6 – 9 m/s;
    - 10 – 15 m/s;
    - 16 – 20 m/s;
    - 21 – 24 m/s;
    - 25 – 28 m/s;
- Annual calm period (%).

All above-mentioned meteorological parameters are included in standard list of measurements for each Ukrainian meteorological station.

3.2 Solar and Wind Potential Assessment

3.2.1 Methodology

The approach for solar and wind potential estimation, undertaken by the project teams, is based on the collection, assessment and analysis of extended information in the environment of a geographic information system. This approach is accepted for the better understanding of regional disparities in the renewable energy potential in the country. The assumptions for the analysis are that the potential is identified as intersection of both factors - the favorable environmental conditions (high wind speeds and solar irradiation) and the lack of constraints (protected areas, water bodies, etc.) for the construction of facilities.

The used software products are predominantly open source (GRASS and Quantum GIS), and the proprietary ArcGIS Desktop, which is used for its visualization capabilities.

The specific methods, used by the partners, are described in details in the Annexes. These methodologies follow in general the procedures, shown in the Figure 1, which reflects the process for solar calculations.

[2] http://www.TEİAŞ.gov.tr/eng/ApkProjection/CAPACITY%20PROJECTION%202009-2018.pdf

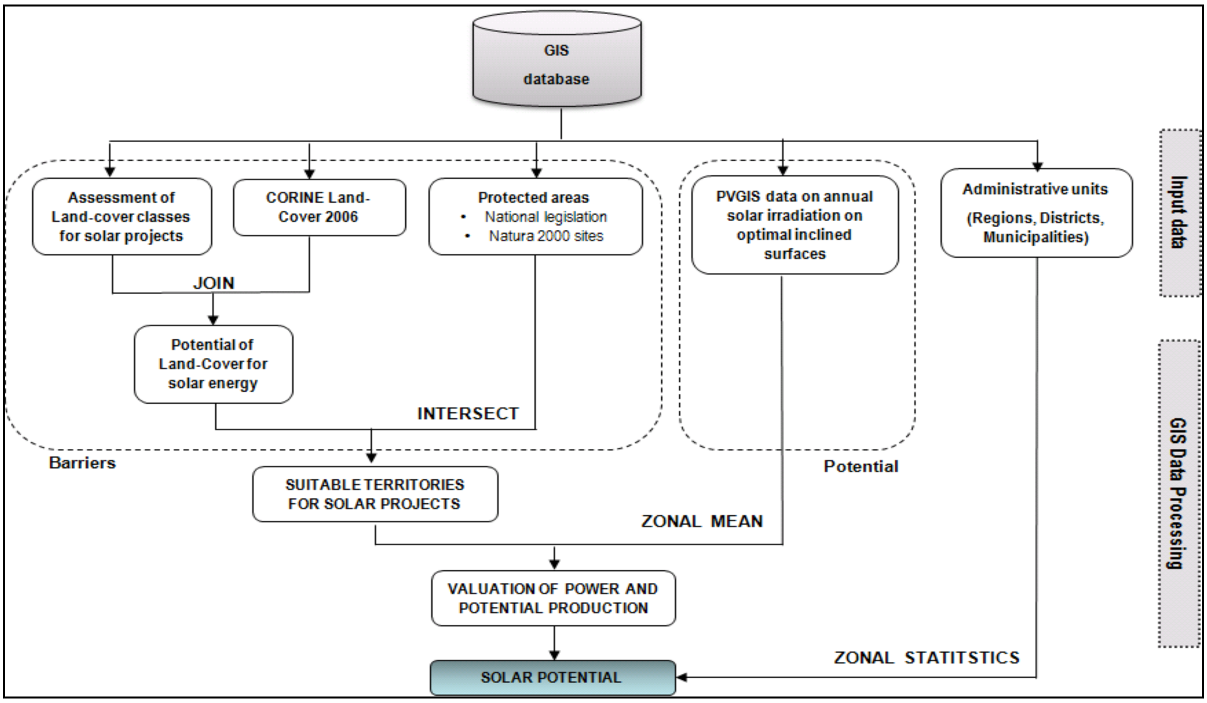

Figure 1: Solar energy potential flowchart

It is worth mentioning here, that the Bulgarian Assessment Procedure includes the relief of the country. All assessments included in the Bulgarian report are made on the basis of 3TIER data.

The partners from Turkey and Ukraine also use the corresponding national information from meteorological sets.

The method used by ITU for mapping meteorological data in Turkey is placed in a separate annex. It includes:

- Power density calculation
- Intersection with barriers
- Choice of suitable areas

Spatial Interpolations Method for mapping meteorological data along the Black Sea cost is applied. The performances of IDW2, Kriging, MQ and NN spatial interpolation methods were used in GIS software for presenting the point source data as raster surfaces.

Forecasts for energy demand by 2050 for Turkey and Bulgaria were developed based on linear modelling. The forecast in the residential and commercial sectors is prepared on the basis of the demand forecast for the different regions. In this context, initially population forecasts for each region were prepared separately, in order to reflect the specific parameters of the processes, which are going to be calculated, and afterwards, forecasts of heating, cooling and hot water demand were made, together with the other processes, as consuming energy for cooking, transportation, electric appliances, etc.

3.2.2 Results

The results of the study show definitely, that the technical potential for transformation of the solar energy into electricity considerably exceeds the present demand of each country.

3.2.2.1 Solar Potential

Bulgaria

Results for the realizable solar potential estimation till 2050, show a potential of 9015 MW, which is distributed unevenly among the Bulgarian municipalities. The predominant share of potential is located in territories with high density and in industrial zones, combined with densely populated residential areas. Sofia (Stolichna municipality) is, naturally, first in terms of potential with an estimated value of 517 MW. The municipality is followed by the LAU1 units of the industrialized district centres of Ruse (147 MW), Sliven (144 MW), Stara Zagora (142 MW), Pleven (142 MW) and Shumen (128 MW).

A considerable share of the theoretical potential (1991 MW – 22.08%) is located in only 13 municipalities with an estimated potential of over 100 MW each.

Turkey

In Turkey solar energy has a technical potential of 8.8 Mtoe electricity generation and 26.4 Mtoe heating capacity. The Solar Water Heating (SWH) are mainly thermosyphon type and consist of two flat plate solar collectors, having an absorber area between 3 and 4 m^2, a storage tank with capacity between 150 and 200 L and a cold water storage tank, all installed on a suitable frame. SWH use is limited to supply of domestic hot water for about 19% of the housing stock.

The model for solar power potential assessment was produced with the "ESRI Solar Radiation Model" used in GIS and the following basic parameters:

- Slope-Shadow Calculations: 500m x 5000m resolution Numerical Height Model generated from 1/100.000 scale topographical maps was used
- Areas at 36-42 Degrees Longitude
- Sky Size Index
- Zenith and Azimuth angles at 32 directions
- Open and Close Sky Calculation Methods
- Solar measurements data taken by EIE and DMI stations in the period from 1985 to 2006 was used for the calculation of parameters used in the model and calibration of the model
- Transmittivity and Diffuse Proportion
- Surface Albedo

As a result of the modelling studies, 500m x 500m resolution map, which indicates the monthly averages computed from daily values for 12 months, was produced.

Ukraine

Solar radiation in Ukraine is of middling intensity. Average annual amount of aggregate solar radiation per 1 m^2 of ground surface at the territory of Ukraine is around 1070 kWh/m^2 in northern Ukraine, 1400 kWh/m^2 and higher in the Crimea.

Solar energy capacity in Ukraine is great enough to introduce photothermal and photovoltaic equipment throughout Ukraine. Photothermal equipment can operate efficiently for eight months (March through October). The Crimean region has a higher level of electromagnetic radiation compared to other Ukrainian regions, making it the most viable site for solar power plant.

Based on the above-mentioned points, USRIEP team has decided to consider this issue in detail and assess the potential contribution of solar energy to hot water supply in private rural settlements for the period of maximum solar activity.

The calculations included the next main issues:

- Estimation of solar collector efficiency
- Determination of solar collector size
- Annual potential contribution of solar energy to hot water supply in private rural settlements.

It has been calculated, that the total annual potential contribution of solar energy to hot water supply in private rural settlements is about 60 GW.

3.2.2.2 Wind Potential

Bulgaria

Wind potential is much more dependent on locality and on the proximity to water basins and elevations, so the results are much more differentiated. In all countries there are limited areas with high energy potential.

The most significant potential for installation of wind turbines, which comes from a favourable intersection of annual average wind speeds and the lack of limiting land use types in East Bulgaria, amounting to 60.6% of the theoretical potential (62 460.8 MW), is located in 53 municipalities in North - East Bulgaria.

Turkey

Turkey enjoys three main climatic regions in its coastal zones, including the Black Sea, Aegean Sea and Mediterranean Sea; in the moderately mountainous regions alongside the coastal regions, and in the rocky plateaus in the central and eastern parts. Etesian winds blowing especially in the summer season from N-NE direction in western Turkey provide a potential area for wind power generation. In central parts of Turkey, high wind velocities are observed, due to the presence of deep valleys and high plateaus. During the wintertime, high pressure systems from Siberia and the Balkan Peninsula, as well as low-pressure systems from Iceland, influence this region. Air clusters coming over the Black Sea also affect the wind characteristics of Turkey.

The overall wind power generation potential of the country at a height of 50 m is computed under two scenarios, after excluding the unfavourable sites. The scenario assumes that capacity of 5 MW can be constructed within a 1 km^2 area.

- Scenario I. Wind power density greater than 400 W/m^2 and wind speed greater than 7.0 m/s, that is, starting from “good” to “outstanding”, wind cluster is taken into account.
- Scenario II. Wind power density greater than 300 W/m^2 and wind speed greater than 6.5 m/s, that is, starting from “middle” to “outstanding”, wind cluster is taken into account.

As a result of the examination of the existing data, wind technical potential was determined and medium hourly wind technical energy potentials for each station are presented.

According to Scenario I, which assumed, that the wind speed is greater than 7.0 m/s and wind power density is greater than 400 W/m^2 , the overall wind power generation capacities in Turkey calculated by WEPA is 47,849 MW. The area occupied under this scenario is 9,569.89 km^2, which corresponds to 1.30% of Turkey’s total surface area.

In Scenario II, which assumes, that the wind speed is greater than 6.5 m/s and wind power density is greater than 300 W/m^2, WEPA calculations show that possible overall wind generation capacity is around 131,756 MW. The surface area occupied under this scenario is 6,511 km^2, corresponding to 3.57% of Turkey’s total area.

Ukraine

An annual average wind speed of the main part of Ukraine is 6,3-6,8 m/s, but wind speed of some regions is exceeding the range of 7-8 m/s. Obviously such territories are more attractive for the building of wind farms. Also it can be expected, that at such windy sites the number of wind turbines per square kilometre might be on average somewhat more than five (for example seven). Generalizing the developed concept, the territories of Ukraine, suitable for wind farms placing, with an average wind speed of 3 different ranges (<6 m/s; 6-7 m/s; >7m/s), were calculated.

According to obtained results, southern and eastern parts of Ukraine have outstanding wind potential, particularly Autonomous Republic of Crimea, Kherson, Donetsk and Lugansk regions.

As for annual specific values of wind power potential, the existing data indicate a promising wind potential around Autonomous Republic of Crimea, Kherson, Donetsk, Chernigiv, and Zhitomyr regions. For these areas the average annual wind speed varies between 5 to 8 m/sec at 75m a.g.l.

4 Forecasts by 2050

4.1 Conditions

The speed of renewable energy sources (RES) development (particularly wind and solar energy) is becoming one of the major factors of sustainable development. Based on cost effectiveness, solar and wind power generation forecast are produced, which major input drivers reflect the following specific characteristics:

- Zero fuel expenses;
- Significant decrease in the investment expenses from year to year, due to the technological progress in the solar technologies;
- Expected increase in the power transformation ratio, due to the better performance of the new technologies;
- Additional incentives (Feed-in tariffs, Special programmes, Subsidies etc.).

At the end of the period a high percentage of energy from solar and wind is expected in the total energy balance – more than 20% in Bulgaria and Turkey.

Ukraine has set a target of 19% energy from RES till 2030.

The results of total residential and commercial consumption from the matrix calculation for the period, including years 2020, 2030 and 2050 are presented in the national reports. The results from the calculations show, that the development of the solar potential utilization is significant after the year 2020. Solar energy for thermal usage (hot water) increases its absolute value about 8 times without any incentives, in order to reach 16% share in the total residential demand. The development of the photoelectric conversion till the year 2020 is based mainly on the incentives from preferential prices.

After 2020 the small residential units gradually gain power to cover 40% of the total installed photoelectric capacity in the year 2050. The so-called hard fuels – coal, wood and biomass - have a stable share in the energy consumption, closely following the increasing demand. Oil and gas increase their quantities in an absolute value, but lose significantly in the share of the total demand, dropping from 43% in 2007 to 32% in 2050.

According to the power system generation forecast (2020 – 2050), wind and solar generation is the major decision goal in this study. The technology development is expected to be the major factor stimulating the growth of RES capacities. Investment expenses are expected to drop down from 2000 to 900 EUR/MW, but with the increase of the wind generation amount the simulation model results in a load factor decrease from 2400 to 2000 hours/year.

Additional forecasts were done and stated in the national reports.

4.2 Maps

Task 5.4 does not only provide the results of the renewable energy potential and forecasting in contributing countries as a report, but it also contributes to GEOSS by providing maps of the result of the studies executed within this task.

The final outcome of the procedures, described above, is a rich set of maps, some with separate layers of geospatial information, representing the spatial distribution of wind and solar potential.

4.2.1 Solar Maps

Solar maps information present the power potential of the solar energy sources at a local level, taking into account different limiting and geographic area parameters.

The map below provides an overview of the estimated potential at municipal level in Bulgaria.

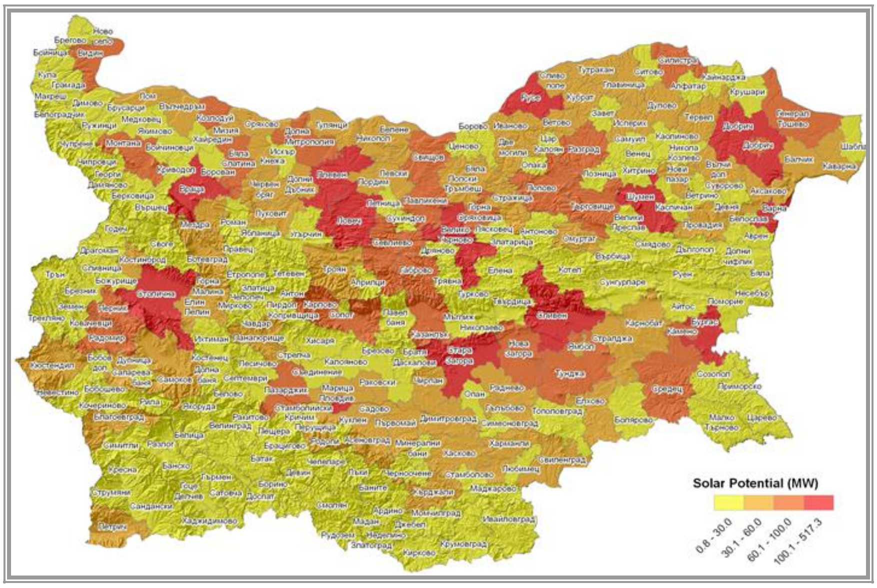

Figure 2: Solar energy potential in Bulgaria in MW

Solar intensity potential in Turkey was calculated, based on the records made at 35 monitoring stations. A thematic map indicates the solar intensity information, designed as it is represented in the Figure.

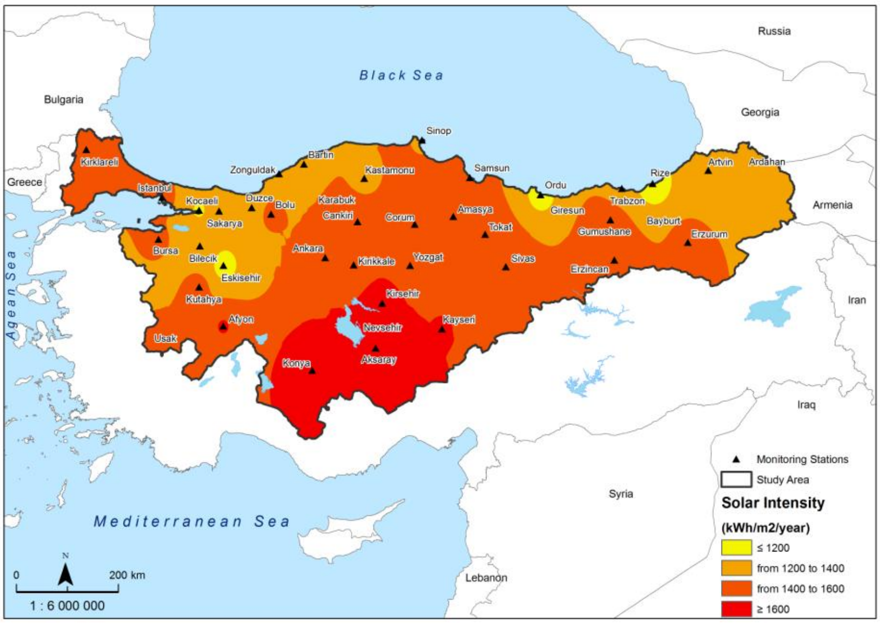

Figure 3: Solar intensity in Turkey, kWh/m^2/year

Solar energy capacity in Ukraine is great enough to introduce photothermal and photovoltaic equipment throughout Ukraine. The distribution of annual solar radiation level over a Ukrainian territory is shown in the figure below.

Solar maps are usually used as a first convenient source for policy makers, to be able to identify municipal territories, based on the relative share of suitable territories, along with the corresponding potential power and energy production.

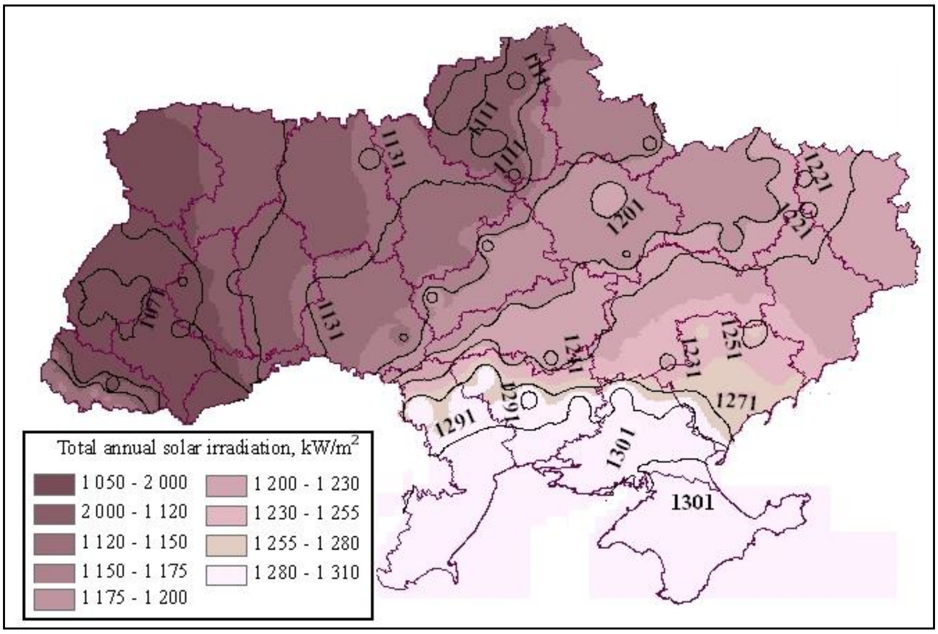

Figure 4: Total values of specific annual solar radiation in Ukraine

4.2.2 Wind Maps

Maps with average wind speed at different levels and wind speed potential at different heights, and for different regions in the countries, are presented in the studies.

The following figure gives the suitable places in Bulgaria for wind energy utilization, taking into account all considered limitations.

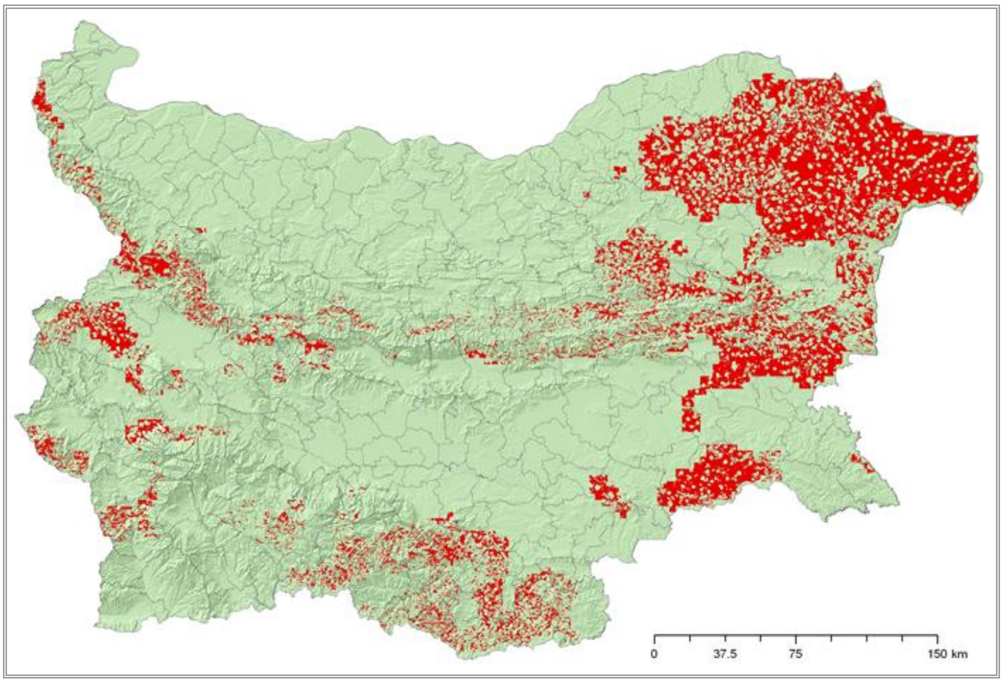

Figure 5: Wind energy potential in Bulgaria (suitable places for wind energy utilization).

In the case study, the mapping methodology, that will be used, while interpolating the raster surfaces by using point source data (measurements at meteorological observation stations), was determined by comparing several spatial interpolation methods. In this context, Kriging, Inverse Distance Weighted, Natural Neighbour, and

Multiquadric spatial interpolation methods were compared in terms of accuracy. Performances of the applied methods were assessed in terms of three different extents, mainly considering the assessment of the root mean square errors (RMSE) of estimated values. In this context firstly, inertial overall accuracy assessment results were considered to compare the accuracies of the applied interpolation methods. Secondly, cross validation technique was used and four monitoring stations were selected as control stations. As a result of these studies second degree Inverse Distance Weighted spatial interpolation method had the best performance for considered studied area and sample data.

Several thematic maps of Turkey, indicating the solar and wind energy potential in the studied area, were produced by using the above stated mapping methodology. The map, presented in Figure 7, is produced by using Inverse Distant Weighted spatial interpolation for estimating raster surfaces by using point source wind speed data recorded (at 10 m) at each monitoring station. The map, indicated in Figure 8, is produced by using the same method and it represents the medium hourly wind technical energy potential within the borders of the study area.

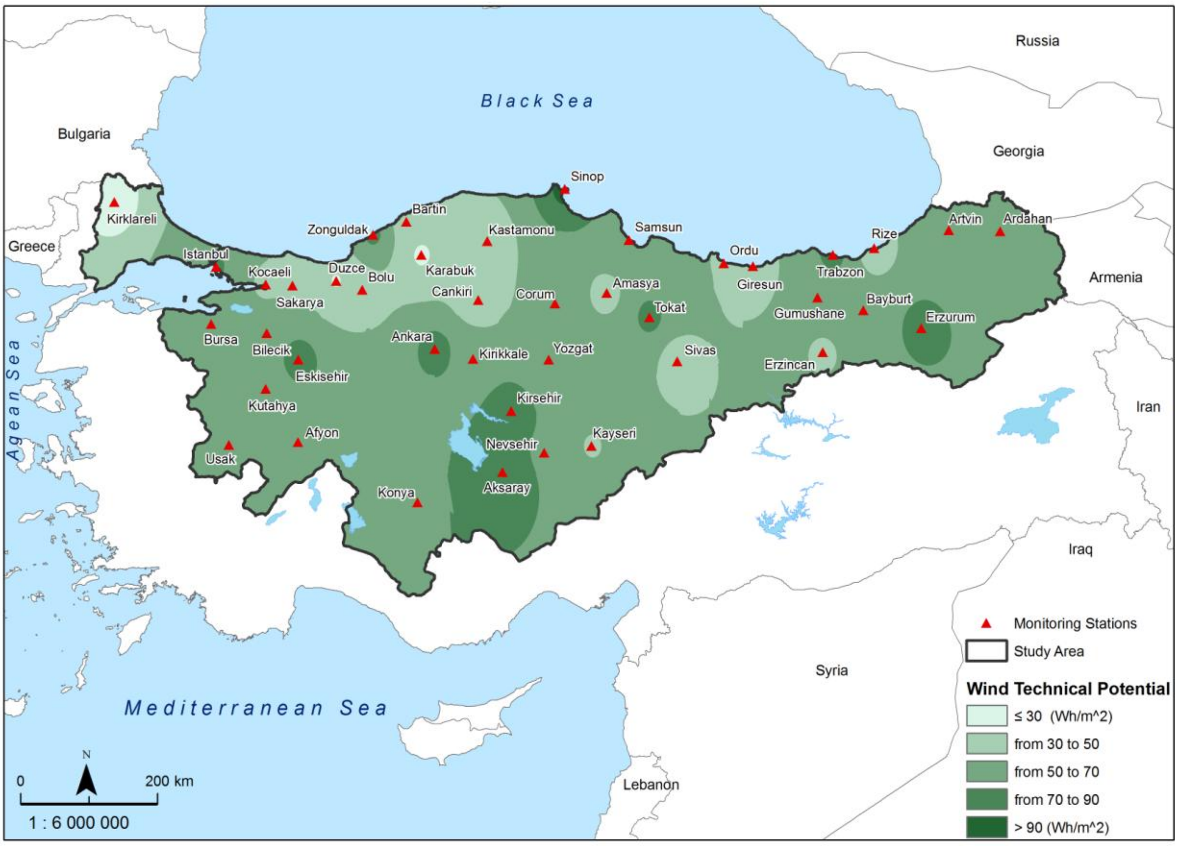

Figure 6: Wind technical energy potential in Turkey.

Wind power density is considered as a better indicator of the wind resource in Ukraine than wind speed, so it is the amount of wind power available per unit of area perpendicular to the wind flow, which is presented in the final result map.

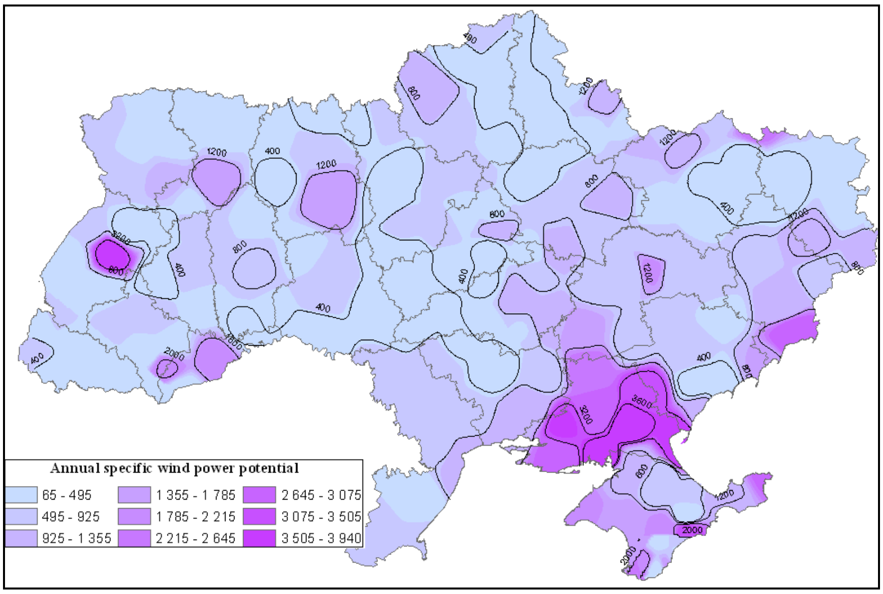

Figure 7: Annual specific wind power potential in Ukraine

5 Conclusions and Further Activities

The utilization of wind and solar irradiation for energy production is determined not only by the climate conditions, but also by the existing technological level and many other restrictive factors - geographical, economical, technical, regulatory, social etc.

The theoretical potential, especially of the solar irradiance, in the target countries is enormous, and even, from the point of view of their energy needs, it is unlimited.

From other point of view, the systems for control and regulation in the existing power generation systems are based on the requirements of conventional generators, which have a stable energy resource supply and a convenient possibility for regulation.

The intermittent and distributed character of RES sets new requirements towards the electric systems – new control and automation technologies for multi-machine systems, new systems for protection, flow management and electricity storage.

Intensive research work is ongoing presently in the technological area mentioned above. The implementation of its results will gradually increase the scope for a possible integration of the produced energy by RES into the power system. Particularly important is the development of small scale apparatus for implementation of individual and local renewable energy generators.

The gradual development of the technologies for transformation, storage and control will raise the technological potential limit and will allow the rapid implementation of wind and solar projects in a degree, which up to 2050 will make RES the major component in the energy balance of the Black Sea countries.

It worth mentioning that photo-thermal technology is unfairly under-estimated compared to the photo-electric one, despite the obvious advantages of the solar thermal panels, namely: simplicity, low price, space availability. Nevertheless, its share is expected to grow, together with the increasing significance of the locally distributed production.

The regulatory framework is another important factor, together with the technological progress, which can stimulate the implementation of renewable energy... For this reason, the final part of the attached reports deals with the factors, which determine the scope of the RES utilization – especially on the bases of the public and technological support. In correspondence with the conclusions, analyses of the regulatory systems are presented. It might be concluded that the regulatory systems are incomplete and does not include enough incentives for the support of the small units, covering own consumption, as well as for the heat production from solar radiation. They also are not flexible enough and follow the technical progress with a certain delay. On the bases of these analyses, proposals for new regulatory measures are included in the reports.

As a serious disadvantage in the process of wind energy utilization in the present moment can be shown the lack and/or the unreliability of the information.

The study has shown serious gaps in the information chain in all three countries. They include:

- Insufficient and inaccurate information
- Lack of specialised contemporary system of metering of wind parameters
- Lack of system for storing all information which is necessary for assessment of wind potential

The input data is gathered mainly by stations destined for meteorological purposes, and because of that reason they are localized in not very suitable for gathering of information for energy projects places. Nevertheless, this information is convenient for a general estimation of the potential and for determination of the limitations, which will help the investors to choose the adequate regions for additional wind tests at site for investment purposes.

The observations made by investors with measuring units at wind turbine heights, and the data from the energy production of already mounted parks and individual facilities, gradually fills the information gaps.

The lack of a united system of data leads to a huge spending of efforts and finances for the sole purpose of acquiring of wind parameters data. The same, but in a smaller scale, is valid for solar energy.

GEOSS, with its advantage of a full scale and freely available information, will present a precious contribution to the quick development of RES production and to the corresponding decrease of the pollution in the region – air, water, soil, rivers and water basins – by carbon, sulfur, nitrogen and other oxides, acids, alkali, ashes and petroleum residues.

Having in mind the serious changes in the environmental, social and economic issues, which can be expected in the future, a serious gap in the possibilities for interpretation of results is also inevitably to appear.

Further activities for the evaluation of the possible changes in technologies, legislation or even climate or environmental aspects of the gathered data, will be of a great importance, especially in the process of medium and long-term planning studies.

Specific recommendations to the deployment of renewable energy, separately for wind and solar, were the final results of the information services, oriented towards the Black Sea Catchment area, for the users of the Global Earth Observation Systems of Systems – the system, which expands the potential and the effectiveness of the information.

6 Abbreviations and Acronyms

BSC	Black Sea Commission
BSREC	Black Sea Regional Energy Centre
CM-SAF	Climate Monitoring Satellite Application Facility
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
GW	GigaWatt
ICPDR	International Commission for the Protection of the Danube River
ITU	Istanbul Technical University
kWh	kiloWatthour
LAU	Local Administrative Unit
m	metre
MW	Megawatt
PVGIS	Photovoltaic Geographical Information System
RES	Renewable Energy Sources
RMSE	Root Mean Square Error
SBA	Societal Benefit Areas
SWH	Solar Water Heating
USRIEP	Ukrainian Scientific and Research Institute of Ecological Problems

7 Annexes

A. Annex I: Assessment of the wind and solar energy potential in Bulgaria and policy recommendations for their promotion

B. Annex II: Assessment of the wind and solar energy potential in Turkey and forecasts by 2050

C. Annex III: Wind and solar energy potential assessment of Ukraine

D. Annex IV: Analysing spatial interpolation methods for mapping meteorological data in Bulgaria and Turkey

A. Annex I: Assessment of the wind and solar energy potential in Bulgaria and policy recommendations for their promotion

ABSTRACT

The study is devoted to assessment of wind and solar radiation for generation of energy, mainly electricity, based on the existing information about sources' parameters and conversion technologies.

Basic or general source of information for wind and solar radiation in Bulgaria is the historical meteorological observation made at the height of 10 m above the ground level. Such data is not specifically reliable because it is intended for specific climate assessment but not for energy evaluation purposes. Due to the above mentioned reason, additional set of information is obtained: from 3 TIER for wind parameters and from PVGIS CM-SAF Database, JRC for solar radiation.

All geographic information and information for restriction is abstracted from existing data base in Bulgaria and in the EU.

The assessment of potential is performed through open source software products (GRASS and Quantum GIS), and the proprietary ArcGIS Desktop, which is used for its rich visualization capabilities.

Analysis of existing national legislation in the field of renewable energy utilisation is executed and improvement measures are proposed.

EXECUTIVE SUMMARY

The main goal of this study is to assess solar and wind energy potential in Bulgaria, and to develop a forecast for potential utilization by 2050.

In the report the following popular definitions of the potential are used:

- **Theoretical / geographic potential** is the energy, generated at areas that are considered suitable;
- **technical potential** is the geographical potential reduced by the losses of the conversion of the primary energy to secondary energy sources;
- **economic potential** is the total amount of technical potential derived at cost level that is competitive with alternative energy applications;
- **realisable / implementation potential** is the total amount of the technical potential that is possible to be implemented in the energy system

The main difficulty for the assessment of energy potential of intermittent sources like wind and solar radiation is the lack of systematic observation and reliable information in Bulgaria.

Because of that, information from all available sources had to be collected.

The following approaches and sources are used in the study:

- historical - meteorological stations data sets for the last 10 years;
- 3TIER wind parameters maps;
- PVGIS CM-SAF Database; JRC for solar irradiation.

The approach for solar and wind potential estimation undertaken by the project team is based on collection, assessment and analysis of extended information in the environment of a geographic information system. This approach is accepted for the better understanding of regional disparities in the renewable energy potential in the country. The assumptions for the analysis are that the potential is identified as intersection of both the favourable environmental conditions (high wind speeds and solar irradiation) and the lack of constraints (protected areas, water bodies, etc.) for facilities construction. Data for the analysis include wind speed at 80 m. digital elevation model, solar irradiation on optimally inclined surfaces and many other additional thematic layers. The software products used are predominantly open source (GRASS and Quantum GIS), and the proprietary ArcGIS Desktop, which is used only for its rich visualization capabilities.

Outcomes of the procedure are separate layers of geospatial information representing the spatial distribution of wind and solar potential. Data is also available for the 264 Bulgarian municipalities, enabling the disclosure of regional disparities.

Chapter 1 represents background information. Chapter 2 is focused on the assessment of the technical solar energy potential, which is executed on the basis of the considerations and information mentioned above, while Chapter 3 is devoted to estimation of wind technical energy potential.

It should be noted that the limited information about statistical distribution of wind parameters does not allow generating reliable quantitative estimations. Due to that reason, the results are tentative and can be used mainly for orientation about promising sites but not for investment purposes.

Chapter 4 offers recommendations for improvement of the outcomes through enriching primary information and collecting additional information.

Chapter 5 includes considerations about assessment difficulties/or challenges of the potential of intermittent energy sources and outlines the important role of GEOSS for alleviation of efforts and reduction of investment cost.

In Chapter 6 the main drivers boosting renewable energy are defined. These are:

- Public support, and
- Technological development.

Of course, many other factors contribute to the deployment of RE but these two are considered as the most important. They are analysed in the next two chapters.

Public support is analysed in Chapter 7. Reasons behind the negative public opinion or attitudes and measures for alleviation are analysed, and policy for improvement of public attitudes are proposed.

Development of technologies for successful integration of intermittent generation into power system is considered in Chapter 8.

Chapter 9 is devoted to the improvement of the regulatory policy. It includes various mechanisms for deployment of renewable energy use with acceptable social price:

- Organized electricity market;
- Geographic information system;
- Plan for allocation of RE facilities;
- Competition between RE projects;
- Reduction of preferential tariffs.

In Chapter 10 two storylines for demand and renewable energy by 2050 are developed using linear model. The main characteristics important for the development of renewable energy in the country, such as suitability of sites, cost, size, network restriction, present conversion technologies, country policy, etc. have been taken into account.

Chapter 11 contains specific recommendations for deployment of renewable energy separately for win and solar energy.

Appendixes 1 – 4 contain additional information used or received for/from analyses.

Appendix 5 contains a Spatial Interpolation Method - case study – developed by ITU for Turkey and Bulgaria.

TABLE OF CONTENTS

ABBREVIATIONS

AGC	Automatic Generation Control
AGL	Above Ground Level
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BAS	Bulgarian Academy of Sciences
BSREC	Black Sea Regional Energy Centre
CM-SAF	Climate Monitoring Satellite Application Facility
DEM	Digital Elevation Model
FiT	Feed-in Tariff
FP7	Seventh Framework Programme for Research
GCP	Ground control points
GEOSS	Global Earth Observation System of Systems
GRASS	Geographic Resources Analysis Support System
GTOPO30	Global 30 Arc Second Elevation Data Set
NIMH	National Institute on Meteorology and Hydrology
JRC	Joint Research Centre of the European Commission
LAU	Local Administrative Unit
NSI	National Statistical Institute
NUTS	Nomenclature of territorial units for statistics
OGC	Open Geospatial Consortium
QGIS	Quantum GIS
PSHPP	Pump Storage Hydro Power Plant
RE	Renewable energy
RMS	Root mean square error
SAGA	System for Automated Geoscientific Analyses
UCATTU	Unified classificatory of administrative-territorial and territorial units
WFS	Web Feature Service
WMS	Web Map Service
WPP	Wind Power Plant
WRF	Weather Research and Forecasting Model

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LIST OF TABLES

1 Background

The EnviroGRIDS project brings together several 21^{st} century information technologies for better understanding of the Black Sea watershed. The Group on Global Earth Observation Systems of Systems (GEOSS) is building a data-driven view of our planet that feeds into models and scenarios to explore our past, present and future. EnviroGRIDS aims at building the capacity of scientists to assemble such a system in the Black Sea Catchment, the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake. EnviroGRIDS will particularly target the needs of the Black Sea Commission (BSC) and the International Commission for the Protection of the Danube River (ICPDR) in order to help bridging the gap between science and policy

This report is elaborated as an output within the implementation of Work package 5, and particularly Task 5.4 through the creation of deliverable D5.6. The main objective of D5.6 is to assess the wind and solar energy potential in Bulgaria; develop forecasts of the wind and solar energy potential in the country by 2050; compare the existing methods for measurement of the solar and wind energy potentials with the opportunities offered by GEOSS. It is one of three national reports for the following countries, participating in the project: Ukraine, Turkey and Bulgaria.

The approach that BSREC and the project team undertake is to estimate the renewable energy potential through integration and analysis of information in the environment of a GIS. The phenomena with relation to the topic of energy potential can by doing so be estimated for a chosen level of subdivision in the country, both administrative (regions, districts and municipalities) and geographic (watersheds, etc.). Detailed information on used methods, data and the entire workflow along with analyses of the results are provided below.

The analytical approach we undertake is to simultaneously assess the following conditions, which are a prerequisite for successful renewable energy projects implementation throughout the territory of Bulgaria:

- Physical, objectively existing environmental preconditions for the development of solar and wind projects
- Limitations for the actual implementation of renewable energy production, as consequence of:
  - Land-use and land cover, not permitting the creation of renewable energy facilities;
  - Administrative limitations for the creation of renewable energy facilities (Environmentally protected areas, territories with special regime of usage, etc.).

We have used open source GIS software for implementation of the analytical procedures. The following products have been extensively used throughout the analytical process – GRASS GIS 6.4, Quantum GIS 1.7.3 Wroclaw, SAGA GIS. A list of products and plug-ins is available in Appendix 1. Proprietary software has only been used for the purposes of visualization, because of the flexibility of the desktop application of ESRI (ArcGIS Desktop, ArcView license). By using open source technology we have proven the maturity of the open source products and their ability to be used in a real world condition, thus saving considerable volumes of budgetary resources, which can, and have been in the case of BSREC allocated to other related initiatives – data creation and capacity building.

Throughout the whole work process we were led by the principle of openness and have provided all necessary information for our results to be repeated and/or improved in the future for sustainability purposes.

2 Assessment of the Solar Energy Potential in Bulgaria

2.1 Methodology

Our major assumption with regard to solar potential is that energy should be produced close to, or within residential and industrial areas, where the major consumption of energy actually takes place. Given the geographical location of Bulgaria in South-East Europe solar energy production is to be seen as a serious means for diversification of the energy mix. It is however strongly dependent on the developments of the technology and the price for purchase and maintenance of solar parks, which are at present rather expensive.

The analytical process we undertake to quantify and visualize the photoelectric potential in the country is illustrated on **Figure 8** below. It represents the whole workflow, from the collection of primary data to the final analytical results.

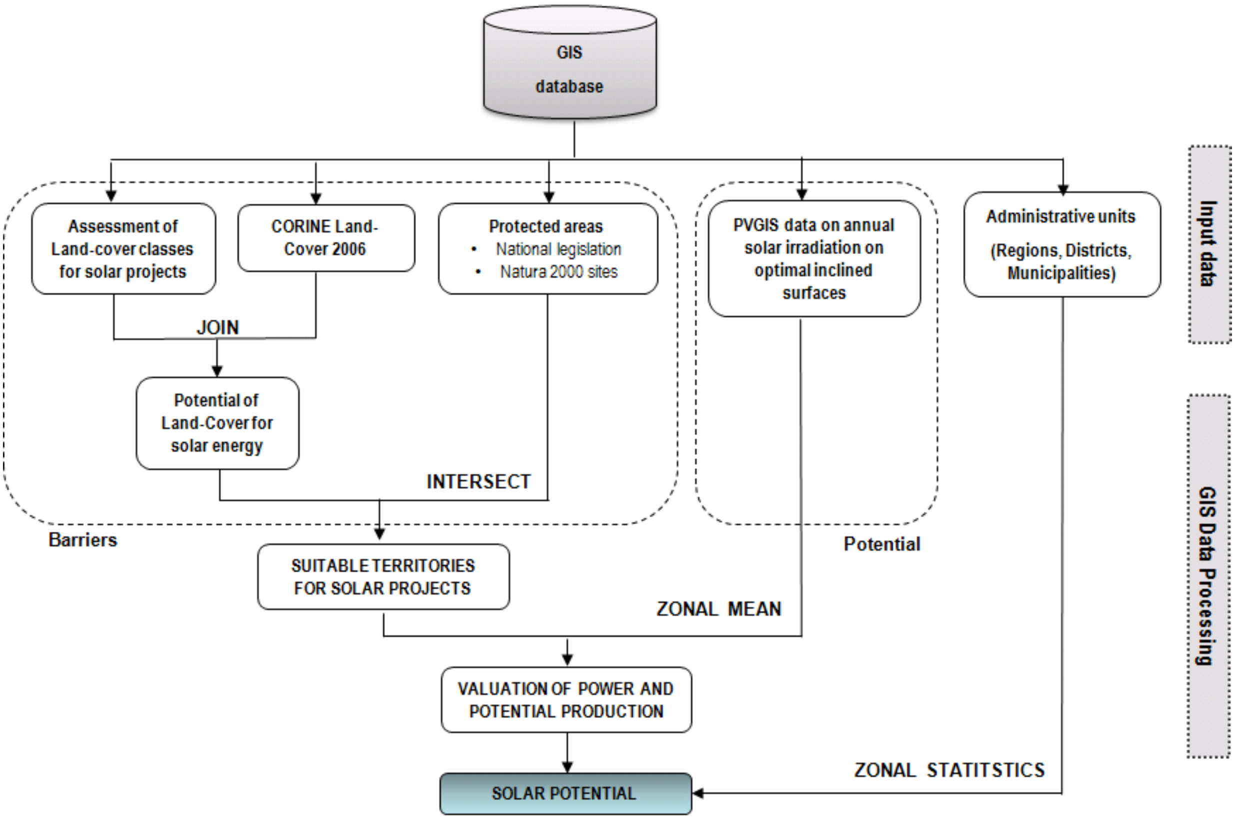

Figure 8: Solar energy potential flowchart

2.1.1 Description of available information

The following data have been included in the analysis process:

1. *PVGIS solar data from CM-SAF*

PVGIS data are in gridded format with a pixel size of 1.5 arc minutes (747 meters). They were provided by the producers from JRC[3]. The grid represents solar irradiation on optimally inclined south facing surfaces (**Figure 9**). The inclinations are calculated for the whole territory considering the further information about the mechanism of generation and verification information is provided by Šúri et. al. (2007) and Huld et. al. (2012).

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3 The authors of this report would like to express their gratitude to Mr Thomas Huld from JRC in ISPRA for the provision of the PVGIS CM_SAF data, which made it possible to better estimate the solar potential in the country.

Data in the country varies in the range 1330 – 1925 kWh/m^2 with notably higher values in the Thracian lowland of South Bulgaria, the southernmost basins of the Struma and Mesta rivers and alongside the Black Sea coast.

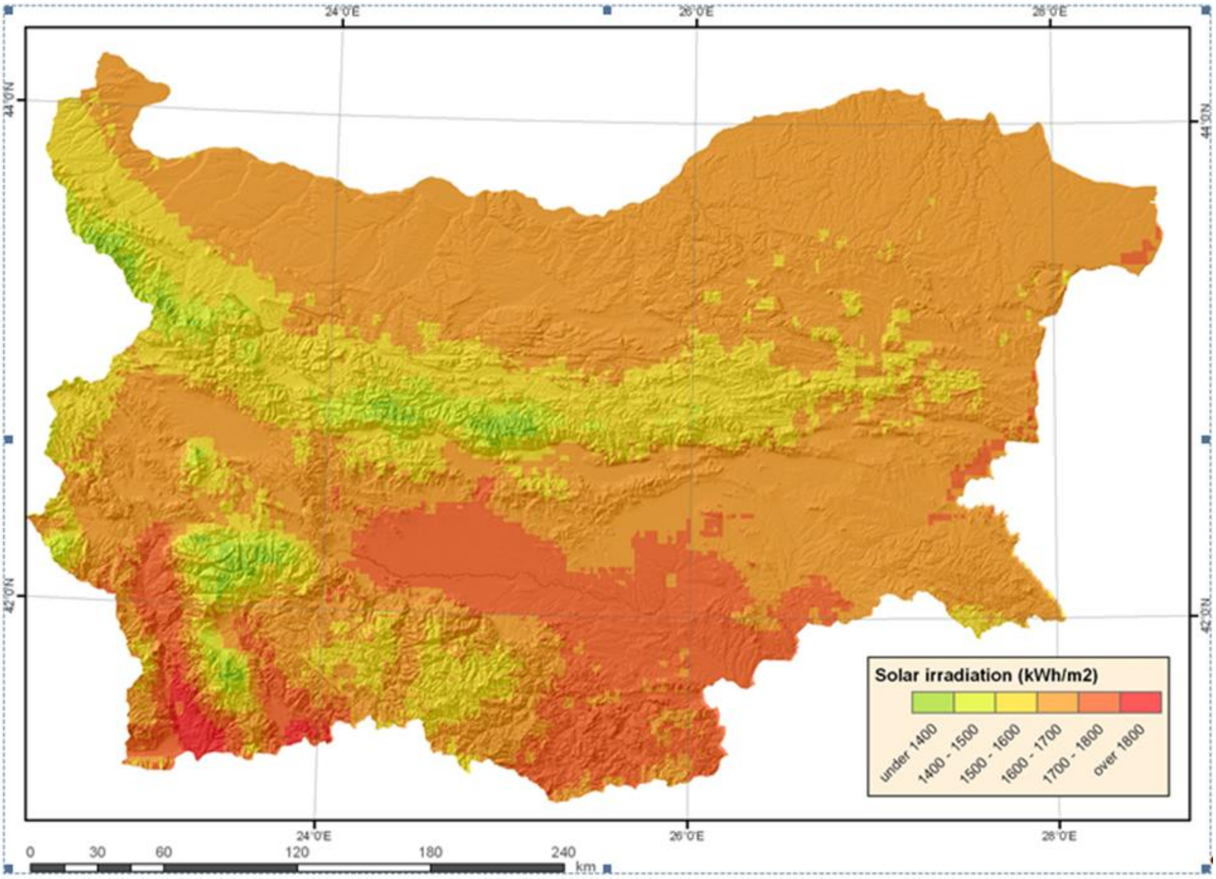

Figure 9: Solar irradiation on optimally inclined south facing surfaces (kWh/m^2)

Source PVGIS CM-SAF Database; JRC

2. *Environmentally protected territories*

Collected data consists of the following:

- Natura 2000 sites (polygons), in accordance with:
  - Birds Directive 2009/147/EC
  - Habitats Directive 92/43/EEC

  National and EU legislation does not prohibit the creation of solar parks in Natura 2000 territories, so the data are used only for reference, and to imply a special regime for the creation of renewable energy projects.

- Protected areas in accordance with national legislation[4]

  Data about protected areas is obtained from Ministry of Environment and Waters and consists of 874 polygons, representing all levels of environmental protection.

3. *CORINE Land-cover*

4 Law on Protected Areas, amended: State gazetteer 133/ 11.11.1998.

Data for the last year of availability – 2006, comprising of polygons for land-cover, subdivided on three level classifications with 44 classes on the lowest level of the classification (36 of them present in Bulgaria).[5]

4. *Administrative breakdown*

Polygonal data for all levels of the administrative breakdown of the country for the three regional levels of the country (regions, districts and municipalities) in accordance to the NUTS classification of EU are taken from a study funded by JICA.[6]

2.1.2 Data processing

The following steps were undertaken in order to evaluate the solar energy potential of Bulgaria[7]:

1. *Data conversion*

All data have been converted in to widely used GIS data formats to ensure that they can be used by both the proprietary ArcGIS Desktop and Quantum GIS and GRASS. We adopted the following formats for the need of interoperability and exchange of information:

2. *Vector format: ESRI Shapefile (*.shp)*
3. *Raster formats: GeoTiff (*.tif)*

The coordinate system we used is Universal Transverse Mercator (Zone 35 North, Ellipsoid: WGS 1984)

Spatial analyses

1. *Choice of suitable areas*

We used CORINE Land cover 2006 as a source of information for identification of areas where it is possible and is economically reasonable to create solar parks. The correspondent classes of CORINE are provided in Appendix 2 to this report. The logic of the choice of territories is based on the assumption that solar panels should be dislocated in urban and industrial territories, where conditions are favourable: generation is at the place of consumption, no need of significant transport of electricity and losses are minimal.

2. *Intersection with barriers*

Territories, chosen as suitable were consequently intersected with protected areas, to remove possible conflicts with them.

3. *Power density calculation*

The calculation of power density was done on the condition that only three CORINE areas are accessible for installing photo-electric facilities. For each area the density of panels is accepted on the basis of information about the surface of the roofs and heuristic considerations. The figures are in the following Table 1.

Intersection with municipalities

A final step we undertook was to intersect the results with municipalities, to generate output, which is relevant for the LAU1[8] administrative breakdown of the country. This would enable policy makers to be able to identify municipal territories based on the relative share of suitable territories, along with the correspondent potential power and energy production.

5 Source of the geospatial data: European Environmental Agency
6 Source of the geospatial data: "Study on Integrated Water Management in the Republic of Bulgaria, JICA
7 Please refer to the flowchart in section 1.1 to better understand the analysis process.
8 Local administrative units

Table 1: Conditions of solar energy / capacity calculations

CORINE AREA	Panels, %	Energy, MWh/y/km2	Capacity, MW/km2
Continuous urban fabric	1,00	1440	1,11
Continuous urban fabric	1,00	1395	1,11
Industrial or commercial units	5,00	7650	5,56

2.2 Results

Results for the solar potential estimation, following the methodology as it is described above show a technical potential of 9015 MW, which are distributed unevenly among the Bulgarian municipalities. The predominant share of potential is located in territories with high density and area of industrial zones, combined with densely populated residential areas. Sofia (Stolichna municipality) is naturally first in terms of potential with an estimated value of 517 MW. The municipality is followed by the LAU1 units of the industrialized district centres of Ruse (147 MW), Sliven (144 MW), Stara Zagora (142 MW), Pleven (142 MW) and Shumen (128 MW).

A considerable share of the theoretical potential (1991 MW – 22.08%) is located in only 13 municipalities with an estimated potential of over 100 MW each. The map below (**Figure**) provides an overview of the estimated potential on municipal level:

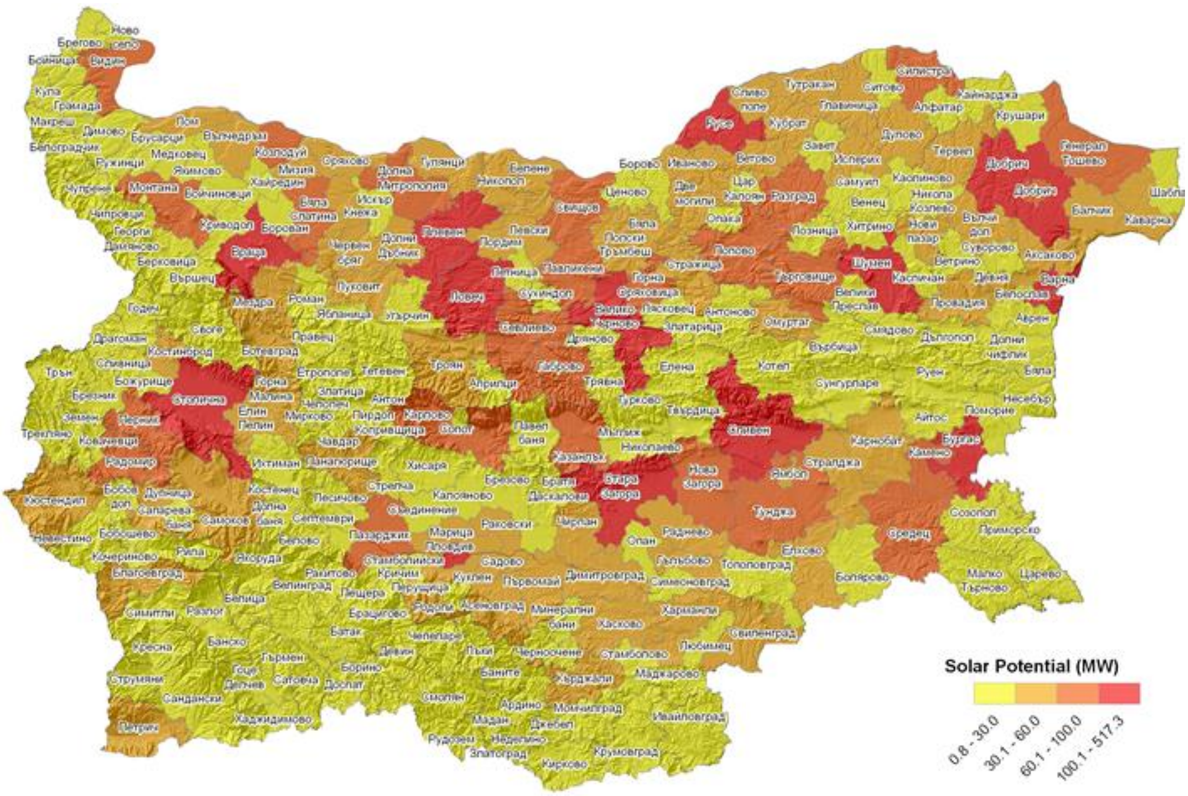

Figure 10: Solar energy potential – estimation on municipal level (LAU1) in MW

Figure 11 presented below shows the solar potential taking into account all considered limitations.

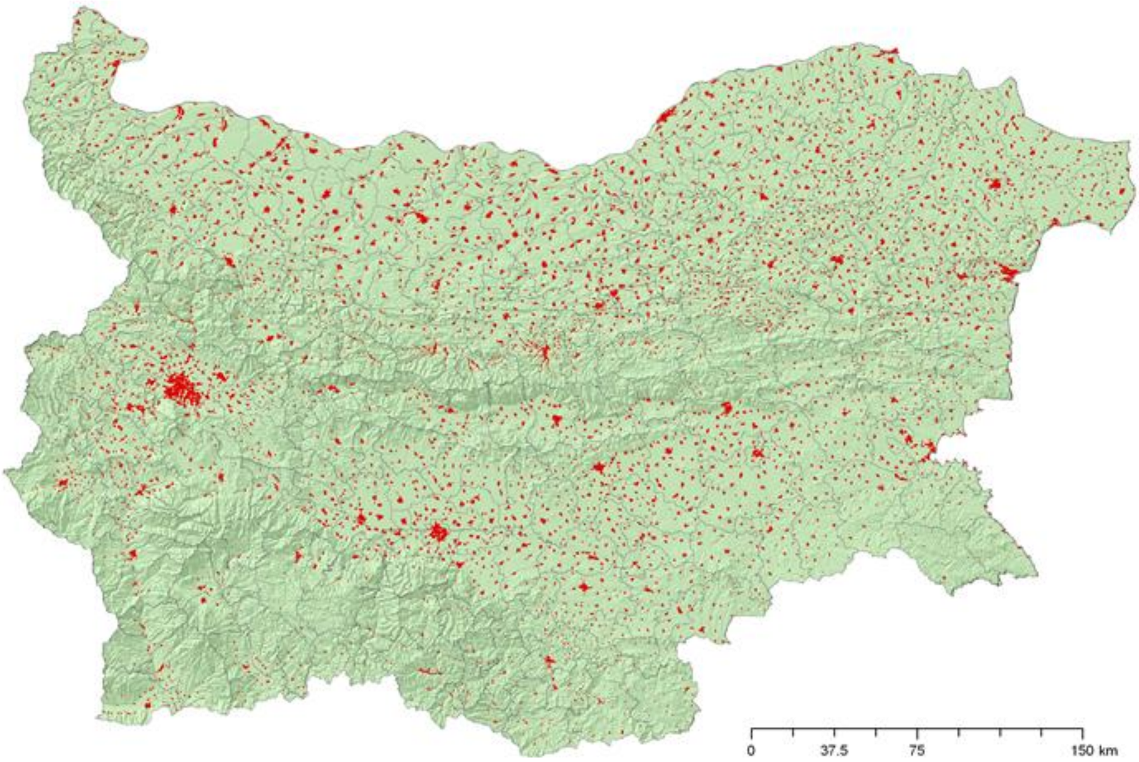

Figure 11: Solar energy potential - suitable places for utilization of solar energy taking into account all considered limitations.

3 Assessment of the wind energy potential in Bulgaria

3.1 Methodology

The approach we undertake with respect to wind potential in the country is to combine limiting factors for construction of facilities with the existing potential, posed by high annual average wind speeds.

The analytical process we undertake to quantify and visualize the wind potential in the country (Figure 12**Error! Reference source not found.**) is similar to that, which is used for solar one.

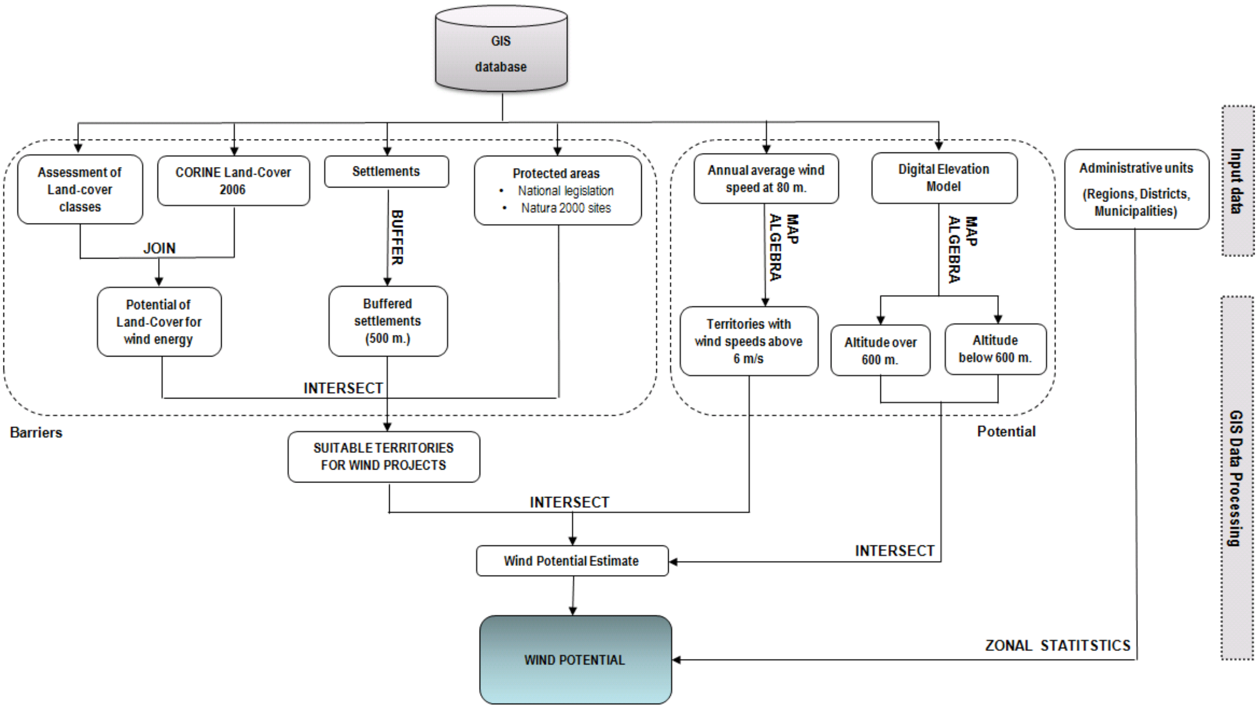

Figure 12: Wind energy potential flowchart

3.1.1 Description of available information

The following data have been included in the analysis process:

Annual average wind speed at 80 m height AGL

NIMH-BAS maintains 36 synoptic and 87 climatic station and rich data base of registered wind parameters at the height of 10 m Agl. This information is collected for meteorological purposes and unfortunately has no the necessary for the wind potential assessment accuracies. Nevertheless, it can be used, completed with additional observations, for tentative estimation of wind potential by regions[9].

In the study (Djambazova, V, 2011)" data series of NIMH are used for evaluation of potential of wind electricity production in Bulgaria.

During the latest several years numerous specific investigations are undertaken by companies interested in construction of wind parks and individual turbines. There is also limited number of measuring masts aiming at wind parameters registration for commercial purposes {for instance the measuring masts of Technical University of Varna). All these information is confidential but together with deployment of wind generation more and more information will be available on the basis of the generated electricity.

[9] The authors express their gratitude to NIMH for providing 10-year series of data for wind parameters registered by Bulgarian meteorological stations.

Another source of information is the data base of 3TIER, developed by modelling of wind parameters on the basis ground control points.

In this section the assessment of wind potential is performed using information received from 3TIER Inc. USA. It consists of a grid with a horizontal resolution of 5 km. Data for the territory of interest shows variation of the parameters of wind speed in the interval 2.87 up to 7.61 m/sec annual average (**Figure 13**).

3TIER have used a complex interpolation technique to produce the annual average winds speed at an altitude 80 meters above the surface. An enquiry for the concrete parameters of the data product has been done and replied on behalf of BSREC to ensure the applicability of the source for the needs of potential wind speed estimation. The results show that the 3TIER data is the best available source to show the potential. The reasons for that are as follows:

- The modelling parameters of the interpolation technique also consider the elevation of the territory, for the GTOPO30 elevation dataset has been used for parameterization of the interpolation output.
- Interpolation technique used is WRF, which is widely used models for atmospheric behaviour prediction, used extensively by laboratories worldwide to better understand atmospheric processes for different time horizons and scales.
- The horizontal scale of the model is 5 km which is satisfactory for the needs of the analysis and estimation of wind potential.
- Data from the same source are extensively used by entrepreneurs in wind energy installations in the country after calibration of the data (vegetation and constructions, topography ruggedness, etc.) to include the local conditions where the installations are to be constructed.

There are some shortcomings with the 3TIER data source. They are summarized below:

- Interpolation technique parameters are not entirely transparent, i.e. users cannot themselves repeat all undertaken steps, which are understandable, for the wind data that are a commercial product.
- The number of GCP for the territory of Bulgaria is very limited.
- Inability to get country-specific information from the producer. Data are produced for large territories and then clipped upon request, which does not allow specific parameters with regard to quality (RMS) to be provided, for only a piece of the information. The producer comments quality issues, but only for the whole dataset.

It is expected that these shortcomings will be overcame gradually along with the process of accumulation of information through ad-hoc studies in the future.

Meteorological data

Point data for monthly average wind speed for July 1983 - June 1993 were integrated in GIS for 89 meteorological stations. Wind speed values are for 50 meters above the surface of the earth.[10] Thorough characteristic of the data source is provided by New et al (2002).

Environmentally protected territories

Collected data consists of the following:

- Natura 2000 sites (polygons), in accordance to:
  - Birds Directive 2009/147/EC
  - Habitats Directive 92/43/EEC

  National and EU legislation does not prohibit the creation of wind parks in Natura 2000 territories, so the data are used only for reference, and to imply a special regime for the creation of renewable energy projects.
- Protected areas in accordance with national legislation[11]

10 Source: NASA Langley Research Centre; Atmospheric Science Data Centre.
11 Law on Protected Areas, amended: State gazetteer 133/ 11.11.1998.

Data about protected areas is obtained from Ministry of Environment and waters and consists of 874 polygons, representing all levels of environmental protection.

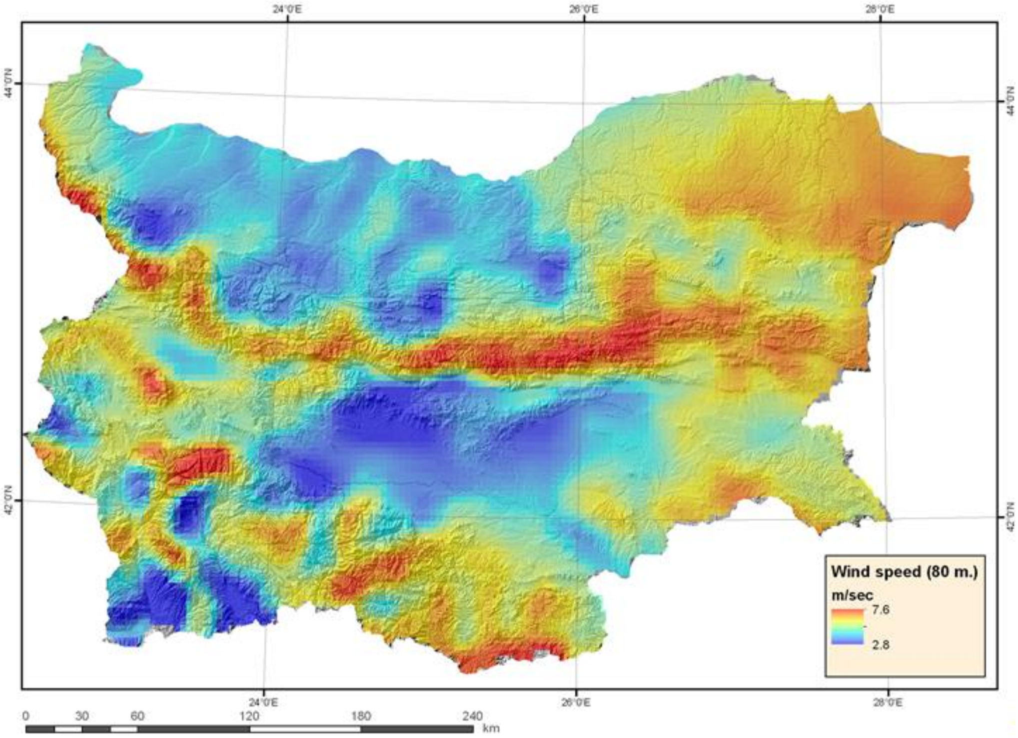

Figure 13: Winds speed potential estimate at 80 m height

Source – 3TIER[12]; Data processing: GRASS GIS. Data visualization: ArcGIS Desktop (ArcView)

CORINE Land-cover

Data for the last year of availability – 2006, comprising of polygons for land-cover, subdivided on three level classifications with 44 classes on the lowest level of the classification (39 of them present in Bulgaria).[13]

Administrative breakdown

Polygonal data for all levels of the administrative breakdown of the country for the three regional levels of the country (regions, districts and municipalities) in accordance to the NUTS classification of EU are obtained from JICA funded study.[14]

Settlements

Data for settlements are obtained from settlement polygons for each of the 5340 settlements in the country, codified in accordance with the unified classificatory of territorial units in the country (EKATTE), maintained by NSI.[14]

Digital elevation model

Data on elevation was obtained and processed from the ASTER Global digital elevation model. The output raster file after conversion is with horizontal resolution of 28.5 m.[15]

3.1.2 Data processing

The following steps were undertaken in order to evaluate the wind energy potential of Bulgaria[16]:

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12 For further information: www.3tier.com
13 Source of the geospatial data: European Environmental Agency
14 Source of the geospatial data: "Study on Integrated Water Management in the Republic of Bulgaria, JICA
15 For further information on ASTER GDEM: http://asterweb.jpl.nasa.gov/data_products.asp

Conversion of formats

All data have been converted in to widely used GIS data formats to ensure that they can be used by both the proprietary ArcGIS Desktop and Quantum GIS and GRASS. We adopted the following formats for the need of interoperability and exchange of information:

- Vector format: ESRI Shapefile (*.shp)
- Raster formats: GeoTiff (*.tif)

The coordinate system we used is Universal Transverse Mercator (Zone 35 North, Ellipsoid: WGS 1984)

Spatial analyses

The following steps were undertaken after the successful integration of all necessary spatial data into the project database:

1. *Wind speed threshold*

Choice of wind speed threshold beyond which the utilization of wind potential is economically ineffective given the present technological capacity of state-of-the-art wind rotors. A value of annual average speed of 6 m/s on 80 m above the topography was chosen as the minimum for economically sound construction of wind energy facilities. Raster calculation in GRASS GIS excluded the territories of the country which are under the threshold (**Figure 14**).

2. *Choice of suitable area*

The CORINE 2006 dataset was used to identify suitable land-cover types where it is normatively allowed and makes sense in terms of economic efficiency and minimum environmental impact. All land covers of the original polygonal dataset are assessed and those, which are considered as non-suitable are excluded from all further analyses. The information on the suitability of land-cover classes is provided in Appendix 2.

3. *Intersection with barriers*

Data for suitable territories with favourable annual average wind speeds were afterwards intersected with data about such parts of the country where it is explicitly forbidden to build turbines. Those include:

- Protected areas polygons
- Settlement polygons with a buffer of 500 m, following the guidelines of Art. 141 (1) of technical norms for geographic locations of turbines.[17]

Intersection with elevation

We used a digital elevation model (ASTER DEM) for identifying the altitude of each polygon, which is considered as suitable for wind power generation in accordance with our methodology.

Power density calculation

For comparability reasons we use the same values for power density calculation as the EEA Report on “Europe's onshore and offshore wind energy potential”.

Calculation of potential density of wind farms is based on the area and the altitude. The number of wind farms, located in mountainous territories in Europe is very limited, which is due to the worse accessibility and the lack of grid connections. Less than two percent of turbine capacity in Austria, France, Italy and other countries is in

16 Please refer to the flowchart in section 2.1 to better understand the analysis process.

17 Regulation No. 15 of Ministry of Regional Development and Public Works. Technical guides and norms for design, construction and use of technology for generation, transformation and distribution of electrical energy. (State gazetteer 53/2005, changed State Gazetteer 73/2006)

mountainous territories. We therefore adapt the same principle and use the following valuation coefficients (Table 1)[18]:

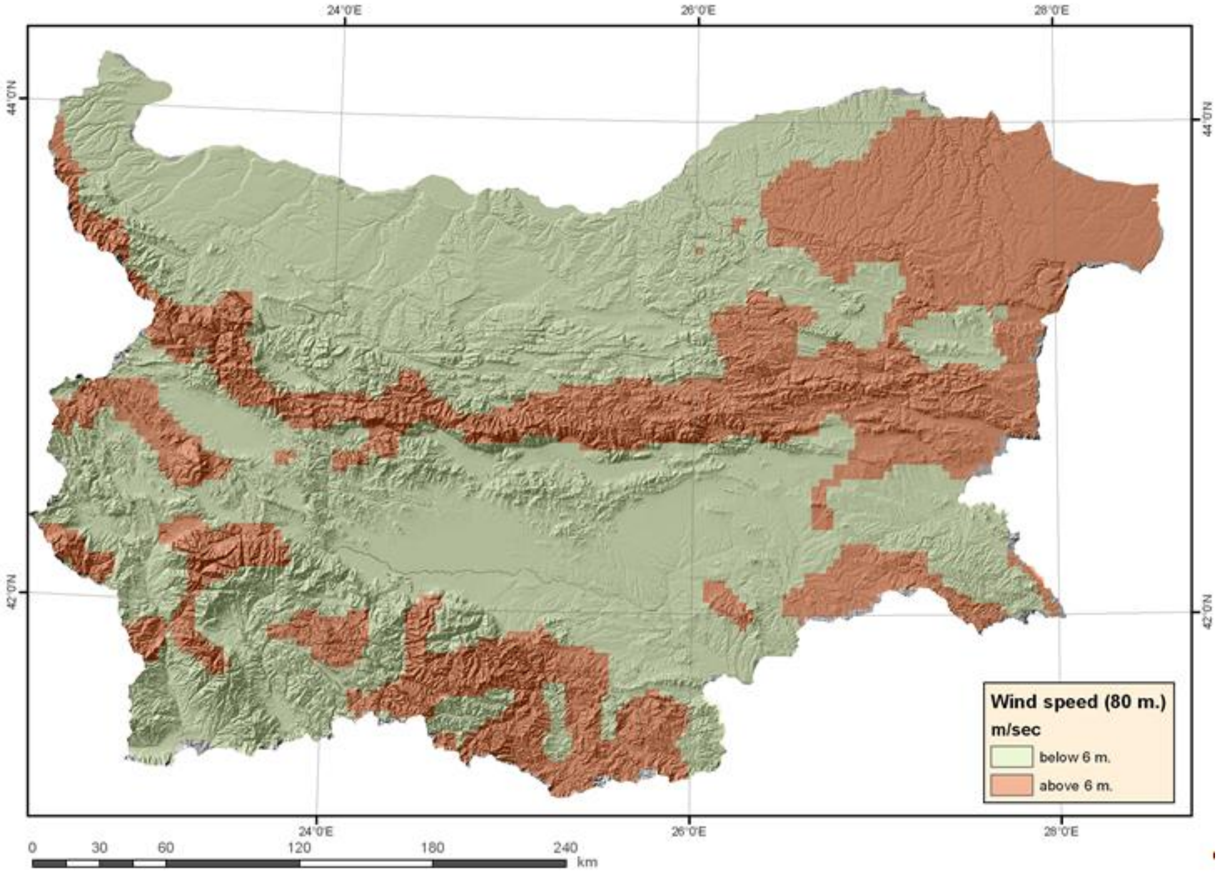

Figure 14: Annual average wind speed above 6 m/sec. Data processing: GRASS GIS. Data visualization: ArcGIS Desktop (ArcView)

Table 2: Accepted distribution of wind turbines depending of altitude

Altitude (meters)	**Potential power density (MW/Sq.km.)**
under 600	8 MW/km^2
600 – 2 000	4 MW/km^2
over 2 000	N/A

Intersection with municipalities

A final step we undertook was to intersect the results with municipalities, to generate output, which is relevant for the LAU1[19] administrative breakdown of the country. This would enable policy makers to be able to identify municipal territories based on the relative share of suitable territories, along with the correspondent potential power and energy production.

18 In accordance with: Europe's onshore and offshore wind energy potential, EEA Report, pp. 20, source: http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential/at_download/file
19 Local administrative units

3.2 Results

The total technical potential of the country is estimated to 103 025 MW. The results of the analyses show a significant variation of values for wind potential throughout the territory of the country. The most significant potential for creation of wind turbines are thanks to the favourable intersection of annual average wind speeds and lack of limiting land use types in East Bulgaria. 60.6 % of the theoretical potential (62 460.8 MW) is located in 53 municipalities in North-East Bulgaria.

The map below (**Figure 15**) provides information for the wind potential on municipal level.

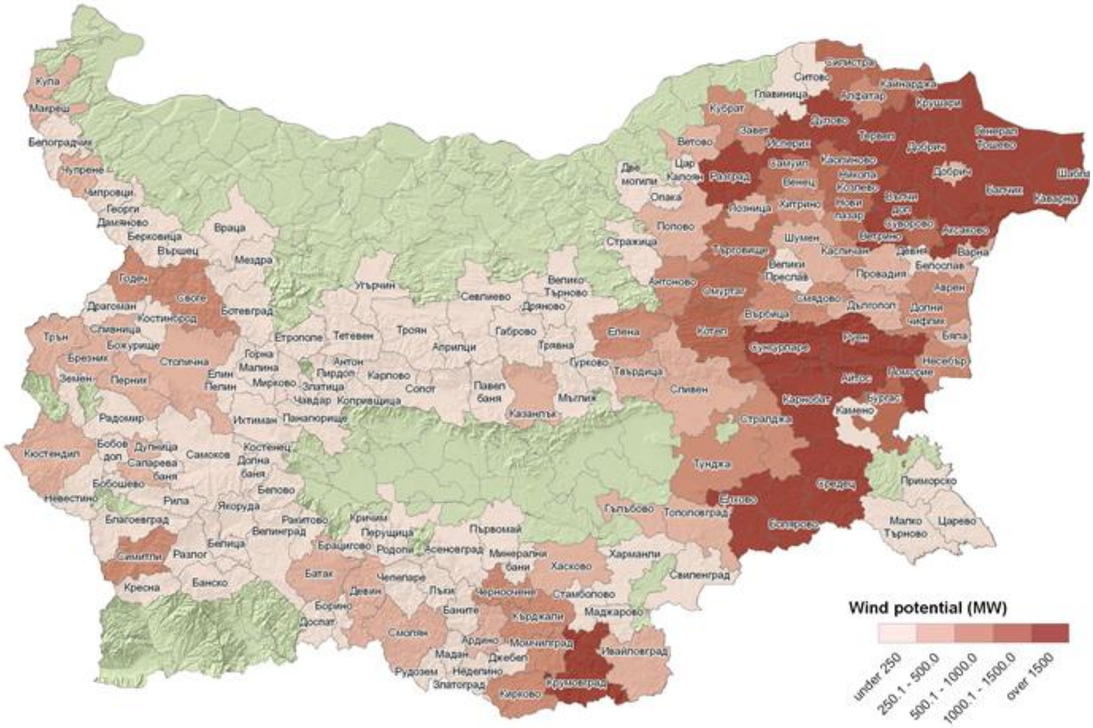

Figure 15: Theoretical wind potential on municipal level (LAU1); Data processing: GRASS GIS. Data visualization: ArcGIS Desktop (ArcView)

The following

Figure gives the suitable places for wind energy utilization, taking into account all considered limitations.

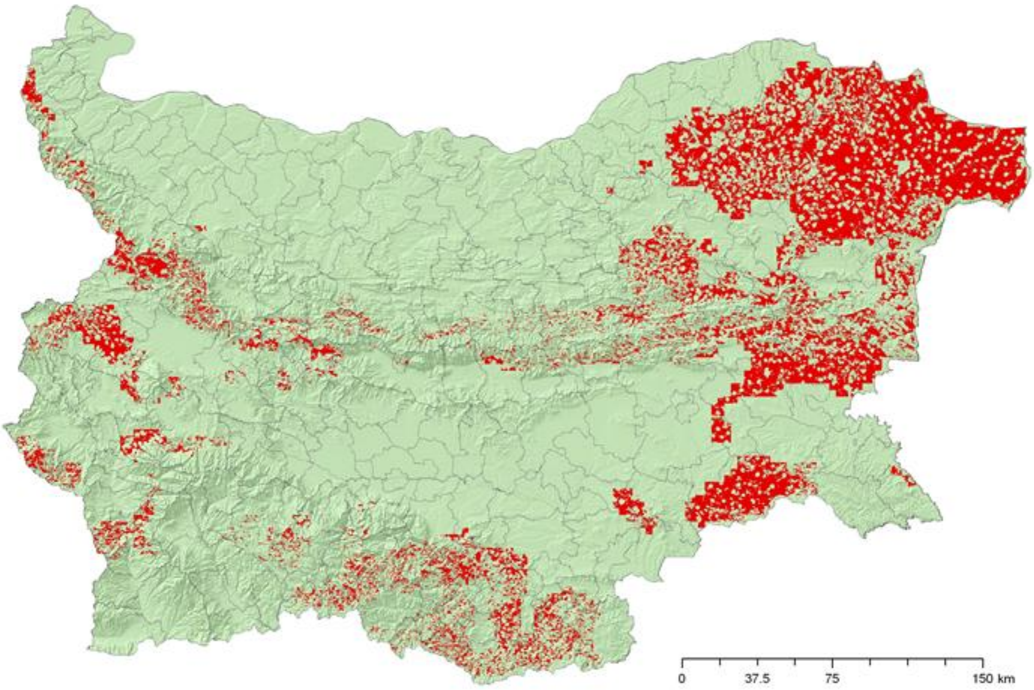

Figure 16: Wind energy potential - suitable places for utilization of wind energy taking into account all considered limitations.

4 Recommendations for Potential Assessment Improvement

The provided analyses are satisfactory, for they are fully coherent with the requirements of the EnviroGRIDS WP5, and are a first attempt to use geospatial data to quantify the potential of Bulgaria. This study is the first to use real geospatial distribution of information with regard to solar and wind energy in the country and to provide all the information to decision makers through the GEOSS mechanisms. The results of what BSREC has achieved can be improved through the following:

4.1 Fuzzy sets

The results so far are dualistic in a sense that the estimation of the potential is binary, i.e. it is either present (1) or non-present (0). In reality the phenomenon, particularly on the potential side for wind and solar irradiation are fuzzy and change continuously over space and time. The use of this dualistic Boolean algebra oversimplifies the results and is due to existing functionality of software products being used.

4.2 Reference scale

The reference scale of the output products, as consequence of the input data used can hardly exceed 1:100000. To support the planning process however data should be of significantly larger scale (1:10 000 and larger). Then the information used will make much more sense of regional planning purposes and supporting the decisions of investors.

4.3 Additional data

The inclusion of some additional layers of spatial information will considerably improve the results. The inclusion of the following layers can be incorporated in the analytical process:

1. *Geographic distribution of consumption*

The estimation of potential should in any case integrate not only preconditions for the construction supply, but also the distribution of demand, which is at present very difficult to estimate, for the combination of population, industry and transportation are very difficult to locate in space. Considerable effort is required to be able to analyse potential in a manner which combines both supply and demand.

2. *Cadastral information*

The results lack reference to information on properties, which is essential for investors. Furthermore, large scale (1:5000 and above) information in rural areas is a precondition for identification of suitable territories for solar energy production, since it is forbidden to develop solar plants in fertile agricultural lands[20].

3. *Geospatial information on energy facilities*

To enrich the database it will be useful to add information about spatial location and distribution of electrical lines and other components of the power distribution network, the proximity of which is essential to decision making of investors, resp. of technical potential.

20 Category 4 and below in accordance with Art. 23 (1) of the Law on the protection of agricultural lands. Last change: State Gazetteer 39/20 May 2011; Source: http://lex.bg/laws/ldoc/2133870081

5 GEOSS – Global Earth Observation System of Systems and renewable energy

5.1 Wind and Solar Potential Estimation

A precondition necessary for the technologies development is the information availability; and the common efforts of researchers, designers, executives, governments, investors, grids operators and the vast society.

The dashing development of wind energy in the last years faces difficulties in three aspects:

- Lack of information on the primary sources;
- Imperfection of the technologies for transforming primary energy to electricity;
- Management of the electricity obtained from these renewable resources.

5.1.1 Random Character of Solar Radiation and Wind

Solar radiation and wind are variable in time and space, dependant on multiple factors and due to these reasons they are difficult to predict. This applies especially to wind. In order to obtain relatively reliable information about the wind parameters, long years of observation are needed at specific spots, where good perspectives for use appear. In the last years the meteorological stations measurements enriched with data from meteorological, military, geographical and other satellites, observation airplanes and probes provide an important amount of data, but its reliability decreases substantially because of the wind random character and its strong dependence of the terrain.

Solar radiation is much easier to predict, but random factors and mostly clouds make the forecasts uncertain as well.

5.1.2 Efficiency of Generators

The industrial development of converting technologies - wind turbines and especially of photoelectric panels - began essentially in the last two-three decades. The abundance of natural resources in the past – fossil fuels like coal, oil, gas, uranium – were giving no ground to humanity to worry about the future over 100 years horizon, especially having in view the perspective of the nuclear synthesis unlimited resource.

For wind energy capture relatively simple machines are used and the technology improvement is not quite difficult. Trends are to implement units of larger scale, better technical solutions of different components and control. Up-to-date turbines with several megawatts capacity are not to far from concurrent participation at the electricity market without additional stimulation. Of course, this could only happen if the electrical system has control means and reserve capacity for integration of intermittent generators.

Solar irradiation conversion to electricity is a new technology, which first technical applications were performed in the last century fifties. Despite the big successes in its improvement and the decrease of costs, an important technological breakthrough is indispensable in order to bring them closer to commercialisation. Hopefully it will be realised in the next decade however further research, applied science activities and implementation is needed.

Even today, after decades of research studies, demonstration projects and support by the promotional energy policy, the solar panel captures less than 10 % of the energy of the falling over its surface electro-magnetic wave.

Low efficiency and high investments impose the use of non-commercial means through political intervention, with the goal to deploy solar technology in the electrical power generation as a precondition for their further improvement. Such process requires of course enormous public costs, which is the price of the natural environment preservation.

5.1.3 Electricity System Control

The operating electricity systems are built in conformity with the existing technologies – mainly fossil fuels, hydro resources and nuclear fission - in the same time endeavouring for rational use of energy resource. The size of units is an important characteristic of contemporary power plants, as normally larger units are more efficient.

Solar irradiation and wind are unsteadily distributed in space. Especially the solar panels are limited in capacity, being convenient for generation at the consumption location. It is important that generated power can not be subject of regulation without primary resource losses.

Therefore, in order to master these technologies, refurbishment of the electrical systems with new control technologies would be necessary: electricity accumulation and storage, systems for control, interconnection, information and communication, automation. .

The wind and solar irradiation potential for electricity generation shall be estimated both for planning the energy policy and for evaluating investments projects in electrical power generation, transmission and distribution.

5.1.4 Information Basis

Pressure on the environment resulting from human activities imposes as soon as possible the replacement of technologies based on fossil fuels by clean, low emissions technologies. This act requires, in addition to the important costs imposed to the society, coordinated efforts by all the energy and researchers community.

Such efforts shall be based on as complete information as possible, not only for the climate and geography data, but also for the technologies achievements, possibilities and perspectives. The necessity in data base is obvious - to collect information from the possible sources, to offer access and processing, analysis and synthesis options, in order to overcome the boundedness of individual, institutional and national observations.

The establishment of a data base will facilitate investigations, planning and investments to reach the sustainable development goals.

The GEOSS is intended to play such role. Energy conversion and consumption - the overwhelming polluters of environment – are considerable components of GEOSS.

One of the main areas of GEOSS with regard to energy is *Improving management of energy resources.* GEOSS 10 Years Implementation Plan defines the goals of the system in the energy field as follows:

“GEOSS outcomes in the energy area will support:

1. environmentally responsible and equitable energy management;
2. better matching of energy supply and demand;
3. reduction of energy infrastructure risks;
4. more accurate inventories of greenhouse gases and pollutants; and
5. a better understanding of renewable energy potential.”

GEOSS represents exactly what researchers, explorers, designers, investors, managers, planners, all energy sector participants are missing now, in order to coordinate their communities actions in all countries. A portal to collect information, to organize it in data bases accessible to all the participants, a portal directing to information sources, estimation methods and models, analytic software etc.

5.2 The role of GEOSS

The system idea is to concentrate the information and to make it available to the experts, institutions and technical systems operators, according to some Data Sharing Principles (The Global Earth Observation System of Systems):

1. There will be full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation;
2. All shared data, metadata, and products will be made available with minimum time delay and at minimum cost;
3. All shared data, metadata, and products being free of charge or no more than cost of reproduction will be encouraged for research and education.

The system will provide statistic information on the random RES parameters, on the characteristics of the up-to-date technologies for wind energy transformation, on control systems etc. That is how enormous costs in time and funds will be spared and forecasted statistical evaluations with admissible confidence intervals will be possible to elaborate. The more accurate evaluation of the generators capacity credit will permit to save investments in reserve capacities, accumulating installations and control tools. Planning will be based on more reliable information and will therefore increase the stable operation of the electrical systems.

Quite naturally, not only power systems will use GEOSS, but also all energy systems – heating, cooling, and transportation – they are all expected to use more and more renewable energy.

6 Renewable Energy Policy Main Drivers

The European Union's ambition to achieve energy stability is realized through two main strategic lines:

- constant improvement of the efficiency of consumption, transfer, conversion and generation of energy and energy resources, and
- utilization of renewable energy resources.

While renewable heat has been in use since the Day of Creation, the electricity generation technologies (after being initially dominated by water resources) have developed towards utilization of fossil fuels, characterized by centralization through larger capacity of generating units.

Environmental protection concerns have imposed the energy generation redirection towards low and no emissions technologies, in particular renewable resources technologies. RES utilization requires technological solutions, reflecting the typical performance of renewable energy, i.e.:

- Variability, and
- Allocation, which determines the small capacities of individual generators/ converters.

Although there are considerable concentrations of wind energy resources in the North Europe, their common character remains almost the same.

Numerous plants operated under medium and low voltage appear, and in order to deliver their resources to the consumers, it is necessary to introduce new technological solutions in the power system. The connection to the grid of many small intermittent generators, imposes different management tasks.

The difficulties, connected with the RE utilization could be divided into two main groups:

- Technological difficulties, related with the operation of the power system;
- Insufficient development of technologies for conversion of renewable resources into electrical power, which determines their high cost.

This is the reason why RE technologies cannot be developed under market conditions. They require availability of support system, providing general and special measures, which lead to an increase of the total expenses for power supply.

Hence, there could be identified the two most powerful factors for the deployment of RE utilization, i.e.:

- Technological progress, and
- Public support.

Public support means that the society has the maturity to accept higher prices of electrical energy, as well as the inconveniences connected with the construction of the installations and the respective infrastructure, in order to protect the environment and mitigate climate change.

Figure 17 below presents the main characteristics of the 4 renewable related policies determined by these factors.

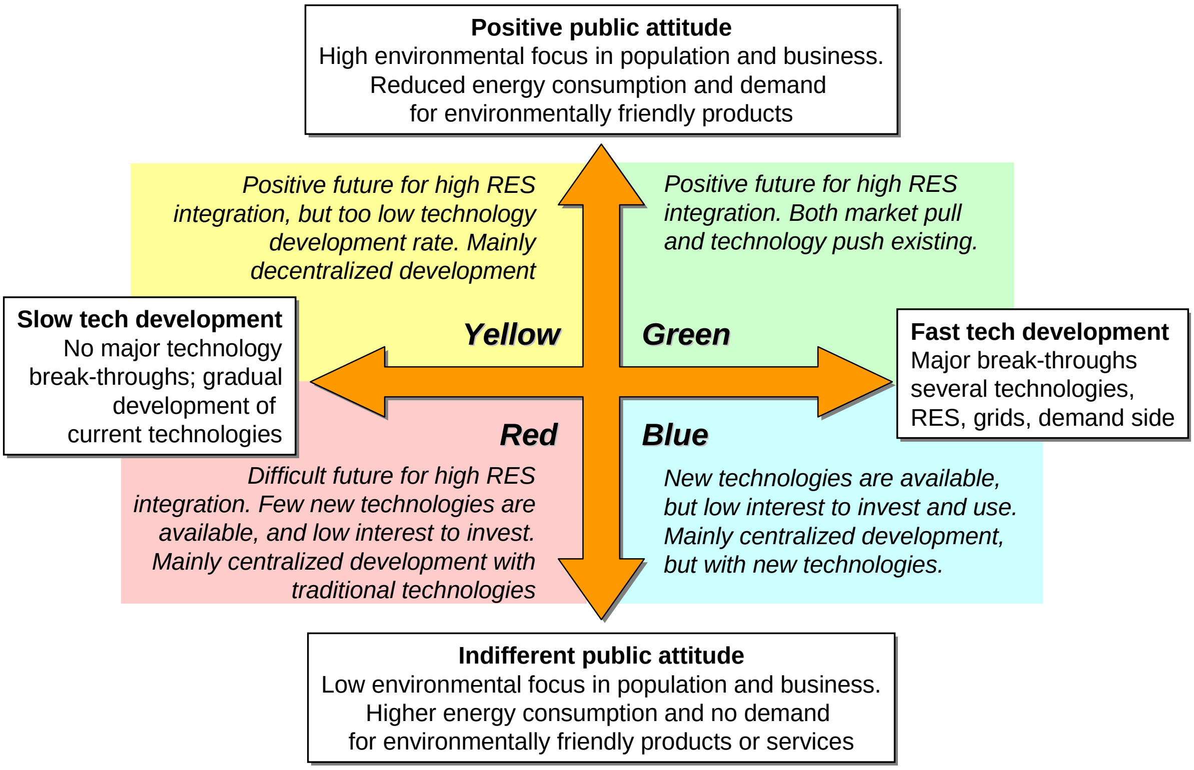

Figure 17: RES development storylines, Source: SUSPLAN project (http://www.susplan.eu/)

The RE utilization strategy is based on the dependency between costs and the level of their growth. At the beginning, as it is usual for all new technologies, the costs are high, but they decrease subsequently with the expansion of their application, due to the improved efficiency and the reduction of costs for generation and mounting of installations.

The mechanisms are obviously globally interdependent, because the costs depend on the implementation of certain technology. Such technology is dependent on the social support.

Bulgaria is a country, which does not produce those technologies and cannot influence the technical progress, but it can use the advanced technologies and contribute to their improvement. This is a binary result and cannot be the leading one. On the contrary, the countries, producing technological equipment and facilities, have direct benefit from their expansion in the world.

The attitude of the society is a powerful factor, which, to a great extent, depends on the purchasing capacity of the consumers, i.e. their economic situation. The performance of renewable energy – territorial allocation close to the consumers, requires significant modifications of the power system and introduction of technologies for storage, transformation, operation, automation, etc. for the consumers. This means that a customer is obliged to make an investment in substitution of the previously existing devices with new ones, which he might face suspiciously. This, in addition to the intentional hostility of media towards the electrical network operators, may lead to the necessity to steer a steady policy despite consumers' will. Such policy shall not be successful and may last for a short time.

Very often the social attitude is prevailing over all other factors and can be decisive for renewable energy deployment.

Therefore, the first step to the successful RE deployment should be the identification and mitigation/elimination of the reasons for consumer opposition to renewable energy.

7 Public Support

7.1 Reasons behind the negative public position and measures for alleviation

7.1.1 Distrust of authorities and investors

The consumers are suspicious by nature and by obligation. This is typical for all societies however for Bulgarians this feeling is particularly strong after having been tormented for centuries. It is normal to expect more distrust of higher level authorities, but in Bulgaria this attitude is directed also towards control bodies.

The distrust towards the responsible people and institutions results in suspiciousness against the policy of sustainable power supply and arguments for its implementation.

The position of the society towards electricity supply companies and towards electricity distribution grids in Bulgaria in general, has its psychological reason. The electricity has been subsidized by the Government for decades and family electricity bills were insignificant. As a result, a great number of Bulgarian consumers have chosen the electricity as a heating source. In the multifamily buildings of big urban districts still the only alternative for heating is electricity. It could be summarized that the understanding of the Bulgarian consumer is that energy is a public welfare.

The transition towards cost oriented prices in the economy does not face such fierce opposition, as in the energy field. This resistance has been supported by speculative calculations, regularly using the support of purchasing power parity to prove that the electricity price in Bulgaria is the highest in the EC.

The truth is that the price of electricity in Bulgaria is the lowest in the European Community. The consumer is indignant and wants the electric power price to be calculated on the basis of living standard level, but no on costs.

Moreover, the importance of these factors is strengthened by the sometimes authoritative behaviour of the employees of the electricity distribution, grid companies and their disregard to other justified consumer demands.

7.1.2 Legal procedures violation

The democratic management system did not still become part of the all Bulgarian society's and institutions' behaviour, and there is still in force the well-known hierarchical top-down system. Passive attitude is demonstrated by the low level institutions and employees, waiting for decisions to be taken at the upper level. Often this attitude is demonstrated by the superiors, who think about themselves as competent in each aspect, even because their competence is determined by the position occupied.

By the level of their position and by the private interest, these persons take decisions without coordination with the experts. Some of the investors use connections with decision makers to help them to boost unprofitable projects, compromising in this way the policy and the mechanism of taking decisions.

This mechanism is often used not only by Bulgarian investors, but by foreign investors as well, who are expected to adhere to laws, as it is in their countries.

As an example, the frequent violations, related with the construction of wind turbines and parks lead to a greater pressure on increasing the installed capacities, which cannot be integrated in the system.

Non-observation of the environmental protection requirements gives rise to campaigns of ecological organizations against investors and insufficient control carried out. Having become public, these contradictions incite negative position of the whole society towards Renewable Energy.

7.1.3 Price increasing

While the share of expensive renewable energy (RE) in the balance of electrical energy generation is insignificant, their cost is not a subject of rebellion, but it can be expected in the near future, especially if solar investments increase.

The energy prices are going up not only due to promotional prices of RE but also due to the need of upgrading the grids, developing and installing new technologies for control accumulation, interconnection, protection, etc.

Consumers are not aware of all details; their invoice displays the RE cost, but not the increased price by RE. That is why the consumer directs its dissatisfaction toward the grid.

7.2 Policy for improvement of public attitude

7.2.1 Local conditions

The consumers would accept the bill increasing in case they realize the direct advantage of the promotional policy in full transparency of costs. The consumer has to be convinced that the institutions have prepared rules, which, if are respected, will direct the investors to justified investments from the point of view of costs, in conformity with the national conditions.

This does not mean to search for an optimal solution - it could not be correct, because it does not take into account the perspective and environmental impact. The historical background and future estimates indicate that the way towards sustainable energy future can be realistic only under the condition “all options open”. Each technology in its initial development phase has to be encouraged till reaching a commercial realization. Feed-in tariffs exclude the competition between such energy technologies in order to ensure their parallel progress. In Bulgaria, however, this system should be implemented considering the local conditions, i.e. technological capacity, economic development, living standard, etc.

As a typical example could be mentioned the photoelectric converters (the so called photovoltaic). This technology is yet to begin developing. It converts less than 9% of the solar radiation falling onto the PV panel, requires considerable investments, and the intermittent generation involves new investments in the grid.

In some European countries, the worried governments introduced rules, which provide development of solar technology, coordinated with panels’ improvement and customers’ possibilities. Such examples are:

- Annulations of preferences in Spain;
- Tariffs reduction and restriction of allowed capacity in the United Kingdom, Czech Republic, Italy, France, Switzerland, etc.;
- Drastic reduction of FiT and even cancellation of these for facilities higher 10 MWp;
- Termination of the USA’s Treasury Grant Program, which provides funding to support solar installations investments;
- At the beginning of 2012 the tariffs in Greece were reduced by 12,5% to the same in 2009 and will be reduced each 6 months by 7% till August 2014.

Besides the imperfection of this technology, it is too expensive as costs per kilowatt hour. Its improvement does not depend on Bulgarian decision, but on the big producers in Europe and China.

That is why Bulgaria should follow a moderate policy, which should restrict the installation of new capacities by years. This has been introduced in other European countries with significant customer solvency and participation in solar panels production, which brings benefits to the countries themselves.

In addition, the Regulator has to monitor the technology development and to correct preferential conditions according to the market advancement. The costs for investments in solar energy and for panels’ production are reducing continuously. There is no sense to allow the penetration of old technology, which cannot be marketed in the European countries, because of market shrinkage, and subsequently the high costs to be imposed on the Bulgarian customer, which is the poorest in the EC.

7.2.2 Direct production of heat

The direct production of heat by solar collectors, instead of photoelectric converters, is one of the most effective methods of solar energy utilization. Unfortunately, this method has been neglected by the energy politics in Bulgaria. Its application would substitute the huge quantity of electrical power for water heating in electrical boilers. It, however, requires an initial investment, which, although not a big one, is constrained due to the low solvency of the average Bulgarian consumer. In the neighbouring to Bulgaria countries this obstacle is overcome by simple mechanisms, which are not applied in Bulgaria due to formal reasons, i.e. the argument who should provide the investment support.

7.2.3 Effective use of biomass

The situation, connected with the utilization of biomass – the biggest component (about 0,7 Mtoe) in the consumption structure of RE in Bulgaria, is similar. Almost the whole amount of energy contained in biomass, as well as in firewood, is used in low effective domestic stoves, fireplaces, etc. There are effective appliances with water jacket present at the market, having significantly reduced heat losses through exhausted gasses, but, like solar collectors, their mass deployment is restricted by the required initial investment. This hindrance could be overcome without much difficulty through various already proved mechanisms. The simultaneous development of industry and the use of the different types of biomass products, like briquettes, pellets and wood chips could become a multipurpose program for energy efficiency and also for reducing energy expenses of consumers, waste utilization and environmental protection with less vegetation destruction.

7.2.4 Efficient energy use

The efficient use of energy is the most powerful mechanism for mitigating the impact of the increasing costs for RE generation. That is why this should be developed in parallel and with greater attention.

8 Development of Technologies

RE technologies have reached significant progress in the last years. This concerns mainly wind generators. From technical and economic point of view, the technology for direct conversion of solar radiation into electrical energy is unsatisfactory. The progress is evident, however, there is much to be desired with reference to the prices and the efficiency of conversion. Intensive research activities are currently underway in this direction.

Along with the development of the generating technologies, the grid technologies are also evolving, especially in relation to management of grids with numerous active elements – allocated generators, information and communication technology development in order to control the network as unified system integrating generation, transfer and distribution, and consumption.

It can be assumed that considerable achievements will be reached in technologies field: modern interconnectors, control systems, automatics, commercial application of accumulating equipment of new type, combustible cells, hydrogen generation and use, etc.

Significant progress has been achieved in the energy consumption – effective devices, improvement of buildings insulation and new industrial technologies. It is expected that these achievements will hold the consumption at least at current levels.

The successful development of technologies in the last years, the active support of the European Community and of the national governments of the advanced European countries to research activities, the collaboration between institutions of the developed countries in Europe, North America, Russia and Asia, as well as the business interest ensure the continuous progress of research and the marketing of the best achievements in RE utilization and of the efficiency of conversion and energy consumption.

8.1 New challenges to the grid

The deployment of RE-e is a result not only of technology improvement, but also of technological update of the power systems. New generating installations, utilizing wind and solar energy, are integrating into the grid. While biomass technologies (pellets, wood chips, biogas) do not differ too much from fossil fuels combustion and, therefore, do not require solving of new technical problems, solar and wind capacities are quite different:

- Their resource is not evenly distributed on the territory, especially for wind technologies. The wind energy can be utilized through multiple installations with different, but limited capacity.
- Capacity varies in time, even until generation interruption.
- The estimation of the potential in short term (for a few hours or days) is not reliable and it hinders additionally the control of the power system.
- The small hydropower plants without reservoirs are also impossible to be regulated, however, their capacity could be estimated with much higher accuracy.
- Under the condition of such great differences, a big part of the electricity generation remains distributed and integrated into medium to low voltage grids, while the increase of intermittent capacities makes it impossible to control the system.

The distribution and availability of numerous generating plants set new requirements towards the control of the system. The management of multi-machine systems is much more sophisticated in comparison to a centralized system with huge generating capacities. Such control requires availability of new technologies based on information and communication systems, intelligent interconnectors and micro-networks.

8.2 Possible technological solutions

Here below are presented the prospective solutions, which would facilitate the RE deployment in generation and consumption.

8.2.1 Smart grid

The changes in the last years, occurring in the generation structure, the penetration of new active elements in the power grids under medium voltage, i.e. the RE generators difficult to predict, require changes in the concept of building and putting into operation the distribution grid from passive to active one. The European industrial initiative (Communication from the Commission, 2009) has determined the following technological targets to the development of electrical grids in the process of RE utilization:

1. Elaboration of modern technologies, particularly high voltage equipment, accumulating devices and control and monitoring systems, aimed at the improvement of grids agility and safety, and at the future reduction of investment and operation expenses.
2. Planning of the long-term electrical grids development, in order to secure the necessary future investments energy generation and consumption.
3. Attraction of active participation of the consumers in the energy markets and energy efficiency through better dissemination of information about their use, the available incentives, as well as about the dynamic price formation and information and communication technologies systems.
4. Development and testing of new market models, aimed at ensuring the operation of internal energy market in Europe and locally.

For the attainment of the above, it is necessary to dispose of modern technical systems and equipment, including information and communication technologies, control interconnectors, accumulation and storage devices, reserved capacities, control systems, smart metering, flow control, participation of load in the management, modern protections and automation, mirco-nets.

The growth of the number of RE generators requires the implementation of new tools for control of the flows, voltages, stability and consumption with large application of information, communication and control equipment. Each subsystem, i.e. generation, storage, distribution and consumption, has to be integrated, controlled and balanced through a smart information and communication system. Load curve should be aligned with the existing capabilities, investments and losses should be reduced, the flexible consumption should be shifted according to the most favourable from the point of view of tariffs period of time, the system reliability should be increased.

8.2.2 Storage

The accumulation and power storage of the intermittent working generators will have a crucial role in the electrical system management. The exceeding of certain limit of RE intensity in the energy system, could not be balanced through the market mechanisms and regulating capabilities of the conventional capacities and those of the pumped hydroelectric power plants. The “capacity credit[21]” of solar panels and wind turbines is very low at certain conditions – less than few percents.

Therefore, additional reserve capacities, or storage devices should be provided, preferably distributed between generators and consumers, but better both of them.

Significant capacities should be installed for short-term storage of energy, i.e.:

- Pumped storage hydroelectric power plants
- Batteries
- Compressed air facilities
- Superconductors
- Supercapacitors
- Flying wheels
- Fuel cells etc

Unfortunately, only the PSHPP technology has been tested until now. The other technologies are in different development phases. This concerns particularly fuel cells, superconductors, and the supercapacitors.

The modern tools, like superconductors, supercapacitors, flying wheels, compressed air facilities, have restrained, but sufficient technical capacities up to few MWh. When situated nearby generators, these tools mitigate considerably the problem. They are insufficient or inappropriate for the wind energy. In this particular case, it is needed powerful accumulating facilities and increasing the range of regulation of hydro and thermal power plants.

[21] The capacity credit is the capacity of a conventional power plant, which may be substituted by a wind (or other) power plant, keeping the same level of operational safety of the system

8.2.3 Hydrogen energy

Hydrogen as an energy source and accumulator deserves special attention, especially in relation to the possibilities for energy storage. Furthermore, the combustion cell will open the doors for the fast development of electrical transport. Despite the low efficiency of hydrogen cycle in RE generation, storage and consumption (about 40%), hydrogen as energy source will allow aligning the load schedules of the system and will make possible the mass utilization of wind energy in North Europe and in other parts of the world.

8.2.4 Demand response

The demand response is a resource, which can significantly facilitate the grid control in the presence of a high share of renewable energy. This means the utilization of opportunities of flexible demands (households included) in order to provide capacity for system balancing.

The use of demand response at “Day ahead” and “Hourly market” is a routine procedure and there are no obstacles to its application.

The Bulgarian electricity grid in its quality of main factor for RE development has so solve serious problems corresponding to the technical revolution in the energy sector.

Grid companies have to take the responsibility to expand and modernize the grid. On the other hand, in order to realize that, the regulatory system should introduce incentives for installation of modern technical systems. Although some applications just recently started their market penetration, the regulatory system has to be prepared to encourage them. Any delay would lead to higher costs for the system.

8.3 Evaluation of the Electricity System Operator (ESO)

Having in mind the forthcoming growth of renewable electricity, the Electricity System Operator made the following conclusion about the conditions and perspectives set in the development plan till 2020 [ESO 2010]:

“… through certain economic mechanisms it is necessary to carry out an optimal control of the investment process in construction of wind power plants and photovoltaic power plants, in order to respect Directive 2009/28/EC EU, the part of Generation and Energy use by HPPs on the one side, and at the same time not to disturb the control quality of the Electrical Energy System and security of energy supply according to ENTSO-E.

The analysis of the technical control capacities of the Bulgarian Electrical Energy System under the existing conditions and in the state of planned development of the generating capacities, shows that in order to guarantee the quality of control and security of energy supply, in conformity with the ENTSO-E standards, it is necessary to keep the installed wind capacities below 1800 MW and PV capacities up to 600 MW by 2020. These parameters have to be updated every year on the basis of the real development of the Power System and available regulating capacities.”

The indicated restrictions are not considered as obstacles to the attainment of the foreseen in NREAP (National Action Plan for Energy from Renewable Sources) targets [MEE 2011]: 1440 MW wind turbines and about 300 MW solar panels.

The text above does not exclude the possibilities for integration of bigger capacities in case of favourable change of circumstances, technical parameters of the system and control tools. It is an evidence of the primary importance that the coordination of investments in new capacities with the power system’s development and improvement has.

This is an objective of the regulatory system.

9 Improvement of Regulatory Policy

9.1 Organized electricity market

Bulgaria is much behind the neighbouring countries with respect to the development of its electricity market. This is considered as an obstacle not only for the liberalization of electricity trade, but also for the gradual commercialization of RE.

With the advancement of the technologies and introduction of the system for emissions trade, the competitive participation of generators, using variable resources (wind turbines, hydro power plants on run-of-river plants) will be possible only if appropriate configurations of organized market and improvement of still imperfect equipment for estimation/prediction are available.

The technological platform of wind energy [Strategic Research Agenda] determines its long-term objective for forecasting of annual and short-term generation of wind turbines (on the basis of location and terrain) to achieve a precision at least 3%. In such situation, wind turbine parks can provide services to the appropriate energy markets, i.e. "Day Ahead" and Intraday in case they are established in Bulgaria.

The introduction of modern technological solutions to the market – the distributed resources aggregated into micro-nets and virtual plants will become possible.

The best option for the Eastern European countries is to create a regional market, based on the achievements of the national markets in Romania and Slovenia.

9.2 Geographic Information System (GIS) for renewable energy

There is no doubt about the importance of the information system. Normally, these systems include the data needed for estimation of the geographical capacity, infrastructure, restrictions – agricultural, social, technological, etc. not only for energy, but also for generation of heat and bio fuels. Further information is needed about the restrictions: unique natural and cultural landscapes and tourism and recreation sites, geospatial data for both the statutory established areas and important biodiversity areas not included in Natura 2000 and in the Protected Areas network (i.e. nests of world threatened birds, limited migration front, etc.).

An operating system, easily supported and accessible by the end customers (investors, institutions, regulating authorities, financial institutions, etc.) will facilitate significantly the process of coordination and implementation of investment projects.

9.3 Plan for RE allocation

In 2009, the European Environment Agency published a study (EEA 2009) which presented estimations of the technical capacity of wind energy in 2020 and 2030 covering all European countries. The study used data information provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). These estimates, covering the European Community as a whole and Bulgaria separately, are shown in the following Table 3. The protected areas included in Natura project have been excluded from the calculations, although the building of wind parks is not forbidden there.

Table 3: Electricity in EU-27 and Bulgaria, TWh

–	**Uncompetitive (> 67 €/MWh)**	**Possibly competitive (55–67 €/MWh)**	**Competitive (<55 €/MWh)**
EC27 2020	29022	3330	8919
EC27 2030	5567	10602	25102
Bulgaria 2020	540	14	54
Bulgaria 2030	309	167	112

Source (EEA 2009)

The technical potential of solar irradiation is even higher, therefore, it can be considered unlimited.

On the basis of these estimations, it could be concluded that the technical potential will be determined by other restrictions, which are clarified by the investors and governmental institutions during the licensing or approval of the projects. Having fulfilled all other preconditions, the grid capacity remains of utmost importance.

The electrical grid is an infrastructure having the scope to serve its customers. Therefore, it should follow the development of consumption and generation. Article 16 of Directive 28 of 2009 regarding renewable energy, requires from EU MSs to develop their transmission and distribution grids in order to secure safe exploitation with future prospective RE generation, including interconnections. The grid should be able to transfer and distribute energy, to provide priority access and priority dispatch to each RE generator.

It is obvious that the grid should develop according to the perspectives for the deployment of RE production, including geographical, alongside all the above requirements. For this reason there should be enough information regarding the prospects, connected with generation, on which basis will be carried out the planning and the provision of development at lowest investment and operational costs.

Therefore, there is a need to coordinate investments in the grid with those in generation capacities. Without plans for grid development, considering RE resources, the whole process of RE utilization inevitably becomes messy.

The elaboration of a plan for development of the power system at all voltage levels, considering its particularities, capabilities and need of investments and new technologies, is an indispensable requirement for RE deployment without conflicts and at the smallest loss.

Given the distribution of electricity transmission lines and the necessity of legal resolution of many cases regarding land properties, where the lines are built, the investment process in grids is slow and requires considerable perspective. It looks acceptable and possible that the plan could cover a period of 5 years, with a perspective of up to 10 years, which is updated every two years and coordinated with the local and national authorities. This would remove a lot of obstacles and will facilitate the decisions taking and application, will simplify the investment process both in generation and in grids.

The existing administrative barriers will be eliminated to a great extent; the procedures for issuing of permits and environmental assessment will be streamlined.

The number of reviewed decisions will be effectively reduced through the introduction of plans for energy production from RES in the local and regional spatial planning.

9.4 Competition between RE projects

Each EC Member State is responsible to reach certain percent of RE in its gross energy consumption, but there are no specific obligations regarding certain technologies. Bulgaria can chose to direct its energy policy towards supporting the most efficient technologies from the point of view of the end price for the consumers. In order to protect consumers, it is fair to introduce a RE incentive mechanism, which would stimulate the competition and hence, would bring to reduction of production costs and prices.

Of course, the stimulation of technologies regardless of their efficiency raises other arguments, for example reaching of “the scale effect”. This means that the costs will reduce, thanks to the wider implementation, support to the national industrial production of these technologies, gaining experience through their application, increased employment, etc.

These considerations cannot be applied in the case of Bulgaria. The Bulgarian market has insignificant contribution for the world solar panels production. Almost all equipment and facilities are imported and there are enough projects, by which the industry can gain more experience. Therefore, it is not worth to implement expensive technologies in comfortable conditions without risks in Bulgaria.

Each country pursues its own policy in accordance with the commitments undertaken and own interests. For the Bulgarian economy it is profitable to give priority to technologies that have reached technological maturity, have been proven in the practice and posses reasonable financial parameters.

The attainment of the above objective could be reached not through artificial advantages or restrictions, but through introduction of competition among RE technologies, especially when no other restricting conditions are available, for example, utilization of waste for energy purposes.

Based on the above assumptions, it could be concluded that the regulatory policy regarding solar parks is wrong. The feed-in tariff is too high and it does not correspond to the real expenses. Furthermore, it is not acceptable from the point of view of the Bulgarian economic conditions and it unreasonably burdens the consumers, at the end to invest in a perspective technology, but still ineffective.

The intensive research and introduction of solar energy technology in the recent years ensure its significant development by 2020. The EU Roadmap (Renewable Energy Technology Roadmap, 2007) sets the following targets by 2020:

- Investments - 1,5 €/Wp
- Efficiency - 23%
- Lifetime - 40 years

According to the same document, the costs of energy generation for the countries at our latitude will be reduced up to the acceptable 0,15 €/kWh.

Similar are the tendencies according to the study by the International Energy Agency (IEA 2010).

Obviously, it is not worth wise to install thousands of Megawatts with insignificant utilization, which will have high price and low efficiency for 25 years, in the presence of many much improved installations.

This does not mean denial of solar technology, but support of its decentralized development close to the consumer. The best solution for solar convertors is their integration into the buildings. In Europe, buildings consume over 40% of the total energy and the European and national policies are oriented towards the rationalization of the consumption through introduction of new concepts of passive building and sustainable construction using the modern technology.

To encourage households, a number of European countries have introduced different tariffs, according to the capacity, with differentiated level of support to the energy sold and consumed. The implementation of such tariffs requires corresponding intelligent measurement, which cannot be an obstacle considering the available metering equipment.

9.5 Systematic reducing preferential tariffs

The aim of the preferences is to protect the new technologies from competition during the initial stage of their development. Their application can be justified by the fact that the climate impact of the emissions of the thermal power plants is not included in the production costs. Within the new favourable environment, it is expected the gradual improvement of RE technologies, reduction of costs, increase of their competitiveness, especially after the damages by the conventional technologies on environment can be managed through the emissions trade.

In conformity with this process, the preferential tariffs should be decreasing in time. Once the installation enters into operation, it is normal to be paid under the preferential tariff in force from the beginning of the license. However, for new installations having license from next year, the price should be lower.

The current rules applied by the State Energy and Water Regulatory Commission should be modified: the feed-in tariffs should decrease every year, but, once defined, they have to remain the same till the expiration of the license.

10 Solar and Wind Economic Potential Forecast

10.1 Introduction

The term “energy potential”, calculated as a difference, determines not only the radiance or available wind mechanical energy, but also reflects the factors, mostly restrictive, which in their turn are not static, for example:

- energy demand type and volume;
- existing energy conversion technologies;
- locality, regulations and restrictions.

From both sources - solar potential is more complicated in defining than wind, because wind is used only for electricity production, while solar can be used as a thermal source.

Energy demand type, covered by solar energy, defines energy not only as a quantity, but also as a quality – production of hot water or hot air is not to be directly compared to the production of electricity.

Heat based process alone as the production of hot water (or air) should be split into sub-processes in accordance to the potential, because of the different characteristic temperatures of the process. A production with lower temperature (pool heating – 30^{o}C) will give as a result a much higher potential, than tap hot water (55^{o}C).

Solar potential of electricity production obviously will have the lower potential available.

From energy demand volume point of view, energy potential can be used to cover a limited amount of demand, for example a limited number of pools is to be heated. Even electricity, as the most universal energy source, should not be calculated unrestrained (at least financial or GDP constraints should be determined).

Potential as a difference can be directly derived from energy conversion technologies. As shown in the study, throughout application of different sets of technology - different potential can be calculated. Energy conversions technologies also are not static – new technologies appear and the old ones disappear or change.

As to the local conditions, they can directly influence both the technology application and the demand type and volume. Local conditions determine the demand in pool heating or space heating, the existence of technology (or network) restrictions / bonuses, ecological barriers, agricultural dependences etc., to be considered.

The concept of potential applied in the forecast, corresponds to the realizable potential, which differs from the theoretical and technical potential as shown below (

Table 4).

Table 4: Used definition of potentials

Theoretical Potential
technical, ecological and legislative restrictions
Technical Potential
restrictions of production capacity
system management and other temporary restrictions
and related expenses
Realizable Potential (economically usable)

The process of determination of solar capacity, possible to be realized, is split between both possibilities:

- production of hot water, considered in residential and service sectors;
- production of electricity, determined separately for residential and service sectors and independently for electricity generation).

Solar potential is determined on monthly and regional bases from stage to stage as follows:

- solar radiance;
- solar technical potential;

- solar economical potential;
- solar production (economic) forecast

The calculations of the potential are done on the bases of statistical mean values for each region in the study.

10.2 Demand forecast22

10.2.1 Households demand

Demand of households is calculated on the basis of the demographic forecast and forecast of specific consumption - per capita, for the processes of cooking, heating, hot water production, lighting, appliances and air-conditioning.

Residential demand distribution in the European statistics point out, that about 60% of the energy sources are used for heating and air-conditioning. Hot-water production covers 15%, lighting and appliances consuming electricity is aiming at 20% and cooking is in the range of 5% of demand.

Temperature measurements for typical villages in the different areas are necessary for the sake of regional calculations.

10.2.2 Industrial, agricultural and commercial demand

Demand of industry and commerce is calculated on the basis of the GDP and energy intensity forecasts.

10.3 Solar technologies

Historically the hot water production is not a modern technology. Hot water production with dark coloured vessels is widely used, especially in Southern parts of Europe - Turkey and Greece.

Nowadays the hot water installation consists of collectors, in which a fluid is heated by the sun, plus a hot-water storage tank where the water is heated by the hot liquid. Low temperature collectors are used for pool heating or rarely for underfloor heating, while medium temperature collectors are used for hot water or air heating.

Solar hot water production efficiency varies from 35% for the vessels production till 90% for solar collectors.

Even in colder areas, like Northern Europe, a solar heating system can provide 50-70% of the hot water demand. In Southern Europe a solar collector is able to cover 70-90% of the hot-water consumption. Heating water with the sun is very practical and cost effective.

The ordinary solar panels efficiency range from 9 - 15% efficiency, the theoretical maximum calculated not to be higher than 24%. Nevertheless the financial support of EU (especially FIT systems) and the simplicity and shorter construction period of the installations (compared to the high temperature technologies), resulted in the boost of its development. The gross solar efficiency, calculated on the basis of the total area, used by the installation here can reach 7 – 10% of the total solar energy, as a result of the higher percentage of land utilization. Practically no electricity storage exists and the stations availability is vulnerable to climate changes.

The solar module cost represents around 50 - 60% of the total installed cost of a solar energy station.

10.3.1 Thermal solar collectors

The shares of the solar water heaters to overcome the annual energy requirements were closely related to the collector types.

Solar collector efficiencies, which are used, are taken from publication, not considering any complex heat loss calculation from first or second order. As seen in Table 5 below, the major factor for efficiency calculation is the temperature difference in the processes, defining the heat losses.

[22] More information on electricity forecast can be found in (Сулакав С.) – see reference list

Table 5: Efficiency of the processes[23]

Collector Type	Pool heating	Hot water	Space heating
Absorbers	90%	20%	-
Ordinary Panels	80%	35%	25%
Vacuum tubes and selective panels	60%	55%	50%

10.3.2 Solar electricity

Corresponding to the manner of construction, the solar panels have been subdivided into two distinct parts – on-roof and on-ground. While for those technologies that are mounted on roofs a maximum roof area suitable for photoelectric applications has to be determined, a maximum ground area has not been determined for large-scale plants.

On-roof solar panels

A regional approach of the theoretical on-roof photoelectric technical potential requires data for the building type distribution in the regions.

Otherwise the statistical value of 45m² per capita (including residential, agricultural, industrial, commercial and other buildings) is used. Densely populated areas have less area per capita available and vice versa.

After application of the methodology the theoretical technical on-roof photoelectric potential results to the estimation that the economic calculations do not need to be restricted in the scope of the study horizon up to 2050.

Solar plant sizes

Due to significant cost differences between the varied plant sizes, three typical solar plant sizes have been determined to cover the relevant cost range.

The smallest plant size of 3 - 4 kW represents the typical small residential roof top system.

Middle sized systems are set at an installed capacity of 30 kW.

Large-scale plants are defined as all sizes of 1 MW and more. The latter is typically built on the ground rather than on top of a roof, that is why they should be calculated rather in the big power generating system models.

Solar plant investment costs

The lower end of all observable net retail prices gives an indication for real costs. It has to be mentioned that cost-differences between the smaller plant sizes are substantial, whereas economics of scale are declining with increasing plant sizes.

In the next Table 6 are shown the current prices of different solar technologies. Higher investments are necessary for a better performance and the decision maker is much influenced by additional incentives.

Table 6: Solar technologies parameters

Type of cells	Performance, %	Power, W/m2	Market Share, %
Organic	3%	30	1%
Thin films	12%	120	13%
Organic Silicon	18%	180	85%
Concentritic PV	25%	250	1%

With the development of the technologies and the lowering of the prices, the investors are expected to stimulate the application of those technologies, which have higher performance parameters.

[23] Solar Book,www.solarbook.co.uk

Solar panels full load hours

Basis for full load hour calculation is the hourly irradiation data for all regions in the study. Combined with regional and hourly data for temperature, the inclination angle, kind of system-elevation and the performance ratio - full load hours are growing.

Solar utilities will have a higher load factor, compared to residential and commercial appliances, due to the investment in solar orienting equipment, while residential panels usually are fixed which will lower their conversion value.

Concentrating Solar Power (CSP)

Concentrating Solar Power (CSP), like parabolic through or solar tower plants, play a minor role in renewable energies so far. Regarding important characteristics such as plant-size and flexibility in power supply due to storage, CSP is very different to all other renewable energy technologies. Parabolic-through is designed as large-scale plant, using solar radiation for electricity generation within conventional power cycles. CSP installations require a lot of plain area and a high direct normal irradiation, which limits their potential significantly.

- *CSP potential*

Basis for the potential is the requirement for an annual direct normal irradiation of more than 1 800 kWh per m^2.

- *CSP costs*

Investment costs of parabolic-through plants amount to about 6 000 €/kW[24] for the projects currently being realized in Spain.

10.4 Wind technologies

10.4.1 Main parameters

Costs

The main parameters determining the cost of wind energy are investment costs (i.e. turbine costs, foundations, electrical installations, connections to the electrical grid, consultancy fees, land costs, financing, security and road construction) and operation and maintenance costs (O&M). As costs depend on various factors, they also vary significantly between different countries. In this project, investment and O&M costs are mainly derived from studies with an international scope.

One significant factor in increasing the feasibility of a new system is the reduction in turbine costs. Though technology costs are decreasing, the recent upswing in raw materials costs, primarily steel, has led some to believe that capital costs may stay steady rather than decrease over time. The more favourable economics and financing options for large utility scale wind turbines may also squeeze the market for components used for both types of systems, which may affect the price and availability of newly manufactured small wind systems. Inevitably, capital costs must decrease while technical efficiency increases for even the best case scenario to be profitable.

Turbine manufacturers expect the production costs of wind power to decline by 3–5% for each new generation of wind turbines or decrease of investment costs of 1–2,2% per year.

Turbine size

Wind turbine size has increased significantly, from an average rated power of less than 50 kW at the beginning of the 1980s to over 1 MW in 2005. The commercial size sold today is typically 750–2 500 kW. In this study we assume that rated power will level off at 2 MW.

[24] *EWI, 2010.* European RES-E Policy Analysis, A model-based analysis of RES-E deployment and its impact on the conventional power market

10.4.2 System requirements

Each power station, connected to the grid, has the obligation to ensure its own stable, economical and environmental participation in the system load coverage.

Renewable Energy Sources power stations (wind, solar and free running water) differ substantially from other conventional generating sources and that is why their exploitation can be submitted to partial and full curtailment from system stability point of view.

Wind Power Plants (WPP) can influence the system stability in the following aspects:

- Influence on the frequency (AGC respond in the frames of 30 seconds);
- Influence on the system balancing (dispatching respond from 5 minutes to 1 hour);
- Influence on the unit commitment (up to 24 hours);
- Influence on the resource planning (more than a year).

All these aspects are a result from the stochastic nature of the wind as a source, which causes the deviation in the production, considered problematic from system point of view.

These deviations include:

- seasonal deviations;
- daily load curve deviations;
- hourly deviations;
- 10 minutes deviations.

The main factors, which are necessary to be taken into consideration during the process of determination of the WPP influence on the Power system, are defined as follows:

- Total installed capacity, connected to the system;
- Generators type and characteristics;
- Installed capacity of WPP, connected to the system, and their share;
- Generation of WPP and their share in the covering of the total demand.
- Concentration of WPP in certain areas.

The main methodology, used by system responsible authorities, is based on the Analyses of the remaining load curve.

Remaining load curve, after subtracting the WPP production, is subject to the analyses of the possibilities and problems to be covered by the conventional generating units.

Main parameters are the daily minimum load and the standard deviation from the load. These parameters vary with the growing participation of WPP and the seasonal deviations in their production and the deviations in the total demand.

Calculations are done on the basis of the collected meteorological and calculated data for the WPP sites, which include: medium wind speed, standard deviation, maximum wind speed gradient (negative or positive).

Final economic results are obtained after a dynamic system simulation, which defines the financial consequences (positive or negative) from system point of view (increased expenses for system reserve), as well as from point of view of other participants (conventional generators).

10.4.3 Network restrictions

The rapid increase of wind power capacities can exceed the possibility of the network to absorb all generated energy from renewable sources.

This inevitably will result in:

- curtailment;
- necessity of strengthening the network (additional investment and time lag)

The situation is even worse in cases of high local concentration of wind capacities.

The restrictions, imposed on the wind power potential can be linked not only to the transmission network, but also to the local distribution network, which have to accommodate the fluctuating production from renewable energy.

10.5 Solar and wind modelling

10.5.1 General terms

Modelling of technologies is based on the technical energy potentials, determined for the different regions in the country.

Solar and wind modelling reflects also the following specific characteristics:

- Zero fuel expenses;
- Significant decrease in the investment expenses from year to year due to the technological progress in the solar technologies;
- Expected increase in the power transformation ratio, due to the better performance of the new technologies;
- Additional incentives (Feed-in tariffs, Green certificates, Subsidies etc.).

The model will minimize the costs for residential and commercial energy consumption, as follows:

Running costs + Capital costs – Incentives (Sale of TGC)

Competition of all energy sources: gas, oil, coal, wood and biofuels, electricity, solar panels and water-heating collectors, is performed on a regional base

10.5.2 Linear matrix of residential and commercial energy demand

Commercial and residential forecast is done separately from big energy and industry forecast. A matrix, defining the demand processes, corresponding to the data, is shown below (Table 7).

Table 7: Processes and sources, included in the matrix decision

Matrix/Process	Total	HEATING	HOT WATER	COOLING	COOKING	TRANSPORT	APPLIANCES
Natural gas	NGE1	NGE2	NGE3		NGE4		
Wood	WOE1	WOE2	WOE3		WOE4		
Coal	COE1	COE2	COE3				
Liquid fuels	OIE1					OIE2	
Central heating / Geothermal	CHE1	CHE2	CHE3				
Electricity (direct)	ELE1	ELE2	ELE3	ELE4	ELE5		ELE6
PV - commercial	WIE1						WIE2
Solar - thermal	STE1		STE2				
PV residential	SOE1						OTE5

10.5.3 Linear matrix of power generation

Big power generation units matrix (Table 8) is different in respect to the energy sources, but the mathematical tool is the same – SIMPLEX method is used.

Table 8: Matrix for the distribution of the power generating units

Matrix/Zone	Total	Base	Semi-base	Semi-peak	Peak	Reserve
Nuclear	NCE1	NCE2				
Lignite	LIE1	LIE2	LIE3			
Coal	COE1	COE2	COE3	COE4		COE5
Oil	OIE1	OIE2	OIE3	OIE4		OIE5
CCGT	CCE1	CCE2	CCE3			
Gas	GTE1		GTE2	GTE3	GTE4	GTE5
Hydro - peak	HPE1		HPE2	HPE3	HPE4	
Hydro - running	HRE1	HRE2	HRE3			
Wind	WIE1	WIE2	WIE3	WIE4		
Solar	SOE1		SOE3	SOE4	SOE2	
Other	OTE1	OTE2	OTE3	OTE4		

Each matrix decision is checked by a simulation model with a scenario, covering the energy balance month by month. The long repairs and fuel charging in nuclear stations are usually scheduled in months with a lower demand (April, May, September, October). Solar stations have a significant production in summer months and lower in winter or cloudy days, which requires additional reserve capacities. Solar usually create system problems in the beginning and at the end of their production period, introducing a big strain to the conventional peak units, which are forced to execute a resulting quick start or shut-off.

10.5.4 Forecast results for the period 2020 - 2050

Scenario Active energy efficiency support

In Table 9 below are shown the results from the matrix calculation for the period, including years 2020, 2030 and 2050. (They are illustrated also on Figure 18 below.)

Table 9: Forecast of residential and commercial energy consumption by sources, 1000 toe

Sources / Year	2010*	2020	2030	2040	2050
Natural gas	155	201	262	262	262
Wood	661	661	595	502	409
Coal	223	245	270	283	297
Liquid fuels, incl biofuel	202	257	285	307	328
Electricity	1496	1151	773	718	662
Local PV (roof and wall)	0	64	222	230	239
Solar - thermal	33	66	132	198	264
Central Heating	462	500	550	648	745
Pellets and biomass	0	331	496	620	744
TOTAL, 1000 TOE	3232	3477	3685	3868	4050

**EIA statistics*

The result from the calculations show, that the development of the solar potential utilization is notable after year 2020.

Solar energy for thermal usage (hot water) increases its absolute value about 8 times without any incentives in order to reach 6.5% share in the total residential demand.

The development of the solar till year 2030 is based mainly on the incentives from FiT. The dominant investments are calculated to be used in the commercial sector (medium size installations) and serious investments in residential small on-roof installations will start after 2020.

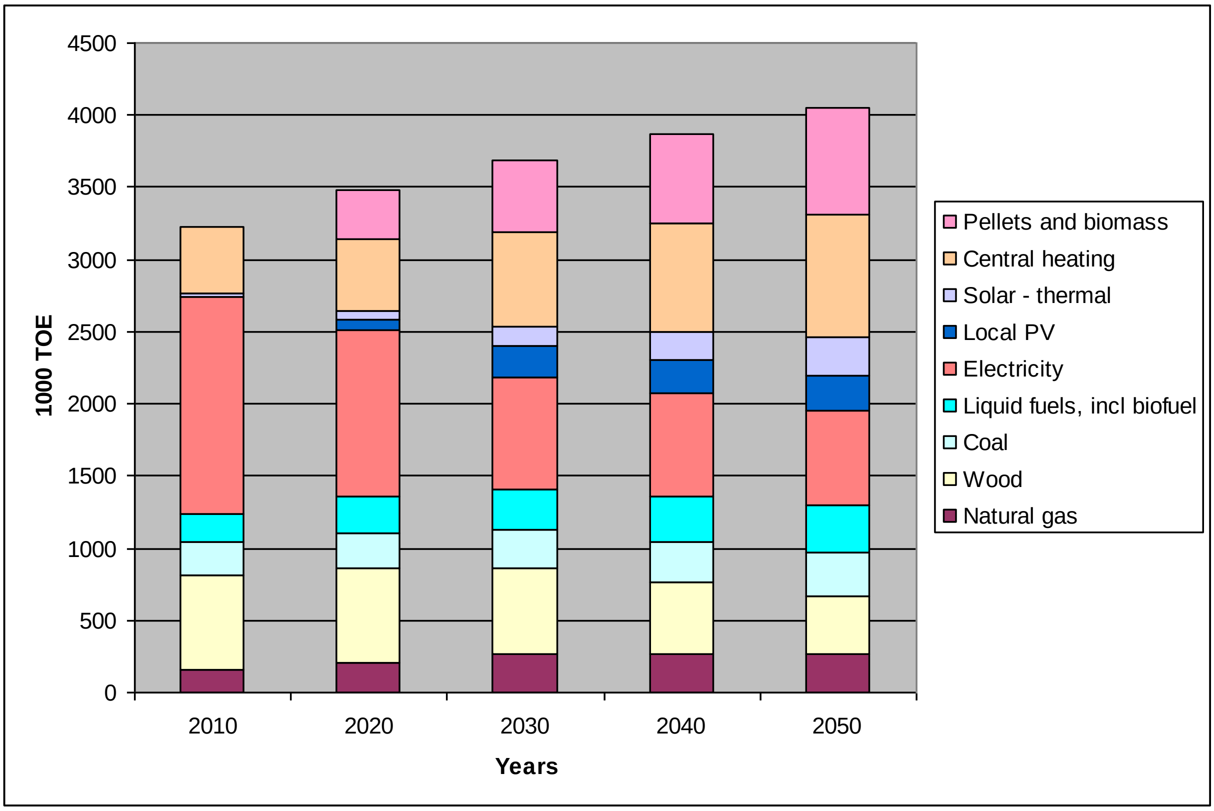

Figure 18: Residential and commercial energy consumption, 1000 toe

Hard fuels – coal, wood and bio-fuels - have a stable share in the energy consumption, closely following the increasing demand.

Oil and gas increase their quantities in an absolute value, but lose significantly in the share of the total demand, dropping from 43 % in 2007 to 32 % in 2050.

There is a reduction in the final consumption of electricity from the net, as a natural result from the RES implementation and the development of power saving measures (at least 20% is expected). Another factor for this negative trend is expected to be the price increase, after the implementation of 100% free electricity market in Europe after 2014. Currently 100% of the residential and commercial demand is based on regulated prices, which are lower, than the average European prices.

There are some factors, not included in the calculations, namely: electric cars implementation, which can increase the residential electricity consumption at the expense of liquid fuels. This factor is indirectly included in the “High demand scenario of Power generation forecast”.

Scenario High electricity consumption

In **Table 10** and Figure 19 below are shown the results from the matrix calculation for the period, including years 2020, 2030 and 2050 for a scenario with increasing electricity mainly due to the technological development of electric vehicles. Year 2040 is added for a presentation.

The steep development of the solar units in the years 2020 - 2030 is based mainly on the incentives (FiT or other bonuses). The major investments are expected to be made in the commercial sector (medium size installations). Notable investments in residential small on-roof installations will start after 2020.

Table 10: Forecast of residential and commercial energy consumption by sources, 1000 toe

Fuels and energy	**2010***	**2020**	**2030**	**2040**	**2050**
Natural gas	155	202	262	301	341
Wood	661	595	535	509	482
Coal	223	223	201	191	181
Liquid fuels, incl biofuel	202	190	170	160	150
ELECTRITY, including:	1496	1536	1570	1613	1655
- Electricity from conventional sources	*1496*	*1472*	*1349*	*1363*	*1377*
- Electricity from local PV		*64*	*222*	*250*	*278*
Solar - thermal	33	66	132	198	264
Central Heating	462	500	600	660	720
Pellets and biomass		165	215	236	257
TOTAL	**3232**	**3477**	**3685**	**3868**	**4050**

**EIA statistics*

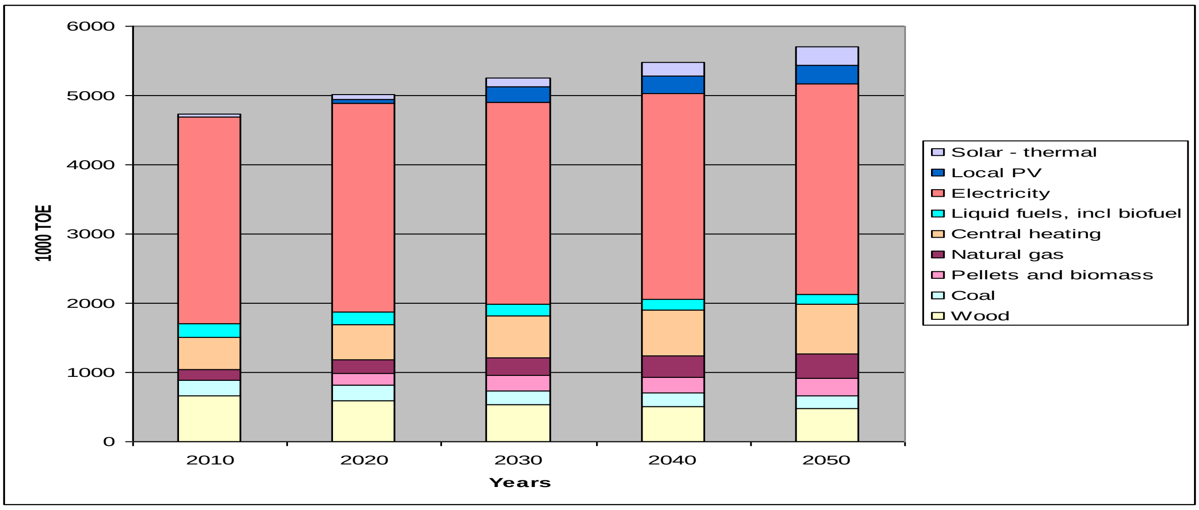

Figure 19: Residential and commercial energy consumption, 1000 toe

Hard fuels – coal, wood and bio-fuels have a slow declining share from 28% in 2030 to 23 % in year 2050.

Oil substantially decreases its absolute and relative value in the period to fall down to 150 toe (4%) in 2050.

Natural gas (for direct usage and as a fuel in the central heating) nearly doubles its quantities from 617 to 1060 toe in the period so increasing its relative share from 19% to 26%.

Solar potential utilization in the electricity sector gains speed after 2020 to reach 222 toe in 2030 and 278 toe in 2050. Relative share is expected to reach 7% from the residential and commercial demand.

Solar energy for thermal usage (hot water) increases its absolute value about 8 times without any incentives in order to reach 6.5 % share.

Solar energy production forecast

Solar energy forecast includes solar energy for heating and hot water and solar energy for electricity (Table 11).

The economic calculations show, that a significant growth in the energy production from solar sources should be expected in the period.

Electricity production from solar sources will reach 8.9% at the end of the period, based on the assumption, that additional incentives, as FiT or investment bonuses, will not be available after year 2020. Heat production from solar sources will cover even a higher percentage, namely 9.2% from the total heat demand, without government support in the whole study period.

Table 11: Forecast of the energy demand coverage by solar units, GWh

Year	2010	2020	2030	2050
Electricity demand /gross	**41 571**	**41 530**	**41 980**	**45 850**
Production from solar units	5	1000	3 170	4 090
Percentage from electricity	*0.01%*	*2.4%*	*7.5%*	*8.9%*
Heating and hot water demand /residential	**29 269**	**30 686**	**31 795**	**33 095**
Production from solar units	*383*	*767*	*1535*	*3070*
Percentage from heating	*1.3%*	*2.5%*	*4.8%*	*9.2%*

On the next Table 12 are shown the dynamics of the development of solar power generating units.

In the beginning small and medium utilities are expected to be dominantly active, while after 2020 the diversity from residential to big utilities is the main characteristics of the development.

Table 12: Forecast of the electricity generation from solar units, MWh

Year	2010	2020	2030	2050
Production from solar units	5000	998158	3169135	4092997
- from residential PV		5000	562500	611250
- from small and medium utilities	5000	745000	2014788	2170750
- from big utilities		248158	591847	1310997

Wind energy production forecast

Wind energy production is exclusively for electricity generation by wind mills, installed in the utility sector. Small turbines can be useful only for small off-grid projects, which can not be economically justified.

Stimulated by the favourable RES legislation and especially the high FiT tariffs, wind generating units quickly reached a significant capacity in a specific area in the North East part of the country and turned out to be a significant problem to the security of the transmission system in the region. The result was a legislative correction, which imposed a system of annual determination of possible amount of capacities to be connected to the grid on regional bases.

This situation leads to a more conservative approach in the forecast, so the low scenario of the demand was used as a base for the modelling.

The results, presented below (Table 13), nevertheless show, that a significant share of about 10% can be reached till year 2020 and subsequently till 2050 more than 5000 GWh electricity to be generated annually.

Table 13: Forecast of the annual production from wind turbines, GWh

Year	2010	2020	2030	2050
Gross demand of electricity	41 571	41 530	41 980	45 850
Production from wind turbines	327	3 990	4 860	5 085
Share	0,79%	9,62%	11,58%	11,09%

In the optimistic scenario the results are nearly double, so in 2030 the wind generation will reach 7 500 GWh, and in 2050 – 9 380 GWh. The relative share in the production in this case also will not overcome 12%.

Total energy production from wind and solar, as shown on Figure 20, will grow rapidly in the beginning, stimulated by the financial incentives, in order to reach at the end of the period the volume of 12 245 GWh annual production.

In this scenario wind potential will reach a point of saturation about year 2030 and will remain at the level of about 5000 GWh / year.

Solar development will have the highest annual temp of growth in the period between 2020 and 2030, after an expected decrease in the price of the equipment.

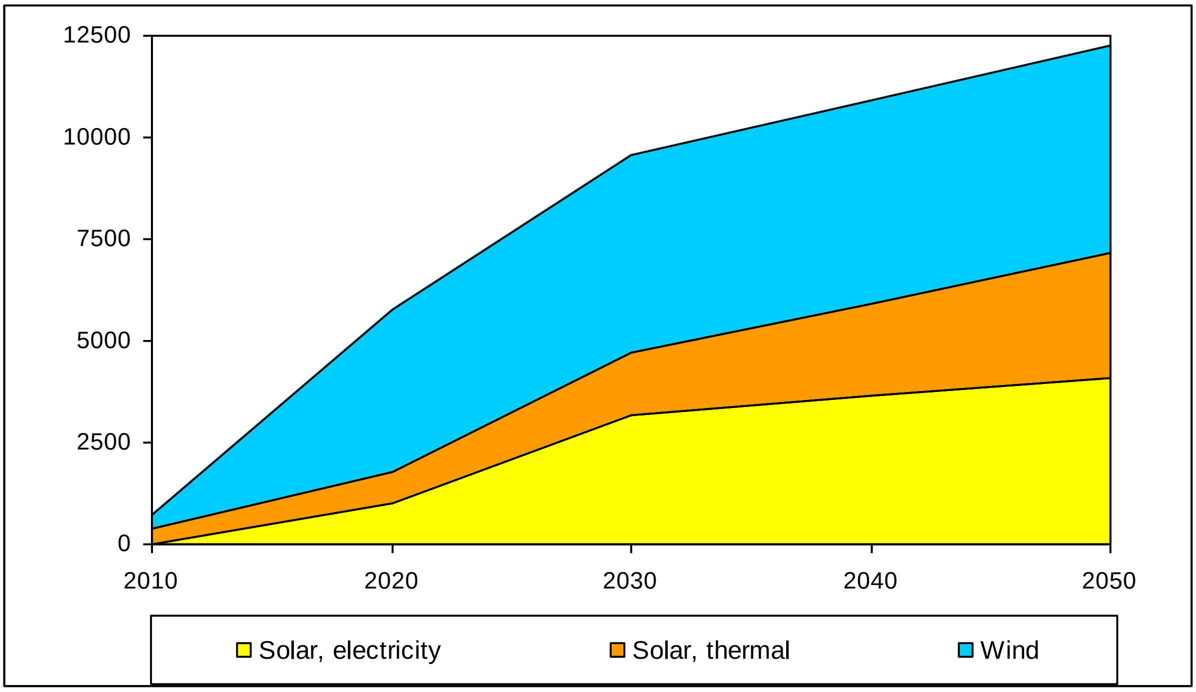

Figure 20: Forecast of the wind and solar energy supply in Bulgaria, GWh/year.

RES storylines – green and red scenario

Additional analyses were made in order to estimate the influence of the both drivers: technology development and the public support.

During the process of study it became clear, that the green scenario (quick technology development and high public support

Figure 21) and the red one (both negative tendencies

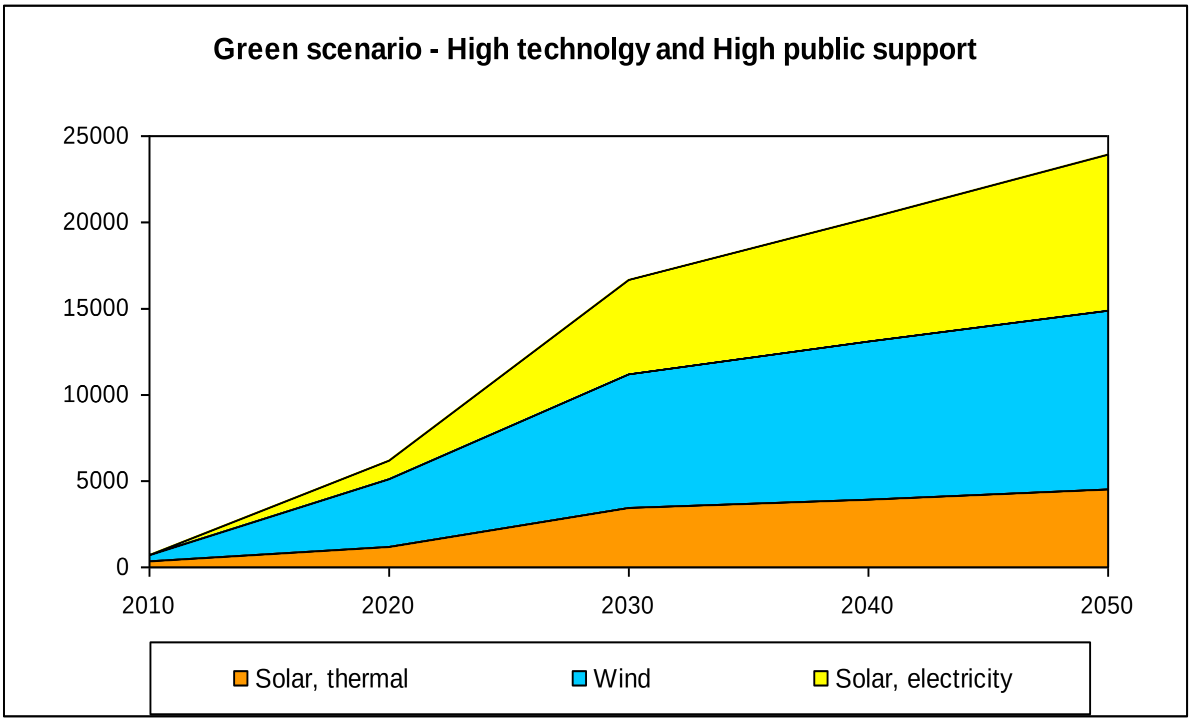

Figure 22) are the one, which of a bigger interest, than the contradictory ones namely: the yellow and blue ones (see Chapter 6).

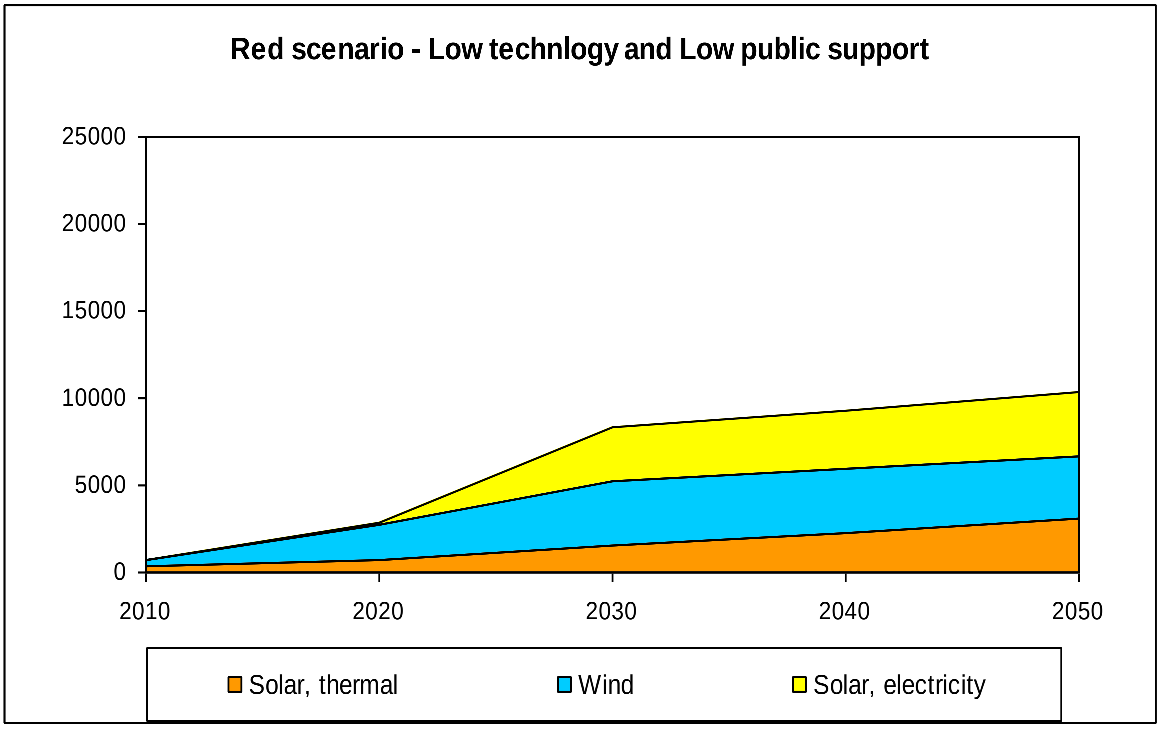

Figure 21: Red scenario storyline.

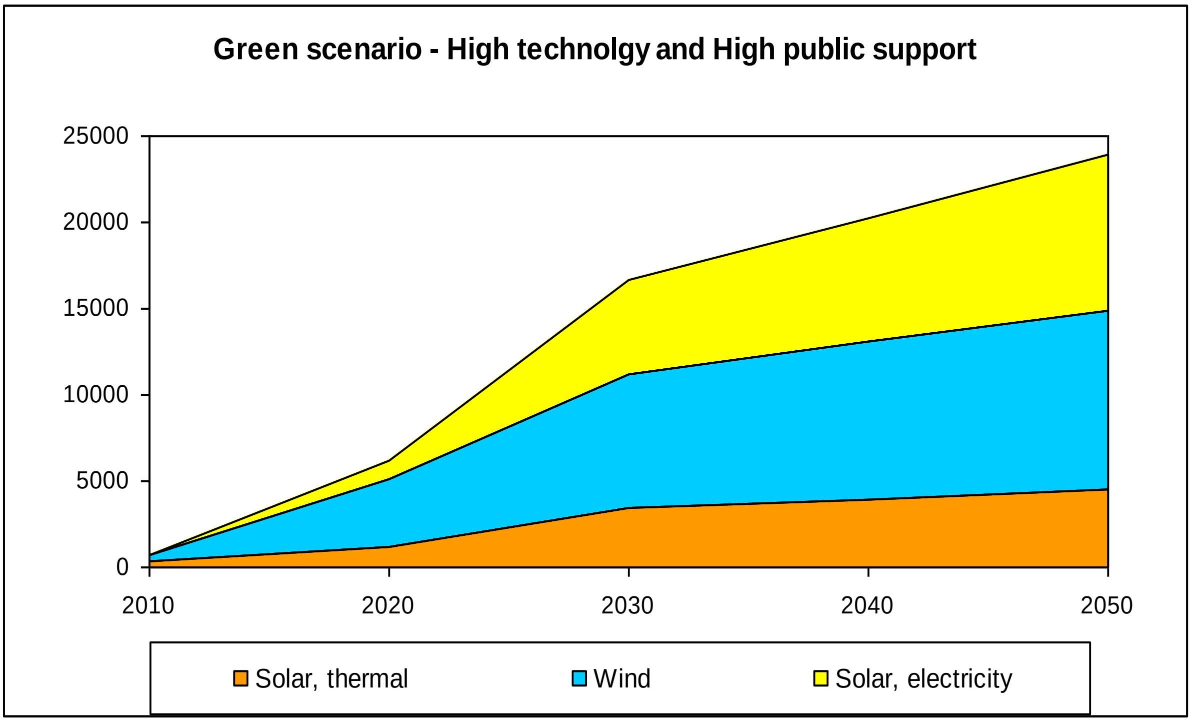

Figure 22: Green scenario storyline.

The forecasts show, that RES development already has received a significant stimulation from the existing government bonus system (FiT), which will result in a constant growth during the study period.

Public support and high technologies, nevertheless, can push the development of RES so strong that at the end of the period the result can be 250% higher, than the other storyline.

Both drivers combine together their influence, in order to gain the biggest speed of development in RES in the period of 2020 – 2030, while after that period the saturation factors appear to be a resisting factor.

Changes in the structure are also very dynamic in the period after 2020, when solar converters are expected to reach the level of cost effectiveness that will allow their independent financing.

Thermal solar heaters have a constant growth, even without incentives, but a favourable factors forecast can move them to a higher level.

Without a technology development, wind generation will stay almost constant after 2030, together with the exhaustion of suitable sites for extensive development.

11 Specific Recommendations by Types of RES

11.1 Photoelectric converters

Despite the high development potential of the direct conversion of heat into electricity, the parameters indicate that it cannot compete with the other resources. Regardless of the significant drop of silicon prices, the long-term estimates of costs for energy generation by PV remain the highest.

In view of the unlimited solar resource, the investments made in the development of this technology and the forthcoming after 2020 implementation of the "passive house" concept, it is recommended to improve the regulatory policy for assistance to PV energy generation. This policy has to encourage the integration of combined photoelectric installations of the type "solar walls" into the roofs and walls of the residential and industrial buildings for production of heat and electricity. The combined installations have good technical parameters and can be stimulated by high purchasing prices, which at the same time, will stimulate heat generation by RES.

An important requirement is the installed capacity to comply with the demand of the building, which ensures that the integration to the grid is carried out under low voltage without replacement of the existing electrical system and without additional costs for transmission and conversion.

Adhering to these requirements, the parameters of this type of installations are getting better (over 30%) in comparison to the industrial ones. They do not occupy fertile lands, no expenses are needed for new infrastructure (road, water, integration into grids), they are integrated in the demand centre, which does not originate further expenses for transmission, conversion and integration into the grid.

Although the energy generated by PV in long terms is not competitive, the development of combined photovoltaic systems integrated in buildings is recommended to be promoted, because of their essential role in the sustainable urban planning and development. These surfaces are visually appealing, they help modern urban environment and their application supports the RE market development. Something more – the economic effect of this encouragement is of benefit of all home-owners.

To prevent the uncontrollable rise of the share of electricity generated by solar panels, it is recommended to limit its support for new buildings and buildings that undergo major renovation and certification under the Energy Efficiency Act. Additional incentives are provided for CHP installations.

With nowadays growth of construction of new public and residential buildings, the technical capacity of combined solar installations will not exceed 20 000 kW.p/year. In the years by 2020 this capacity will be utilized slowly, due to the high investment costs, long payback period and lack of legal obligations for implementation of "passive house" standard.

The development of industrial photoelectric parks of big installed capacity, requiring integration under medium or high voltage, should be stimulated only after the technology becomes competitive. For this reason, besides the reduction of investments costs, the conversion factor should considerably increase and the temperature dependency should decrease, the operating lifetime has to be prolonged and the operating cost of installations should decrease.

The elaboration of regulatory policy should take into account the following:

- The access to the low voltage grid should be clearly stated as a duty of the grid operator and should not, at any reason, be denied;
- The procedures for administrative assistance and grid integration should be simplified as much as possible;
- The technical conditions for integration into the installations should be simplified, unified and made public;
- The integration of small capacity installations (the exact size will be determined according to building parameters) in residential buildings should be carried out by the grid operator shortly after being informed of, in case the installation meets all technical criteria. It is very important to elaborate standards and technical norms for PV installations integrated in buildings;
- The installers should be encouraged to create voluntary code in working with clients;
- The price of purchasing has to be defined by the regulations and should remain unchanged for the term of purchasing contract;

- o Elaboration of different tariffs for purchase, depending on:
  - the electricity calculation method (gross or net)
  - own consumption
  - coincidence in time of own consumption and generation
  - combined or differentiated generation of electricity and heat (for domestic hot water preparation and air-conditioning)

Along with the deployment of solar energy generation the costs of projects will go down and the boosting policy has to follow this process. Specific and ad-hoc measures have to be taken by the regulator to avoid unbalances between grid control possibilities and the investment process.

11.2 Wind power plants

Wind energy has reached technological maturity and after the introduction of the emissions trade (ETS) probably their price will become competitive to the new constructed conventional fossil fuel power plants. This gives the opportunity to stimulate the entering of wind power in the free market.

However, it should be noted that the increase of the share of wind energy is connected with an increase of the costs for system control and development. A share of 5% of wind energy does not affect the costs, however, when the share reaches 10-15%, this brings the necessity to increase the size of spinning reserve of the system, as well as to build generating capacities ready to substitute wind generators if needed. The expenses connected with investment in new accumulating installations and enlargement and reinforcing the transmission grid also raise the price.

Reduction of costs, occurring with the increase of the share of wind energy, can be achieved through implementation of organizational measures for development of the electricity market and establishment of Energy Exchange, including "Day Ahead" market, market in real time, "Hour Ahead", virtual plants, balancing groups, etc. After depletion of the market opportunities, the regulatory policy has to encourage the competition among investors for further costs reduction.

In order to enter the market, wind plants can be assisted by investment subsidies focused on enhancement of the transmission grid, covering of direct costs for the integration, construction of reserved capacities, improvement of accumulating opportunities of the system, etc.

When the grid integration is ensured by investment subsidies, a condition for the plant integration might be the refusal of investor from preferential price and consent for participation at the free market. In the presence of high interest the integration can be realized even after completion of a tendering procedure.

The development of regulatory policy for promotion of wind generation should take into account the following:

- o The access to the grid under high voltage should be legally regulated as operator's duty;
- o The procedures for administrative assistance and grid integration should be simplified as much as possible;
- o The purchase price should be defined by the regulations and should remain unchanged for the term of purchase contract;
- o The technical conditions integration of installations into the grid should be unified and made public;
- o The integration to the grid should be carried out at a competitive basis among investors;
- o The investor should be encouraged to refuse the use of feed-in tariffs, through provision of investment incentives in the form of guaranteed integration, free tax period, etc.
- o Remote control of wind parks should be obligatory for their integration;
- o Wind parks should use modern software for estimations of wind power.

Wind technology is advancing, larger and more effective turbines are already in use. Some of the most effective parks have possibilities (or will have in the near future) to operate commercially proposing balancing capacity. Bulgarian regulatory policy is too conservative (in the same time – unilateral, using limited number of mechanisms) with regard to wind and solar promoting policy. More flexibility has to be added in order to avoid ungrounded feed-in-tariffs.

12 Conclusions

The estimation of the wind and solar energy production potential is a process, which is determined by the existing theoretical / geography / climate potential as well as by other technical and other restriction factors, which make it necessary to clarify its definition.

The theoretical potential, especially the solar irradiance potential in Bulgaria, is huge, according to the preliminary rough estimations, but this figure does not have a big significance at all. The present study aims at the calculation of the technical potential, taking into consideration other restrictions: geographical, economical, technical, regulatory etc.

As a result, the average potential of all regions was estimated. An attempt was made also for the preparation of a forecast not only of the demand, but also of the development of the RES, till the year 2050.

The assessment of potential is performed through open source software products (GRASS and Quantum GIS), and the proprietary ArcGIS Desktop, which is used for its rich visualization capabilities.

The data for the average wind speed was obtained from 3TIER – United States and the data for the solar radiation – from PVGIS solar data of CM-SAF.

The technical potential for generation of electricity from solar is estimated at about 9 GW, based on the condition, that arable land is not used for building of solar generating systems.

The technical potential for generation of electricity from wind is estimated at about 110 GW, respecting environment and social requirements and calculating suitable locations of average wind speed higher than 6 m/s.

The final part of the report deals with the factors, which determine the scope of the RES utilization – especially on the bases of the public and technological support. In correspondence with the conclusions, analyses of the regulatory system are presented. The final conclusions are, that the regulatory system is limited, and does not include enough incentives for the support of the small units, covering own consumption, as well as for the heat production from solar radiation. The regulatory system is not flexible enough and follows the technical progress with a certain delay. On the bases of these analyses, a proposal for new regulatory measures is included.

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APPENDICES

APPENDIX 1

USED SOFTWARE

Software product	Project specific functions
GRASS GIS 6.4	Processing of raster information (elevation, wind speed, solar irradiation)
Quantum GIS 1.7 Wroclaw	Analysis and processing of vector information Data visualization and mapping
SAGA GIS	Conversion and processing of elevation data
ArcGIS Desktop (ArcView license)	Data visualization and mapping

Quantum GIS Plugins	Project specific functions
fTools	Processing of vector data (intersect, clip, join, buffering)
Zonal Statistics	Intersection of municipalities with girded potential surfaces Calculation of relative shares of territory with high potential
GDAL Tools	Raster algebra operations
Table manager	Attributive selections of data

APPENDIX 2

LAND-COVER CLASSES SUITABLE FOR SOLAR AND WIND ENERGY PRODUCTION

Code	CORINE Land-Cover 2006 class	Wind facilities	Solar facilities
111	Continuous Urban Fabric		X
112	Discontinuous Urban Fabric		X
121	Industrial or Commercial Units		X
122	Road and Rail networks		
123	Sea Ports		
124	Airports		
131	Mineral extraction sites		
132	Dump sites		
133	Construction sites		
141	Green Urban areas		
142	Sport and Leisure facilities		
211	Non-irrigated arable land	X	
213	Rice fields		
221	Vineyards	X	
222	Fruit trees and berries plantations		
231	Pastures		
242	Complex cultivation patterns		
243	Land principally occupied by agriculture with are*	X	
311	Broad Leaved forest		
312	Coniferous forest		
313	Mixed forest		
321	Natural grassland	X	
322	Moors and heathlands		
324	Transitional woodland scrub	X	
331	Beaches, dunes, sand		
332	Bare rocks	X	
333	Sparsely vegetated areas	X	
334	Burnt areas	X	X
411	Inland Marshes		
412	Peat Bogs		

Code	CORINE Land-Cover 2006 class	Wind facilities	Solar facilities
421	Salt Marshes		
422	Salines		
511	Water courses		
512	Water bodies		
521	Coastal lagoons		
523	Sea and ocean	X	

APPENDIX 3

DISTRIBUTION OF SOLAR AND WIND POTENTIAL BY DISTRICT (NUTS3)

District	Potential for solar energy			Potential for wind energy		
	Power (MW)	Suitable territories		Power (MW)	Suitable territories	
		Area (km^2)	Relative share (%)		Area (km^2)	Relative share (%)
Burgas	429.2	225.2	2.9	14312	1792.6	23.2
Blagoevgrad	183.0	112.7	1.7	828	176.4	2.7
Dobrich	462.1	261.3	5.5	25548	3193.5	67.8
Gabrovo	194.1	113.4	5.6	220	39.7	2.0
Haskovo	274.3	179.7	3.3	2023	259.6	4.7
Jambol	249.4	137.4	4.1	6205	775.6	23.1
Kyustendil	147.6	83.2	2.7	1027	231.3	7.6
Kardzhali	97.4	60.8	1.9	5083	713.1	22.2
Lovech	269.7	159.9	3.9	320	76.3	1.8
Montana	331.0	173.4	4.8	318	70.2	1.9
Pazardjik	239.6	133.2	3.0	397	99.2	2.2
Plovidv	596.2	305.2	5.1	546	111.0	1.9
Pernik	178.5	110.5	4.6	1455	363.7	15.2
Pleven	564.4	276.3	5.9	0	0.0	0.0
Razgrad	245.3	146.7	6.1	6969	871.2	36.1
Ruse	393.3	179.8	6.3	457	57.1	2.0
Sofia	404.4	227.7	3.2	2967	718.9	10.2
Shumen	328.7	194.2	5.7	8102	1013.0	29.9
Silistra	248.8	156.7	5.5	6048	756.0	26.5
Sliven	280.5	140.9	4.0	1674	260.4	7.4
Smolyan	68.4	42.7	1.3	1746	410.7	12.8
Sofia (capital)	517.3	217.0	16.2	283	70.8	5.3
Stara Zagora	445.3	240.1	4.7	850	128.9	2.5
Targovishte	251.5	172.2	6.4	3426	430.2	15.9
Varna	440.1	240.5	6.3	10264	1283.0	33.6
Vidin	209.4	130.1	4.3	1141	158.9	5.2
Vratsa	435.1	217.3	6.0	85	12.1	0.3
Veliko Tarnovo	530.8	277.2	5.9	729	100.1	2.1

APPENDIX 4

BULGARIAN RENEWABLE ENERGY STRATEGY

Legal and regulatory background

The use of renewable energy sources (RES) in Bulgaria's energy mix is a priority in the energy policy agenda. In line with EU requirements, the Government of Bulgaria has set a target of 16% as the share of RES in total energy consumption in 2020. Transport is the only sector with a mandatory sector-specific target as per EU obligation: 10% of energy consumed must originate from RES production by 2020.

In order to achieve these targets, Bulgaria has recently developed legal, regulatory and policy framework defined by the following key documents:

- New Renewable Energy Resources Act (June 2011),
- Energy Strategy of the Republic of Bulgaria till 2020 (June 2011), and
- National Renewable Energy Action Plan (June 2010).

The New Renewable Energy Resources Act passed in June 2011 is the most important recent change in Bulgaria's RES strategy. It confirms the main national financial support scheme for RES development: the Feed-in Tariff (FiT) system. The FiT system guarantees a fixed off take price (by NEK as RES-E buyer) for RES producers over a period of 12 years (wind and hydro) and 20 years (all other RES plants). This will remain the major economic incentive mechanism to meet renewable energy targets. Besides the FiT system, the Bulgarian Government provides other support measures for producers of electricity from RES through its recently developed new RE policy framework. These include:

- priority connection to the grid: The Transmission System Operator (TSO) and Distribution Companies (DISCOs) are obliged to connect RES facilities with priority. As per the New Renewable Energy Resources Act, RES producers face shallow connection costs. This means that operators cover all costs associated with the connection up to the boundary of the generation facility. The costs from the boundary of the facility to the connection point are borne by the TSO or DISCO.
- issuance of certificates of origin: The State Energy and Water Regulatory Commission (SEWRC) issues certificates of origin for the RES electricity. The validity of these certificates in other EU Member States is based on the principles of reciprocity. The certificates of origin are tradable within the EU.
- investment incentives: To promote RES, the Bulgarian Energy Efficiency and Renewable Energy Credit Line has been set up. The Fund provides grants of up to 20% of the disbursed loan principle for RES projects financed prior to 30 September 2009 and up to 15% grants for financing received after that date. However requirements for these funds are strict and mainly limited to small RE facilities.

According to the National Action Plan for Energy from Renewable Sources, the total technical potential for generation of energy by RES in Bulgaria is approximately 4 500 ktoe per year. Biomass and hydropower account for a combined 63% of the technical potential (34% and 29% respectively). Particular emphasis in the RE strategy is put on maximising the utilisation of these RES sources. Solar and wind energy representing 9% and 7% of the estimated energy potential respectively are also expected to contribute to the RES target by 2020, albeit with a much smaller share than hydro and biomass.

RES integration into the power market

As noted in the previous section, the main incentive support measure for RES electricity (RES-E) production is the FiT system. SEWRC sets the limit of RES capacities which can be connected to the network, every year by territory, voltage and type of RES. In the near future, there are annual capacity quotas for investors willing to apply for a grid connection contract. These quotas are determined by SEWRC and announced each June. The quota will define the maximum number of projects to be processed each year.

NEK has the obligation to buy the electricity from RES for the period of 12 years (wind and hydro) and 20 years (all other RES plants) at the FiT. The FiT is determined by SEWRC every year for new projects on the basis of a pre-defined methodology. The FiT is determined by the cost of the equipment (which is expected rapidly to decrease in the solar panel market). FiTs for existing projects do not change over the lifetime of these projects.

The participation in the FiT scheme exempts RE generators from trading on the deregulated market and from payment of charges for grid access. Generators are also not responsible for balancing when participating in the FiT scheme. RES-E producers can however choose not to participate in the FiT support scheme, in which case they are allowed to trade freely in the market, pay charges for grid access and be responsible for balancing.

NEK or other suppliers (if the generator is not connected to transmission system) are obliged to purchase RES-E, except those quantities for which the producer has contracts on the deregulated electricity market or which that have been sold in the balancing market. Even though participation in the FiT scheme is optional, all RES producers choose to participate as the FiT level is set higher than market prices. Also, the volatility of solar and especially wind production make it difficult for RES generators to forecast their production levels and balancing costs could therefore be substantial.

Procedures for RES integration

Ordinance 6 of 2004 sets out the grid connection procedures, universal to all RES installations, irrespective of whether they are connected by a DISCO or the TSO[25].

Figure 23: shows the steps that need to be followed for RES projects before operations can start.

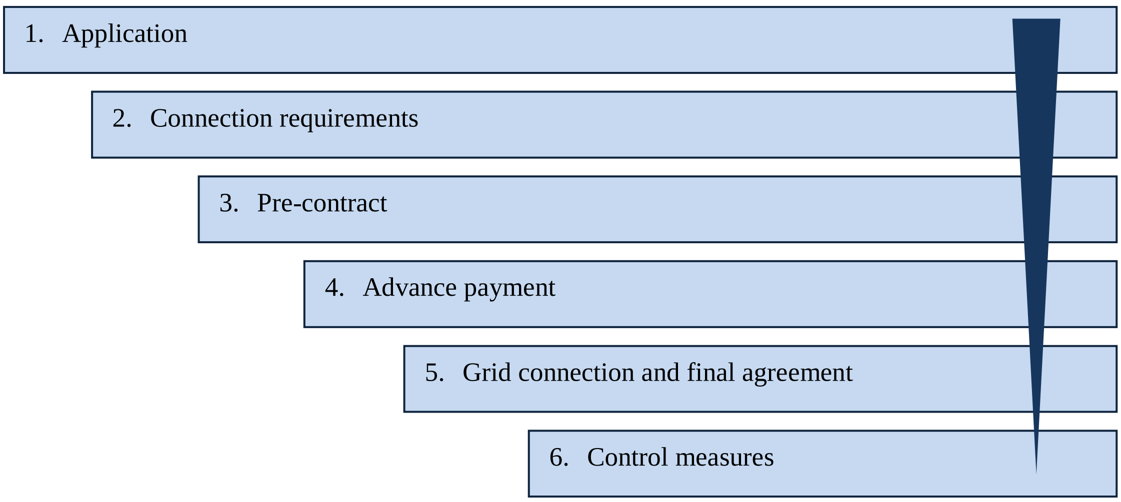

Figure 23: Procedure for grid connection of RES projects

Each of the steps is briefly outlined in the following

1. Operators apply for a connection
2. The operator must prove that the location where the RES-E plant is installed belongs to or is rented by the applicant, while the plant itself has to fulfil the technical and security requirements defined by the Energy Act.
3. Upon fulfilment of all technical requirements, a pre-contract has to be concluded, in which the RES plant's capacity is defined and guaranteed. The pre-contract has a validity of one year.
4. For the connection to the high-voltage grid, as well as to the distribution grid, a connection price should be paid to TSO or DISCO. The validity of the period for which connection is guaranteed is two years and starts upon payment of the connection cost. The connection price is currently fixed at:
   - BGN 25,000 (€12,820) for each installed MW up to 5 MW;
   - BGN 50,000 (€25,640) per MW for installations above 5 MW.
5. the RES-E installation is constructed by the operator and connected to the grid. It is also tested and approved by construction control authorities. Once approved the facility can start feeding electricity into

[25] DG Energy (2011)

the system. Only once the plant has been put into operation, the final agreement is concluded and FiT levels are set.

6. Step 6: SEWRC monitors whether RES plants are granted priority connection. In case RES plants have not been given priority, SEWRC sets a financial penalty on the grid operator for failure to connect RES producers

APPENDIX 5

AVERAGE WIND SPEED AT SELECTED STATIONS

Station Name	Latitude	Longitude	Elevation (m)	Wind speed at 10m (m/s)
Ahtopol	42.08	27.95	31	4.63
Emine	42.70	27.90	55	7.44
Burgas	42.48	27.48	21	6.46
Karnobat	42.65	26.98	194	4.79
Blagoevgrad	42.02	23.10	416	5.39
Sandanski	41.57	23.28	206	4.93
Dobrich	43.57	27.83	251	4.38
Kaliakra	43.37	28.47	60	6.88
Shabla	43.53	28.62	6	6.09
Sofia	42.65	23.38	586	4.04
Dragoman	42.93	22.93	715	4.98
Chernivryh	42.62	23.27	2286	9.41
Murgash	42.83	23.67	1687	8.99
Musala	42.17	23.58	2925	7.96
Elhovo	42.18	26.57	139	4.90
Chirpan	42.20	25.33	173	4.58
Kazanlyk	42.62	25.40	392	4.98
Kjustendil	42.27	22.72	520	4.54
Kyrdjali	41.65	25.37	331	6.14
Lom	43.82	23.22	32	5.30
Montana	43.42	23.22	202	5.04
Lovech	43.13	24.73	220	4.84
Botev	42.72	24.92	2376	9.61
Plovdiv	42.07	24.85	154	5.09
Pazardjik	42.22	24.33	212	5.40
Kneja	43.48	24.07	117	5.26
Pleven	43.42	24.63	160	5.18
Razgrad	43.52	26.52	345	4.74
Rojen	41.88	24.73	1750	4.36
Ruse	43.85	25.95	46	5.80
Silistra	44.12	27.25	16	5.26
Sliven	42.67	26.32	259	5.69
Varna	43.20	27.95	39	5.75
Svishtov	43.62	25.35	24	5.96
Veliko tarnovo	43.08	25.65	195	4.48
Novoselo	44.17	22.77	36	5.43
Vidin	43.99	22.85	31	4.11
Orjahovo	43.72	23.97	29	5.74
Vraca	43.20	23.53	309	4.92

Distribution of meteorological monitoring stations in Bulgaria

Meteorological Stations and Data and Wind Speed
Source: NIMH[26]

[26] Average values are calculated from detailed each three hour recording for 10 years (1996 - 2005) of NIMH

B. Annex II: Assessment of the wind and solar energy potential in Turkey and forecasts by 2050

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1 Introduction

One of the most important aims of the EnviroGRIDS project is to contribute Global Earth Observation Systems of Systems (GEOSS), which is being built by the Group on Earth Observations (GEO) on the basis of a 10-Year Implementation Plan running from 2005 to 2015, by providing data/information available at Black Sea Catchment. GEOSS is building a data-driven view of Earth that feeds into models and scenarios to explore past, present and future. The Fifth Work Package of the EnviroGRIDS Project mainly works on providing data/information to GEOSS system in terms of Societal Benefit Areas (SBAs) already considered by GEO. Partners contributing the Task 5.4 directly deal with Energy SBA. Task 5.4 does not only provide the results of the Renewable energy potential and forecasting in contributing countries as a report but it also contributes to GEOSS by providing maps of the result of the studies executed within this task.

The National Report of Turkey was prepared by a collaborative work of ITU and BSREC. In this context, BSREC, as the energy specialist in energy issues, took the responsibility of assessment of the wind and solar energy potential in Turkey together with the responsibility of preparing wind and solar energy forecasts for Turkey. ITU provided the main data that used in assessment and forecasting processes. Stated data includes meteorological data recorded at 41 meteorological monitoring stations, which are distributed in the study area, for the period of 2000-2009 and available literature data already published in national reports and scientific studies on energy, official statistics official statistics and data provided by companies producing energy or services in the relevant areas. ITU is also responsible for preparing the parts related with "Evaluation of Meteorological Data Used Solar and Wind Power Potential Assessment Studies in Turkey" and general overview of "Legal Framework for Wind and Solar Energy in Turkey" together determination of the mapping methodology used in mapping the results of the study for Bulgaria and Turkey.

According to this task allocation, BSREC prepared a report on the assessment of the wind and solar power energy and forecasting wind and solar energy potential by the year of 2050. In this national study, the same methodology, which was also applied for assessment and forecasting wind and solar energy in Bulgaria, was mainly used. BSREC developed two main scenarios – maximum and minimum development of RES (solar and wind).

As a result, this part of Deliverable 5.6 covers the National report of Turkey. Regarding the task allocation for preparation of this report, the progress report prepared by BSREC including the information related with Chapters 3-7 were reviewed and reported by ITU. The Chapter 2 and Chapter 8 were formed by ITU by considering the overview of the existing and available information on legal and technical issues on wind and solar energy studies.

2 Evaluation of Meteorological Data Used Solar and Wind Power Potential Assessment Studies in Turkey

Turkish State Meteorological Service (TSMS) operates a meteorological observation system (Figure 1) which consists of 440 stations. These stations are categorised as below[27]:

- 110 Synoptic stations for weather forecasting
- 55 Meteorological stations at airports
- 420 Climatological Stations
- 7 Radiosonde stations
- 4 Radar stations

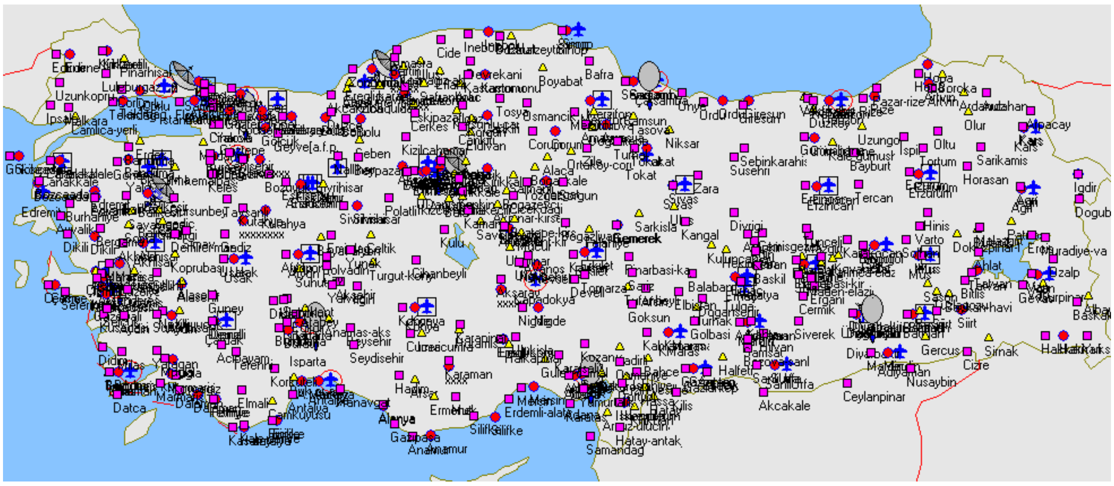


Figure 24. Turkish State Meteorological Service (TSMS) operates a meteorological observation network

The 420 stations which collect climatological data are basically categorised as Major Climate Stations and Minor Climate Stations. The distribution of major and minor climate stations is shown in Figure 2. The distribution of the synoptic stations is also presented in Figure 3.

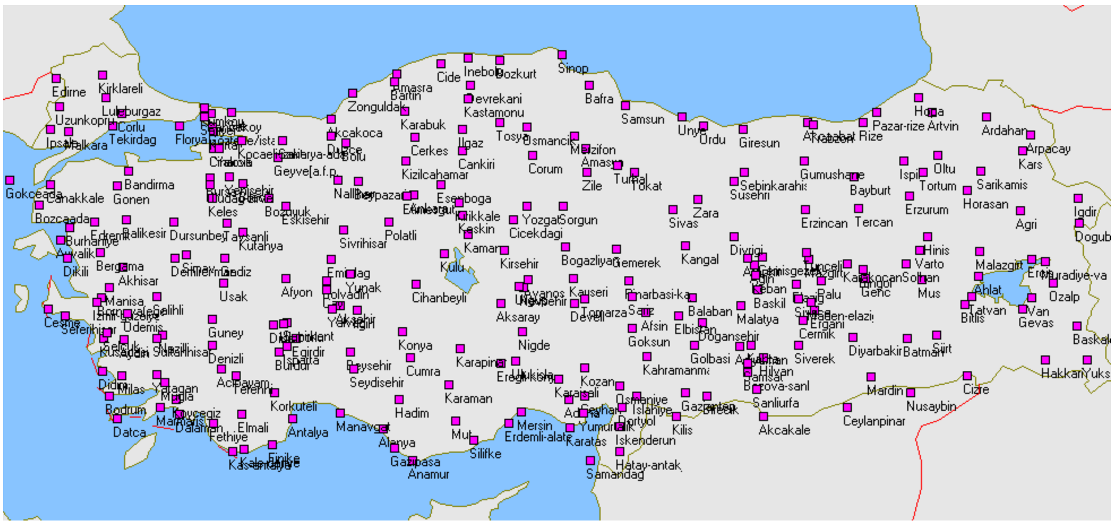


Figure 25. Climatological stations (Major climate and Minor climate stations)

[27] Database for Monitoring Station Information, the official website of State Meteorological service, http://www.dmi.gov.tr/kurumsal/istasyonlarimiz.aspx?sSirala=AL&sStatu=tm

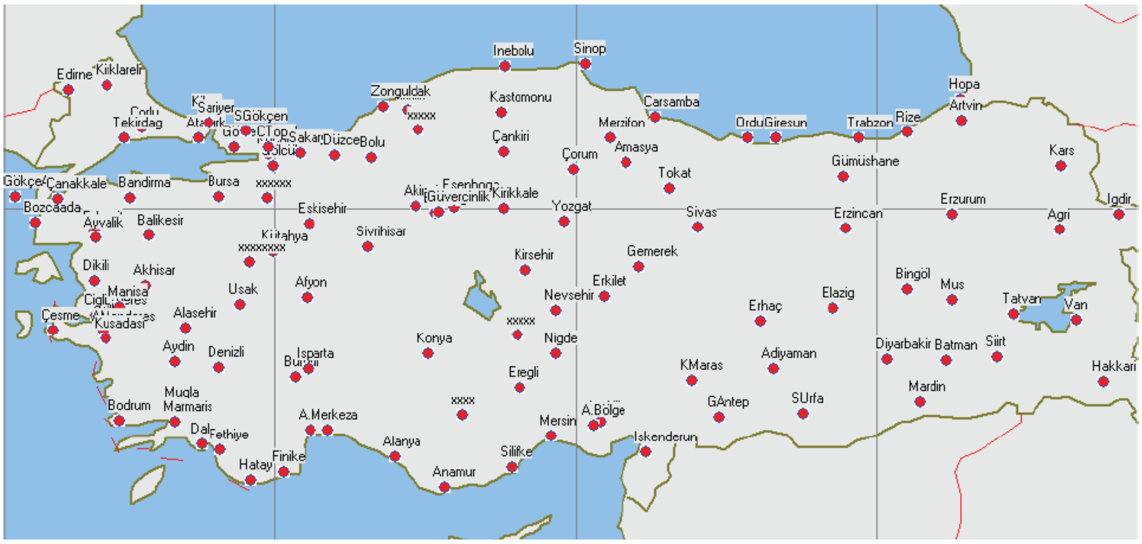


Figure 26. Distribution of the synoptic stations in Turkey

The meteorological parameters monitored at major and minor climate stations are listed in Table 1.

Table 1. Meteorological parameters monitored at major and minor climate stations

Major Climate Stations	Minor Climate Stations
• Local pressure(Mb.)	• Max. Temperature (°C)
• Sea level pressure (Mb.)	• Min. Temperature (°C)
• Max. Temperature (°C)	• Top Soil Min. Temperature (°C)
• Min. Temperature (°C)	• Dry Thermometer Temperature (°C)
• Top Soil Min. Temperature (°C)	• Wet Thermometer Temperature (°C)
• Dry Thermometer Temperature (°C)	• Relative Humidity (%)
• Wet Thermometer (°C)	• Cloudiness
• Relative Humidity (%)	• Type of Cloudiness
• Cloudiness	• Wind Speed & Direction (m/sn.-16 -360°)
• Type of Cloudiness	• Precipitation (mm.)
• Horizontal sight (km.)	• Thunderstorm observations
• Solar Radiation (Cal/ cm².dak)	
• Sunshine hours (hr)	
• Wind Speed & Direction (m/sn.-16 direction-360°)	
• Precipitation (mm.)	
• Snow cover thickness (cm.) and density (kg/cm)	
• 5, 10, 20, 50, 100 cm. Soil Temperature	
• Thunderstorm observations	

2.1 Wind Measurement

2.1.1 Wind Measurements in General

Wind resource assessment measurement campaigns have traditionally been conducted with mast based instrumentation consisting on cup anemometers and wind vanes. Such measurement campaigns used as baseline by energy analysts remain to be the mostly implemented with this type of instruments.

Additionally, other meteorological instruments like temperature, pressure and humidity sensors are being used. Wind monitors (propeller anemometers that measure both the wind speed and direction) have a limited use (around 18%), while sonic anemometers and remote sensing instruments (lidar, sodar and satellites) are used more commonly by the consultants or researchers.

Wind energy developers and manufacturers stick to the standard mast configuration for long-term measurement campaigns. Sonic anemometers or remote sensing instruments are still far from being standard instruments in wind assessment although they are being used more and more by consultants and researchers for detailed measurement campaigns or power performance testing.

Time span of the measurement campaigns is mostly very limited and it is necessary to extrapolate in time to a period of at least 20 years in order to predict the long-term average energy yield. At this point, Measure-Correlate-Predict (MCP) methods are used, which is very important for the wind energy developers.

For the preparation of Turkish Wind Atlas, hourly wind data spanning the years 1989 – 1998 from 45 meteorological stations homogenously distributed around Turkey. Majority of the wind measurements were taken at 10 height and measurements at taken from different heights were approximated to 10 m. According to the World Meteorology Organisation, the Standard measurement height is 10 m for in-land wind measurements intended for meteorological purposes (climatological, synoptic, air pollution, etc.).

In the case of wind measurements intended for energy potential assessment, parameters such as wind speed, wind direction and terrestrial temperature shall be measured periodically at 30m and at the intended turbine height for a minimum of 1 year and determined as a data set suitable for evaluation via computer applications. It is also important to measure other parameters such as pressure, temperature and humidity which are used to calculate the air density.

Table 2. Parameters measured and heights

Measurement Height (m)	Parameter
2	Temperature, Pressure
10	Wind speed
20	Wind speed
30	Wind speed, Wind direction

2.1.2 Wind Measurements in Turkey and Related Projects

In the case of Wind Energy Potential Atlas (WEPA) of Turkey, data obtained from the TSMS, EIE wind power measurement stations (Figure 5) and neighbour countries in 2006 were used.

WEPA has been produced through running of 3 different numerical air analysis models (global scale, mesoscale and micro scale) consecutively. Global air archive data, data from meteorological stations, numerical satellite images, numerical topographical models and off shore meteorological data were used to run these models.

However these maps and tools only provide a very basic and rough data which could be useful for decision maker who intend to prioritize investment regions and or investors to narrow down possible investment regions.

In the case where a particular wind power investment is planned, a proper wind assessment is the foundation for a feasible wind energy project. Here proper measurement and data collection become the crucial step. Experts' opinion is that it is not possible to prepare a good Technical Due Diligence (TDD), based on wind data, collected on a 50 m mast with NRG sensors, the mast being 10 km away from the project area. TDD which is prepared based on proper input data enables the developer to understand the feasibility of his project before bidding with TEİAŞ.

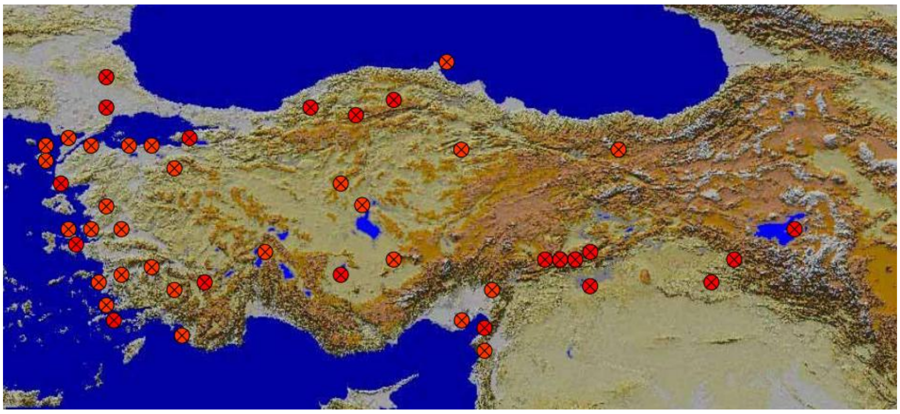


Figure 27. EIE wind power measurement stations

The RITM Project: Development of a Monitoring and Forecast System for the Electrical Power Generated from Wind in Turkey

The RITM project aims to serve to the integration of the Wind Power Plants (WPPs) into the Electricity System of Turkey. A wind power monitoring and forecast system will be developed and this system will be made widespread over the whole electricity system in the country[28]. The project is implemented by three national partners which are; General Directorate of Electrical Power Resources Survey and Development Administration (EIE), TÜBİTAK -UZAY (The Scientific and Technological Research Council of Turkey - Space Technologies Research Institute) and TSMS.

The project is designed to realize large-scale electrical power generation out-of wind sources in Turkey and to define the necessary countermeasures for the integration of the WPPs into the electricity system, involves development of five subsystems:

- WPP Measurement Subsystem
- Wind Forecasting Subsystem
- Forecasting Subsystem for Electrical Power Generated from Wind
- Monitoring and Forecast Center Subsystem
- Client Subsystem

The overall system of Wind Power Monitoring and Forecast, which is planned to be developed though the project, is illustrated in Figure 6. The general operation of the five subsystems altogether can be summarized as follows:

Meteorological information such as heat, wind speed, and direction at the existing WPPs are collected by the wind observation stations, whereas the "turbine status" are obtained from the SCADAs at the WPPs. Additionally, "wind power analysers" installed at the transformer substations of the WPPs are used to measure electrical quantities such as current, voltage, and power. The collected data is immediately transmitted to the Wind Power Monitoring and Forecast Center (WPMFC). In addition to the data coming from the WPPs, meteorological forecasts obtained by the TSMS are regularly input to the WPMFC in particular time intervals. All the data is collected through the data accumulator software at the WPMFC and is managed by a database system developed specifically for the WPMFC. Based on the systematically collected data, wind-generated power forecasts are constituted individually for all WPPs, for the next 48 hours.

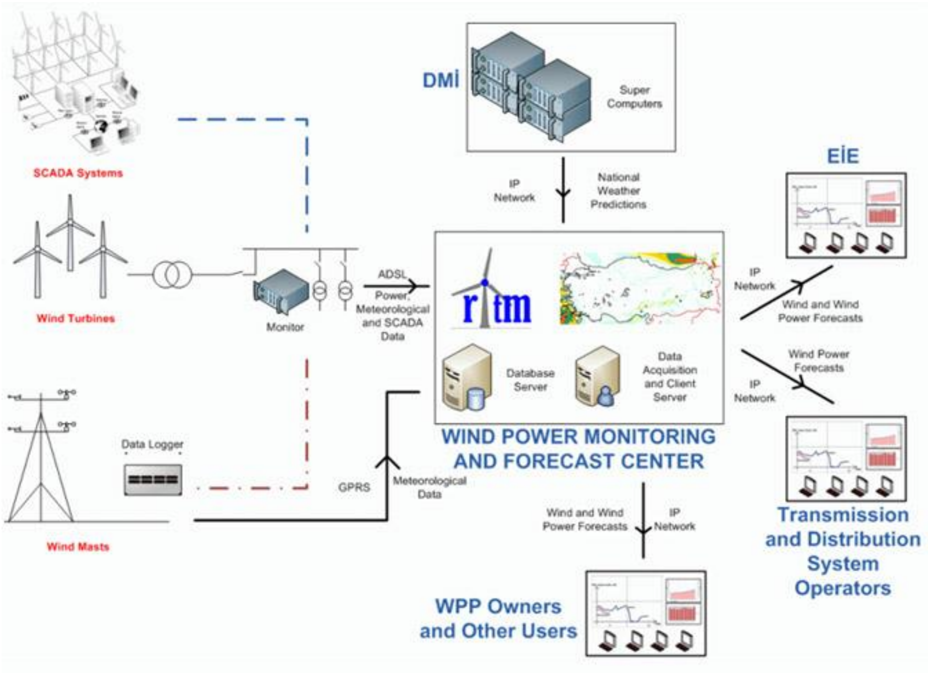


Figure 28. Overall system of wind power monitoring and forecast

[28]RITM Project, official website, http://www.uzay.tubitak.gov.tr/ritm/en/project/

2.1.3 Wind Power Plant Status in Turkey

The wind power development in Turkey started with a 1.5 MW capacity wind turbine installation in 1998. The plant consisted of three 500 kW wind turbines erected in Cesme-Germiyan.

Implementation of wind power plants have increased drastically in the recent years. The total wind power capacity was 20 MW at the end of 2005, and then the wind power market witnessed an impressive growth. 528 MW of new wind power installations, referring to an annual growth rate of 66%, was implemented in 2010. The total installed wind power capacity reached 1,329 MW and this represents more than 2% of the overall electricity generation capacity of Turkey. The introduction of wind generation support mechanisms in 2005 and the subsequent amendment in 2007 helped the Turkish wind energy market to experience such a remarkable progress.

Current wind power projects in operation in Turkey are shown in Figure 7, which is the Turkish Wind Power Plant Atlas published by Turkish Wind Power Plants Association (TWPPA) in 2011. Detailed information on wind power plants together with their location, installed capacity, commission date and turbine manufacturer data can be found in TWPPA web-site[29].

Figure 29. Wind power plant atlas of Turkey, 2011

2.2 Solar Measurement

2.2.1 Solar Measurements in General

Different measurement devices are used for measuring solar radiation as explained below;

- Direct Normal Radiation: Direct radiation is best measured by use of a pyrheliometer, which measures radiation at normal incidence. For continuous readings Pyrheliometer is mounted on a solar tracker.
- Global Radiation: Global irradiation is the sum of direct and diffuse radiation. Global irradiation is measured by a pyranometer.
- Diffuse Radiation: Diffuse radiation is measured by shading a pyranometer from the direct radiation (tracking shading balls) so that the thermopile is only receiving the diffuse radiation.

[29] http://www.ruzgarenerjisibirligi.org.tr/attachments/article/112/TURSAT-2011_A3.pdf

2.2.2 Solar Measurements in Turkey

Solar measurements have been taken by TSMS since 1966. However EIE and TSMS have been taking new measurements since 1992 to determine more accurate solar energy data. The parameters monitored, frequency of data, period of data collection and location of measurement sites used for the solar power potential assessment in Turkey are provided in Table 3. A model was developed with the data from the 8 measurement stations of EIE and with the data from the TSMS measurement stations.

The data obtained from the measurement process summarized in Table 3, which was used for the current solar power potential atlas, is considered to be highly insufficient for a proper potential assessment study. The data measurement locations are very few and not all parameters can be measured according to standard methodologies at every site. The solar data measurement and collection process needs to be improved in order to obtain a more accurate and reliable solar potential assessment.

2.2.3 Solar Power Plant Status in Turkey

At present, Turkey does not have an organized commercial and domestic photovoltaic (PV) programme. However, there is good potential for PV applications in the local market since the country is highly suitable due to high rates of solar radiation and available land for PV applications.

The amount of solar collectors installed in Turkey is 12 million m^2. The installed solar cell capacity which is used mostly in public bodies for supplying small amounts of power and for research purposes, has reached 1.5 MW.[30]

Table 3. Measurement of solar data for solar power potential assessment in Turkey

Parameters Measured	Data	Stations and measured years
- Global Solar Radiation (Wh/m²) - Diffuse Radiation (Wh/m²) - Sunshine Hours - Temperature	- Hourly - Daily, - Monthly Average	Ankara (1995-1996), (2002-2003), (2008) Antalya (1993) İzmir (1997-1998) Aydın (1998), (2010-2011) Adana (1997-2005) Isparta (2001-2007) Kayseri (1998 – on going) Balıkesir (2000 - on going) Erzincan (2005 - 2009) Yalova (2005 - on going) Bodrum (2000 - 2001) Yozgat (2009- on going) Birecik (2010- on going)

Istanbul Metropolitan Municipality, TUBITAK Marmara Research Center and Inosol Energy are jointly implementing a solar project in Istanbul. The project realized the first locally manufactured solar collector field in İkitelli, Istanbul. The installed power of the solar field is 500 kW which is currently being increased to 2 MW. Successful implementation of the project will enable multiplication of such solar fields in places where there is high electricity consumption such as airports, shopping mall, etc. The project being designed by Turkish engineers and using 100 % locally manufactured equipment lists Turkey among the five countries that are able to produce solar energy technology which include Spain, USA, Germany and Israel.

2.3 Wind Power Potential Assessment Studies in Turkey

The occurrence of wind and the magnitude of wind speed are mainly determined by the topographic characteristics of a location. The sites where there is a land-sea intersection are supposed to be primary windy areas with stable conditions for wind speed and direction. Secondary areas for windy conditions are valleys, due to high variations between heating and cooling effects in a day period. The geographical position of Turkey allows the country to enjoy the potential offered by both conditions.

Turkey is located between Europe and Asia, connecting these two continents. The country is surrounded by seas on three sides; the Black Sea in the north, the Marmara and the Aegean Sea on the west, and the Mediterranean Sea in the south. The surface area of land is 781,000 km^2.

[30] http://www.emo.org.tr/ekler/9f2051206250683_ek.pdf?dergi=5

Turkey enjoys three main climatic regions in its coastal regions including the Black Sea, Aegean Sea and Mediterranean Sea; in the moderately mountainous regions alongside the coastal regions, and in the rocky plateaus in the central and eastern parts. Etesian winds blowing especially in the summer season from a N-NE direction in western Turkey provide a potential area for wind power generation. In central parts of Turkey, high wind velocities are observed due to the presence of deep valleys and high plateaus. During the wintertime, high pressure systems from Siberia and the Balkan Peninsula, as well as low- pressure systems from Iceland influence this region. Air clusters coming over the Black Sea also affect the wind characteristics of Turkey.

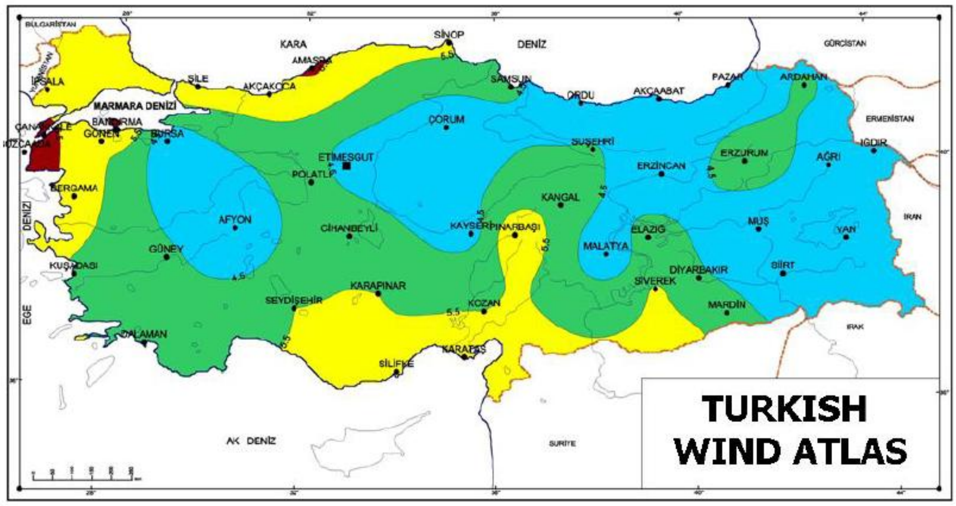
There have been several methods for the estimation of wind potentials. Turkish Wind Atlas (Figure 8) was prepared by using WAsP (Wind Atlas Analysis and Application Program) model used for European Wind Atlas. In this study, onsite surveys have been done for 96 meteorological stations, distributed homogeneously over Turkey, and 45 of these stations were used for the preparation of the Atlas. Turkish Wind Atlas was prepared and published by State Meteorological Services and Electrical Power Resources Survey and Development Administration in 2002.

WAsP model requires 4 different parameters for the calculation of wind resources. These parameters are;

i. hourly wind data,
ii. roughness of the terrain,
iii. obstacle information,
iv. topography of the region.

This model has some sub-models for the calculation of the environmental effects on observed wind data such as the effects of obstacles, roughness and orography.

Wind data used in this study were measured hourly at the State Meteorological Observation Stations between the years 1989 and 1998. These measurements have been obtained at 10 m above ground level. The data measured at different height are extrapolated to 10 m by WAsP. The obstacles around the measurement point were defined by onsite surveys for all stations. The orography and the roughness information for the selected regions were obtained by using topographical maps.



Wind resources at 50 m above ground level for open plains (roughness class 1)

v (m/s)	> 7.5	6.5 – 7.5	5.5 – 6.5	4.5 – 5.5	< 4.5
P (W/m²)	> 500	300 - 500	200 - 300	100 - 200	< 100

Figure 30. Turkish wind atlas

Later in 2005, with the need for obtaining more accurate data about the characteristics and distribution of Turkey's wind energy resources in order to assess the wind power potential of the country, General Directorate of Electrical Power Resources and Development Administration implemented a new project. The deliverable of this project was the Wind Energy Potential Atlas (WEPA), a wind energy potential map of the country with 200x200 m. resolution, which was published in 2006. The Weather Research and Forecasting (WRF) model and some other regional models are applied to compute the numerical potential of the country. The outputs of WEPA can be listed as:

- Annual, seasonal, monthly, and daily average wind speed values at different heights, e.g., 30, 50, 70 and 100 m. Wind speed distribution of the country at 30 m is presented in Figure 9. Figure 10 shows a 3-D view of WEPA indicating annual average wind speeds at different heights.

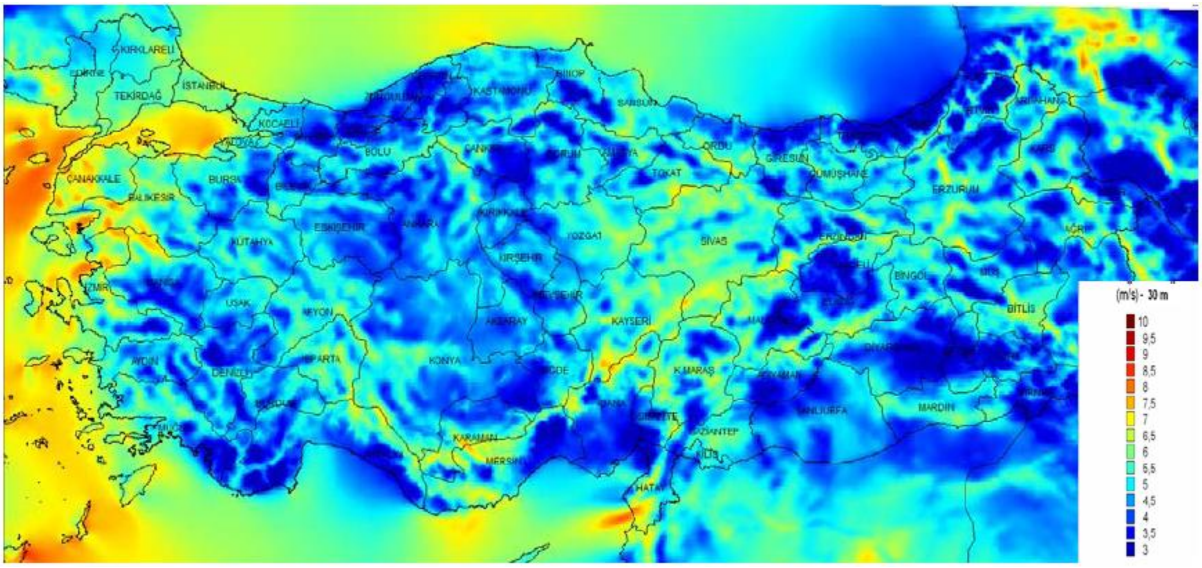


Figure 31. Wind speed map of Turkey (at 30 m)

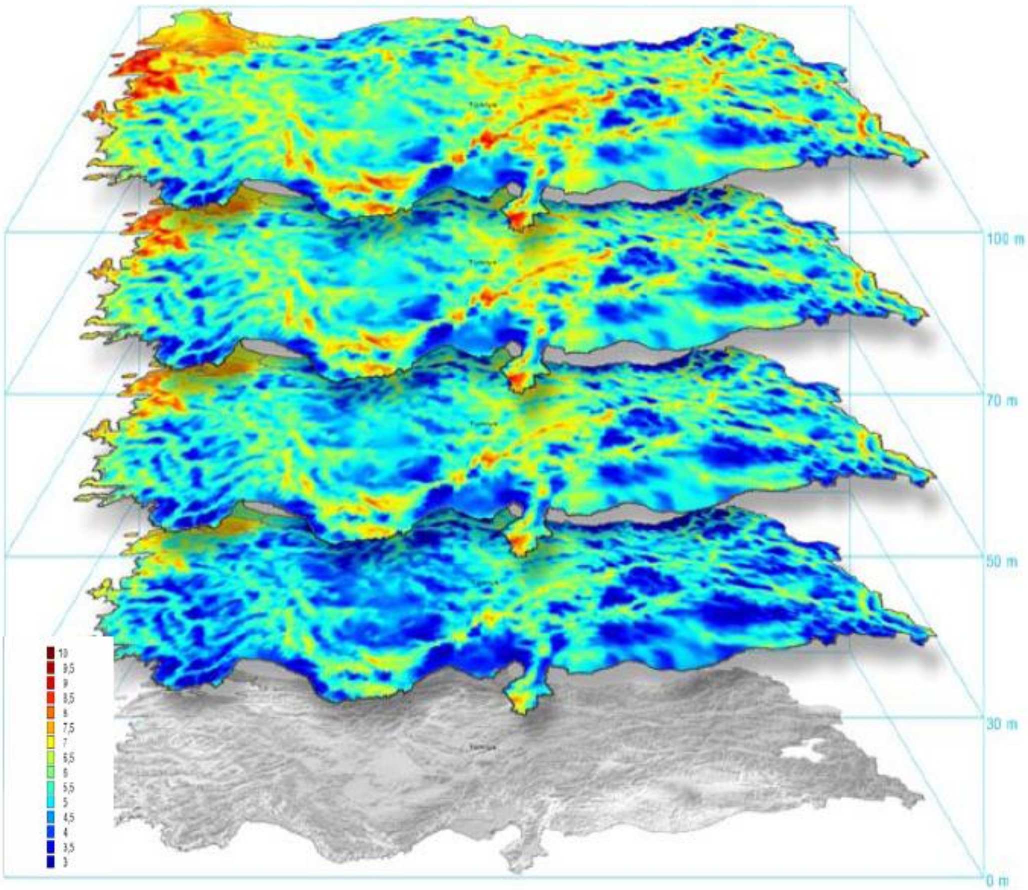


Figure 32. A 3-D View of WEPA indicating annual average wind speed

- Annual, seasonal, and monthly wind power densities at 50 and 100 m. Figure 11 indicates the annual wind power density at a height of 50 m.

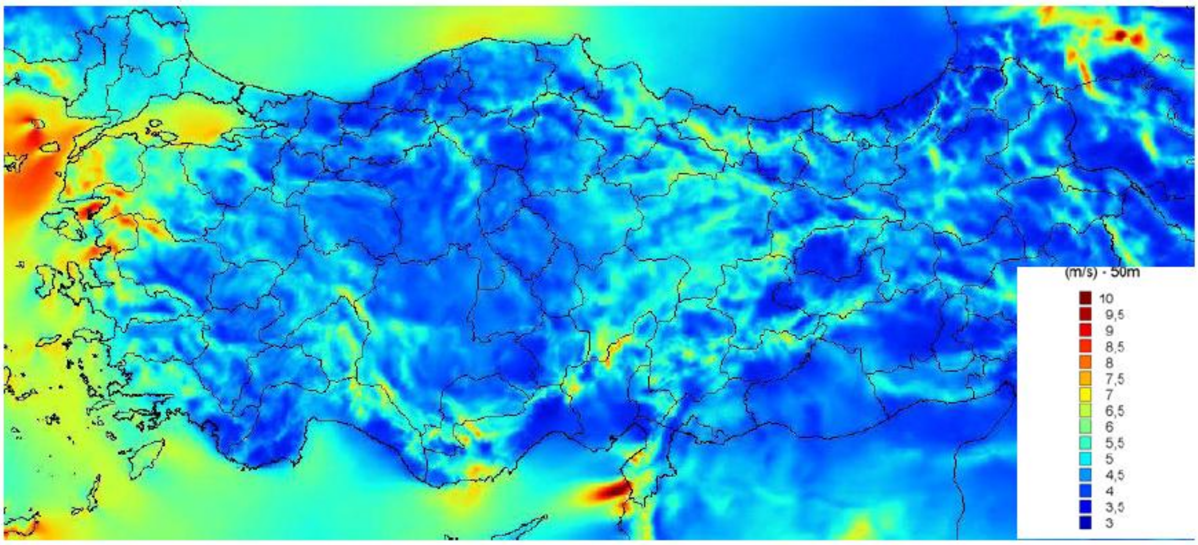


Figure 33. Wind power density map at 50 m

- Average capacity factors at 50 m (see Figure 12).

Capacity factor is one of the most significant indicators in the evaluation of a turbine. The capacity factor is defined as the rate of energy produced by the system to the energy to be produced in nominal power. It reflects how efficient the energy is used by the turbine. The lower the speed of a turbine to initiate electric production is, the higher the capacity factor of the turbine. Similarly, the higher the speed of a turbine to exit from electric production is, the higher the capacity factor. On the other hand; entry-exit wind speeds of a turbine are not the only parameters having an impact on capacity factor. The type of the turbine used and the wind regime of the place of installation are also other important parameters.

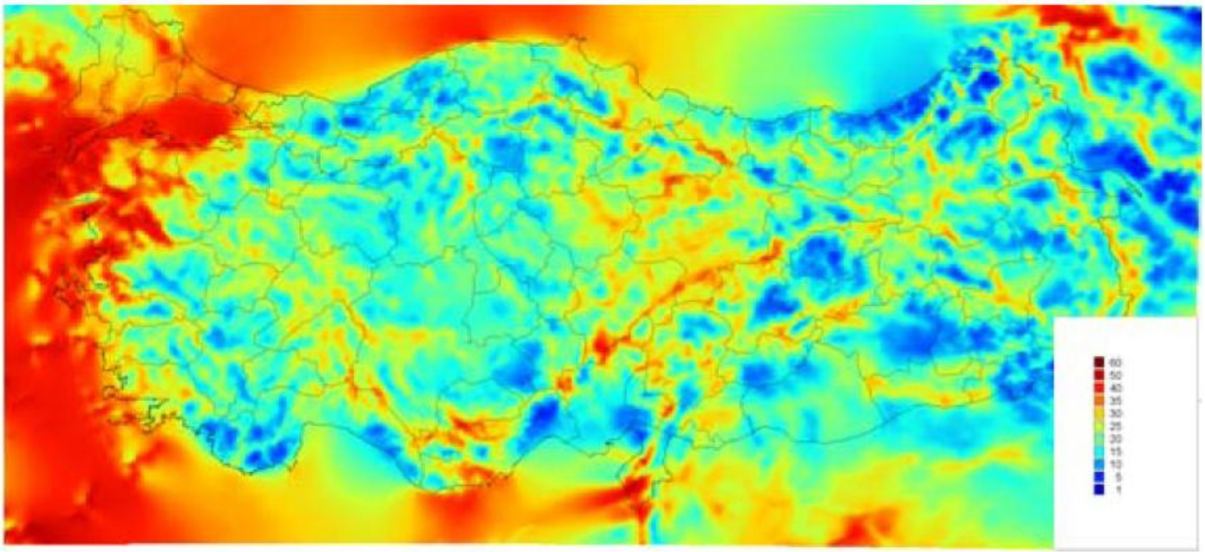


Figure 34. Map indicating capacity factors at 50 m

- Annual average wind clusters at 50 m (Figure 13). WEPA categorizes wind power clusters into seven classes, from weak to outstanding. The characteristics of wind clusters are listed in Table 4.

Table 4. Wind Clusters and Their Properties as categorized in WEPA

Wind Source Grade	Wind Cluster	Wind Speed at 50 m (m/s)	Wind Power at 50 m (W/m^2)
Weak	1	<5.5	< 200
Low	2	5.5 - 6.5	200 – 300
Medium	3	6.5 – 7.0	300 – 400
Good	4	7.0 – 7.5	400 – 500
Very Good	5	7.5– 8.0	500 – 600
Excellent	6	8.0 – 9.0	600 – 800
Outstanding	7	> 9.0	> 800

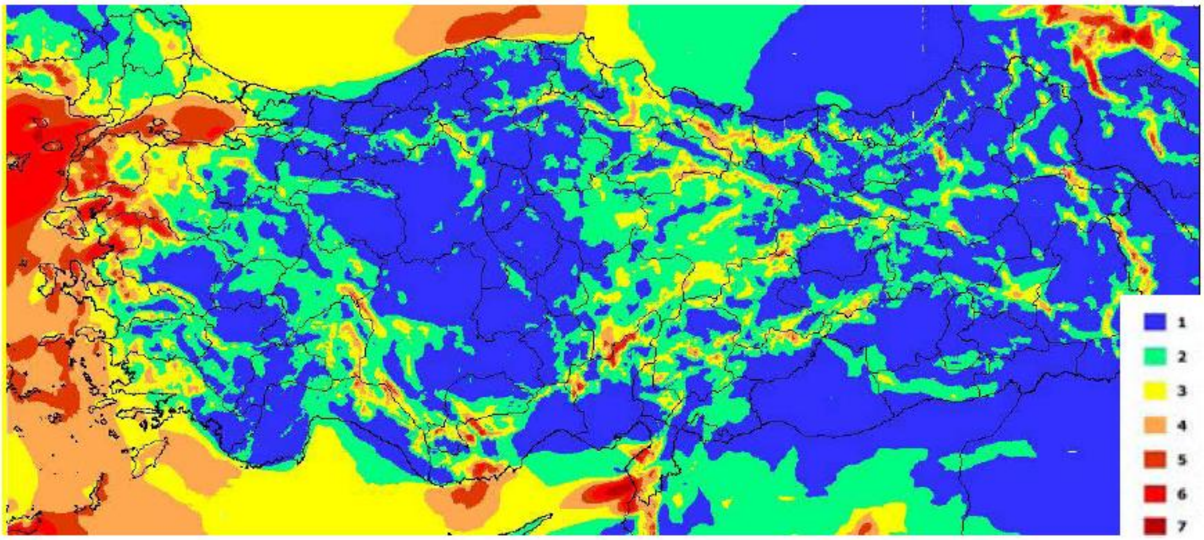


Figure 35. Wind clusters map at 50 m

- Average temperature in degrees at 2 and 50 m.
- Monthly average atmospheric pressures at sea level and 50 m.

The atlas enabled 3-D view of the wind resource parameters and allowed the analysis of variation in wind resource characteristics with respect to time, location, and height.

Information presented by WEPA formed an infrastructure for determination of the favourable regions for wind power generation, which is very important for policy makers, decision makers and investors.

The overall wind power generation capacity has been assessed on a 200x200 m resolution scale by excluding all parameters that may affect electricity generation. More than 20 underlying maps are embedded in WEPA, namely terrain roughness, topography and altitude, sea depth, land slope, residential units and areas, lakes, rivers, wetlands, ports, power transmission lines and substations, power plants, earthquake fault zones, forests, environmental protection areas, bird migration routes, highways, railways and airports. Underlying maps of some other obstacles (mines, oil and natural gas pipelines, military areas, private property, tourism regions and so on) for wind power generation were excluded in WEPA computations. For this reason, the areas that are not favourable to construct wind power plants are increased by certain amounts in specific locations to mitigate uncertainty.

The areas excluded from the capacity calculations are listed as follows:

- Lands with an annual average wind speed of less than 6.5 m/s,
- Lands with an altitude greater than 1500 m,
- Offshore areas with depth greater than 50 m,
- Lakes, rivers, wetlands, and dam reservoirs,
- National parks and other environmentally protected areas,
- The terrestrial lands with an inclination greater than 20%,
- The areas remaining within the 100 m radius safety zone of highways and railways,
- Coastal areas within the 100 m radius zone of coastal protection,
- Lands within 3 km radius to the airports,
- Urban areas and areas within 500 m radius of safety zones.

The overall wind power generation potential of the country at a height of 50 m. is computed under two scenarios after excluding the unfavourable sites as listed above:

- Scenario I. Wind power density greater than 400 W/m2and wind speed greater than 7.0 m/s, that is, starting from “good” to “outstanding” wind cluster is taken into account.
- Scenario II. Wind power density greater than 300 W/m 2and wind speed greater than 6.5 m/s, that is, starting from “middle” to “outstanding” wind cluster is taken into account.

The scenarios assume that capacity of 5 MW can be constructed within a 1 km^2 area. The capacity results are presented in Table 5 and Table 6.

According to Scenario I, which assumed that the wind speed is greater than 7.0 m/s and wind power density is greater than 400 W/m^2 overall wind power generation capacities in Turkey calculated by WEPA is 47,849 MW. The area occupied under this scenario is 9,569.89 km^2 which corresponds to 1.30 % of Turkey's total surface area.

Table 5. Total wind power potential under Scenario I

Wind Source Grade	Wind Cluster	Wind Power at 50m (W/m^2)	Wind Speed at 50m (m/s)	Total Area (km^2)	Windy Area (%)	Total Capacity (MW)
Good	4	400 – 500	7.0 – 7.5	5,851.87	0.79	29,259.36
Very Good	5	500 – 600	7.5– 8.0	2,598.86	0.35	12,994.32
Excellent	6	600 – 800	8.0 – 9.0	1,079.98	0.15	5,399.92
Outstanding	7	> 800	> 9.0	39.17	0.01	195.84
TOTAL				**9,569.89**	**1.30**	**47,849.44**

In Scenario II, which assumes that the wind speed is greater than 6.5 m/s and wind power density is greater than 300 W/m^2, WEPA calculations show that possible overall wind generation capacity is around 131,756 MW. The surface area occupied under this scenario is 6,511 km^2 corresponding to 3.57 % of Turkey's total area.

Table 6. Total wind power potential under Scenario II

Wind Source Grade	Wind Cluster	Wind Power at 50m (W/m^2)	Wind Speed at 50m (m/s)	Total Area (km^2)	Windy Area (%)	Total Capacity (MW)
Medium	3	300 – 400	6.5 – 7.0	16,781.4	2.27	83,906.96
Good	4	400 – 500	7.0 – 7.5	5,851.87	0.79	29,259.36
Very Good	5	500 – 600	7.5– 8.0	2,598.86	0.35	12,994.32
Excellent	6	600 – 800	8.0 – 9.0	1,079.98	0.15	5,399.92
Outstanding	7	> 800	> 9.0	39.17	0.01	195.84
TOTAL				**26,351.3**	**3.57**	**131,756.4**

2.4 Solar Power Potential Assessment Studies in Turkey

Turkey lies in a sunny belt between 36N and 42N latitudes. The yearly average solar radiation is 3.6 kWh/m^2.day and average sunshine duration is 2,640 h, corresponding to around 30% of the year. Solar energy potential in Turkey is shown in Table 7 and Table 8.

Solar energy technologies are not extensively used, except for solar water heaters (SWH) in Turkey. Turkey has a total installed capacity of 12 million m^2 collector area with a total energy production of 420,000 TOE, as of 2007 which increased from a value of 210,000 TOE as of 1998[31].

In Turkey solar energy has a technical potential of 8.8 Mtoe electricity generation and 26.4 Mtoe heating capacity. The SWH are mainly thermosyphon type and consist of two flat plate solar collectors having an absorber area between 3 and 4 m^2, a storage tank with capacity between 150 and 200 L and a cold water storage tank, all installed on a suitable frame. SWH use is limited to supply domestic hot water for about 19% of the housing stock.

[31] http://www.nukte.org/node/163

Table 7. Monthly average solar energy potential of Turkey

Months	Monthly Total Solar Energy (kcal/cm^2-mo.) - (kWh/m^2-mo.)		Sunshine Duration (hr/mo.)
January	4.45	51.75	103.0
February	5.44	63.27	115.0
March	8.31	96.65	165.0
April	10.51	122.23	197.0
May	13.23	153.86	273.0
June	14.51	168.75	325.0
July	15.08	175.38	365.0
August	13.62	158.40	343.0
September	10.60	123.28	280.0
October	7.73	89.90	214.0
November	5.23	60.82	157.0
December	4.03	46.87	103.0
Total	**112.74**	**1311**	**2640**
Ave.	**308.0 cal/cm^2-day**	**3.6 kWh/m^2-day**	**7.2 hour /day**

Table 8. Average solar energy potential of Turkey by regions

Region	Total Solar Energy (kWh/m^2-yr)	Sunshine Hours (hr/yr)
S. Eastern Anatolia	1,460	2,993
Mediterranean	1,390	2,956
East Anatolia	1,365	2,664
Central Anatolia	1,314	2,628
Aegean	1,304	2,738
Marmara	1,168	2,409
Black Sea	1,120	1,971

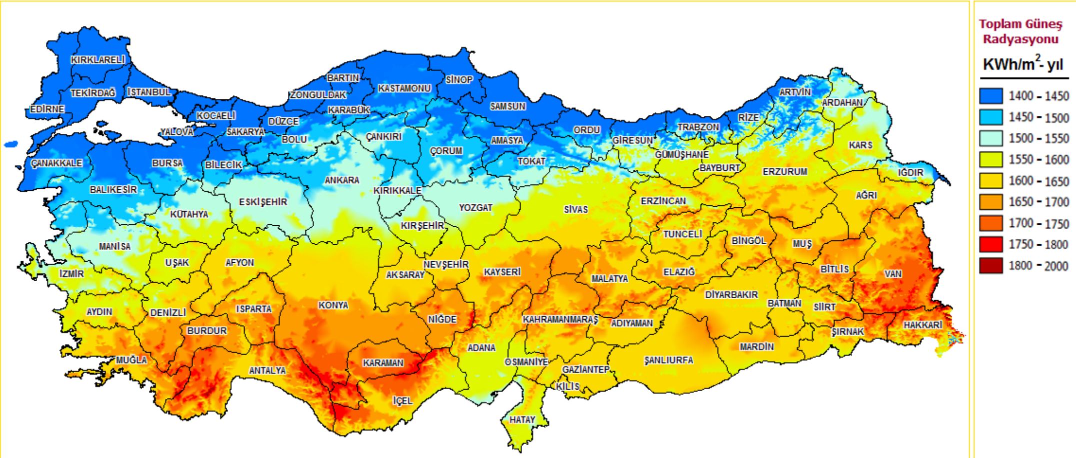
The solar energy potential evaluations made by EIE, based on the data measured by the State Meteorological Services during 1966-1982 revealed:

- The annual average total insolation duration as 2640 hours (7,2 hours/day)
- Average annual solar radiation as 1311 kWh/m^2-year (3,6 kWh/m^2-day)

However it has been recognized that the existing meteorological data indicates a lower value than the actual solar energy of Turkey. EIE and TSMS have been taking new measurements since 1992 to determine the more accurate solar energy data.

A model was developed with the data from the 8 measurement stations of EIE and with the data from the TSMS measurement stations (See Table 3).

Accordingly, the solar radiation and sunshine hours are calculated for 57 cities of Turkey. The Solar Power Potential Atlas indicating the total solar irradiation in Turkey is shown in Figure 14.



The title of the legend: Total Solar Radiation

Figure 36. Solar power potential atlas of Turkey

The model for solar power potential assessment was produced with the "ESRI Solar Radiation Model" used in GIS and the following basic parameters:

- Slope-Shadow Calculations: 500m x 5000m resolution Numerical Height Model generated from 1/100.000 scale topographical maps was used.
- Areas at 36-42 Degrees Longitude
- Sky Size Index
- Zenith and Azimuth angles at 32 directions
- Open and Close Sky Calculation Methods
- Solar measurements data taken by EIE and DMI stations in the period from 1985 to 2006 was used for the calculation of parameters used in the model and calibration of the model.
- Transmittivity and Diffuse Proportion
- Surface Albedo

As a result of the modelling studies, 500m x 500m resolution map which indicate the monthly averages computed from daily values for 12 months was produced. The map indicates the;

- Total Solar Irradiation (kWh/m^2-day)
- Direct Solar Irradiation (kWh/m^2-day)
- Diffuse Solar Irradiation (kWh/m^2-day)

The areas excluded in the study, from the capacity calculations are listed as follows:

- Areas with a slope greater than 3 degrees,
- Urban areas and areas within 500m radius of safety zones.
- The areas remaining within the 100m radius safety zone of highways and railways,
- Lands within 3 km radius to the airports,
- National parks and other environmentally protected areas,
- Lakes, rivers, wetlands, and dam reservoirs,

However, according to Chamber of Electrical Engineers, it is not a right approach to assess the 'Areas with a slope greater than 3 degrees' as 'not suitable for solar power production'. This argument is supported with an example, where it is stated that in the South-eastern Anatolia, in order to obtain highest efficiency from the solar panels, the degree of the panels shall be between 38-42 degrees (depending on the summer and winter conditions). It is also stated that in many solar panel applications, the panels are placed on roof tops, mast tops and mountainous areas[32].

[32] http://www.emo.org.tr/ekler/f7e78ec76c2c19b_ek.pdf

3 Basic Data and Assumptions Used in the Study

3.1 Energy Prices

Prices of primary energy sources are a decisive factor in the process of planning and investment decision making. Radical changes in primary energy prices usually lead significant turns in the development of the technology. As it is shown in the diagram indicated in Figure 15, there is a swift increase of fuel prices after year 2000. This increase has provoked the European authorities to take decisive measures for stimulating wind and solar power generating utilities. Additionally the diagram also indicates that expectations for the stabilization of prices will take long period. Price levels of 1990 will not be exceeded even in 2030. In such cases the forecasts can be adequately executed on fixed current energy prices, giving priority to technological development, resulting from the dynamics in the previous time period.

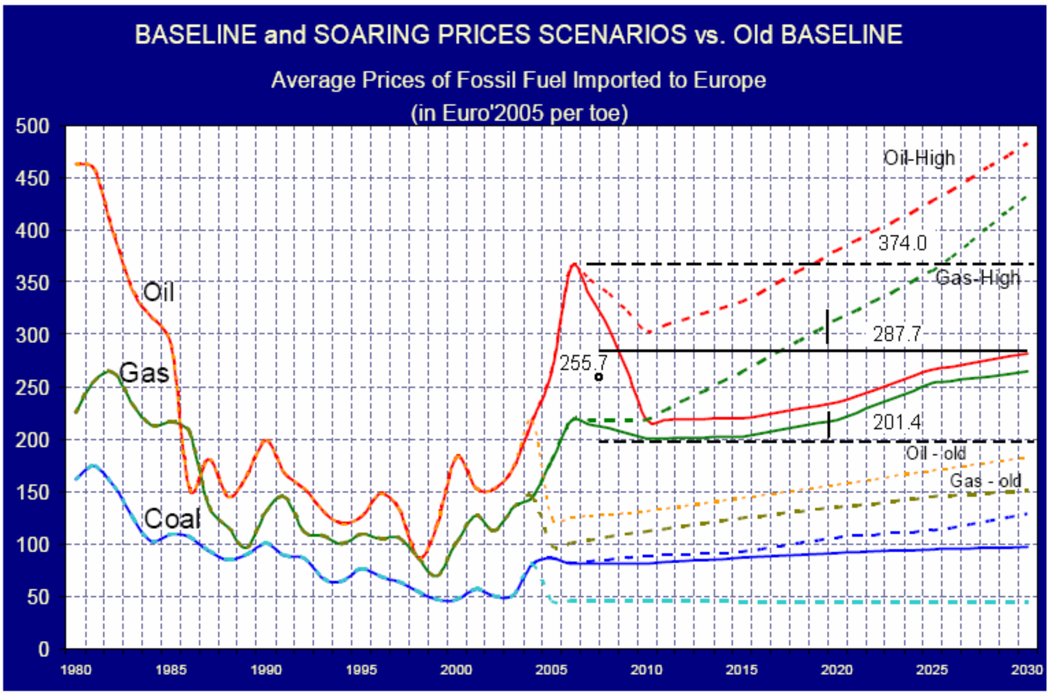


Figure 37. New PRIMES energy scenarios for DG TREN[33]

Input prices for modelling are defined on the bases of country statistics and are specified for industrial and residential demand, separately. According to statistics energy prices in Turkey for the years of 2007/2008 are presented in the Table 9.

3.2 Gross Domestic Product (GDP) Development and Forecasts

The Turkish economy is recovering strongly after severely contracting in 2009. GDP tumbled - 4 % - a sharp contrast to the 6 % average annual growth rate in 2004-2008. The global financial crisis hit the economy hard, thereby fixed investment and external demand dramatically reduced (see Table 10). Fiscal and monetary measures combined with a healthy banking sector, helped cushion the blow.

A return to a positive and robust annual growth after 2010 is foreseen. GDP growth could be close to 5%, helped by base effects and the turn in the inventories cycle. Ultimately, a sustained upturn in growth hinges on a lasting global recovery.

[33] Technical University of Athens

Table 9. Expert prices 2007/2008

Expert prices 2007/2008	Unit	Value
Oil for heating	USD/L	1.4
Diesel	USD/L	1.5
Gasoline	USD/L	1.7
Nat gas - industry	USD/TOE	580
Nat gas - households	USD/TOE	660
Coal-industry	USD/TCE	93
Coal-house	USD/TCE	140
Lignite-industry*	USD/TON	30
Lignite-industry*	USD/TCE	84
El. For industry	USD/KWH	0.14
El. For households	USD/KWH	0.17
Pellets*	USD/TON	170
Wood	USD/TON	120

Table 10. Main features of country forecast - Turkey

		2008		Annual percentage change						
	bn TRY	Curr. prices	% GDP	92-05	2006	2007	2008	2009	2010	2011
GDP		948.7	100.0	4.2	6.9	4.7	0.9	**-4.7**	**4.7**	**4.5**
Private consumption		663.0	69.9	4.3	4.6	5.5	-0.1	**-2.3**	**3.5**	**3.7**
Public consumption		121.9	12.8	3.8	8.4	6.5	1.9	**7.8**	**2.2**	**1.0**
Gross fixed capital formation		188.8	19.9	5.5	13.3	3.1	-5.0	**-19.2**	**4.6**	**8.4**
of which : equipment		98.4	10.4	-	10.2	1.2	-3.4	**-21.4**	**5.0**	**10.0**
Exports (goods and services)		227.7	24.0	9.5	6.6	7.3	2.3	**-5.4**	**5.7**	**7.2**
Imports (goods and services)		275.3	29.0	10.6	6.9	10.7	-3.8	**-14.4**	**9.5**	**9.6**
GNI (GDP deflator)		938.6	98.9	4.2	6.8	4.8	0.9	**-4.7**	**4.7**	**4.5**
Contribution to GDP growth :	Domestic demand			4.7	7.4	5.4	-1.1	**-5.0**	**3.7**	**4.3**
	Inventories			0.0	-0.1	0.6	0.3	**-2.4**	**2.1**	**1.0**
	Net exports			-0.4	-0.4	-1.3	1.7	**2.8**	**-1.1**	**-0.9**
Employment				0.8	1.3	1.1	2.2	**0.4**	**0.9**	**1.4**
Unemployment rate (a)				7.8	10.2	10.3	11.0	**14.0**	**13.9**	**13.4**
Compensation of employees/head				55.3	12.7	12.7	8.6	**-0.8**	**6.4**	**7.2**
Unit labour costs whole economy				50.2	6.8	8.9	10.0	**4.6**	**2.5**	**4.0**
Real unit labour costs				-2.6	-2.3	2.5	-1.5	**-0.2**	**-3.5**	**-2.0**
Savings rate of households (b)				-	-	-	-	-	-	-
GDP deflator				54.3	9.3	6.2	11.7	**4.7**	**6.3**	**6.2**
Harmonised index of consumer prices (HICP)				-	9.3	8.8	10.4	**6.3**	**9.0**	**7.8**
Terms of trade of goods				-0.1	-4.9	3.3	-2.7	**-0.5**	**-1.0**	**-1.0**
Trade balance (c)				-4.8	-7.5	-7.3	-7.0	**-4.5**	**-5.4**	**-6.1**
Current-account balance (c)				-0.5	-6.1	-5.9	-5.7	**-2.2**	**-4.5**	**-5.4**
Net lending(+) or borrowing(-) vis-à-vis ROW (c)				-	-	-	-	-	-	-
General government balance (c)				-	-1.2	-1.0	-2.2	**-5.5**	**-3.5**	**-3.0**
Cyclically-adjusted budget balance (c)				-	-	-	-	-	-	-
Structural budget balance (c)				-	-	-	-	-	-	-
General government gross debt (c)				-	46.1	39.4	39.4	**45.5**	**45.1**	**44.5**

(a) as % of total labour force. (b) gross saving divided by gross disposable income. (c) as a percentage of GDP.

A recent forecast by Merrill Lynch shows Turkish GDP growing by an average of 4.5 percent between 2010 and 2019 (supported by strong growth demographics). If inflation is successfully kept under control, this could easily rise to an average of 5.5 percent.

3.2.1 Turkey Economy: Ten-Year Growth Outlook

Experts[34]'s outlook for 10 year growth in Turkish economy is indicated in Table 11.

Table 11. Turkey economy: 10 Year Growth Outlook

Parameter	**2006-10**	**2011-20**	**2021-30**	**2006-30**
Population (% change; annual av)				
Total population	1.28	0.76	0.46	0.74
Growth and productivity (% change; annual av)				
Growth of real GDP per head	3.9	3.5	3.6	3.6
Growth of real GDP	5.3	4.3	4.0	4.4
Labour productivity growth	3.4	3.1	3.3	3.2

In 2010-30 the Economist Intelligence Unit expects Turkey's macroeconomic environment to be considerably more stable, helped by the IMF-backed stabilization programme and reforms to be introduced under EU formally opened in October 2005.

Real GDP is forecast to grow by 4.4% per year in 2006-30. After averaging over 5% a year in 2006-10, the pace of growth will slow to around 4% in 2030. This is well above the average rates expected for the EU25.

3.2.2 Income and Market Size

Turkey's GDP per head is projected to raise from about US$8,000 at purchasing power parity (PPP) exchange rates in 2005 to just under US$40,000 in 2030 (see Table 12).

However, catch-up with the EU25 is likely to be slow, given that in the five years to 2010, Turkey's GDP per head at PPP exchange rates is only forecast to rise from 29% of the EU25 average in 2005 to about 32% in 2010.

Table 12. Income and market size

Parameter	**Unit**	**2005**	**2010**	**2020**	**2030**
Population	million	73.3	78.1	84.2	88.2
GDP	bn USD	362,614	493,172	1,060,503	2,292,651
Private consumption	bn USD	244,541	331,348	761,095	1,681,533
GDP per head (at PPP)	USD	8,100	11,460	20,990	38,320
GDP (at PPP)	bn USD	593,502	736,900*	1,767,683	3,380,876

PPP – purchasing power parity
*revised value

3.3 Demographic Trend of Population

Trend in demographic change is also another important parameter considered in energy modelling. According to the Turkish statistics a lower demographic trend is considered (see Table 13).

Table 13. Income and market size

Parameter	**Years**								
	1990	**2000**	**2010**	**2015**	**2020**	**2025**	**2030**	**2040**	**2050**
Population increase rate (‰)	17.0	13.8	11.0	9.9	8.8	8.0	7.2	6.5	6
Mid-year population - thousands	55 120	64 259	72 698	76 598	80 257	83 566	86618*	89470*	92187*

*expert values calculated by BSREC

When the annual number of births are considered, its Spending Wave shows strength from 1992 (1950's increasing birth trend plus 42 years) until 2024 (1982's peak birth year plus 42 years). (see Figure 16)

[34] http://www.ekodialog.com/Articles/turkey_economy_tenyear_growth_outlook.html

3.4 Energy Consumption

Final energy consumption in the country for the years before the economic crisis was increasing steadily with about 5% annual growth. As a result, Turkey has become one of the countries with a significant share of energy in the GDP as is presented on the diagram indicated in Figure 17.

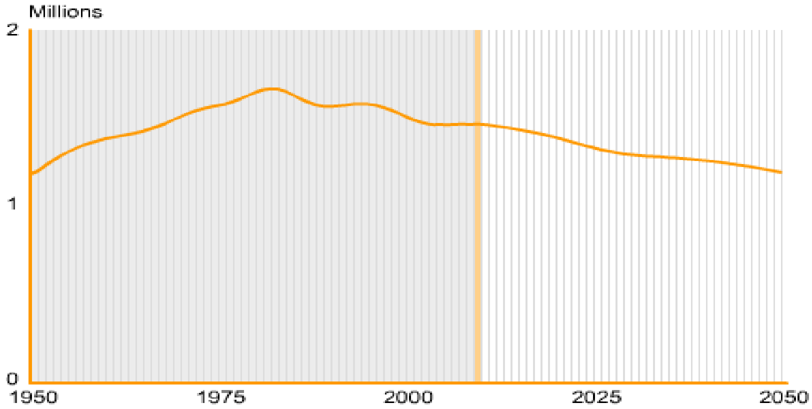


Figure 38. Annual number of births in Turkey (in millions)[35]

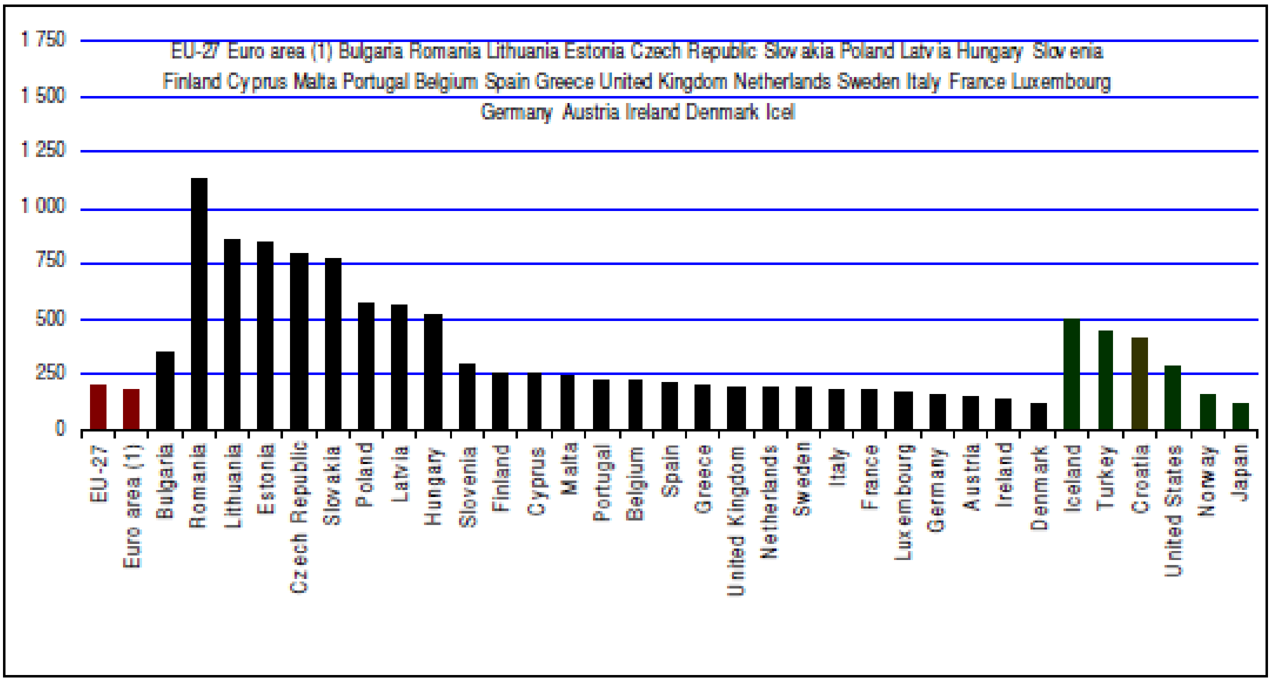


Figure 39. Energy share of some countries (Source: EUROSTAT)

The future development of the energy consumption is going to reflect the following factors:

- dynamic growth of GDP,
- demographic tendencies,
- energy saving technologies implementation,
- stimulation of RES,
- energy price factors (not to be considered in this study),
- economic processes in Europe and in the world.

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[35] Source: UN 2007 and Insitut National d'Etudes Demographiques

3.5 Financial Parameters and Interest Rate

The interest rate is the often the key financing parameter involved in investment decisions. The central value of the interest rate is determined through practical advice from commercial lending officials. It varies in magnitude to collect both the risk associated with the current lending situation with the prime interest rate at 8% along with possible rate changes in the future. There are a variety of financing options open to agriculture producers such as lines of credit, and interest rate re-evaluation over the course of the loan, however, the fixed rate term provides a simplified model along with a realistic final outcome concerning the loan.

4 Modelling of the Turkish Electricity Industry

4.1 The Overall Generation Market

As it is indicated in Table, the generation market is dominated by the public producer, Electricity Generation Corporation (EÜAŞ), although The Power Purchase Agreements that the Build-Operate-Transfer/Build-Own-Operate (BOT/BOO) plants have mean that they take a much higher share of generation than of capacity. There is a total of 4100MW of autoproducer capacity using various fuels.[36]

Table 14. Market shares of generators[37]

	2000		2006	
EÜAŞ	78	75	58	46
Autoproducers	11	13	10	9
BOO/BOT	7	10	21	33
TOR	1	1	2	2
Concession companies	2	2	0	0
Free gen companies	0	0	7	7

4.2 Supply and Demand Trends

Table 15 shows the remarkable growth in electricity demand in Turkey - demand growing on average by more than 8% per annum with little sign of the saturation of demand that is evident in Northern European countries.

Table 15. Power installed of power plants, gross generation and net consumption of electricity[38]

	Power Installed (MW)	Gross generation	Net Consumption
		(GWh)	
1975	4 186.6	15 622.8	13 491.7
1980	5 118.7	23 275.4	20 398.2
1985	9 121.6	34 218.9	29 708.6
1990	16 317.6	57 543.0	46 820.0
1995	20 954.3	86 247.4	67 393.9
2000	27 264.1	124 921.6	98 295.7
2001	28 332.4	122 724.7	97 070.0
2002	31 845.8	129 399.5	102 948.0
2003	35 587.0	140 580.5	111 766.0
2004	36 824.0	150 698.3	121 141.9
2005	38 843.5	161 956.2	130 262.9
2006	40 564.8	176 299.8	143 070.5
2007	40 835.7	191 558.1	155 135.2
2008	41 817.2	198 418.0	161 947.6

4.3 Generation System Units

In this study the power plants connected to Turkish Power System and in operation as the end of the year 2008 are considered as existing system. Table 16 presents the installed capacities of the different generating units for

[36] Thomas S., Erdogdu S., Turkyilmaz O., The future of the Turkish electricity industry, Paper presented at the TMMOB (UCTEA - Union of Chambers of Turkish Engineers and Architects) VI. Energy Symposium, Ankara, Oct 22-24, 2007.
[37] Basaran M. (2007) 'Turkey: Moving towards the liberalisation in the electricity sector', International Gas Congress, April 30, 2007.
[38] TETC (TEİAŞ) Electricity Generation - Transmission Statistics of Turkey, http://www.turkstat.gov.tr

the years of 200, 2005 and 2008. As the input of the study the following data were obtained from stated organizations and some assumptions are done as followings:

- The maximum generating capacity called as Project Generation and reliable generating capacity called as Firm Generation for Electricity Generation Company (EÜAŞ) thermal power plants are obtained from EÜAŞ.
- Nominal generating capacity called as Project Generation and reliable generating capacity called as Firm Generation for EÜAŞ hydro power plants are also obtained from EÜAŞ.
- Project Generation and Firm Generation amounts of thermal power plants owned by affiliated partnerships are obtained from EÜAŞ for the period from 2009 to 2018.

Table 16. Installed capacities of the different generating units

Installed Capacities, Gw	2000	2005	2008
Thermal	16,0	25,9	27,5
Hydro	11,1	12,9	13,8
Geothermal + Wind	0,036	0,035	0,393
Total	27,2	38,8	41,8
Increase (%)	4,4	5,5	2,4

Source: TEİAŞ

- Project Generation and Firm Generation amounts of Autoproducer and Generation Company power plants are obtained from their licences and these generation amounts are accepted as to remain at the same level for the next 10-year period. Generating capacity amounts indicated on their licences are obtained from the Republic of Turkey Energy Market Regulatory Authority (EPDK).
- Generating capacity amounts of power plants under BO contract for the future ten-year period are the energy sale amounts indicated on their contracts and obtained from another Electricity Generation Company, TETAŞ.
- Generating capacity amounts of power plants under BOT and Transfer of Operating Rights (TOR) contract for the future 10-year period are the energy sale amounts indicated on their contracts and obtained from TETAŞ. In spide of the agreements of some power plants under BOT contract expiring with TETAŞ in the period of the projection; it is assumed that these power plants will continue to produce electricity in a different structure. The generation amount is taken as the same in the period of the projection after expiring of their contracts.
- The installed capacities of Autoproducer and Generation Company power plants (except for decomissioning) whose licences have been cancelled are kept in total installed capacity and their generation capacities are taken as zero.
- The contracted generation amounts of Mobile Plants are used as Generating Capacity Amount for mobile plants and these amounts are used till the end of their contracts with EÜAŞ. Due to expiration of mobile power plant contracts with EÜAŞ, the corresponding generation amounts by year will be decreased from the total generation capacity and only the mobile power plants going on their contracts are put in the lists. After finishing their contracts, the power plants will be able to produce by taking Generation Company license. The power plants with the licence of Generation Company till the end of 2008 are taken into consideration in the study. But the plants not only expiring their contracts and but also not taking the new generation licence are not taken into consideration.
- Firm and Project generation capacity amounts of natural gas fired power plants are given by related ownerships by assuming that there will be no constraint on natural gas supply during the study period.
- By taking into consideration of rehabilitation investments and maintenance-repair program for state owned power plants, the generation amounts of the plants are given by EÜAŞ.
- On line dates and Project (in average hydro conditions) and Firm (in dry hydro conditions) generation amounts of hydro power plants having total installed capacity of 2835.7 MW which are constructed by State Hydraulic Works (DSİ) and expected to be in service between the years of 2009 and 2016 are obtained from DSİ. Annual generation amounts of the projects whose commissioning dates are given project by project in detail taken into consideration in the balance tables by calculating as of their commissioning dates.
- Installed capacity, project generation and firm generation data for power plants granted by license as the end of December 2008, under construction and expected to be in service on proposed time are obtained

according to two separate scenarios (Scenario 1 and Scenario 2) from January-2009 Progress Report by EPDK. The scenarios are prepared, by considering assumptions below, by EPDK.

Deviations from the official scenario:

- Shortages in demand will be covered by import.
- Wind and solar capacities will be subject to additional optimization without restrictions in the total investment costs.
- Capacity factors of the generating units will be recalculated with a simulation model.
- Capacity factors of wind and solar will be recalculated with regards to possible curtailments.

4.4 Projection in the Period up to 2018

The forecast considered for the period up to year 2018 is based on the "Turkish Electrical Energy 10-Year Generation Capacity Projection Plan (2009 – 2018)"[39] Stated report includes demand and resources for 10-year capacity projection for two different scenarios. Results also presented in report depending on those scenarios. However in this part of the report, results of the first scenario are presented.

4.4.1 Demand

In the Generation Capacity Projection study covering the period between years 2009 and 2018, the demand series are calculated by using Model for Analysis of Energy Demand (MAED) model. By assuming no change on annual load curve characteristic for the study period, annual peak load values are obtained by using annual demand growth rates (see Table 17 and Table 18).

Table 17. Demand forecast (High Demand)

	Peak Demand	Consumption
Year	**GW**	**TWh**
2010	31,2	202,7
2012	35,7	232,1
2015	44,4	288,3
2017	51,2	332,5
2018	55,1	357,2

Source: Turkish Electricity Transmission Corporation Research Planning And Coordination Department

Table 18. Demand forecast (Low Demand)

	Peak Demand	Consumption
Year	**GW**	**TWh**
2010	31,2	202,7
2012	35,2	228,2
2015	42,7	277,2
2017	48,6	315,0
2018	51,8	335,8

Source: Turkish Electricity Transmission Corporation Research Planning And Coordination Department

[39] http://www.TEİAŞ.gov.tr/eng/ApkProjection/CAPACITY%20PROJECTION%202009-2018.pdf

4.4.2 Generating Units

Table 19. Breakdown of installed capacity by utilities and by primary resources in MW (Including Existing, State-owned under construction and Private Sector under construction granted by licence and expected to be in service on proposed time Power Plants)

EÜAŞ and Affiliated Partnership Power Plants

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fuel Oil	680	380	380	380	380	380	380	380	380	380
Diesel	181	181	181	181	181	181	181	181	181	181
Hard Coal	300	300	300	300	300	300	300	300	300	300
Lignite	7461	7461	7461	7461	7461	7461	7461	7461	7461	7461
Natural Gas	3903	3903	3903	3903	4743	4743	4743	4743	4743	4743
Geothermal	0	0	0	0	0	0	0	0	0	0
Hydro	11951	12422	13092	13092	13092	13092	13092	14292	14292	14292

Power Plants under TOR Contract

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Lignite	620	620	620	620	620	620	620	620	620	620
Hydro	30	30	30	30	30	30	30	30	30	30

Power Plants under BO Contract

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Naturalgas	4782	4782	4782	4782	4782	4782	4782	4782	4782	4782
Importedcoal	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320

Power Plants under BOT Contract

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Naturalgas	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450
Hydro	982	982	982	982	982	982	982	982	982	982
Wind	17	17	17	17	17	17	17	17	17	17

Mobile Plants

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fuel Oil	263	263	263	263	263	263	263	263	263	263

Autoproducers

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fueloil	799	799	799	799	799	799	799	799	799	799
Diesel	10	10	10	10	10	10	10	10	10	10
Imported Coal	196	196	196	196	196	196	196	196	196	196
Hard Coal	255	255	255	255	255	255	255	255	255	255
Lignite	178	178	178	178	178	178	178	178	178	178
Lpg	52	52	52	52	52	52	52	52	52	52
Natural Gas	1388	1388	1388	1388	1388	1388	1388	1388	1388	1388
Biogas	13	13	13	13	13	13	13	13	13	13
Naphta	71	71	71	71	71	71	71	71	71	71
Other	22	22	22	22	22	22	22	22	22	22
Hydro	554	554	554	554	554	554	554	554	554	554
Wind	1	1	1	1	1	1	1	1	1	1

Generation Companies by License

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fuel Oil	358	358	358	358	358	358	358	358	358	358
Diesel	15	15	15	15	15	15	15	15	15	15
Lignite	2	2	2	2	2	2	2	2	2	2
H.Coal+Asphaltit	0	0	0	0	0	0	0	0	0	0
Import Coal	322	322	732	1948	3162	3162	3162	3162	3162	3162
Natural Gas	3171	3317	4123	6034	6034	6034	6034	6034	6034	6034
Naphta	107	107	107	107	107	107	107	107	107	107
Geothermal	85	85	85	85	85	85	85	85	85	85
Hydro	1369	2394	3401	5220	5220	5220	5220	5220	5220	5220
Biogas+Waste	28	39	47	47	47	47	47	47	47	47
Wind	551	724	994	994	994	994	994	994	994	994

Breakdown of Total Installed Capacity by Primary Resources (MW)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Lignite	8260	8260	8260	8260	8260	8260	8260	8260	8260	8260
Hardcoal	555	555	555	555	555	555	555	555	555	555
Importedcoal	1838	1838	2248	3464	4678	4678	4678	4678	4678	4678
Naturalgas	14693	14839	15645	17556	18396	18396	18396	18396	18396	18396
Geothermal	85	85	85	85	85	85	85	85	85	85
Fueloil	2100	1800	1800	1800	1800	1800	1800	1800	1800	1800
Diesel	206	206	206	206	206	206	206	206	206	206
Other	251	251	251	251	251	251	251	251	251	251
Thermaltotal	27989	27835	29051	32179	34232	34232	34232	34232	34232	34232
Biogas+Waste	41	52	60	60	60	60	60	60	60	60
Hydro	14886	16381	18058	19877	19877	19877	19877	21077	21077	21077
Wind	570	743	1012	1012	1012	1012	1012	1012	1012	1012
Total	**43485**	**45011**	**48182**	**53128**	**55182**	**55182**	**55182**	**56382**	**56382**	**56382**

Breakdown of Total Firm Generation Capacity by Primary Resources (GWh)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Lignite	41105	40384	39961	42198	48148	48058	48010	48051	48100	48660
Hardcoal	3039	2609	2293	2609	2912	2912	2912	2912	2912	2912
Importedcoal	12148	12701	14376	19910	28197	31706	31955	32646	32211	32258
Naturagas	105664	108534	113152	123159	137324	134956	136919	137032	136720	132329
Geothermal	391	579	579	579	579	579	579	579	579	579
Fueloil	10961	10169	10169	10169	10169	10169	10169	10169	10169	10169
Diesel	1219	1199	1199	1199	1199	1199	1199	1199	1199	1199
Other	1663	1663	1663	1663	1663	1663	1663	1663	1663	1663
Thermaltotal	**176190**	**177837**	**183392**	**201485**	**230190**	**231240**	**233405**	**234250**	**233551**	**229768**
Biogas+Waste	257	311	385	415	415	415	415	415	415	415
Hydro	31615	34486	36837	39890	41229	41180	41141	43645	43645	43645
Wind	1452	2066	2755	3168	3168	3168	3168	3168	3168	3168
Total	**209514**	**214700**	**223368**	**244957**	**275002**	**276003**	**278128**	**281477**	**280779**	**276995**

4.5 Generation Capacity Projection in the Period After 2018

The forecast for the period after year 2018 was done on the bases of the existing methodology and models, used by BSREC. The system is calculated as a one firm system in order to apply least-cost planning model. The so-called public cost is going to be subject to the minimization.

4.5.1 Demand Forecast

Two scenarios of demand were produced on the bases of both scenarios, created for the period up to 2018, which will reflect the scenarios for development of GDP and the growth of population in Turkey.

4.5.2 Generation Forecast

4.5.2.1 Power Generation Units

Linear programming models have proven to be an invaluable tool for energy producers and traders, allowing them to explore future market scenarios. Power station developers use the models to screen projects in different countries and regions, by investigating the value of an additional megawatt of power coming on line. Existing generators can examine the impact of different strategies on their market share and revenue.

The objective is to minimize the cost of providing electricity to cover the aggregated system load. The constraints include minimum and maximum capacity for generation units, maximum transmission line flows, spinning reserve levels, and the overall supply demand balance.

The electrical unit commitment problem is the problem of deciding which electricity generation units should be running in each period, so as to satisfy a predictably varying demand for electricity.

In long range planning, a decision making period can be extended from one to six hours. In six hour determination the ranges are considered as peak, under-peak, base and semi-base.

In a typical electrical system there is a variety of units available for generating electricity, each with its own characteristics.

Base Units

The lignite and nuclear power unit (the so called base units) can provide electricity at a very low incremental cost for each additional megawatthour of energy, but it has both a high cost of starting up again once it has been shut down and it takes a while to bring it back up to full power. Base units usually have a high technical minimum – 90%.

A typical base unit may be shut down only in months, when there is very little heating or air-conditioning demand, so demand is lowest.

Peak Units

At the other hand, a gas turbine generator (a peak unit) can be started up in a few minutes; however its incremental cost per megawatthour is much more expensive.

Hydro stations with water storage are also used as peak units, but they are restricted with the water inflow, depending on the month of the year, and the volume of the water dam.

Semi-Base

As semi-base and under-peak units can be considered coal and oil units with a lower technical minimum - 65% and lower. A “combined cycle” gas fired unit additionally produces electricity by using the hot exhaust gas to convert water to steam and generate electricity by sending the steam through a steam turbine. Some of these turbines are also flexible with as low as 50% possibility to decrease the power generation. On the other hand increased fuel consumption in the lower regime should be considered.

Other Types

For some power generation units, the amount of power that can be generated depends upon the time of day, year, meteorological conditions etc. Such examples are wind and solar generated power where the amount of power available depends upon the amount of wind and solar radiance, a factor that may vary in a partially predictable way over the period of a day or year. Some hydro power units are located on rivers, but without a significant storage reservoir. Thus, the power generation capacity is proportional to the current flow in the river. Such a unit is called run-of-river hydro. For these kinds of units, there is not a single capacity that applies to every period, but rather an amount of electricity, generated for each period.

Because of the higher uncertainty factor, characteristic for the run-of-river hydro, wind and solar generation – additional reserves should be ensured for the system security.

Pump-storage units are not considered in the study.

The obvious policy is that as demand increases we first turn on the efficient but costly to start generators and lastly turn on the least efficient by cheap to start. As demand decreases, we shut down units in the reverse the order.

Existing Units

We classify all thermal, hydro and wind and solar units, commissioned before 2010 as existing units. All of these types, from a day-to-day economic perspective can, to a good first approximation, be described by the following data:

SCi = cost of starting up generator i,
FCi = fixed cost of having generator i running (or "spinning") during a period,
GCi = cost of generating one megawatt of energy from unit i,
ECi = emission cost of generating one megawatt of energy from unit i,
ULi = upper limit on number of megawatts of power generated by unit i in each period.
The data, driving the whole process are:
Dt = megawatthours of energy demanded in period t,

The decision variables are:

xit = megawatthours of energy generated by unit i in period t,
yit = 1 if unit i is running or "spinning" in period t,
zit = 1 if unit i starts to run in period t,

In other words, the goal of the model at this point is to minimize costs of the existing units:

Start-up costs + Running costs + Energy generation costs + Emissions costs

For each period t:

1. Amount of energy generated = the demand in period t,
2. For each period t and generator i: The amount generated in the period does not exceed the generator's capacity,
3. A startup cost is incurred if the generator starts up, and a running cost is incurred if the generator is running or spinning.

New Candidates

All of new candidates can be described by the same data as existing, including the necessary investment expenses, which can be characterized with the following data:

QC – cost of equipment and construction costs;
FC – financial costs, including interest, insurance, additional financial expenses.
CC – capital costs
CC = QC + FC

The parameters of the new candidates are given in Table 20.

In other words, the goal of the model at this point is to minimize costs of the new candidates:

Start-up costs + Running costs + Energy generation costs + Emissions costs + Capital costs

Solar and wind candidates will be discussed separately although they will be included as new candidates in the model to compete freely with conventional candidates.

Other Considerations

The model above should be considered as starting point for a variety of practical generalizations. For example:

Import and export: There may be multiple markets with the possibility of shipping electricity among the markets.

Pollution restrictions: Pollutants such as sulfur dioxide, nitrous oxides, ash, and carbon dioxide are undesirable. Some generators pollute more than others and there may be limits on how much total pollution may be generated in total in a period or under certain conditions.

Uncertainty and Spinning Reserve: Demands are not known with certainty. Generation units may unexpectedly fail. One reaction to this is to require a certain amount of additional capacity to be quickly available (or spinning) in a period so that additional power is quickly available if by chance it is needed. Providing this backup is sometimes referred to as ancillary services.

Table 20. The parameters of the new candidates

	Construction time	Price of equipment	Capital with 4% discounting the construction time
	Year	**EUR/KW**	**EUR/MW**
Nuclear	8	1 750	2 394 996
Lignite	5	1 416	1 722 781
Coal	4	1 118	1 307 902
Oil	4	1 118	1 307 902
CCGT	3	750	843 648
Gas	3	300	337 459
Hydro – High Investment	8	1 700	2 326 567
Hydro – Low Investment	8	1 200	1 518 383
Hydro - Running	8	700	818 901

Ramp-up features: One may have a "ramp up" constraint that constrains the rate at which output can be increased for a generator. This feature is not going to be considered in the study.

Technical Minimum: Each generator also may have a minimum output level above which it must operate if it is operating at all, the so called technical minimum. Technical minimum is high for nuclear and lignite units (70 – 90%) and low for hydro and simple gas turbines (0-30%). In the simulation model, technical minimum will be specified for each unit separately.

Maintenance: Each generator is subject to a planned annual maintenance of 30-45 days. In the simulation model maintenance will be scheduled in an optimal way for the system. The production will reflect the maintenance schedule and the possible critical periods with unserved energy.

Unserved energy: This is a common parameter for the planning models. A price of 1200 USD/MWh will be applied.

Decommissioning

The plan for decommissioning of the existing plants is concerning only thermal plants, built before 2010, which have an average life of about 30 years.

Hydro stations usually have a much longer life and usually rehabilitation is an adequate solution for its prolongation. That is why decommissioning of hydro plants is not considered.

The average life-time of the existing types of energy equipment is set-up on the bases of the existing statistics and the following plan for decommissioning is prepared (see Table 21).

Table 21. Decommissioning plan

Decommissioning	2020 -2025	2030	2035	2040
Lignite plants	4800	1200	500	600
Coal plants	700		145	1655
Oil plants	200	200	400	
Gas/CCGT plants	2200	700	4100	6300
Total	**7900**	**2100**	**5145**	**8555**

System Losses

Transmission system has been designed appropriate to European standards by considering population density, location of supply resources and geographical conditions and the line losses around 3% which is at the level of international performances.

High voltage transmission losses will be considered a constant of 3% for the period, due to their narrow interval – 2-3 % (see Table 22).

Two contradictory trends are expected to neutralize each other:

- decreasing trend due to growth in production of the system
- increasing trend due to growing percentage of RES

Table 22. Transmission losses (Source: Turkish Electricity Generation-Transmission Statistics, TEİAŞ-APK)

Year	%	GWh
2001	2.8	3374.4
2002	2.7	3440.7
2003	2.4	3330.7
2004	2.4	3422.8
2005	2.4	3695.3
2006	2.7	4543.8
2007	2.5	4523.0
2008	2.3	4388.4

5 Wind Energy Modelling

5.1 Wind Measurements

Wind measurements (velocity and direction) are usually organized at the height of 10 m above the surface of the site. For the purposes of this study Corine Land Cover database and hub height conversion ratio is used:

$$VH = V10\ (LN(H/z)/LN(10/z)) \quad (1)$$

Where:

H - stands for the hub height expressed in metres;
VH - is the wind speed at hub height expressed in metres per second;
V10 - is the wind speed at 10 m height expressed in metres per second;
z - is the roughness length expressed in metres.

Wind power density at 10 m height is used for small village wind farms. Wind power density for heights of 50 and 100 m, at which level usually is situated the hub of the wind mills, are be recalculated, using the formula.

5.2 Wind Technical Potential

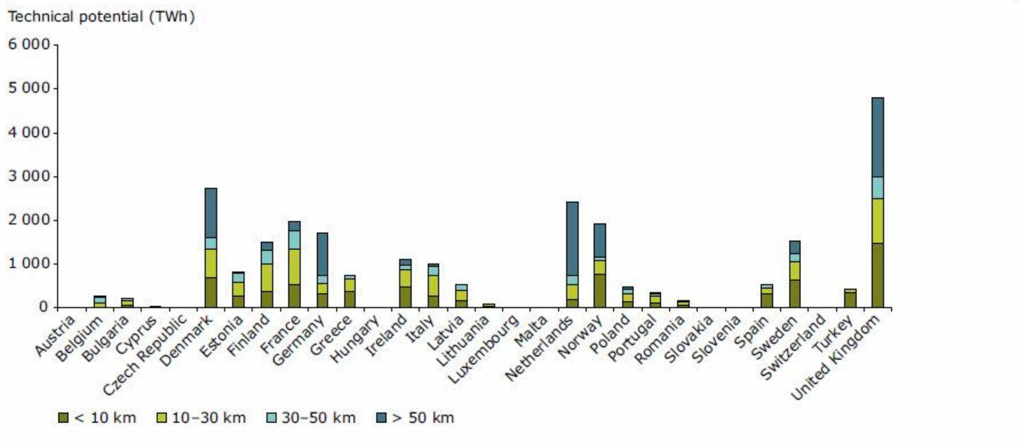
Determination of on-shore wind potential is calculated as the possibility to be used as a primary mechanical source for production of electricity. The capacity for production of electricity depends on several preconditions:

- technically usable wind range (4 – 25 m/s)
- tower height (up to 100 m)
- rotor diameter (up to 150 m)
- landscape characteristics
- technology parameters.

Wind power density is calculated on levels declining in value as follows:

- theoretical potential,
- technical potential,
- economical reasoning.

Offshore possibilities for power generation are not going to be determined in the present study, because it is considered, that the region does not have a significant technical potential (See Figure 18).



Note: A recent Norwegian study (NVE, 2008) estimates Norwegian offshore wind power capacity to be around 55 300 MW (at maximum depths of 50 m and minimum distances to the coast of 1 km).

Source: EEA, 2008.

Figure 40. Unrestricted technical potential for offshore wind energy in 2030 based on average wind speed data (Source EEA)

5.3 Wind Energy Modelling Issues

Modelling of wind will use as a base the technical energy potentials, specified for the different regions in the country. Wind modelling should reflect also the following specific characteristics:

- Zero fuel expenses;
- Significant decrease in the investment expenses from year to year due to the technological progress in the solar technologies. The decrease in wind technologies is not so steep, because bigger and higher tower is going to be projected – for higher wind speeds and load ratio;
- Expected increase in the power heat ratio, due to the better performance of the new technologies;
- Additional incentives (Feed-in tariffs, Green certificates, Subsidies etc.).

The model minimizes the costs for solar and wind as follows: Running costs + Capital costs – Incentives (Sale of GC)

5.3.1 Investment Costs in Wind Technologies

The main parameters determining the cost of wind energy are investment costs (i.e. turbine costs, foundations, electrical installations, connections to the electrical grid, consultancy fees, land costs, financing, security and road construction) and operation and maintenance costs (O&M). As costs depend on various factors, they also vary significantly between different countries. In this project, investment and O&M costs are mainly derived from studies with an international scope.

One significant factor in increasing the feasibility of a new system is the reduction in turbine costs. Though technology costs are decreasing, the recent upswing in raw materials costs, primarily steel, has led some to believe that capital costs may stay steady rather than decrease over time. The more favourable economics and financing options for large utility scale wind turbines may also squeeze the market for components used for both types of systems, which may affect the price and availability of newly manufactured small wind systems. Inevitably, capital costs must decrease while technical efficiency increases for even the best case scenario to be profitable.

Turbine manufacturers expect the production costs of wind power to decline by 3–5 % for each new generation of wind turbines or decrease of investment costs of 1–2.2 % per year.

5.3.2 Wind Turbine Technology

When assessing wind energy potential in 2020 and 2030, it is necessary to make projections with respect to the technological and economic developments of wind turbines. Turbine technologies in detail will not be discussed, but rather financial parameters will be applied. These include factors such as rated power, hub height and investment costs.

Wind modelling is mostly depending on the unit capacity of wind turbines and the capacity factor of the site. The Table 23 is given for a turbine selection for IZTECH Campus Area, Turkey.

A cost breakdown is given for two types of turbines. Obviously the second choice seems economically more profitable, with regards also to the possibilities of additional incentives discussed earlier.

5.3.3 Turbine Size

Wind turbine size has increased significantly, from an average rated power of less than 50 kW at the beginning of the 1980s to over 1 MW in 2005[40]. The commercial size sold today is typically 750–2500 k). In this study we

[40] DWIA, 2006: www.windpower.org

assume that rated power will level off at 2 MW. That assumption is in accordance with the findings of various other studies[41,42,43,44].

Because of economies of scale, turbine sizes may increase further. For instance, European Wind Energy Association (EWEA) assumes an average wind turbine size of 10 MW in its briefing paper 'No Fuel'. The rotor diameter of such large turbines would be around 150 m.[45]

Table 23. Cost break down[46]

WECS:kW **Item Cost, USD**	**600**	**1500**
Equipment	1349680	1546240
Feasibility	40600	40600
Development	157000	157000
Engineering	36100	36100
Plant	512000	512000
Miscellaneous	90815	90815
Total Capital	2186195	2382755
Specific investment costs, USD/kW	3644	1589
O&M cost	186615	176384
Production (cap. Factor estimation 2000h), kWh/year	1200000	3000000
O&M cost USD/kWh	0.16	0.06

Table 14. Investment costs targets for wind technologies, USD/kW/year

Rated Power, kW	**200**	**400**	**600**	**1000**	**1400**	**2000**
Rotor Diameter, m	10	20	30	50	70	90
Investment Costs, USD/kW	-	-	3600	2000	1600	1500

5.3.4 Operation and Maintenance Costs

Based on experiences from Denmark, Germany, Spain and the United Kingdom, EWEA[47] reports that O&M costs are, in general, estimated to be approximately 0.012–0.015 EUR/kWh of produced wind power over the total lifetime of a wind farm. O&M costs thus correspond to 2–3 % of total turnkey investment costs in the early years of the farm and around 5 % at the end of the lifetime.

5.3.5 Related Costs

Related costs for this additional reserve are estimated at a level of 2–4 eurocents/kWh, assuming proper use of forecasting techniques[48]. The most important factors determining these costs are wind penetration, forecasting technique, interconnection, geographical distribution and generation system.

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[41] No Fuel. Available at www.no-fuel. org/index.php?id=241
[42] Greenpeace and EWEA, 2005. Wind force 12. A blueprint to achieve 12 % of the world's electricity from wind power by 2020. Greenpeace, Amsterdam and European Wind Energy Association, Brussels.
[43] Greenpeace and GWEC, 2006. Global wind energy outlook 2006. Available at: www.gwec.net/fileadmin/ documents/Publications/GWEC_A4_0609_English. pdf
[44] EWEA, 2006a. No Fuel. Available at www.no-fuel. org/index.php?id=241
[45] EEA Technical Report No 6/2009. Europe's onshore and offshore wind energy potential: An assessment of environmental and economic constraints
[46] Özer S., A Feasibility Study and Evaluation ofFinancing Models for Wind Energy Projects: A Case Study on Izmir Institute of Technology Campus Area, MSc Thesis, Izmir Institute of Technology, July 2004.
[47] EWEA, 2003. Wind energy: the facts. Volume 2: Costs and prices. Available at: www.ewea. org/fileadmin/ewea_documents/documents/ publications/WETF/Facts_Volume_2.pdf
[48] EWEA, 2006b. Large scale integration of wind energy in the European power supply: analysis, issues and recommendations. Available at: www.ewea.org/index.php?id=178

5.3.6 System Performance

The system performance parameter comes in the form of the capacity factor for the wind energy system. The capacity factor is unique to each wind turbine size even in the same wind conditions. It is calculated by taking the predicted kWh output over the course of the year, which is determined by meteorological conditions and the turbine power curve, and dividing it by the potential rated output of the turbine. The range used of 15% - 25% is consistent with capacity factors in the literature.

5.3.7 Wind Mills Load Curves

Load curves of wind production depend on the wind speed and the velocity-power curves of the wind turbine chosen for the site. The steep rise in the curve after the so-called cut-in wind speed (usually 4 m/s) is followed by a horizontal part after the rated wind speed (14 m/s) and steep fall to zero at the cut-off speed of 25 m/s. Smaller turbines can have a lower cut-off speed as shown on the diagram presented in Figure 19, which depends on the type of tower construction.

5.3.8 Land Cover Influence

Land cover is a significant factor in the determination of the wind mill site. High elevations are usually not suitable for building activities. After the peak slope also is not used, while on the opposite side the wind climbing area is favourable for speed acceleration. Forests, marshes, build-up and agricultural areas also put restrictions to wind-mill construction. Area available per type of aggregated land cover class is indicated in Figure 20.

Land cover data will be processed with the intention of influence factor coefficient determination for the different areas of the study. Most of the restrictions are valid also for solar power production.

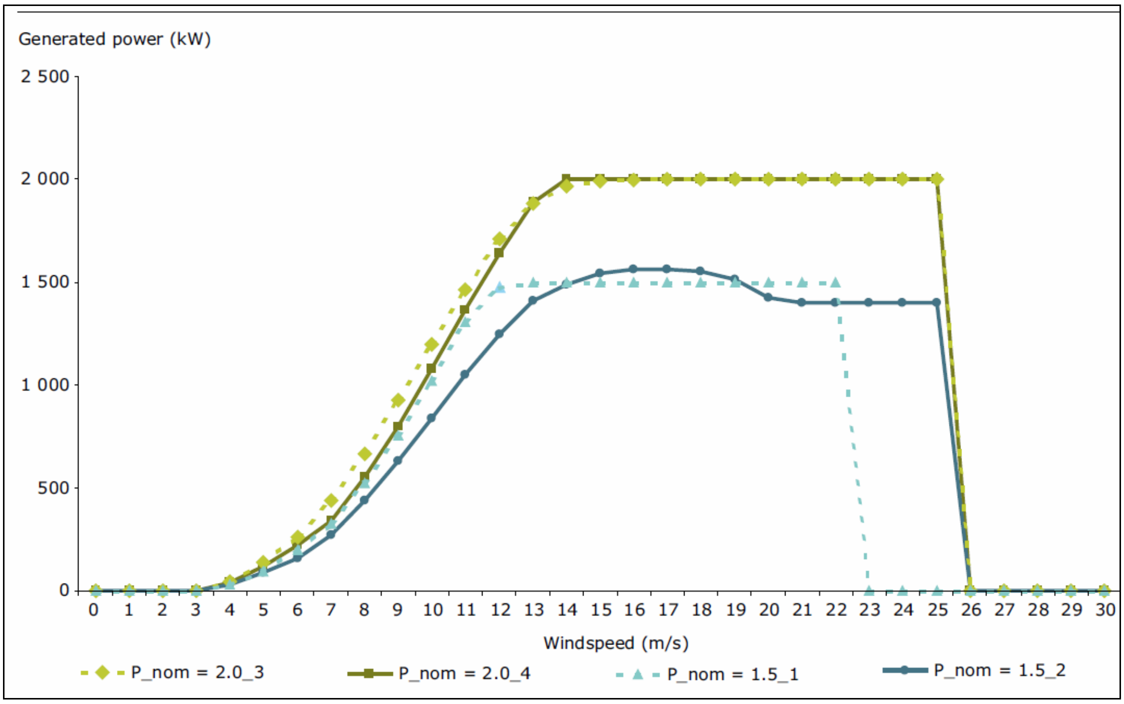


Figure 41. Power–velocity curves of four existing wind turbines[15]

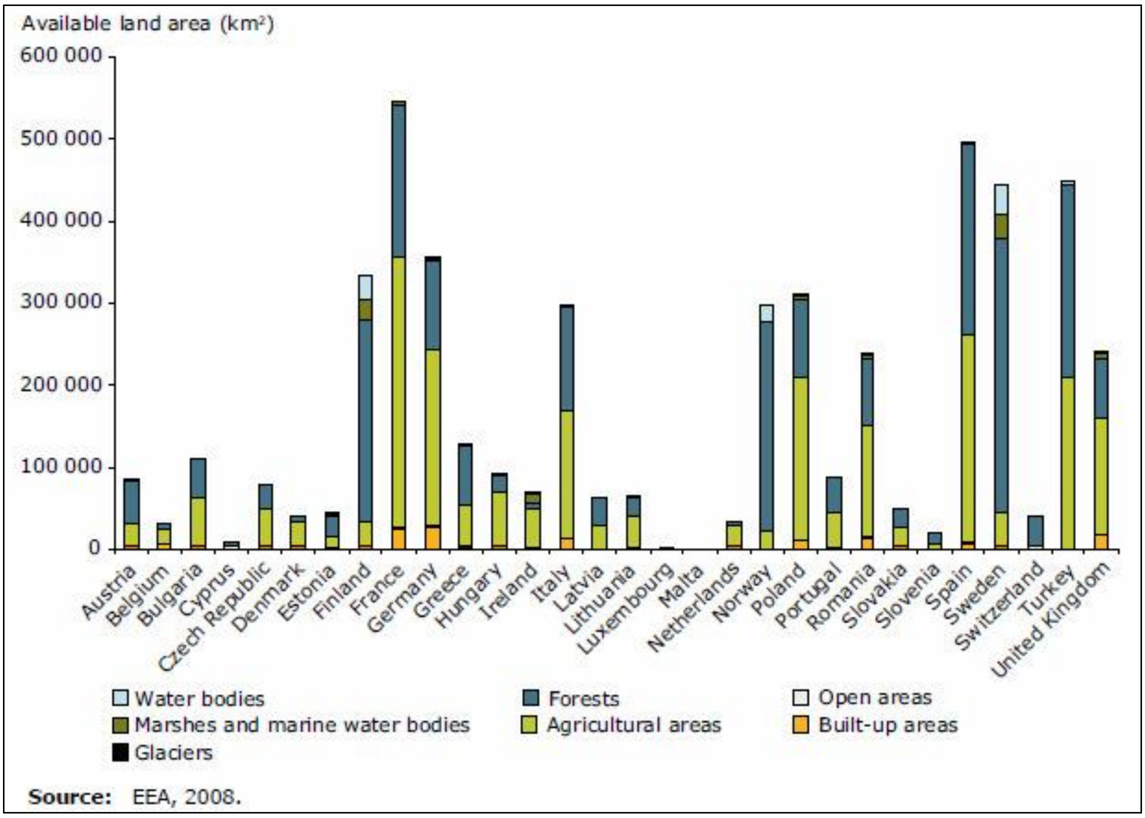


Figure 42. Area available per type of aggregated land cover class (km^2)

6 Solar Energy Modelling

6.1 Short Methodology of Solar Power Potential Assessment

The main goal of the project is to present to the users of the GEO system the best possibilities of finding the useful information beneficial for decision making processes in the Black Sea Catchment.

The presented solar power potential assessment methodology aims at the initial site choice, made by the investors, after which phases of the detailed observation and calculation should be performed in order to take the final economic decisions. The result from the solar potential assessment will be used as bases for the purposes of mapping of the whole region.

The solar energy potential assessment includes assessment and analysis of the theoretical and technical potential of solar energy. Theoretical potential is all the solar radiation available at the land surface at the site, while technical potential can be assessed with respect to the technology used as a result of a preliminary decision taking. The two main technologies to be discussed in the study are: electricity producing technologies and heat producing technologies.

6.2 General Data

6.2.1 Extra-terrestrial Radiation

Solar radiation falling on the outside of the earth's atmosphere is called as extra-terrestrial radiation. The average extra-terrestrial irradiance is 1367 Watts/meter^2 (W/m^2). This value varies by ±3% as the earth orbits the sun. The earth's closest approach to the sun occurs around January 4th and it is furthest from the sun around July 5th. The extra-terrestrial radiation is:

$$Io = 1367 * (Rav / R)^2 \ W/m^2 \qquad (2)$$

where Rav is the mean sun-earth distance and R is the actual sun-earth distance depending on the day of the year. Near noon on a day without clouds, about 25% of the solar radiation is scattered and absorbed as it passes through the atmosphere. Therefore about 1000 w/m^2 of the incident solar radiation reaches the earth's surface without being significantly scattered. This radiation, coming from the direction of the sun, is called direct normal irradiance. Some of the scattered sunlight is scattered back into space and some of it also reaches the surface of the earth. The scattered radiation reaching the earth's surface is called diffuse radiation.

Solar annual and monthly averages can be found present in the meteorological stations. Usually the data is collected in a generalized way with no respect to the solar potential calculation. Nevertheless 10- year data is quiet useful for our study, while for investor site study a specific measurements should be taken. The tools in the study allow only a general review in order to facilitate the decision taking for investment in the process to target the suitable locations for further investigation and to identify the major obstacles and disadvantages early in the process.

At this early stage, average annual and monthly solar irradiance values can be used to assess the overall feasibility of a particular site and to select the appropriate solar technology to be installed. The major question is which group is going to be selected: heat production or electricity generation.

Hourly time series covering a period of years provide a more complete record for calculating accurate estimates of solar resource variability.

The problems with solar energy, coming into the grid, raise the questions of its management. For a station in the market economy environment, forecasting plays a vital role in estimating hour and day-ahead solar production and variability. This information is critical for estimating production, scheduling energy, avoiding imbalance charges and curtailment.

6.2.2 Solar Potential – General Terms

The term “energy potential” used recently in the documents, concerning Renewable Energy Sources (RES), needs some clarification. Most of the studies have as a subject not the potential as “energy derived from difference of state”, but energy as a total (usually is calculated the solar radiance, falling on the surface of the ground) and for this reason the results are very superficial and confused. In many “optimistic” publications the total solar radiance or total mechanical wind energy is “presented” as a potential, while the real potential, calculated as a difference, includes not only the radiance, but also additional factors – mostly restricting, which in their turn are not static, for example:

- energy demand type and volume;
- existing energy conversion technologies;
- local factors, regulations and restrictions.

Having this in mind, it is obvious that solar potential is much harder to be defined than wind, because wind is basically used for electricity production. (Installations, using mechanical force for example for grain mills, are considered outdated.)

Energy demand type, covered by solar energy, defines energy not only as a quantity, but also as a quality – production of hot water or hot air is not to be directly compared to the production of electricity. Heat based process alone as the production of hot water (or air) should be split into different sub-processes in accordance to the potential, because of the different characteristic temperatures of the process. A production with lower temperature (pool heating – 30 ^{o}C) will give as a result a much higher potential than tap hot water (55 ^{o}C).

Solar potential of electricity production obviously will have the lower potential value. From energy demand volume point of view, energy potential can be used to cover a limited amount of demand, for example we have a limited number of pools to heat. Even electricity as the most universal energy source, is meaningless to be calculated unlimited (at least financial or GDP constraints should be defined).

Potential as a difference is directly derived from energy conversion technologies. As will be shown in the study through application of different sets of technology, different potential can be calculated. Energy conversion technologies also are not static – new technologies appear and the old ones disappear or change. As to the local conditions, they can directly influence both the technology application and the demand type and volume. Local conditions determine the demand in pool heating or space heating, the existence of technology (or network) restrictions / bonuses, ecological barriers, agricultural dependences etc.

6.2.3 Solar Radiation

Solar radiation, falling on the surface of the site, is the main factor driving the process of solar utilisation. Turkey is a country in Europe with one of the highest levels of solar radiation throughout the year. Sunshine duration is about 7.2 h daily and the solar energy intensity equals 3.6 kWh/day. The highest theoretical energy potential of Turkey is in the Southeast Anatolian region with an average solar radiation 4.0 kWh/day and daily sunshine duration 8.2 h. Even the lowest value in the Black Sea region with an average solar radiation of 3.1 kWh/day and sunshine duration of 5.4 h daily is high enough to be considered.

The data of The Turkish State Meteorological Service recorded daily at 41 meteorological stations, which are distributed in the Black Sea Catchment area in Turkey, for 10 year period from 2000 to 2009 were used in this study. The average solar intensity per region was calculated by using the data. The stated data was provided by ITU Partner and following geographical regions, which are fully or partly included by the Black Sea Catchment in Turkey, are covered:

- Aegean – 1534 kWh/m^2/year
- Black sea – 1467 kWh/m^2/year
- Marmara - 1496 kWh/m^2/year
- Central Anatolia - 1635 kWh/m^2/year
- Eastern Anatolia - 1645 kWh/m^2/year

The other two regions namely: South Eastern Anatolia region and Mediterranean region were not included in the meteorological stations observations and the calculations for these regions, aiming at a full coverage of the economic calculation for Turkey, was based on common data as follows:

- South Eastern region – 1748 kWh/m^2/year;
- Mediterranean – 1690 kWh/m^2/year.

Total radiation (as energy) is calculated to be equal to more than 100.10^3 MTOE (1 200 000 TWh) as shown in the Table 25.

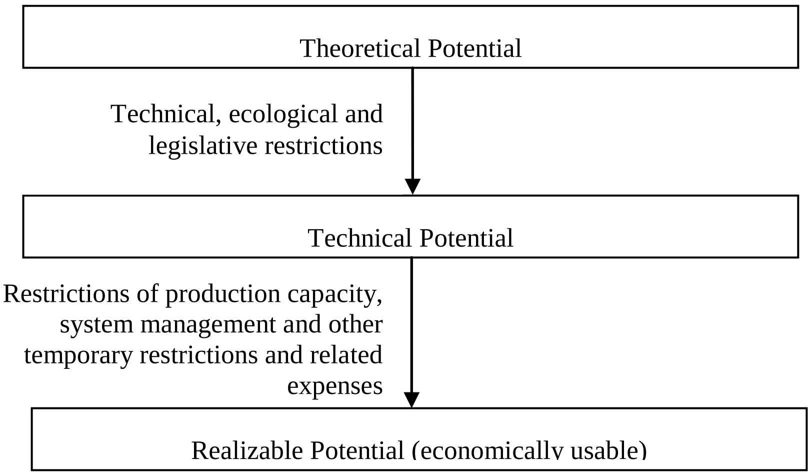
Table 25. Solar radiation

Regions	Average Solar Intensity kWh/m^2.yr	Territory km^2	Radiation TWh/Year
South Eastern Anatolia	1748	76509	134000
Mediterranean	1690	89838	152000
Eastern Anatolia	1645	150069	247000
Central Anatolia	1635	166657	272000
Aegean	1534	89997	153000
Marmara	1496	92531	138000
Black Sea	1467	109076	16000
Istanbul	1527	5315	8000
TURKEY	1614	779992	1264000

Theoretical technical solar potential, unconstrained by technical, economic or environmental requirements of Turkey was cited in official publications to be not more than 1% or 88 million tons oil equivalent (TOE) per year, 40% of which was considered economically usable.

Three-fourths (24.4 MTOE per year) of the economically usable potential is considered suitable for thermal use, with the reminder (8.8 MTOE per year) for electricity production.

In the last years a much more optimistic figure of 32 MTOE is cited by General Directorate of Electric Power Resources in Turkey. The concept of potential applied in this study, corresponds to the realizable potential which differs from the theoretical and technical potential as shown below.



In this study; the process of determination of solar capacity, possible to be realised, is split between both possibilities:

- production of hot water is considered in residential and service sectors;
- production of electricity is determined separately for residential and service sectors and independently for electricity generation).

Solar potential is determined on monthly and regional bases from stage to stage as follows:

- solar irradiance;
- solar technical potential;
- solar economical potential;
- solar production (economic) forecast

The calculations of the potential are done on the bases of statistical mean values for each region in the study.

6.2.4 Demand

Demand forecasts data can be derived throughout standard statistical methods, using correlation and extrapolation techniques, which will not be discussed in details in this study.

6.2.4.1 Household Demand

Demand of households is calculated on the bases of the demographic forecast and forecast of specific consumption - per capita, for the processes of cooking, heating, hot water production, lighting, appliances and air-conditioning.

Residential demand distribution in the European statistics point out, that about 60% of the energy sources are used for heating and air-conditioning. Hot-water production covers 15%, lighting and appliances consuming electricity is aiming at 20% and cooking is in the range of 5% of demand.

Temperature measurements for typical villages in the different areas are necessary for the sake of regional calculations.

6.2.4.2 Industrial, Agricultural and Commercial Demand

Demand of industry and commerce is calculated on the bases of the GDP and energy intensity forecasts. A more detailed sector forecasting can also be applied, which is required a substantial database about different energy processes. Standard future forecasting technique is applied in this study.

6.2.5 Technologies

Historically the hot water production is not a modern technology. Hot water production with dark coloured vessels is widely used, especially in Southern parts of Europe - Turkey and Greece.

Nowadays the hot water installation consists of collectors in which a fluid is heated by the sun, plus a hot-water storage tank where the water is heated by the hot liquid. Low temperature collectors are used for pool heating or rarely for underfloor heating, while medium temperature collectors are used for hot water or air heating.

Solar air heating is not typical for Europe so it is not considered in details in the study.

Solar hot water production efficiency varies from 35% for the vessels production till 90% for solar collectors. Even in colder areas, like Northern Europe, a solar heating system can provide 50-70% of the hot water demand. In Southern Europe a solar collector is able to cover 70-90% of the hot-water consumption. Heating water with the sun is very practical and cost effective.

Electricity production started with projects, using thermal produced liquids for electricity generation with the so-called high temperature collectors. Total capacity online as of 2011 is considered to be 1170 MW–82 MW in Spain and 507 MW in USA. Another 17540 MW are under development – USA leading, followed by Spain and China. Thermal efficiency of this type of project is similar to the efficiency of the typical steam electricity production (30-40%). The gross solar efficiency, calculated on the bases of the total area, used by the installation is reported to be only 2-3% of the total solar energy that falls on the territory of the solar plant. Thermal storage is possible and if also fossil backup is available, than this generation unit will have a much higher reliability.

The photovoltaic panels range only from 10-15% efficiency, the theoretical maximum calculated not to be higher than 24%. Nevertheless the financial support of EU (especially FIT systems) and the simplicity and shorter construction period of the installations (compared to the high temperature technologies), resulted in the boost of its development. The gross solar efficiency, calculated on the bases of the total area, used by the installation here can reach 7–10 % of the total solar energy, as a result of the higher percentage of land utilization. Practically no electricity storage exists and the stations availability is vulnerable to climate changes.

The photovoltaic module cost represents around 50-60% of the total installed cost of a solar energy station.

6.2.5.1 Thermal Solar Collectors

The shares of the solar water heaters to overcome the annual energy requirements were closely related to the collector types. Solar collector efficiencies, which are used, are taken from publication, not considering any complex heat loss calculation from first or second order. As will be seen in the Table 26, the major factor for the efficiency calculation is the temperature difference in the processes, defining the heat losses.

Table 26. Efficiency for the different processes

Collector Type	Pool Heating	Hot Water	Space Heating
Absorbers	90%	20%	-
Ordinary Panels	80%	35%	25%
Vacuum Tubes and Selective Panels	60%	55%	50%

Most important criterion for collector type selection is the purpose of its utilization. A comparison of different collector types and their parameters are given in the Table 27.

Table 27. Collector types

Purpose of the Collector Type	**Temp. in °C**	**Production kWh/m²/year**	**Price in €**	**€/kWh***
Pool Heating				
Absorber	20-40	250-300	100-200	0.15-0.03
Warm Water Preparation				
Panels	20-70	250-450	600-1400	0.10-0.15
Vacuum Tubes	20-100	350-450	1000-2000	0.15-0.20
Air Collector	20-50	300-400	300-800	0.04-0.10

* per m^2 under 20 years collector life expectation for West Europe

6.2.5.2 Flat Plate Solar Collectors

Flat plate solar collectors are the most widespread solar thermal applications, which are generally used for the production of commercial and domestic hot water, especially throughout the coastal regions

The present Turkish collector manufacturing capacity is estimated to be capable of producing 1 million m^2 per year, so the growth of solar thermal market is expected to continue unrestrained, thus increasing the quantity and quality of collectors. Vacuum tubes production is included in this study as a subgroup and is not considered separately.

The most common way of using solar energy is through hot water by solar water heaters. Hot water is required for domestic and industrial uses such as houses, hotels, hospitals, and mass-production and service industries. Solar water heaters are affordable and a cheap substitute for fossil fuels, which renders them increasingly popular.

The household energy consumption of Turkey includes electricity, coal, natural gas, petroleum and renewable energy sources. Ten years ago the biggest share, as an energy source, was coming from wood, but in the last year natural gas share increased rapidly and now has the biggest – about 32% in year 2007. Share of renewable energy sources (solar etc.) was only about 3%.

According to official statistics, in Turkey, 11 million m^2 of collector surface area (an equivalent of 0.15 m^2 collector surface per capita) were installed with a heat output of 0.4 MTOE in 2005.

The most commonly used solar water heating system for domestic needs is through natural circulation type that consists of a flat plate solar collector connected to an insulated storage tank. These are simple to assemble; low cost; simple in design and fabrication; durable; do not require sun-tracking; can work on cloudy days; and require minimum maintenance. The average life of typical solar water heating system is generally assumed to be 20 years.

The daily useful energy output of a solar collector can be calculated on the bases of the mathematical formulas, describing their efficiency parameters:

Zero-loss efficiency: n0
- 1st order heat loss coefficient: a1
- 2nd order heat loss coefficient: a2 (not to be considered in the study)

Using these parameters, the collector efficiency can be expressed as:

$$n = n0 - a1*(Tm-Ta)/G \quad (3)$$

and hence the power:

$$P = A*(n0*G - a1*(Tm-Ta)) \quad (4)$$

where:

G = solar irradiation W/m^2
Ta = ambient air temperature
Tm = collector mean temperature
A = collector area

A constant collector temperature is assumed and the annual energy output is calculated by integrating it over a year including all positive contributions.

Qannual = ∫ [A*(n0*G – a1*(Tm,constant-Ta)]+ dt (5)

Practically to calculate the annual output per m^2 of a given collector is necessary to take the typical mean temperature of its operation and the hourly weather data and the collector efficiency parameters. In the study the efficiencies are taken from publications sources.

Air heating collectors are not typical for the region, so they are not considered in the study.

For calculating the hot water demand: The energy requirement to heat water to 55 ^oC for consumption can be calculated as follows

Q = G.Cp ΔT (6)

where:

G is amount of water (equal to 50 L per person), and ΔT is temperature differences between tap water temperature and required water temperature (equal to 55 ^oC).

Medium family is considered to be 4 persons so about 200L are required for a family. In order to heat 200L of water to temperature of 55°C, the energy required varied between 2800 and 4000 kWh /annually for different sites of Turkey.

It has been estimated that in average 1-1,5 m^2 solar collector area is needed per 50 litres daily consumption of hot water. The calculation of cost for a household solar system depends on a number of factors.

Some of these are:

- Price of solar water heating system
- Efficiency of the system,
- Installation cost,
- State or government subsidy for installation of a solar water heater,
- Price of electricity per kWh,
- Number of kWh of electricity used per month by a household for water heating,
- Annual subsidy for using renewable energy,
- Annual maintenance cost (1-2% is not considered).

Resulting average price for hot water production from flat plate collector for Turkey was calculated to be not higher than 30 EUR /MW, which is significantly lower than the reference price for West Europe.

Solar systems usually supply a fraction of warm water needs (50 – 80 %) and are reserved by gas or electric heating on a daily basis. In the calculations a minimum of 25% additional energy was put as a requirement.

6.2.5.3 Photovoltaics

Corresponding to the manner of construction, the photovoltaics have been subdivided into two distinct parts: on-roof and on-ground. While for those technologies that are mounted on roofs a maximum roof area suitable for photovoltaics applications has to be determined, a maximum ground area has not been determined for large-scale plants.

On-roof photovoltaics

A regional approach of the theoretical on-roof photovoltaic technical potential requires data for the building type distribution in the regions. A separate data for Istanbul is applied because of the specific density of the defined region, as shown in the Table 28. Building Classification in Turkey and Specifically in İstanbul are also indicated in Table 29 and Table 30 respectively.

As a general approach the approach of Gutschner and Nowak (2002)[49] was used. This approach is based on the estimation that every $1m^2$ of ground floor area results in a solar architecturally suitable roof area of 0.4 m^2. The calculation takes into account architectural suitability (including construction, historical and shading elements)

[49] Gutschner M, and Nowak S., Potential for Building Integrated Photovoltaics, a Summary of IEA Photovoltaic Power System Program Annual Report PVPST7-4:2002.

and solar suitability, defined as surfaces with "good" solar yield (≥ 80% of the maximum local annual solar input). Regarding the base area per capita country-specific data is considered. Otherwise the statistical value of 45m^2 per capita (including residential, agricultural, industrial, commercial and other buildings) is used. Generally, densely populated areas have less area per capita available and vice versa.

Table 28. Households and buildings[50]

Type	Persons in Household	Rooms in Dwelling	Dwelling Size (m^2)	Person/Room	Space/Person (m^2)	Type, House/Apartment*
Inmates	5.8	3.6	106	1.61	18.17	50/50
Single Parent	2.1	3.3	98	0.62	47.09	40/60
Nucleic	3.8	3.5	104	1.10	26.89	38/62
Other	2.6	3.6	100	0.71	38.86	35/65
Mean	4					

* Apartment type buildings are considered 3 or 4 storey buildings

Table 29. Building classification in Turkey[51]

Construction Type		Storeys Type	
Concrete Frame	3837576	Low Rise (1-2 Storeys)	6647014 (88.5%)
Bricks	2977263	Mid Rise (3-4 Storeys)	763143 (10.1%)
Earth Bricks	472562	High Rise (>4 Storeys)	10223 (1.4%)
Stone	255976		
Total	7513377	**Total**	7513377

Table 30. Building classification in İstanbul

Storeys	1-4	5-8	9-19	>20	Total
Num. of Buildings	739328	352630	71225	196	1163379
Percentage	63.5%	30.3%	6.1%	0.1%	

After application of the methodology for Turkey the theoretical technical on-roof photovoltaic potential results to about 500 000 MW. This means, that the on-roof development forecast will be unrestricted in the scope of the study horizon up to 2050. The potentially useable are for the installation of large-scale photovoltaics plants is identified by summing up the area of arable lands and the grasslands of the country. This contradicts to the interest of crop growing parties, so a fair price competition and government restrictions are usually to be expected as a backward reaction.

Competing land uses should be considered (e.g. agriculture). See Table 31 for the land use distribution of Turkey in the year of 2000.

Using only the 22.2% land area, not included in the agricultural and forest area, means, that the technical potential for large-scale photovoltaics or CSV plants amounts to more than 25 000 000 MW. Restrictions, regarding land use, in this study are not considered.

Photovoltaic Plant Sizes

Due to the significant cost differences between different plant sizes, three typical photovoltaics plant sizes have been deemed necessary to cover the relevant cost range.

- The smallest plant size of 4 kW represents the typical small residential roof top system.
- Middle sized systems are set at an installed capacity of 30 kW.
- Large-scale plants are defined as all sizes of 1 MW and more. The latter is typically built on the ground rather than on top of a roof, that is why they should be calculated rather in the big power generating system models.

[50] Sarioglu Erdogdu G.P., 2010. A comparative analyses of entry to home ownership profiles, METU JFA 2010/2 (27:2) *95-124*
[51] Erdik M., 2011. Building Inventory Data, European Building Inventory Workshop, Pavia, 23-23 May 2011.

Table 31. Land use distributions*

Land Use	Thousand Hectares	Percentage Distribution
Arable Land	23826	30.8%
Permanent Crops	2553	3.3%
Meadows and Pastures	12671	16.4%
Subtotal: Agricultural Land	39050	50.4%
Forest and Woodlands	20703	26.7%
Other	17210	22.2%
Total Land Area	76963	99.3%
Total Area	77482	100%

* Source: Food and Agriculture Statistical Database (2000)

Photovoltaics Investment Costs

The lower end of all observable net retail prices gives an indication for real costs. It has to be mentioned that cost-differences between the two smaller plant sizes are substantial whereas economics of scale are declining with increasing plant sizes. The current prices of different solar technologies are indicated in Table 32. Higher investments are necessary for a better performance and the decision makers will be much influenced by additional incentives.

Table 15. Prices of different solar technologies

Type of Cells	Price of Equipment (USD/kW)	Performance (%)	Power (W/m^2)	Market Share (%)
Organic	1800	3%	30	1%
Thin Films	2000	12%	120	13%
Organic Silicon	2500	18%	180	85%
Concentrated PV	4000	25%	250	1%

The investment costs for solar roof are calculated to be as much as double the big solar generating utilities investments (see Table 33).

Table 33. Investment costs targets for solar roof technologies

Year	2020	2030	2050
Turnkey Price, EUR/kW	2660	1800	1000

One solar photovoltaic panel usually can produce 150 W/m^2 with a medium module efficiency of 15%. The cost of the panel is about 200 EUR/m^2. Total turnkey cost is 400 EUR/m^2 so resulting in 2660 EUR/kW = 4000 USD/kW. The total turnkey costs used in the modelling are presented in Table 34.

Photovoltaics Price Relevance

We assume the possibility of net-metering for small PV plants. Therefore, the relevant price for comparison here is the price to the end-consumer and not the wholesale market price. Thus the relevant price includes also grid costs as well as taxes and levies. For the big photovoltaics above 1MW the wholesale power price should be the correct cost comparison.

Scenarios for the utilities are modelled according to the forecast of the annual cost targets for the Power generating units (see Table 35).

Table 34. Turnkey costs, USD (EUR)/kW

Year / Sectors	2020	2030	2050
Residential	4000 (2660)	2500 (1800)	1500 (1050)
Commercial	3500 (2500)	1800 (1300)	1500 (1050)
Utility	3200 (2300)	1800 (1300)	1400 (1000)
Off-grid	3500 (2140)	1800 (1300)	1400 (1000)
Maximum Performance	18%	21%	24%
Cell Power Peak Performance, W/m^2	170	200	230

Table 35. Annual costs targets for solar technologies for power generating utilities, EUR/MWh

Year	2020	2030	2050
Turnkey Price ,EUR/kW	2300	1300	1000
Capacity Factor, h/year			
2200	n/a	n/a	58.00
2000	n/a	77.00	64.00
1800	131.00	85.00	71.00
1600	148.00	96.00	77.00

Assumptions: Interest rate 8%, technical lifetime 20 years, O&M costs 45 EUR/kW/year.

Photovoltaics Full Load Hours

Basis for full load hour calculation is the hourly irradiation data for all regions in the study. Combined with regional and hourly data for temperature, the inclination angle, kind of system-elevation and the performance ratio - full load hours are growing.

Presently at the level of 10 to 15% efficiency and solar potential in the region of about 1400–2000 kWH/m^2, technically possible utilization should be no more than 210–270 kWh/m^2. Realistic load factor is estimated to 1400–1800 hours/year. Each decade progress should move this figure upwards.

Solar utilities will have a higher load factor, compared to residential and commercial appliances, due to the investment in solar orienting equipment, while residential panels usually are fixed which will lower their conversion value.

Table 36. Load factors of solar appliances

Load Factor	Hours/Year
Residential	< 1500
Commercial	1450-1650
Utility	1800-2200
Off-grid	1600-1700

6.2.5.4 Concentrating Solar Power Installations[52]

Concentrating Solar Power (CSP), like parabolic through or solar power plants, play a minor role in renewable energies so far. Regarding important characteristics such as plant size and flexibility in power supply due to storage, CSP is very different to all other renewable energy technologies. Parabolic-through is designed as large-scale plant, using solar radiation for electricity generation within conventional power cycles. CSP installations require a lot of plain area and a high direct normal irradiation, which limits their potential significantly.

As a reference technology the plants that are currently realized and planned in Spain are chosen. They use molten salt thermal energy storage and co-firing of gas. In the period from 2008 to 2020 a plant size of 50 MW is set as a typical plant size and from 2021 the plant size is assumed to increase to 200 MW.

CSP Potential

Basis for the potential is the requirement for an annual direct normal irradiation of more than 1 800 kWh per m^2.

CSP Costs

Investment costs of parabolic-through plants amount to about 6,000 €/kW for the projects currently being realized in Spain. According to the EWI Report[21] CSP investment costs were 6000 $€_{2007}$/kW and annual O&M costs were 100$€_{2007}$/kW in Spain.

[52] EWI, 2010. European RES-E Policy Analysis: A model-based analysis of RES-E deployment and its impact on the conventional power market, Final Report, Institute of Energy Economics at the University of Cologne (EWI), April 2010

6.2.6 Support Schemes for RES (Wind and Solar)

Different support schemes are applied in order to stimulate the RES development:

- feed-in tariffs (FIT),
- investment subsidies,
- green certificates (premiums).

Although at present FIT prevails in Europe, majority of experts point, that this instrument is not market oriented and can cause serious side effects as oversupply or curtailment of renewable generation, despite their priority access.

The ENTSO-E(European Network of Transmission System Operators for Electricity) is in favor of support schemes, that give incentives for investors to respond to market prices, according to their marginal costs – support schemes, based on premiums or tradable certificates.

Support schemes (FIT and Investment subsidies) are planned to be active until 2020, when a significant decrease in investment costs is expected.

The present study calculations are based on the Tradable Green Certificates (TGS). The price of TGS differs in the different countries from 20 EUR in Poland to approximately 100 EUR in Sweden.

For the purposes of the present study a bonus of 30 for utilities and 60 EUR/MWh for households is going to be defined (corresponding to the expected level of green certificates). After 2020 the energy source competition will be based mainly on economic principle. A possible tail bonus price of 10-15 EUR / MWh can be expected to be valid not later than 2030. Another factor, which affects the decision, is the CO_2 emissions payments, which cost for the period is defined as 25–30 EUR/ton.

6.3 Regional Solar Potential Modelling

Modelling of solar technologies for residential and commercial sector use as a base the technical energy potentials, specified for the different regions in the country.

Solar modelling should reflect also the following specific characteristics:

- Zero fuel expenses;
- Significant decrease in the investment expenses from year to year due to the technological progress in the solar technologies;
- Expected increase in the power heat ratio, due to the better performance of the new technologies;
- Additional incentives (Feed-in tariffs, Green certificates, Subsidies etc.).

The model minimizes the costs for residential and commercial energy consumption as follows:

Running costs + Capital costs – Incentives (Sale of TGC)

Competition of all energy sources: gas, oil, coal, wood and biofuels, electricity, photovoltaics and water-heating panels, are performed on a regional base. Wind is excluded from the calculations, because small wind farms with a height of about 10 m have a very low potential to be considered.

Consumption taken in account should be the residential and commercial, while industrial consumption is usually on the high-voltage grid and is quite vulnerable to price distortions, so it is the main objective, together with the uncovered part of the residential and commercial consumption, to the big energy optimization.

Big photovoltaics and units, based on concentrating solar power (CSP), are defined with a least-cost linear model.

The following sources are considered as competing energy sources:

- Hydro power (big and small),
- Lignites and coal,
- Gas and oil,
- Nuclear,
- RES – Solar and wind,
- Other.

The model minimizes the costs for energy consumption as follows:

Running costs + Capital costs –/+ Incentives/Obligations (Buy-Sell of TGC, CO_2 tax).

6.3.1 Linear Matrix of Residential and Commercial Demand

A joint linear function, defining the demand processes, corresponding to the data, is shown below.

Table 37. Processes and sources, included in the matrix decision

Matrix/Zone	Total	Heating	Hot water	Cooling	Cooking	Transport	Appliances
UNIT	MWh	MWh	MWh	MWh	MWh	MWh	MWh
Natural gas	NGE1	NGE2	NGE3		NGE4		
Wood	WOE1	WOE2	WOE3		WOE4		
Coal	COE1	COE2	COE3				
Liquid fuels	OIE1					OIE2	
Central heating / Geothermal	CHE1	CHE2	CHE3				
Electricity (direct)	ELE1	ELE2	ELE3	ELE4	ELE5		ELE6
PV - commercial	WIE1						WIE2
Solar - thermal	STE1		STE2				
PV residential	SOE1						OTE5
Pellets and biomass	BIE1	BIE2	BIE3				
Natural gas - NEW	NGN1	NGN2	NGN3		NGN4		
Wood - NEW	WON1	WON2	WON3		WON4		
Coal - NEW	CON1	CON2	CON3				
CH-geothermal NEW	CHN1	CHN2	CHN3				
PVcommercial - NEW	WIN1			WIN3			WIN2
Solar - thermal - NEW	STN1		STN2				
PV residential - NEW	SON1			SON3			SON2
Pellets and biomass - NEW	BIN1	BIN2	BIN3				

The installations are considered to have a limited life (about 20 years), for which reason the matrix sources divided into two separate groups – existing (no capital value) and new. The investments in electricity installations are considerably low and for them no division is made.

The objective function is defined as follows:

MIN k1 NGE2 + k2 WOE2 + k3 COE2 + k4 CHE2 + k5 ELE2 + k6 BIE2 + k7 NGN2 + k8 WON2 + k9 CON2 + k10 CHN2 + k11 BIN2 + k12 NGE3 + k13 WOE3 + k14 COE3 + k15 CHE3 + k16 ELE3 + k17 STE2 + k18 BIE3 + k19 NGN3 + k20 WON3 + k21 CON3 + k22 CHN3 + k23 STN2 + k24 BIN3 + k25 ELE4 + k26 NGE4 + k27 WOE4 + k28 ELE5 + k29 NGN4 + k30 WON4 + 92.0 OIE2 + 123.0 ELE6 + 1.0 WIE2 + 1.0 OTE5 + 57.0 WIN2 + k31 SON2 + k32 WIN3 + k33 SON3 - Inc1 SON1 – Inc2 WIN1

Where k1– k33 are the specific expenses (EUR / MWh) for the demand, specified for the process in the matrix and Inc1, Inc2 – are the incentives, bonuses for RES technologies.

Sum of the columns gives the total demand. Restrictions of the technically possible amount of fuel in the processes are defined in the matrix (especially coal and wood).

A separate matrix decision is applied for each region and as a result - total demand coverage is defined.

6.3.2 Linear Matrix of Big Energy Production

Big energy matrix is more complicated as can be seen in Figure 21, but generally the mathematical tool is the same – usually SIMPLEX method is used.

Each matrix decision is checked by a simulation model with a scenario covering the energy balance month by month. The long repairs and fuel charging in nuclear stations are usually scheduled in months with a lower demand (April, May, September, and October). Solar stations have a significant production in summer months and lower in winter or cloudy days, which requires additional reserve capacities. Photovoltaics usually create system problems in the beginning and at the end of their production period, introducing a big strain to the conventional peak units, which are forced to execute a resulting quick start or shut-off.

Mtrix/Zone	Total MWh	Base MWh	Semi-base MWh	Semi-peak MWh	Peak MWh	Reserve MW
EXISTING UNITS						
Nuclear	NCE1	NCE2				
Lignite	LIE1	LIE2	LIE3			
Coal	COE1	COE2	COE3	COE4		COE5
Oil	OIE1	OIE2	OIE3	OIE4		OIE5
CCGT	CCE1	CCE2	CCE3			
Gas	GTE1		GTE2	GTE3	GTE4	GTE5
Hydro - peak	HPE1		HPE2	HPE3	HPE4	
Hydro - running	HRE1	HRE2	HRE3			
Wind	WIE1		WIE3	WIE4	WIE2	
Solar	SOE1		SOE3	SOE4	SOE2	
Other	OTE1	OTE2	OTE3	OTE4		
NEW CAPACITY						
Nuclear - new	NCN1	NCN2				
Lignite - new	LIN1	LIN2	LIN3	LIN4		
Coal - new	CON1	CON2	CON3	CON4		CON5
CCGT - new	CCN1	CCN2	CCN3			
Gas - new	GTN1		GTN2	GTN3	GTN4	GTN5
Hydro 1 – new	H1N1		H1N2	H1N3	H1N4	
Hydro 2 – new	H2N1		H2N2	H2N3	H2N4	
Hydro - small, new	HRN1	HRN2	HRN3			
Wind technology - 1	W1N1		W1N3	W1N4	W1N2	
Wind technology – 2	W2N1		W2N3	W2N4	W2N2	
Wind technology – 3	W3N1		W3N3	W3N4	W3N2	
Solar – 1	S1N1		S1N3	S1N4	S1N5	
Solar – 2	S2N1		S2N3	S2N4	S2N5	
Solar – 3	S3N1		S3N3	S3N4	S3N5	
Biomas	BIN1	BIN2	BIN3	BIN4		
Other	OTN1	OTN2	OTN3	OTN4		

Figure 43. Matrix for the distribution of the power generating units

6.3.3 Conclusions of Regional Solar Potential Modelling

The process of utilization of solar energy has received an obvious priority in the investment process, stimulated by the government decisions and resulting bonuses (FIT tariffs, certificates etc.).

A general calculation of the solar potential of a country seems insufficient for a decision taking. Regional measurements and calculations should follow the positive results from the general study. Site measurements and economic evaluation should fill the final page before the project preparation.

7 Forecasts and Results

7.1 Residential and Commercial Energy Demand Forecast

The forecast of the energy demand in the residential and commercial sectors is prepared on the bases of the demand forecast of the regions separately.

7.1.1 Population Forecasts by Regions

The basic criteria for the energy demand forecast is the population forecast, as shown in the Table 38. The forecast was done for each region separately, in order to reflect the specific parameters of the processes, which are going to be calculated.

Table 38. Population forecasts by region

Forecast	2020	2030	2040	2050
TOTAL	80 257 000	86 875 000	93 493 000	100 111 000
South-Eastern Anatolia	8025700	8687500	9349300	10011100
Mediterranean	9464100	9810200	10090000	10303700
East Anatolia	6242700	6323100	6337400	6385500
Central and West Anatolia	13586900	15141700	16762600	18449700
Aegean	10433400	11293800	12154100	13014400
Marmara	10032100	10859400	11686600	12513900
Black Sea	9229600	9990600	10751700	11512800
Istanbul	13242500	14768700	16361300	17919900

7.1.2 Process Forecast

7.1.2.1 Heating and Cooling

The main process in the demand is the process of space heating. On the bases of the data, provided by ITU for the temperatures and heating degree, days a specific value was determined for each region, which was checked and correspondingly corrected statistically. Results are presented in Table 39.

Table 39. Heating and cooling data for stations

Region Num.	Region Name	Station Name	Heating, degree,days	Cooling, degree,days
1	Aegean	Afyon	2810	1453
1	Aegean	Aydın	1255	2907
1	Aegean	Denizli	2074	2200
1	Aegean	Kütahya	2459	1702
1	Aegean	İzmir	1502	2630
1	Aegean	Uşak	2427	1747
2	Black Sea	Bolu	2880	1193
2	Black Sea	Çorum	2946	1327
2	Black Sea	Giresun	3375	893
2	Black Sea	Gümüşhane	3606	809
2	Black Sea	Karabük	2413	1365
2	Black Sea	Ordu	3213	970
2	Black Sea	Rize	2435	1350
2	Black Sea	Samsun	1852	1804
2	Black Sea	Sinop	1882	1789
2	Black Sea	Tokat	3091	1075
2	Black Sea	Trabzon	1691	1956
2	Black Sea	Zonguldak	1877	1665

Region Num.	Region Name	Station Name	Heating, degree,days	Cooling, degree,days
3	Central Anatolia	Aksaray	2977	1411
3	Central Anatolia	Sivas	3431	1165
3	Central Anatolia	Eskişehir Anadolu	2809	1480
3	Central Anatolia	Kayseri	3039	1407
3	Central Anatolia	Kırıkkale	2985	1348
3	Central Anatolia	Kırşehir	3133	1228
3	Central Anatolia	Konya	2820	1682
4	Eastern Anatolia	Ardahan	4036	775
4	Eastern Anatolia	Bingöl	3054	1834
4	Eastern Anatolia	Erzincan	3080	1633
4	Eastern Anatolia	Erzurum	4887	770
4	Eastern Anatolia	Hakkari	3151	1777
4	Eastern Anatolia	Iğdır	3962	975
4	Eastern Anatolia	Muş	3277	1707
4	Eastern Anatolia	Van	3378	1352
5	Marmara region	Balıkesir (Tur-AFB)	2036	2015
5	Marmara region	Çanakkale	1748	2165
5	Marmara region	Bursa	1902	2015
5	Marmara region	Edirne	2212	2009
5	Marmara region	Tekirdağ	1990	1914
6	South-eastern Anatolia	Batman	2137	2719
6	South-eastern Anatolia	Diyarbakır (Civ/AFB)	2091	2781
6	South-eastern Anatolia	Gaziantep	1904	2689
7	Mediterranean	Adana	1071	3154
7	Mediterranean	Antalya	1043	3087
7	Mediterranean	Isparta	2604	1615
7	Mediterranean	Kahramanmaraş	2284	2165
7	Mediterranean	Mersin	1287	2792
8	İstanbul	İstanbul	1844	1945

The forecast of the heating and cooling ratio shows a constant increase per capita, based on the expected increase in the standard of living and the decreasing number of the members of the households (see Table 40 and Table 41).

Table 40. Annual specific ratio for heating, MWh/per capita

Region	2020	2030	2040	2050
South-eastern Anatolia	2.24	2.33	2.42	2.51
Mediterranean	1.77	1.84	1.91	1.98
East Anatolia	3.86	4.02	4.18	4.34
Central and West Anatolia	3.23	3.36	3.49	3.62
Aegean	2.19	2.28	2.37	2.46
Marmara	2.09	2.18	2.27	2.36
Black Sea	2.71	2.82	2.93	3.04
Istanbul	1.98	2.06	2.14	2.22
Medium	2.45	2.55	2.65	2.75

In the second table some corrections were done in order to lower the values in SE Anatolia and East Anatolia, because the model decisions showed clearly, that the energy consumption in both regions is significantly lower than the required quantity.

7.1.2.2 Hot Water Demand

The energy requirement to heat water to 55 ^{o}C for consumption was calculated according to the standard formula of

$Q = G.Cp \Delta T$

where G is amount of water (equal to 50 L per person), ΔT is temperature differences between tap water temperature and required water temperature (equal to 55 ^{o}C) (see Chapter 6.2.5.2.)

Table 41. Annual specific ratio for cooling, MWh/per capita

Region	2020	2030	2040	2050
South-eastern Anatolia	0.50	0.60	0.70	0.76
Mediterranean	1.17	1.24	1.31	1.38
East Anatolia	0.50	0.60	0.70	0.76
Central and West Anatolia	0.64	0.68	0.72	0.76
Aegean	0.96	1.02	1.08	1.14
Marmara	0.85	0.90	0.95	1.00
Black Sea	0.55	0.60	0.65	0.70
Istanbul	0.85	0.90	0.95	1.00
Medium	0.85	0.90	0.95	1.00

Medium family is considered to be 4 persons, so about 200 L are required for a family. In order to heat the necessary water for a household to the temperature of 55°C, the required energy varies between 2800 and 4000 kWh /annually for different sites of Turkey. The reason for this can be attributed to the difference in the tap water temperatures. The specific demand per capita is shown in the Table 42.

Table 42. Annual specific ratio for hot water, MWh/per capita

Region	2020	2030	2040	2050
South-eastern Anatolia	0.80	1.00	1.30	1.50
Mediterranean	0.85	0.90	1.00	1.10
East Anatolia	1.50	1.80	2.20	2.50
Central and West Anatolia	1.20	1.50	1.80	2.10
Aegean	0.80	1.00	1.20	1.40
Marmara	0.80	1.00	1.20	1.40
Black Sea	1.00	1.20	1.50	1.80
Istanbul	0.80	0.90	1.10	1.30
Medium	0.95	1.20	1.40	1.60

The steep increase in the hot water demand is calculated with the task to reach the usual norms, linked to the increasing standard of living.

7.1.2.3 Other Processes

The processes, which are also separately calculated in the optimization task and for which specific ratios are determined as follows:

- Cooking – 0.4 MWh per capita
- Appliances (Electric) – 0.3 MWh per capita
- Transportation – 0.05 TOE per capita

Because of the controversy in their tendencies, no dynamics is forecasted in the values.

7.1.3 Energy Prices

Energy prices are considered constant for the forecasted period, which is a standard procedure for a optimization modelling, when the purpose is to define the influence of the developing technology – in this case solar and wind energy production. Energy prices are indicated in Table 43.

7.1.4 Energy Sources and Technologies

Sources and technologies, included in the modelling, are shown in Table 44.

After the first test small wind turbines were excluded from the calculations, because of their low competitiveness in the whole period, as a result of the low energy potential at the height of 10 m. A tower with a height 50 or 100 m is included in the scope of utility wind production.

Table 43. Energy prices for households

Energy Source	Price	Unit	EUR/MWh
Oil for Heating	1000	EUR /TOE	86
Diesel	1070	EUR /TOE	92
Gasoline	1210	EUR /TOE	104
Nat Gas - Households	470	EUR /TOE	40
Coal-Households	100	EUR /TCE	12
Electricity for Households	120	EUR/MWh	120
Pellets	140	EUR /Ton	27
Wood	90	EUR /Ton	31

Table 44. Sources for residential consumption

Processes	Coal and Peat	Petroleum Products	Gas	Wood and waste	Geothermal, Solar, etc.	Solar	Electricity
Heating	YES	YES	YES	YES	Heat pumps	NO	YES
Cooling	NO	NO	NO	NO	NO	PV	YES
Hot water production	YES	YES	YES	YES	YES	Thermal panels	YES
Lighting and appliances	NO	NO	NO	NO	NO	PV	YES
Cooking	YES	YES	Rare	YES	NO	NO	YES

7.1.5 Solar Data

The available data for solar consists of two sets of data:

1. Data from 41 meteorological stations for 10 year period covering 2000-2009. Stated daily recorded data, which include solar intensity, global solar radiation, minimum and maximum temperature data recorded at 41 monitoring stations, provided by ITU and detailed information and distribution of the meteorological stations are presented in the chapter covering the determination of the mapping methodology;
2. Data from General Directorate of Electric power Resources: Stated data is more inclined to be a result of a predetermined pessimistic scenario. Data from the 10 years meteorological set and data from 50 towns data differ insignificantly, namely: 4 – 9 %.

Table 45. Solar radiance and sunshine duration

Set of data	**1**	**2**	**3**	**Sun duration**
Region	kWh/m2.year	kWh/m2.year	kWh/m2.year	Hours/year
SE Anatolia	-	1748	1460	2993
Mediterranean	-	1690	1390	2956
East Anatolia	1527	1645	1365	2664
Central Anatolia	1558	1635	1314	2628
Aegean	1534	1701	1304	2738
Marmara	1370	1496	1168	2409
Black Sea	1346	1467	1120	1971

7.1.6 Matrix Zone Determination

The linear function, which was also indicated in Table 37, was created with zones, corresponding to the data (see Section 6.3.1).

7.1.7 Results

The results of total residential and commercial consumption from the matrix calculation for the period, including years 2020, 2030 and 2050 are presented in Table 46 and Figure 22. Table 46 both presents the absolute consumption values together with their share of the total demand.

The results from the calculations show that the development of the solar potential utilization is significant after year 2020. Solar energy for thermal usage (hot water) increases its absolute value about 8 times without any incentives in order to reach 16 % share in the total residential demand. The development of the photovoltaics till year 2020 is based mainly on the incentives from TGS (Tradable green certificates – REMARK: Some countries use FIT, which is a bigger incentive). The critical value of TGS is just below 60 EUR/MWh, which means, that without incentive the number of Photovoltaics will be significantly lower. The dominant investments are calculated to be used in the commercial sector (medium size installations) and practically there is no investment in residential small installations till 2020.

Table 46. Total residential and commercial consumption, 1000 TOE

Years / Energy Sources	2007		2020		2030		2050	
Oil and gas	13424	43%	15943	40%	16783	37%	18669	32%
Wood and biofuels	4984	16%	6348	16%	7787	17%	9860	17%
Coal	2750	9%	4618	12%	5080	11%	5588	10%
Electricity (big plants)	6914	22%	7706	20%	5013	11%	4305	7%
Electricity from small and medium RES / solar and wind	0	0%	1110	3%	4713	10%	8910	15%
Solar - thermal energy	1208	4%	2485	6%	4695	10%	9305	16%
Central heating /Geothermal and other/	1746	6%	1200	3%	1300	3%	1560	3%
TOTAL	31026	100%	39409	100%	45372	100%	58196	100%

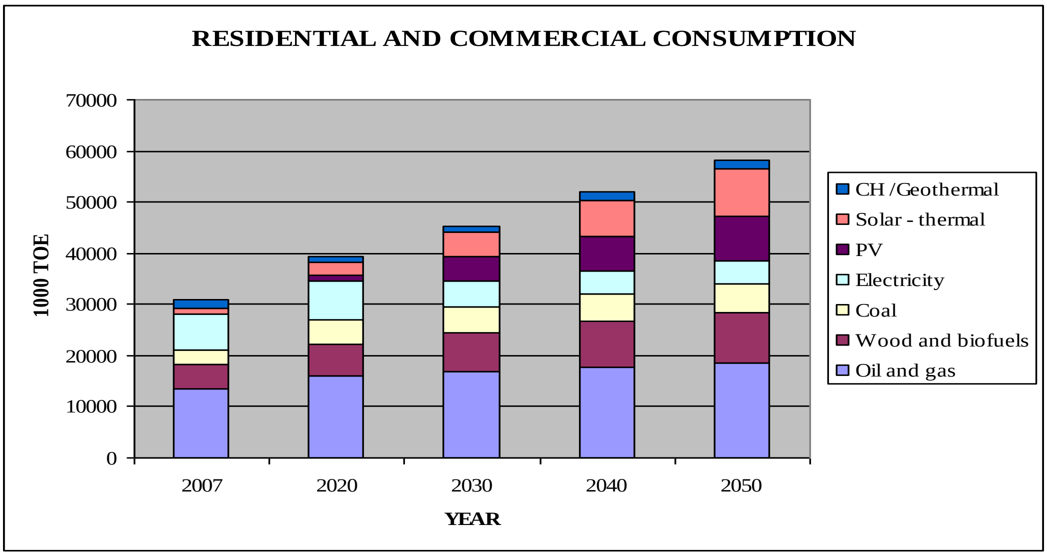


Figure 44. Residential and commercial consumption

After 2020 the small residential units gradually gain power to cover 40% of the total installed photovoltaic capacity in year 2050. The so-called hard fuels – coal, wood and bio-fuels have a stable share in the energy consumption, closely following the increasing demand. Oil and gas increase their quantities in an absolute value, but lose significantly in the share of the total demand, dropping from 43 % in 2007 to 32 % in 2050. The most significant reduction can be observed in the consumption of electricity from big producers, as a natural result from the RES energy production growth.

There are some factors, not included in the calculations, namely: electric cars implementation, which can increase the residential electricity consumption at the expense of liquid fuels. This factor is indirectly included in the “High demand scenario of Power generation forecast”.

The balances of this optimistic scenario show that the expected development in the solar technologies will lead to a significant growth in the solar potential realization in the residential and commercial sector, based mainly on 2 technologies – flat water collector (vacuum tubes) and on-roof photovoltaics.

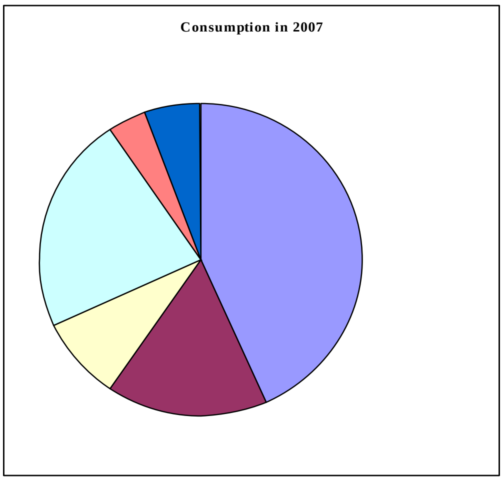


Figure 45. Pie graphic indicating consumption in 2007

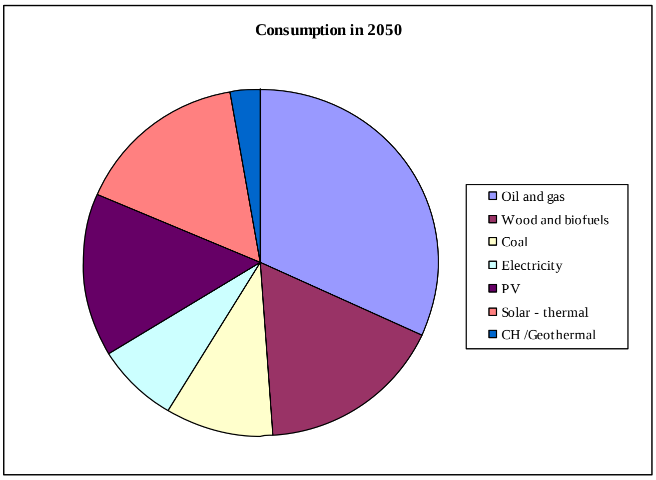


Figure 46. Pie graphic indicating consumption in 2050

They are expected to cover in 2050 a total share of 31 % of the demand and to reach an absolute energy value, amounting to 18.2 million TOE.

7.2 Power System Generation Forecast 2020 – 2050

7.2.1 Demand Forecast

7.2.1.1 High Demand Scenario Forecast

Based on the “Turkish Electrical Energy 10-Year Generation Capacity Projection Plan (2009 – 2018)” (TYP) two scenarios were developed for the period 2020 – 2050 (see Table 47). Forecasts for high demand scenario are represented in Figure 25.

Table 47. Demand forecasts for the period 2010-2050

Year / Items	2010	2015	2020	2025	2030	2035	2040	2045	2050
High demand forecast, GWh	202 730	288 300	408 958	511 198	613 437	736 125	858 812	987 634	1116 456
Annual increase		7.3%	7.2%	4.6%	3.7%	3.7%	3.1%	2.8%	2.5%
Peak, MW - high demand	31 246	44 400	63 000	78 750	94 500	113 400	132 300	152 145	171 990

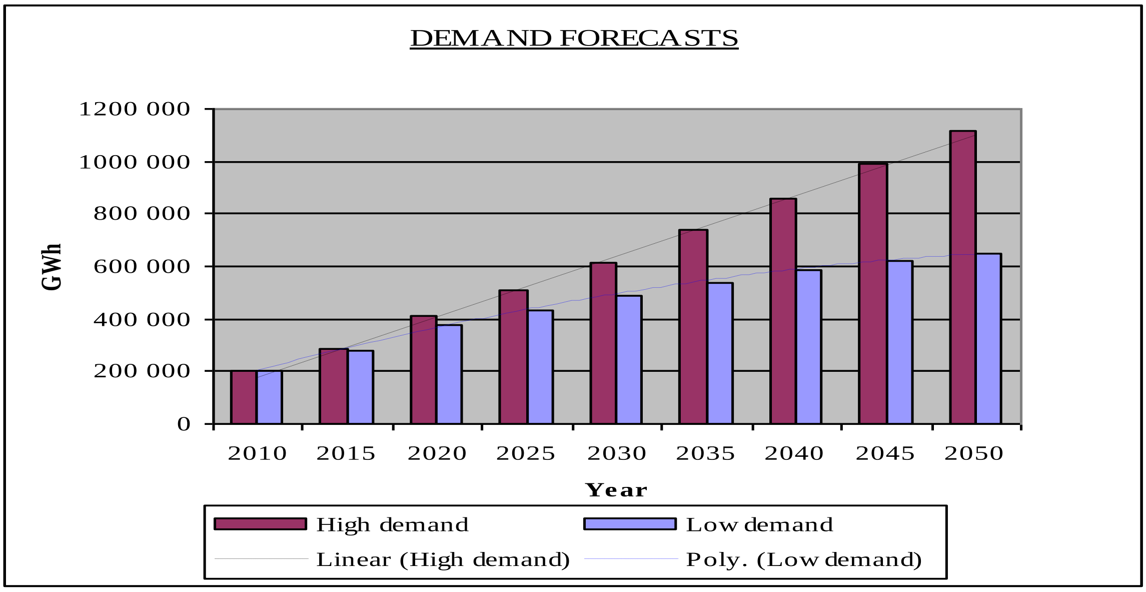


Figure 47. Demand forecasts

First scenario was developed as a linear forecast, based on the high scenario of the 10-year plan (TYP) which seems very optimistic and certainly will demonstrate the serious investments and construction efforts necessary for its implementation.

7.2.1.2 Low Demand Scenario Forecast

Second scenario was developed as a polynomial function, based on the low scenario of the TYP. This plan seems to require an effort in the decrease of the energy share in the GDP, which seems a logical step, taking in consideration, that the energy share in the GDP in Turkey seems considerably high.

Table 48. Demand forecasts for the period 2010-2050

Year / Items	2010	2015	2020	2025	2030	2035	2040	2045	2050
Low demand forecast, GWh	202 730	277 200	377 305	433 901	490 496	539 546	588 596	618 025	647 455
Annual increase		6.5%	6.4%	2.8%	2.5%	1.9%	1.8%	1.0%	0.9%
Peak, MW - low demand	31 246	42 700	51 800	58 000	75 400	90 480	99 528	99 528	99 528

The future decrease in the energy intensity is stimulated by the following factors:

- dynamic growth of GDP,
- demographic tendencies,
- energy saving technologies implementation,
- stimulation of RES,
- energy price factors,
- economic processes in Europe and in the world.

7.2.2 Generation Capacity Forecast

7.2.2.1 High Demand Scenario Forecast

High demand forecast requires the power generation capacities to increase more than five times its present value of 45000 MW and to reach the amount of 235800 MW.

Table 49. Forecast of the installed capacities by plant type, MW

Year / Item	2010	2020	2030	2040	2050
Nuclear stations	0	3 000	10 000	20 000	30 000
Lignite and coal	10 650	16 300	21 500	30 300	39 100
Gas and oil	16 850	29 400	42 100	55 300	68 550
Hydro stations	16 400	23 080	29 580	33 100	36 600
Wind	750	3 400	9 400	14 750	20 100
Solar	0	200	9 200	24 200	39 200
Other	350	1 650	2 250	2 250	2 250
TOTAL	**45 000**	**77 050**	**124 050**	**179 900**	**235 800**
Peak, MW - high demand	**31 246**	**63 000**	**94 500**	**133 245**	**171 990**
Reserve	**30.6%**	**18.2%**	**23.8%**	**25.9%**	**27.1%**

Nuclear Stations

Nuclear power is going to be a new source of energy for Turkey, but for a country with a considerable energy growth expectation, this will be a significant power generation technology. Following a difficult beginning with about 3000 MW till 2020, an ambitious program should be developed in order to reach 30000 MW in 2050, which is equal to 12.8% of the total installed capacity.

Table 50. Electricity generation of nuclear plants for the period 2020 – 2050, GWh

Year / Item	2020	2030	2050
Nuclear plants, GWh	21 960	72 160	211 400
Share	5 %	12 %	19 %
TOTAL, GWh	**408 958**	**613 437**	**1 116 456**

As it is presented in Table 50, it is forecasted that the nuclear plant generation gradually will increase its share in the total production from 5 to 19%.

Lignite and Coal

Lignite and coal power generating units are basic for the system and their constant growth is expected in the period in order to reach 39000 MW of installed capacities in 2050. As it is presented in Table 51, the share of electricity generation seems stable 22-25% for the whole period.

Table 51. Electricity generation of lignite and coal plants for the period 2020 – 2050, GWh

Year / Item	2020	2030	2050
Lignite and coal	100379	132200	240927
Share	25%	22%	22%

The expenses linked to the CO_2 emissions are the basic restriction for an even greater development of the coal and lignite units. The ratio between lignite and coal is about 60:40 in 2010, but coal utilization will progress faster and at the end the installed capacities are expected to be equal.

Gas and Oil

Combined cycle generation turbines are the backbone of the system, forming 25% of the total installed capacity and more than 30% of the generation (50400 MW). Electricity generation with combined cycle gas turbine (CCGT) plants for period of 2020-2050 is indicated in Table 52.

Table 52. Electricity generation of CCGT plants for the period 2020–2050, GWh

Year / Item	2020	2030	2050
CCGT	177569	234573	356049
Share	43%	38%	32%

Peak gas turbines will reach the considerable capacity of 18000 MW, mainly serving as a reserve. Solar and especially wind generation capacities have a lower reliability and this will require the reserve power generation capacity share to be increased. Load factor of the gas turbines will be not higher than 2500 hours/year and energy production 2 – 4% of the total.

Table 53. Electricity generation of simple gas turbines for the period 2020–2050, GWh

Year / Item	2020	2030	2050
Gas turbines	7756	18502	44172
Share	2%	3%	4%

Oil generation units will constantly decrease to reach the marginal value of 200 MW in 2050.

Hydro Stations

Hydro stations require high investment and are vulnerable to climatic (hydrological) and ecological influences. Dam stations are major sources of peak energy and their amount is expected to grow to reach 24 000 MW in 2050.

Running-water stations substantially will increase their volume to reach 12500 MW in 2050. Although the share of hydro stations is decreasing, their role in the total balance is of very high importance, as dominant capacities to cover the peak.

Table 54. Electricity generation of hydro stations for the period 2020 – 2050, GWh

Year / Item	2020	2030	2050
Hydro	82 210	107 219	135 701
incl. running water and small hydrostations	42 000	57 000	75 099
Share	20%	17%	12%

Wind and Solar

Wind and solar generation is the major decision goal in this study. The technology development is expected to be the major factor stimulating the growth of RES capacities.

Table 55. Wind technology parameters

Year / Wind	2020	2030	2050
Wind utility, EUR/kW	2000	1400	900
Load factor, h/year	2400	2200	2000

Investment expenses are expected to drop down from 2000 to 900 EUR/MW, but with the increase of the wind generation amount the simulation model results in a load factor decrease from 2400 to 2000 hours/year.

Investment expenses are forecasted in correspondence to the great expectations in the technology development in photovoltaics. Here the load factor is observed to grow, which helps the positive trend.

Price of CO_2 emissions and of the Green certificates also influences the decision taking in the investment process of solar and wind capacities. After 2030 the price of green certificates will not influence the decision, so their price is determined to be zero.

Table 56. Solar technology parameters

Year / Solar	2020	2030	2050
Solar utility, EUR/kW	3200	1300	1000
Maximum performance	18%	21%	24%
Cell power peak performance, W/m^2	170	200	230
Load factor, h/year	1800	2100	2200

Year 2030 is forecasted with a lower price, which is foreseen as a compromise.

Table 57. Prices of CO_2 emissions and Green certificates

Year / Factor	2020	2030	2040	2050
Emissions EUR/Ton	25	30	30	30
Green certificates EUR/MWh	30	15	0	0

Electricity production from wind turbines is growing with a constant rate, so their share in the total balance is 2 – 3 % for the whole period (see Table 58).

Table 58. Electricity generation of wind turbines for the period 2020–2050, GWh

Year	2020	2030	2050
Wind	7820	19800	38540
Share	2%	3%	3%
TOTAL, GWh	**408 958**	**613 437**	**1116456**

Solar capacities will start their implementation significantly after 2020 in order to gain speed and at the end of the period to reach 7% of the total generation.

Table 59. Electricity generation of solar sources for the period 2020–2050, GWh

Year	2020	2030	2050
Solar	319	17260	78974
Share	0.1%	3%	7%

This optimistic forecast is based on the assumption for a big technological breakthrough, which will allow the serious price drop, as shown in the input data.

Reserve Margin

The last 2018 year in the forecast of the “Turkish Electrical Energy 10-Year Generation Capacity Projection Plan (2009 – 2018)” shows a serious lack of reserves in the power generating system. The shortage in the power generation can be covered by import, which is an achievable task, having in mind the existing interconnections with the neighbouring countries.

Table 60. System peak load and reserve

Year	2018	2020	2030	2050
Peak Load, MW	55100	63000	94500	171990
Reserve	2%	18%	24%	27%

In the study the simulation model shows, that at least 20- 25% of reserves are considered adequate in order to ensure the stability of the system. Calculations were done on the assumptions of unserved energy price equal to 1000 EUR/MWh.

Turkish power system was successfully connected to the European network of ENTSO-E and despite the existing problems during the trial period, it is certain, that the new connection will provide better trade opportunities for the country.

The higher reserve margin in the end of the period is a result of the higher percentage of solar and wind power generating units, which have a low reliability.

Monthly Energy Balance

The simulation model shows a scenario covering the energy balance month by month. The long repairs and fuel charging in nuclear stations are usually scheduled in months with a lower demand (April, May, September, and October). Solar stations have a significant production in summer months, while wind production, which is considered most unreliable, is distributed statistically.

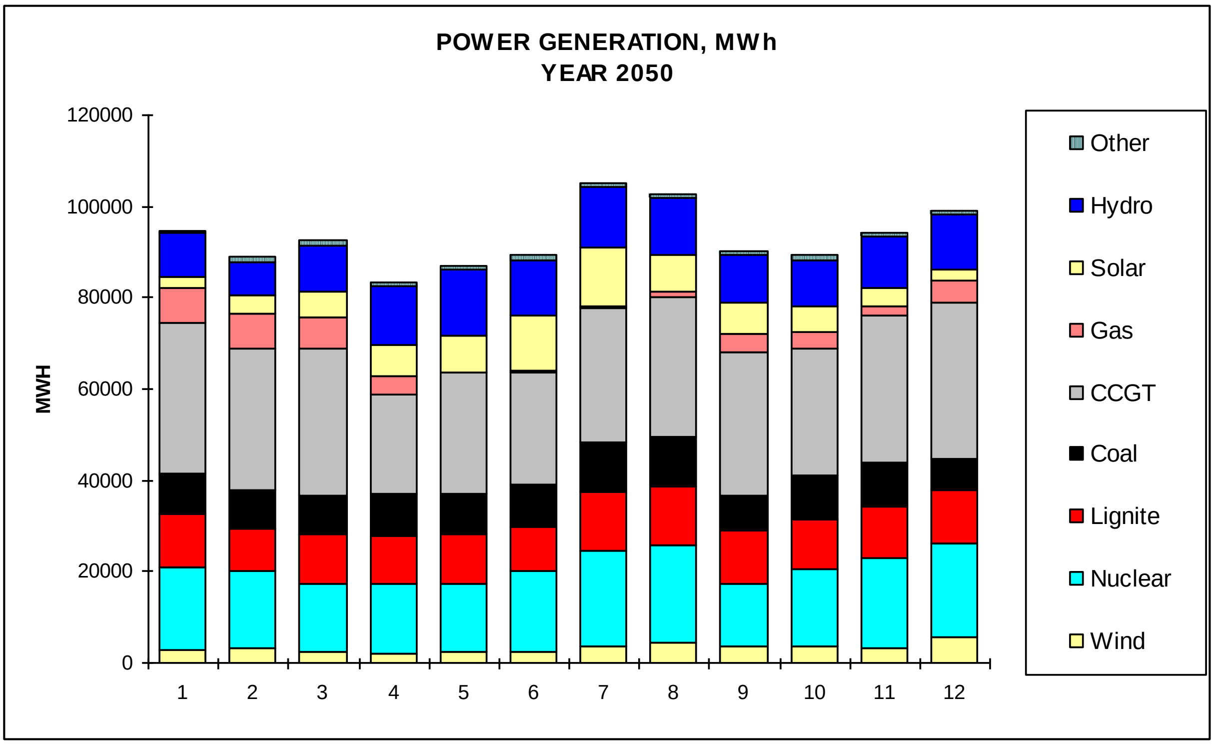


Figure 48. Monthly distribution in 2050 (High demand scenario)

Coal and lignite units have a nearly uniform production, while CCGT production is dominating to cover about 40% of the total generation.

Simple gas turbines have an important role for regulation, so their production varies significantly throughout the year.

Load Factor

Load factors of the energy sources change with the development of the structure. Nearly constant seem the hours of the nuclear (7000), lignite and coal (6200) and CCGT (7200) as base load units. Their monthly distribution is a result of a optimization repair program, refueling for the nuclear stations and economic and technical parameters as reliability and expenses.

Wind generation site determination will start with the most suitable sites for wind generation, but afterwards places of a lower wind potential and lower number of hours suitable for electricity production should also be included. This will result in a load factor expectation to decrease from 2300 to 1900 hours/year.

As it is indicated in Table 61, solar generation load factor will increase with the energy-efficiency growth (from 15% to more than 20%). Additionally, oil and fuel will be used mostly as a reserve capacity with a low load factor value. Peak units – hydro and gas normally have a load factor of about 2500 hours/year. Running hydro stations depend on the quantity of water. Here a wet year is shown with a high load factor of 6000 hours.

Total energy system load factor is decreasing with the increasing number of wind and solar generating capacities.

Table 61. Load factor by energy sources for the period 2020-2050

Year **Load Factor, (Hour/Year)**	**2008**	**2020**	**2030**	**2050**
Nuclear		7300	7200	7000
Lignite and Coal	5400	6170	6160	6150
Oil and Fuel	4170	1700	800	1000
CCGT	6560	7300	7200	7100
Gas		2600	2300	2500
Hydro-peak	2360	2500	2500	2500
Hydro-running	4000	6000	6000	6000
Wind	2000	2300	2100	1900
Solar		1600	1900	2000
Biomass and other	2340	4400	4600	4700
Total	**4750**	**5300**	**5000**	**4700**

Daily Load Curves

In the TYP the demand series for the period between 2009 and 2018, were calculated with MAED model. Assuming that there is no change in the shape of the annual load curve for the study period 2020 – 2050 will take place - the annual peak load values were obtained through rates, proportional to the annual demand growth (see Figure 27).

As it is represented in Figure 27, a peak day in December is presented. Wind generation is placed at the bottom, because of the RES (wind and solar) higher priority, nevertheless, that in critical situations the dispatcher will be forced to curtail their production.

On the bases of their daily production, the solar units are placed below the peak hydro units. For the purpose of the study their production is shows as a band and cloudy hours and days are not considered.

Nuclear, lignite, coal and CCGT have a constant band production with little or no deviations. Gas turbines and dam stations are scheduled to cover the peak. In this example the night minimum does not present any difficulties for dispatching.

Big challenges in the regulation are the weekends and days with low consumption, as it is shown on the Figure 28. During the night some of the basic stations (in this case CCGT) also should lower their production in order to overcome the minimum. When the water quantity in dams is not sufficient to cover the peak, the gas turbines are loaded from zero to maximum.

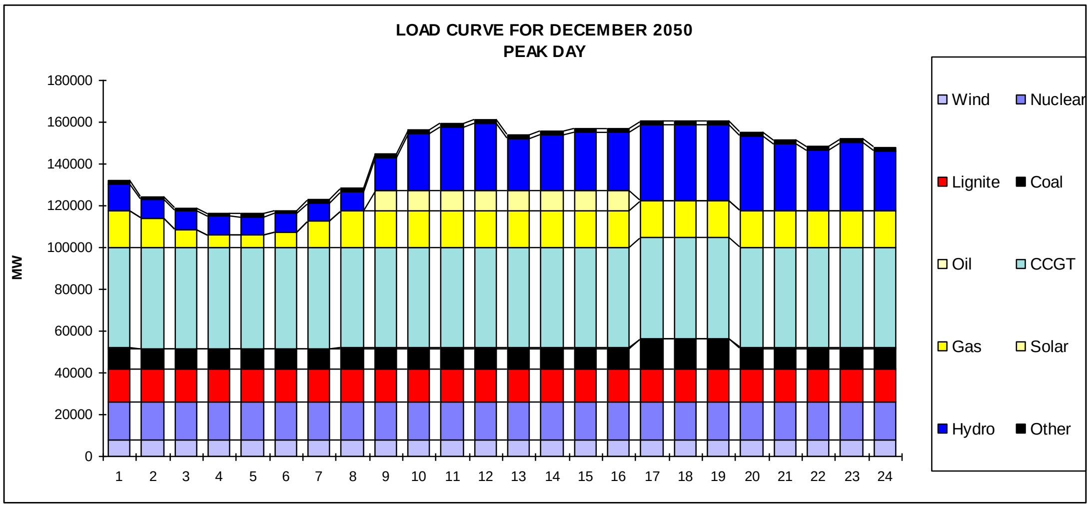


Figure 49. Load curve for a peak day in December 2050

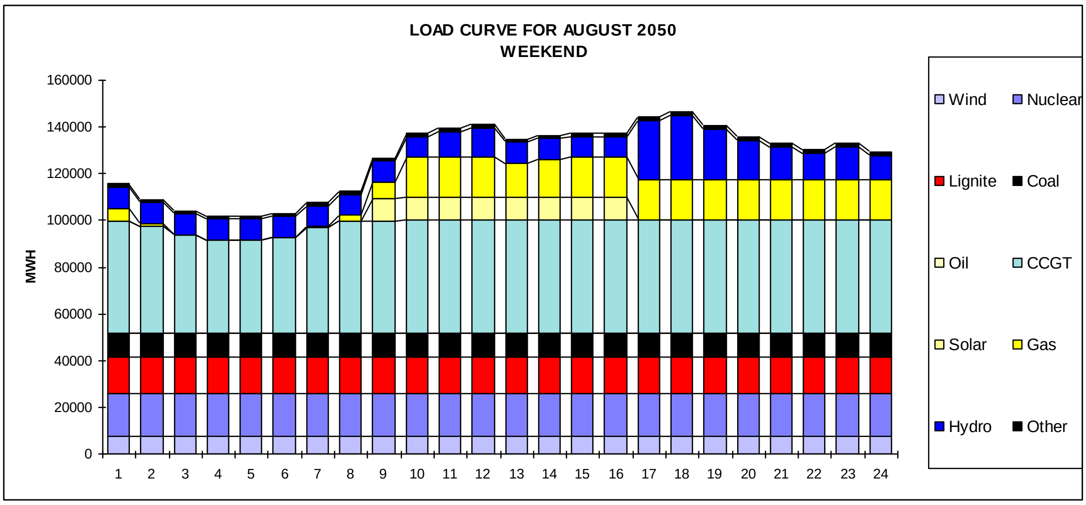


Figure 50. Load curve for a weekend in August 2050

7.2.2.2 Low Demand Scenario Forecast

Low demand forecast requires less strain in the investment, than the high scenario. Nevertheless, the power generation capacities will increase nearly three times its present value to reach the amount of 124 800 MW. Compared to the figure of 235 800 MW in the high scenario this means, that about 48% of the generating units (and the investments) will be spared. This scenario will be realized following the European trend of Energy saving, so a 48% is a realistic goal for 2050. (see Table 62 and Table 63)

Nuclear Stations

Nuclear power is also a major energy source in this scenario and the installed capacity will reach about 16% of the total generation capacities in 2050. As a base load capacity, nuclear stations will produce about 146 000 GWh or a 22% of the total generation. Nuclear program in this scenario requires, that about 20 000 MW will be in operation in 2050.

Lignite and Coal

Lignite and coal power generating units will reach their maximum in year 2020 and will remain almost constant till the end of the period to cover 13% of the generation.

Gas and Oil

Combined cycle generation turbines will cover about 40% of the generation in the study period and will follow the growing consumption with a steady pace. In this scenario simple gas turbines will reach the amount of 2000

MW in 2050, producing only 2% of the energy. Load factor of these peak turbines in this scenario can reach 3200 hours/year. Oil generation units will constantly decrease to reach the marginal value of 200 MW in 2050.

Table 62. Forecast of the installed capacities by plant type in MW (Low demand scenario)

Year / Plant Type	2010	2020	2030	2040	2050
Nuclear stations	0	2 000	8 000	15 400	20 000
Lignite and coal stations	10 650	15 700	14 800	14 200	13 600
Gas and oil stations	16 850	26 400	33 100	40 000	39 600
Hydro stations	16 400	23 100	27 100	28 600	30 100
Wind stations	750	2 200	4 200	6 800	8 200
Solar stations	0	200	4 200	9 000	12 200
Other	350	1 100	1 100	1 100	1 100
TOTAL–generating capacities	**45 000**	**70 700**	**92 500**	**115 100**	**124 800**
Peak, MW	31 246	58 000	75 400	90 480	99 528
Reserve	**30.6%**	**18.0%**	**18.5%**	**21.4%**	**20.2%**

Table 63. Forecast of the generation by plant type in MW (Low demand scenario)

Year / Plant Type	2018	2020	2030	2050
Nuclear		14600	58600	146300
Lignite	54090	64600	62900	66800
Coal	31879	33900	29600	18200
Oil	11788	4900	3900	500
CCGT	135418	157600	203600	252400
Gas		6700	6700	6600
Hydro	72850	82200	99100	106700
incl running water		42000	54000	54000
Wind	3660	5300	9300	16400
Solar	91	300	7700	23800
Other	2193	5400	5500	5700
UNSERVED KWH (IMPORT)	22633	1800	3600	4000
TOTAL, GWh	**334602**	**377300**	**490500**	**647400**

Hydro Stations

Hydro stations will continue successfully their development in the period and dam stations are expected to reach 21000 MW in 2050. Running-water stations will increase their volume to reach 9000 MW. Both types will produce about 17% of total electricity.

Wind and Solar

Wind and solar development in this scenario foresees a less strenuous, but also quite significant development. Wind power capacities will reach 8200 MW and solar – 12200 MW in 2050, which is about 14% of the installed capacities. Energy production share is expected to grow from 1% in 2008 to 7% in 2050.

Reserve Margin

Reserve margin in this scenario is forecasted to be almost constant – 20% overcoming the 2% minimum in 2018. As mentioned above, the connection to the European network is going to be a positive factor for the stability of the system. The lower amount of wind and solar production is also a factor, which allows lower reserve margin.

Table 64. System peak load and reserve

Year	2018	2020	2030	2050
Peak Load, MW	55100	63000	94500	171990
Reserve	2%	18%	19%	20%

Monthly Energy Balance

In this scenario the monthly balances seem more even. Solar production plays a significant role in the summer, while wind is distributed statistically. In some months gas turbines production exceeds the normal peak production (see Figure 29).

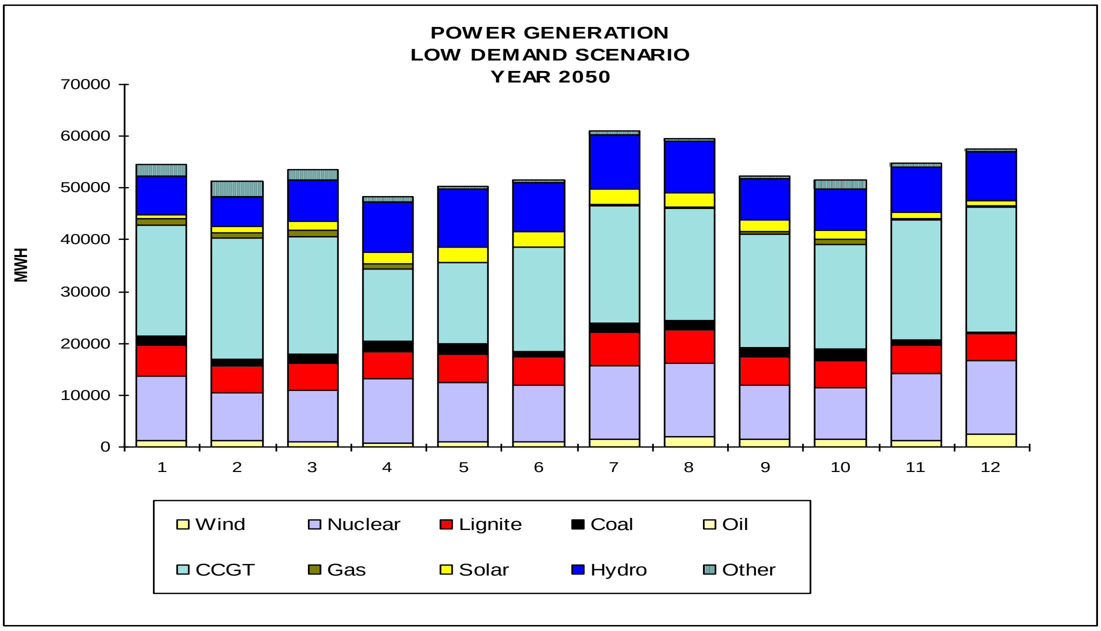


Figure 51. Monthly distribution in 2050. (Low demand scenario)

Load Factor

Load factor in this scenario is higher than the maximum scenario, because of the lower reserve margin. Gas turbines have a higher load factor value as explained above. Other units also increase their load factor value, which increases the total.

Table 65. Load factor by energy sources for the period 2020-2050

Year **Load Factor, (Hour/Year)**	2008	2020	2030	2050
Nuclear		7300	7300	7300
Lignite and coal	5400	6300	6300	6300
Oil and Fuel	4170	2700	2700	2700
CCGT	6560	7300	7100	7000
Gas		3400	3100	2800
Hydro-peak	2360	2500	2500	2500
Hydro-running	4000	6000	6000	6000

Load Factor, (Hour/Year) Year	2008	2020	2030	2050
Wind	2000	2400	2300	2000
Solar		1600	1800	2000
Biomass and other	2340	4800	5100	5100
Total	**4750**	**5300**	**5300**	**5200**

Daily Load Curves

Load curves in this scenario show, that the problems with the dispatching of the system are not so serious. As it is presented in Figure 30, in peak days hydro stations have enough water to cover the peak and gas turbines (December) work almost as base units.

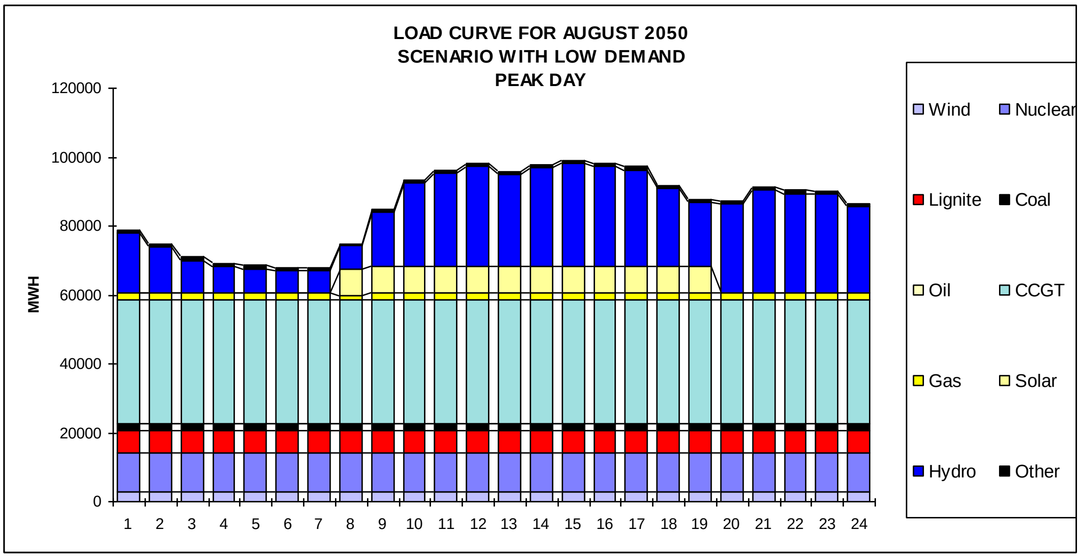


Figure 52. Load curve of a peak day in December 2050

Figure 31 presents forecasts of the weekend load curve in August for the year of 2050. In weekends there are again some problems with the night minimum, but with fewer efforts from the side of CCGT (or coal units).

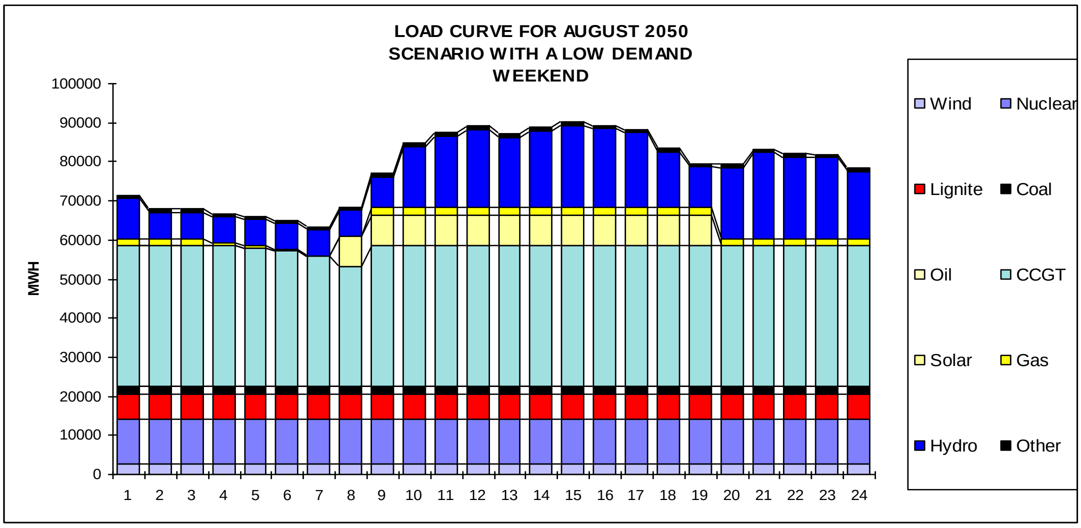


Figure 53. Load curve of a weekend in August 2050

8 Legal Framework for Wind and Solar Energy in Turkey

8.1 Residential and Commercial Energy Demand Forecast

The forecast of the energy demand in the residential and commercial sectors is prepared on the bases of the demand forecast of the regions separately.

8.1.1 Population Forecasts by Regions

Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy was first enacted on 18.05.2005. Following this law, certain regulations were enacted and amendments have been made over time.

The long awaited amendments to Turkey's renewable energy regime were enacted on 8 January 2011. Following this, the Ministry of Energy and Natural Sources and Energy Market Regulatory Authority (EMRA) has promulgated four regulations for the implementation of the recent amendments to the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (Renewable Energy Law). These regulations are listed as the following:

- Regulation on Certification and Support of Renewable Energy Sources (Regulation on Renewable Energy Support Mechanism), promulgated by EMRA effective from July 21, 2011.
- Regulation on Domestic Manufacturing of Components used in Renewable Energy Electricity Generation Facilities (Regulation on Domestic Components), promulgated by the Ministry of Energy effective from June 19, 2011.

These regulations implement the renewable energy support mechanism which encompasses the various incentives provided in the Renewable Energy Law such as the feed-in tariffs (the Support Mechanism), incremental price incentives for generators that use certain domestically manufactured mechanical and electromechanical components in their projects and the certification process for opting into such Support Mechanism. These incentives are described in Table 66.

Table 66. Renewable energy support mechanism; incentives

Type of renewable Energy	Feed-in Tariff (dollars/mWh)	Maximum Domestic Component Incentive (dollars/mWh)	Maximum Total Price for Power Output (dollars/mWh)
Hydraulic	73	23	96
Wind	73	37	110
Solar (photovoltaic)	133	133	67
Solar (concentrated)	92	200	225
Biomass	133	56	189
Geothermal	105	27	132

Feed-in Tariff incentives are valid for a period of 10 years for (i) power generators that utilize the renewables defined in the Regulation on Renewable Energy Support Mechanism and commence operations between May 18, 2005 and December 31, 2015 and (ii) license-exempt renewable energy generators through the retailers operating in the same region. The incremental price incentives apply only to projects that commence operations before December 31, 2015 and which have opted into the Support Mechanism, and they are available for five years after a project commences operations.

The domestic component price incentives require submission of a "domestic manufacturing certificate" attesting to the domestic origin of the relevant component, and a "product certificate" to be prepared by a national accreditation agency recognized by the International Accreditation Forum.

1. **Regulation on Electricity Generation without a License ("Regulation on License-Exempt Generation"), promulgated by EMRA effective from July 21, 2011.**

This regulation defines the suppliers who are exempt from the power generation licensing requirement, and certain special rules that apply to their power sale arrangements. These are categorized as: to (i) entities which establish co-generation facilities meeting certain efficiency requirements solely with the purpose of satisfying their own power needs (co-generation facility), (ii) facilities with an installed capacity of 500 kWe or less that utilize renewable energy resources (small renewable generation facility), and (iii) micro co-generation facilities with an installed capacity of 50 kWe or less (micro co-generation facility).

2. Regulation on Solar Electricity Generation Facilities ("Regulation on Solar Plants"), promulgated by the Ministry of Energy effective from June 19, 2011.

This Regulation specifies the required standards and test methods applicable for the components of the solar power plants and the procedures for their audits by The Ministry of energy and Natural Resources (MENR). Important notes from this regulation are listed below:

- The information regarding transformer centres and their connection capacities applicable for each year until 31 December 2015 shall be announced by MENR within 6 months of the effective date of the New Law. The information regarding transformer centres and their connection capacities for the years following 31 December 2015 shall be determined and issued annually by MENR. The first determination (applicable for the year 2016) shall be made on 1 April 2014.
- License applications for solar energy based power plants must be accompanied by appropriate, standard compatible measurements.
- If the owner of a site where the solar power plant shall be located applies for a license, another real or legal person cannot apply for a license for the same site.
- In the event there is more than one solar application for the same area and/or same transformer center, in order to determine which applicant shall connect to the system, a competition shall be held by an underbidding procedure with respect to the prices set forth within the New Law.
- The total installed capacity of solar energy based power plants, connected to the transmission system until 31 December 2013 shall not exceed 600 MW.

Additionally "Draft Communiqué on Measurement Standards regarding the License Applications for Wind and Solar Power" is also used in Turkey. This communiqué sets forth the measurement criteria that must be taken into account by applicants applying to obtain licenses for wind and solar power plants. It is expected to enter into force in the near future as EMRA has prepared the draft text of this communiqué and recently presented to stakeholders review until 22.08.2011.

If the communiqué enters into force in its current form, companies intending to apply for licenses will have to start measurements at places where their wind and solar power plants will be located for a period of at least one year.

The draft communiqué is criticized that it lacks significant points related to proper wind measurement data which in the past have led to overbidding at the TEİAŞ tenders and underperforming wind farms. Referring to the generation data reported by TEİAŞ, it is argued that very few wind farms operate with capacity factor above 35%.

An official decision of EMRA was published on 11 August 2011, which announced the list of transformer stations (sites chosen for the set-up of solar power plants) and their connection capacity limits to which generation facilities can be connected until 31 December 2013. The total generation capacity determined in this announcement was 600 MW. The decision also provided a map indicating the regions authorized for solar power investments. However very recently this decision was amended on 4.02.2012, keeping the list of available transformer stations but determining the threshold for total annual horizontal solar irradiation as greater than or equal to 1,620 kWh/m2.year hence invalidating the previously announced map.

9 Abbreviations and Acronyms

BOO	Build-Own-Operate
BOT	Build-Operate-Transfer
CCGT	Combined Cycle Gas Turbine
CSP	Concentrating Solar Power
DMI	State Meteorological Institute
EIE	General Directorate of Electrical Power Resources Survey and Development Administration
EMRA	Energy Market Regulatory Authority
EPDK	Republic of Turkey Energy Market Regulatory Authority
EU	European Union
EÜAŞ	Electricity Generation Corporation
EWEA	European Wind Energy Association
GDP	Gross Domestic Product
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
IMF	International Money Fund
MAED	Model for Analysis of energy Demand
MCP	Measure-Correlate-Predict
MENR	Ministry of Energy and Natural Resources
O&M	Operate and Management
PPP	Purchasing Power Parity
PV	Photovoltaic
RES	Renewable Energy Sources
SBA	Societal Benefit Area
SCADA	Supervisory Control and Data Acquisition
SWH	Solar Water Heater
TDD	Technical Due Diligence
TEİAŞ	Turkey Electricity Transmission Company
TGS	Tradable Green Certificate
TOE	Tons Oil Equivalent
TOR	Transfer of Operating Costs
TSMS	Turkish state Meteorological Service
TÜBİTAK	The Scientific and Technological Research Council of Turkey
TWPPA	Turkish Power Plants Association
TYP	Ten Year Plan
WAsP	Wind Atlas analysis and Application Program
WEPA	Wind Energy Potential Atlas

WPMFC	Wind Power Monitoring and Forecast Centre
WPP	Wind Power Plant
WRF	Weather Research and Forecasting

C. Annex III: Wind and solar energy potential assessment of Ukraine

Table of contents

1 Introduction

One of the main goals of the project is to expand the information potentialities of GEO system by establishing the information services oriented at Black Sea Catchment area users.

The project is intended for information potentialities of modeling and forecasting the situations, concerned with climate change, and their impacts on Societal Benefit Areas within predication period. Based on the tasks of Work Packages, the models and scenarios of climatic, demographic and land cover changes should be founded.

The rise of Renewable Energy Sources (RES) development (particularly wind and solar energy) is becoming one of the major factors of sustainable development. It is caused by the fact, that energy is a basic sector of the economy. The strategic goal of the economic development of any country is to maximize share of the energy in its energy balance, produced by country's own energy resources.

Energy resources of Ukraine consist of three main branches: nuclear power, thermal power and hydropower. All above-mentioned areas of energy in industrialized countries are unpromising and environmentally unsafe. The intensive use of thermal power plants led to a number of environmental problems [1]. During the last decades the issues related to the development of renewable energy in the world and in Ukraine are extremely relevant because of the scarcity and limitedness of energy resources and environmental deterioration.

Based on the obtained results of Task 5.4, the corresponding information services for RES potential assessment of Black Sea Catchment area are scheduled. Such services should be oriented at wind and solar energy potential forecasting as easily accessible and non-polluting energy sources.

For this period in accordance with work plan, USRIEP team has assessed an existent wind and solar energy potential of Ukrainian part of Black Sea Catchment region. Pursuant to the objectives of Task 5.4 "Energy", the results of wind and solar energy potential of Ukraine were analyzed and mapped in GIS environment.

Based on the problem put by Task 5.4 "Energy", the models suitable for wind and solar power potential assessment of Ukrainian part of Black Sea Catchment region had been selected and tested for assessing the current state of RES potential in Ukraine. Such models are based on identical and available data for all project partners.

It is well known that model complexity, its accuracy should not exceed input data accuracy requested for its content. Accordingly, models for wind and solar energy potential assessment are quite simple and available for all EnviroGRIDS project participants and for future users of developed information services.

At the same time, obtained data is adequate to real RES potential and might be used for business planning in order to decide the investment in energy supply development from RES.

Hence, at this stage USRIEP team has performed all planned activities on assessing the current state of wind and solar energy potential, stipulated by project's work plan.

Wind Power Potential Assessment

Wind power is a very attractive field. Wind technologies have grown in scope, and in various places wind is becoming a feasible source of energy. This kind of natural resource is vulnerable to weather conditions, but in certain locations, mainly in coastal offshore areas and at high altitudes, there is a steady stream of wind.

Wind power is harnessed through the use of wind turbines, which are turned by the wind to produce electricity. Wind energy is reliable and efficient. Unlike other power plants, wind energy systems require minimal maintenance and have low operating expenses.

Wind power is an affordable, efficient and inexhaustible source of electricity. It's pollution-free and cost-competitive with energy from new coal- and gas-fired power plants. In respect of the importance of this issue, USRIEP team has developed the methodology for wind power potential assessment.

1.1 Theoretical wind power potential assessment

Renewable energy potential assessment includes assessment and analysis of the theoretical and technical potential of renewable energy [2].

Theoretical potential is all the natural resources of renewable energy sources. Technical potential is that part of the theoretical potential of the renewable resource whose energy use is limited by technical (technology) and non-technical terms (financial, legal and others).

Exactly technical potential of renewable energy is the potential which is important and necessary for selection of specific technology for renewable energy conversion.

For estimating the wind energy potential of Ukraine, the following statistic parameters were calculated:

1.1.1 Vertical wind speed gradient

The wind speed at the surface is zero due to the friction between the air and the surface of the ground. The wind speed increases with height most rapidly near the ground, increasing less rapidly with greater height. The vertical variation of the wind speed, the wind speed profile, can be expressed by different functions. One of the most common functions which have been developed to describe the change in the mean wind speed with the height is Power Exponent Function [2]:

$$V(z) = V_r \cdot \left(\frac{Z}{Z_r}\right)^{\beta}$$

where Z is the height above ground level (m); V_r is the wind speed (m/s) at the reference height Z_r (m) above ground level; $V(z)$ is the wind speed (m/s) at height Z (m); β is an exponent which depends on the roughness of the terrain, can be calculated in approximation by using the formula:

$$\beta = \frac{1}{\ln \frac{Z}{Z_0}}$$

The parameter Z_0 for different types of terrain is shown in Table 1.

Table 1. Roughness lengths and roughness classes for various surface characteristics [2]

Z_0 (m)	Types of terrain surfaces	Roughness class
1.00	City	III
0.80	Forest	
0.50	Suburbs	
0.30	Built-up terrain	
0.20	Many trees and/or bushes	II
0.10	Agricultural terrain with a closed appearance	
0.05	Agricultural terrain with an open appearance	
0.03	Agricultural terrain with very few buildings, trees, ect.	I
0.02	Airports with buildings and trees	
0.01	Airports, runway	
0.005	Meadow	
$5 \cdot 10^{-3}$	Bare earth (smooth)	0
10^{-3}	Snow surfaces (smooth growth)	
$3 \cdot 10^{-4}$	Sand surfaces	
10^{-4}	Water surfaces (lakes, seas, etc.)	

1.1.2 Average wind speed

Wind speed is the most important constituent for assessing the wind energy potential of investigated area. The wind speed measurement period must be long enough to cover all meteorological conditions in that region with a sufficient amount of data. In order to obtain the stable value of mean wind speed, the observation period should cover no less than 10 years [3]. For obtaining wind frequency data, observation period has to be longer (about 25 years).

In order to assess wind potential of Ukraine, USRIEP team has obtained an averaged climatic data from the State Hydrometeorological Service of Ukraine, measured at 187 meteorological stations of Ukraine. Meteorological stations are uniformly distributed all over Ukraine and distance between them does not exceed 50-100 km (Fig. 1). Observation period covers 30 years.

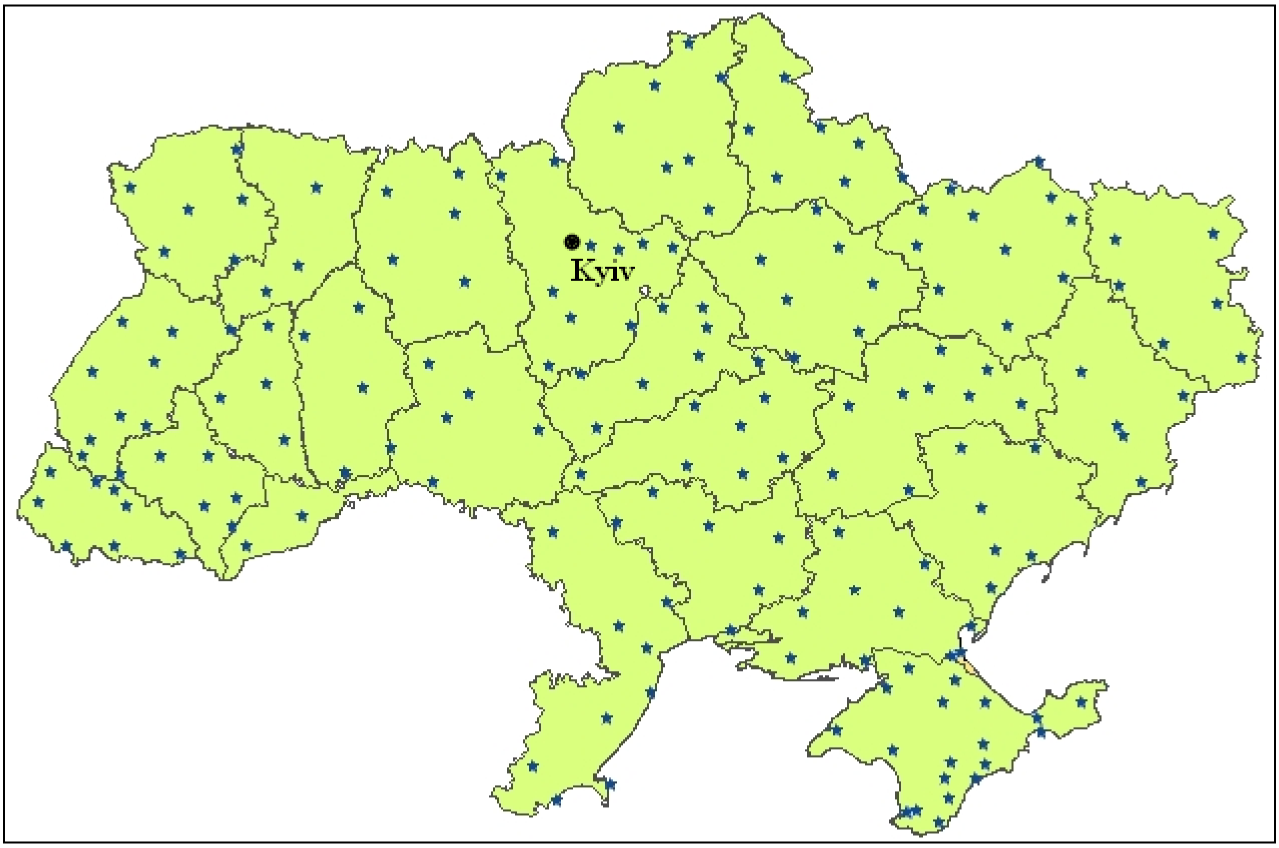


Figure 1. Location of hydrometeorological stations

Obtained data includes:

- Averaged wind speed values for 30 years (m/s), measured at 10 meters above ground level;
- Wind speed frequency (%) for the following wind speed ranges:
  - 0 – 1 m/s;
  - 2 – 5 m/s;
  - 6 – 9 m/s;
  - 10 – 15 m/s;
  - 16 – 20 m/s;
  - 21 – 24 m/s;
  - 25 – 28 m/s;
- Annual calm period (%).

All above-mentioned meteorological parameters are included in standard list of measurements for each Ukrainian meteostation.

Mean wind speed ($\mathbf{V_c}$), as the most commonly used indicator of wind production potential, is defined as [4]:

$$V_c = \frac{\sum_{i=1}^{n} \Delta V_i \cdot P_i}{\sum_{i=1}^{n} P_i}$$

where $\Delta \mathbf{V_i}$ is a middle of i^{th} wind speed range; $\mathbf{P_i}$ is the wind speed frequency of i^{th} wind speed range; *n* is a number of wind speed ranges.

The averaged values of wind speed measured at 10 m above ground level were analyzed and mapped in GIS invironment (Figure 2).

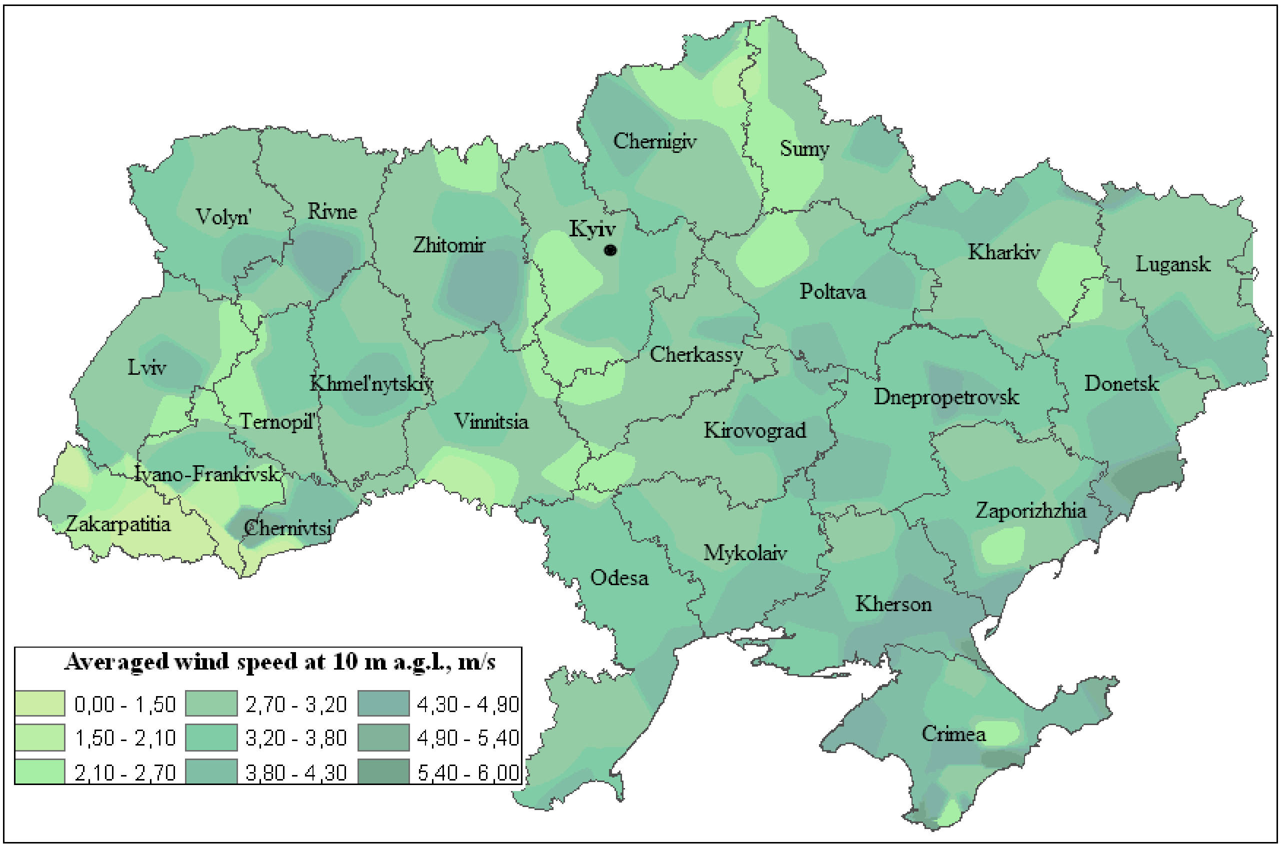


Figure 2. Averaged wind speed at 10 m a.g.l.

1.1.3 Standard deviation

Standard deviation is a widely used statistic measurement of variability or diversity. The standard deviation of wind speed is an indicator of the turbulence level and atmospheric stability.

$$\sigma = \sqrt{\sum_{i=1}^{n} (\Delta V_i - V_c)^2 \cdot \frac{P_i}{\sum_{i=1}^{n} P_i}}$$

1.1.4 Coefficient of variation

The coefficient of variation (C_v) is a normalized measure of dispersion of a probability distribution. The coefficient of variation is defined as the ratio of the standard deviation to the mean wind speed:

$$C_v = \frac{\sigma}{V_c}$$

1.1.5 Full medium cube of a wind speed

To achieve lasting results, such parameter as medium cube of a wind speed, required for wind-power density assessment, should include as well statistic parameters:

$$\overline{V_c^3} = (V_c)^3 \cdot (1 + 3 \cdot C_v^2 - 0,9 \cdot C_v^3 + 2,9 \cdot C_v^4)$$

where $\overline{V_c^3}$ is a medium cube of a wind speed (m3/s3).

The value of the full medium cube of a wind speed should be calculated for each meteostation at the reference height. Usually wind speed measures at 10 m height above ground level and average height of a wind turbine is about 70-80 meters. Therefore, in current article, cube of wind speed is calculated for 75 m above ground level.

Distribution of the wind speed at 75 m a.g.l. through the territory of Ukraine is shown in Figure 3.

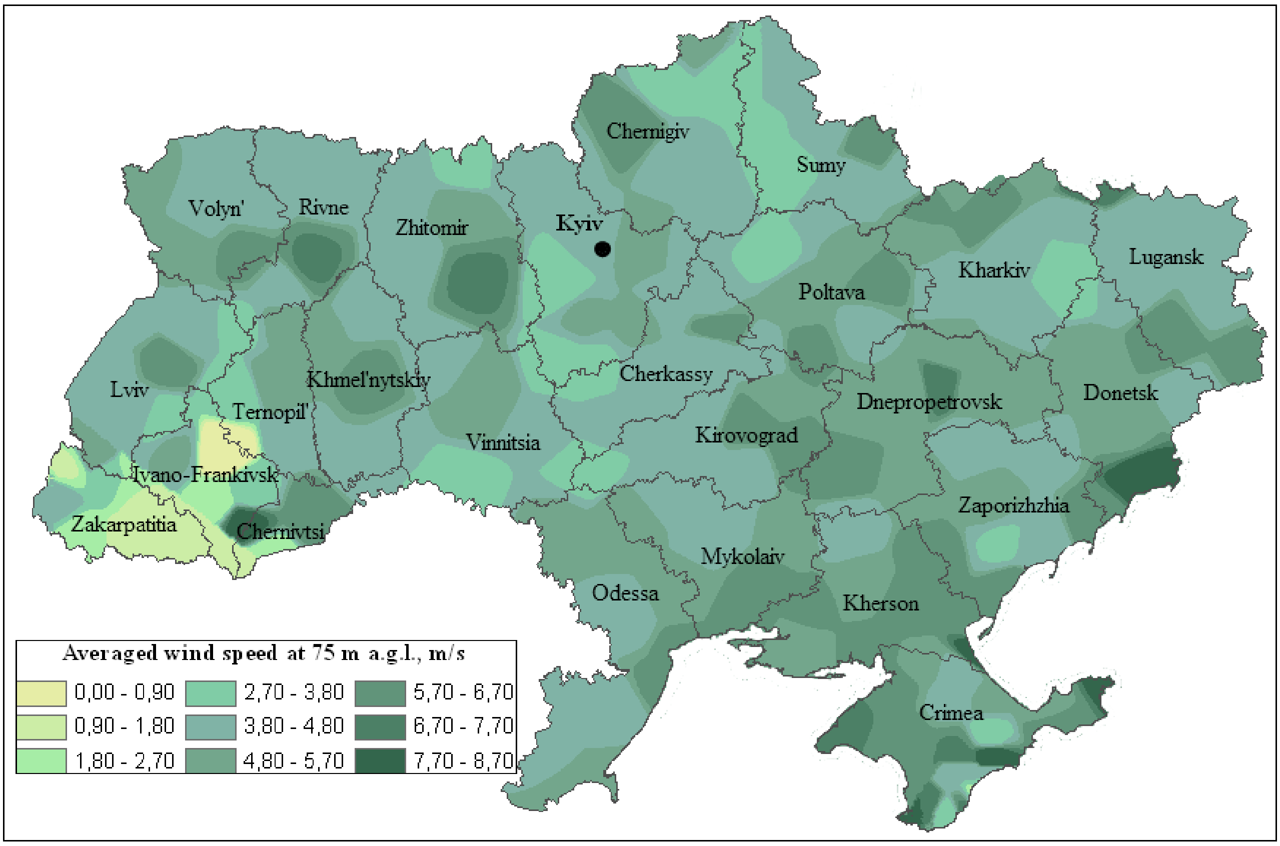


Figure 3. Averaged wind speed at 75 m a.g.l.

1.1.6 Wind power density

Wind power density is generally considered as a better indicator of the wind resource than wind speed, so, it is the amount of wind power available per unit of area perpendicular to the wind flow. Wind power density (WPD) should be calculated at the height of expected wind turbine (here it is assumed that the height is 75 m a.g.l.). WPD (W/m2) can be calculated using the following equation:

$$WPD = \frac{1}{2}\rho \cdot \overline{V_c^3}$$

where ρ is an air density (kg/m3); $\overline{V_c^3}$ is the full medium cube of a wind speed (m3/s3) at the height 75 meters).

1.1.7 Annual specific wind power density:

Annual specific wind power density WPD_{annual} is calculated from the following formula:

$$WPD_{annual} = WPD \cdot 24 \cdot 365 \cdot \left(1 - \frac{F}{100}\right)$$

Where WPD_{annual} is an annual specific wind power density (Wh/m2); F is an annual wind calm period, %.
Annual values of specific wind power density for Ukrainian territory were calculated (Table 3) and mapped (Figure 4).

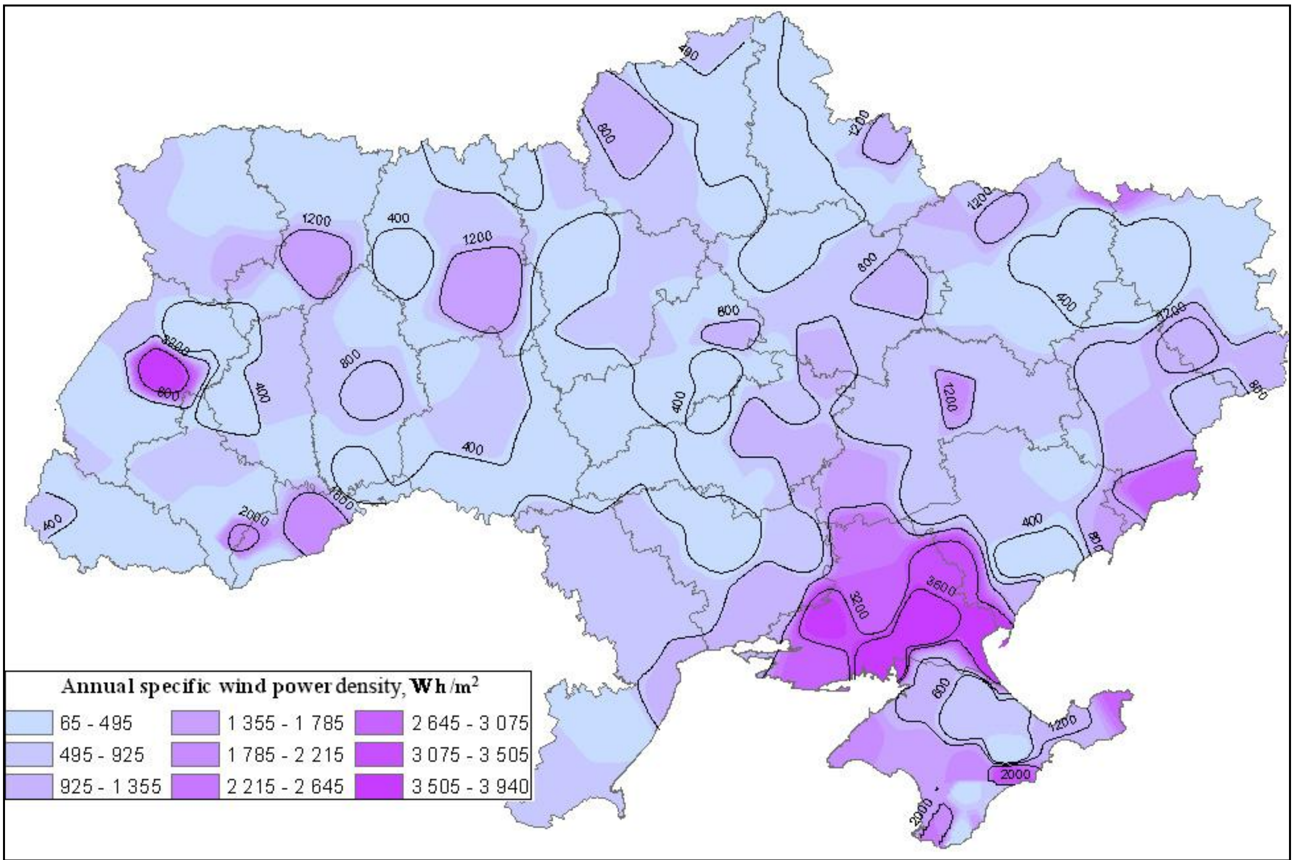


Figure 4. Annual specific wind power density

1.2 Technically achievable wind power potential of Ukraine

Wind farms require large sites, potential wind farm sites are preferably open areas of flat land or on top of hilly areas. Obviously, the sites should be known to be windy, with high and recurrent wind resources. Considerable percent of Ukrainian area is unsuitable for wind turbine placing. For technically achievable wind power potential assessment the following areas unsuitable for wind turbine placing were chosen and excluded from the calculations:

- urbanized areas;
- roads, highways and railways; and 300m of buffer zone around each side of the road;
- forests;
- water bodies surface;
- cultivated areas.

The total area unsuitable for wind turbine placement was calculated using GIS software, the results are shown in Table 2.

Table 2. Areas excluded out of the calculations, suitable area for the wind turbines placing

Region name	Total area of the region, km^2	Urbanized area, km^2	Forest-lands, km^2	Roads, railways + buffer zone, km^2	Water bodies surface, km^2	Cultivated area, km^2	Total area suitable for the placing of wind turbines, km^2
Kherson	28500	230,9	1324	3022	1096,7	11341	11485,43
Crimea	27000	225,8	3087	4032,4	8,6	6819	12827,3
Donetsk	26500	1097,4	1855	4915,7	203,9	11944	6483,99
Zhytomyr	29900	367,9	9890	5197,2	111,8	4549	9784,18
Chernihiv	31900	324,1	6566	4688,6	251,9	7571	12498,4
Luhansk	26700	746,3	2829	3547	64,7	8513	11000,07
Odesa	33300	305	1953	5025,6	1311,2	16388	8317,15
Rivne	20100	98,1	7317	3086,7	88,5	3236	6273,74
Dnipropetrovsk	31900	777,2	1528	5605,6	1038,6	16884	6066,59
Mykolaiv	24600	262,3	949	2949,3	354	13720	6365,38
Kharkiv	31400	578,9	3727	5830,9	371,6	13838	7053,56
Volyn	20200	118	6324	3784,5	180,1	2972	6821,34
Sumy	23800	330,6	4038	4445,1	88,7	7820	7077,61
Poltava	28800	248,7	2362	5394,4	880,8	14502	5412,18
Ivano-Frankivsk	13900	163,8	5767	2539,7	121,1	1465	3843,39
Zaporizhzhia	27200	336,1	1054	4257,6	2386	14759	4407,24
Kyiv	28900	394,9	6322	5183,1	2005,7	8496	6498,27
Lviv	21800	396,2	6264	5087,9	68,3	3158	6825,57
Khmelnytskyi	20600	215,7	2627	4356,5	210,5	7552	5638,33
Kirovohrad	24600	243,2	1588	3995,7	388,9	14585	3799,21
Chernivtsi	8100	92,4	2378	1751,5	151	1658	2069,11
Vinnytsia	26500	213,6	3514	5811,3	234,8	12024	4702,2

Region name	Total area of the region, km^2	Urbanized area, km^2	Forest-lands, km^2	Roads, railways + buffer zone, km^2	Water bodies surface, km^2	Cultivated area, km^2	Total area suitable for the placing of wind turbines, km^2
Zakarpattia	12800	68,6	6529	2033	68,2	891	3210,18
Cherkasy	20900	281,4	3193	3735	544	9772	3374,6
Ternopil	13800	125,4	1924	3091	59,9	6178	2421,7
TOTAL	**603700**	**8242,3**	**94909**	**103367,4**	**12289,6**	**220635**	**164256,72**

Wind turbines operate over a limited range of wind speeds. If the wind is too slow, they won't be able to turn, and if too fast, they shut down to avoid being damaged. To make wind farms profitable enough, annual average wind speed should be unless 6 m/s, otherwise wind farm placing at low wind speed sites is not reasonable.

The mutual distance between the wind turbines has to meet the requirements of the manufacturers. If the wind turbines are too close together output may be reduced. Another, more serious, consequence may be damage to primary structural parts caused by the wake of wind turbines sited upwind. The minimum distance depends on the placing with regard to the prevailing wind direction. For turbines sited perpendicular to the prevailing wind direction, the mutual separation distance has to be at least four and preferably five times the rotor diameter [5]. In current report, the methodology for wind power potential assessment takes as its foundation the Technical report on Europe's onshore and offshore wind energy potential [6], so technically achievable wind energy potential is calculated assuming the use of 2 MW wind turbines onshore with view on prospects for 2030. Regarding average wind energy production potential per square kilometre, it is considered that five 2 MW wind turbines can be sited per square kilometre onshore within the area suitable for wind turbine placing [6]. And for the average turbine of 2 MW, the related rotor diameter would be 80 m.

It was mentioned above that areas with annual average wind speed lower than 6 m/s are unsuitable for wind farms placing, so, such areas should be excluded from the calculations. An annual average wind speed of the main part of Ukraine is 6,3-6,8 m/s; but wind speed of some regions is exceeding the range of 7-8 m/s. Obviously such territories are more attractive for the building of wind farms. Also it can be expected that at such windy sites the number of wind turbines per square kilometer might be on average somewhat more than five (for example seven). Generalizing the developed concept, the territories of Ukraine, suitable for wind farms placing, with an average wind speed of 3 different ranges (<6 m/s; 6-7 m/s; >7m/s) were calculated and presented in Table 3.

The wind power capacity of each region of Ukraine $W_{capacity}$ was calculated using the following equation:

$$W_{capacity} = \sum_{i=1}^{n} S_{i} \cdot N_{i\,turb} \cdot P_{turb}$$

where S_i – area with respective wind speed range, km2; $N_{i\,turb}$ is a number of wind turbines per square kilometer corresponding to wind speed range; P_{turb} is power of wind turbine (2 MW); n is number of ranges (note that one of the ranges has been excluded, so, calculations perform only for two left ranges). The results of calculations are shown in table 3.

In accordance with obtained results, the technically achievable wind power capacity has been assessed and mapped (Figure 5).

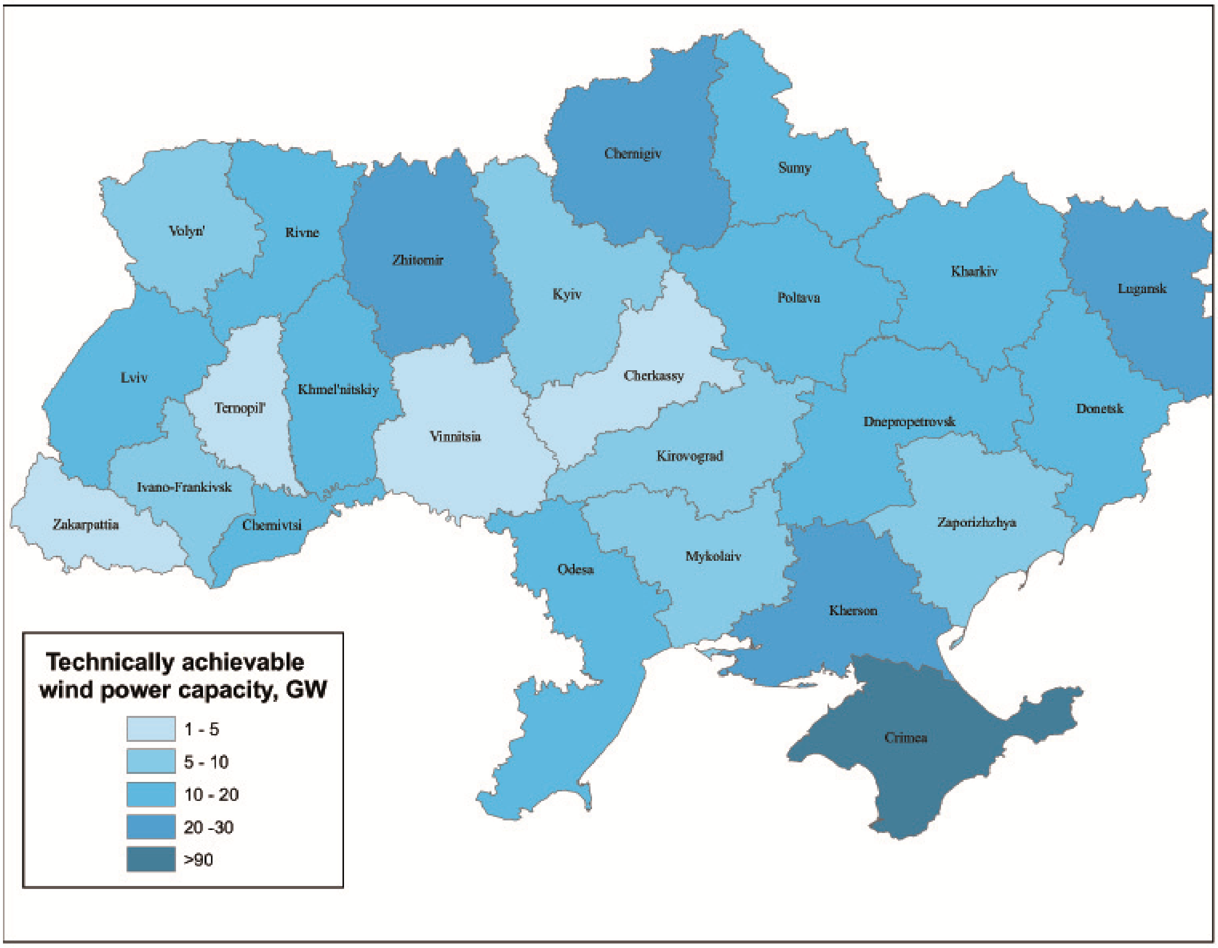


Figure 5. Technically achievable wind power potential

The actual power will be somewhat less than the calculated one, because available power cannot be totally extracted by any wind machine. The maximum extractable power from any wind machine is limited by famous Betz relation which assigns a power co-efficient Cp=16/27 for the maximum performance of a wind machine [1]:

$$WP(Max.ExtractablePower) = \frac{1}{2} \cdot \rho \cdot C_p \cdot A \cdot \overline{V_c^3}$$

Where WP is maximum extractable power (W); A is the rotor swept area, (m2); $\overline{V_c^3}$ is the cube of the wind speed at the reference height, expressed as m3/sec3.

According to obtained results, southern and eastern parts of Ukraine have outstanding wind potential, particularly Autonomous Republic of Crimea, Kherson, Donetsk and Lugansk regions.

As for annual specific values of wind power potential, the existing data indicates a promising wind potential around Autonomous Republic of Crimea, Kherson, Donetsk, Chernigiv, and Zhitomyr regions. For these areas the average annual wind speed varies between 5 to 8 m/sec at 75m a.g.l.

Table 3. Results of wind power potential assessment of Ukraine

Region name	Annual averaged specific wind power density, kWh/m^2	Total area suitable for the placing of wind turbines, km^2	The area of average wind speed			Wind power capacity for the areas of following wind speed ranges, GW		Total technically achievable wind power capacity, GW
			<6 m/s	6-7 m/s	>7m/s	6-7 m/s	>7m/s	
Kherson	3236,77	11485,43	8843,78	2297,09	344,56	22,97	4,82	27,79
Crimea	1420,52	12827,30	4489,56	6413,65	1924,10	64,14	26,94	91,07
Donetsk	1308,42	6483,99	4992,67	518,72	972,60	5,19	13,62	18,80
Zhytomyr	711,07	9784,18	7533,82	782,73	1467,63	7,83	20,55	28,37
Chernihiv	524,68	12498,40	9998,72	624,92	1874,76	6,25	26,25	32,50
Luhansk	549,73	11000,07	8800,06	2200,01	0,00	22,00	0,00	22,00
Odesa	687,39	8317,15	7069,58	1247,57	0,00	12,48	0,00	12,48
Rivne	840,24	6273,74	5018,99	501,90	752,85	5,02	10,54	15,56
Dnipropetrovsk	848,87	6066,59	4489,28	1213,32	364,00	12,13	5,10	17,23
Mykolaiv	745,16	6365,38	5410,57	954,81	0,00	9,55	0,00	9,55
Kharkiv	618,71	7053,56	5995,53	1058,03	0,00	10,58	0,00	10,58
Volyn	560,80	6821,34	6139,21	682,13	0,00	6,82	0,00	6,82
Sumy	523,39	7077,61	5662,09	1415,52	0,00	14,16	0,00	14,16
Poltava	626,33	5412,18	4329,74	1082,44	0,00	10,82	0,00	10,82
Ivano-Frankivsk	826,83	3843,39	3420,62	115,30	307,47	1,15	4,30	5,46
Zaporizhzhia	706,73	4407,24	3658,01	749,23	0,00	7,49	0,00	7,49
Kyiv	463,16	6498,27	5523,53	974,74	0,00	9,75	0,00	9,75
Lviv	427,94	6825,57	5801,73	1023,84	0,00	10,24	0,00	10,24

Khmelnytskyi	507,75	5638,33	4510,66	1127,67	0,00	11,28	0,00	11,28
Kirovohrad	739,27	3799,21	3039,37	759,84	0,00	7,60	0,00	7,60
Chernivtsi	1044,61	2069,11	993,17	931,10	144,84	9,31	2,03	11,34
Vinnytsia	438,04	4702,20	4231,98	470,22	0,00	4,70	0,00	4,70
Zakarpattia	583,25	3210,18	3049,67	160,51	0,00	1,61	0,00	1,61
Cherkasy	448,25	3374,60	3138,38	236,22	0,00	2,36	0,00	2,36
Ternopil	504,57	2421,70	2058,45	363,26	0,00	3,63	0,00	3,63
	TOTAL	**164256,72**	**128199,16**	**27904,77**	**8152,80**	**279,05**	**114,14**	**393,19**

2 SOLAR POWER POTENTIAL ASSESSMENT

Solar radiation is a renewable energy resource that has been used by humanity in all ages. Solar radiation represents the largest energy flow entering the terrestrial ecosystem. After reflection and absorption in the atmosphere, some 100 000 TW hit the surface of Earth and undergo conversion to all forms of energy used by humans, with the exception of nuclear, geothermal, and tidal energy. This resource is enormous and corresponds to almost 6 000 fold the current global consumption of primary energy. Thus, solar energy has the potential of becoming a major component of a sustainable energy portfolio with constrained greenhouse gas emissions [7].

Solar power has a great deal of potential in the field of home electricity generation and water heating. It is an attractive natural energy source because sunlight is free and the only cost involved is the cost of solar panels. Solar is also very environmentally friendly, as it produces no pollution or waste byproduct, and it is therefore essential for a greener future [8].

2.1 Total solar energy potential of Ukraine

Solar radiation in Ukraine is of middling intensity. Average annual amount of aggregate solar radiation per 1m2 of ground surface at the territory of Ukraine is around 1070 kW*hour/m2 in northern Ukraine, 1400 kW* hour/m2 and higher in the Crimea (Table 3, Fig. 5).

Table 3. Daily solar radiation, kWh/m^2*day

Region	Month												Total annual
	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	
Crimea	1,31	1,92	3,15	4,30	5,62	5,84	6,41	5,52	4,07	2,76	1,60	1,11	43,61
Vinnytsia	1,11	1,76	3,04	3,92	5,36	5,30	5,33	4,84	3,21	2,04	1,14	0,93	37,97
Volyn	1,05	1,65	2,92	3,91	5,22	5,08	5,10	4,70	3,01	1,89	1,09	0,82	36,45
Dnipropetrovsk	1,25	1,86	3,08	4,05	5,74	5,57	5,89	5,25	3,66	2,35	1,20	0,99	40,88
Donetsk	1,25	1,86	3,04	4,04	5,66	5,55	5,85	5,26	3,67	2,31	1,27	0,99	40,75
Zhytomyr	1,04	1,70	2,97	3,88	5,33	5,19	5,21	4,82	3,06	1,93	1,07	0,86	37,06
Zakarpattia	1,17	1,78	3,11	4,03	5,18	5,31	5,43	4,98	3,33	2,09	1,23	0,91	38,54
Zaporizhzhia	1,25	1,87	3,01	4,20	5,81	5,72	6,08	5,35	3,87	2,52	1,29	0,98	41,94
Ivano-Frankivsk	1,23	1,80	2,93	3,68	4,69	4,75	4,92	4,55	3,06	2,07	1,24	0,97	35,89
Kyiv	1,11	1,75	3,05	3,96	5,43	5,22	5,43	4,83	3,12	2,00	1,05	0,89	37,82
Kirovohrad	1,24	1,82	3,06	4,07	5,65	5,49	5,76	5,08	3,57	2,31	1,18	0,99	40,23
Luhansk	1,27	1,92	3,15	4,05	5,64	5,57	5,84	5,16	3,62	2,30	1,30	0,96	40,79
Lviv	1,12	1,71	2,91	3,78	4,83	4,83	4,99	4,60	3,00	1,91	1,10	0,86	35,63
Mykolaiv	1,29	1,96	3,17	4,38	5,84	5,85	6,23	5,52	3,93	2,60	1,41	1,07	43,26
Odesa	1,29	1,97	3,18	4,38	5,84	5,85	6,24	5,51	3,93	2,60	1,41	1,07	43,28
Poltava	1,22	1,83	3,15	4,00	5,58	5,44	5,69	5,03	3,42	2,18	1,19	0,94	39,68
Rivne	1,04	1,69	2,92	3,87	5,25	5,17	5,15	4,73	3,02	1,93	1,07	0,84	36,69
Sumy	1,17	1,80	3,15	3,98	5,45	5,32	5,56	4,83	3,19	2,05	1,14	0,89	38,51
Ternopil	1,13	1,74	2,95	3,85	5,00	5,00	5,09	4,66	3,08	1,97	1,13	0,88	36,47
Kharkiv	1,23	1,89	3,15	3,92	5,56	5,46	5,75	5,04	3,49	2,17	1,23	0,93	39,81

Region	Month												Total annual
	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	
Kherson	1,34	1,99	3,18	4,36	5,87	5,76	6,20	5,47	4,00	2,66	1,41	1,07	43,31
Khmelnytskyi	1,13	1,74	2,97	3,85	5,25	5,21	5,21	4,73	3,14	2,05	1,14	0,90	37,30
Cherkasy	1,19	1,78	3,04	3,99	5,62	5,46	5,72	5,03	3,40	2,20	1,13	0,94	39,51
Chernivtsi	1,23	1,80	2,93	3,68	4,69	4,75	4,92	4,55	3,06	2,07	1,24	0,97	35,89
Chernihiv	1,02	1,68	3,02	3,96	5,34	5,19	5,29	4,69	3,00	1,92	1,01	0,78	36,90

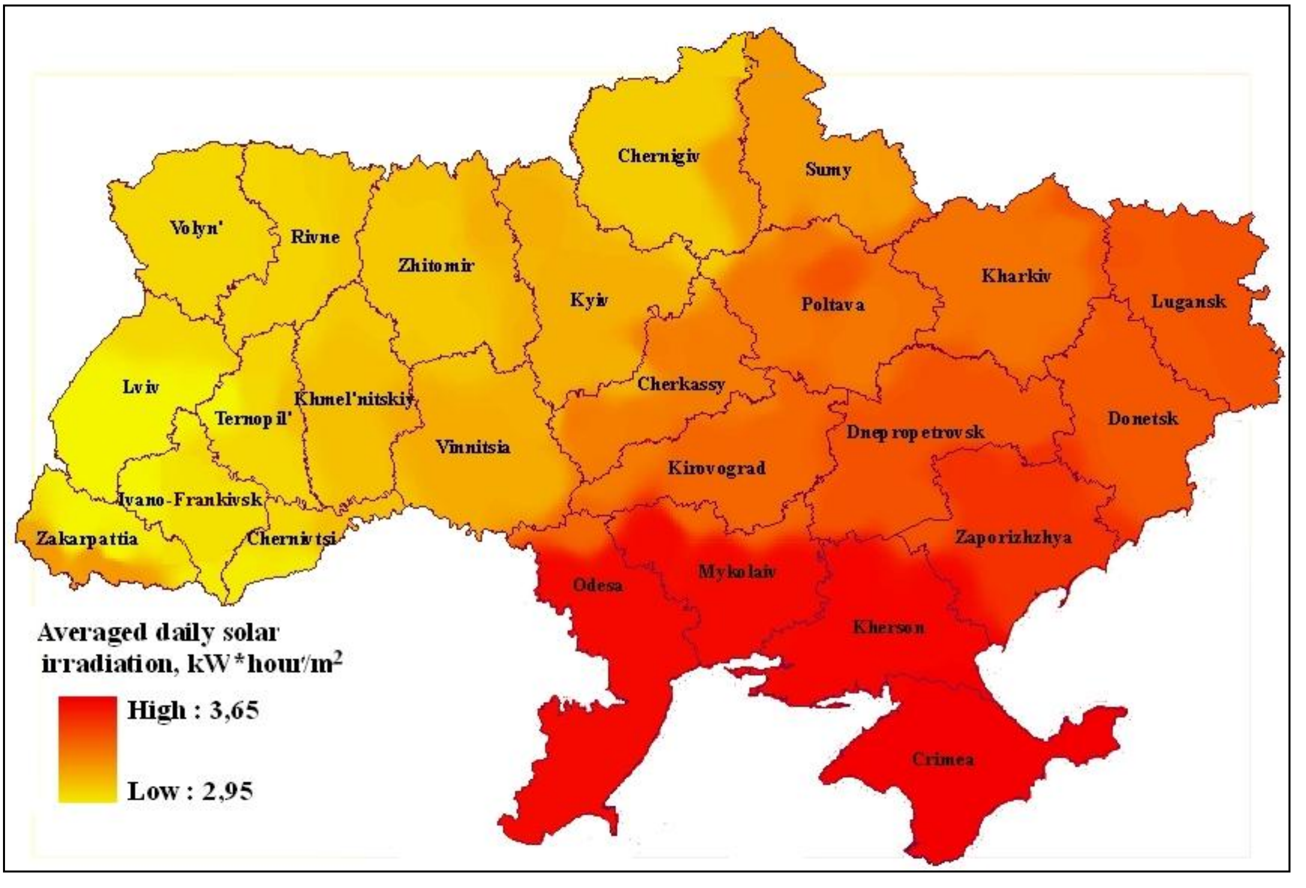


Figure 5. Averaged daily solar irradiation, kWh*hour/m^2

Solar energy capacity in Ukraine is great enough to introduce photothermal and photovoltaic equipment throughout Ukraine. Photothermal equipment can operate efficiently for eight months (March through October) [9]. The Crimean region has a higher level of electromagnetic radiation compared to other Ukrainian regions, making it the most viable site for the solar power plant [10]. The distribution of annual solar radiation level over a Ukrainian territory is shown in Figure 6.

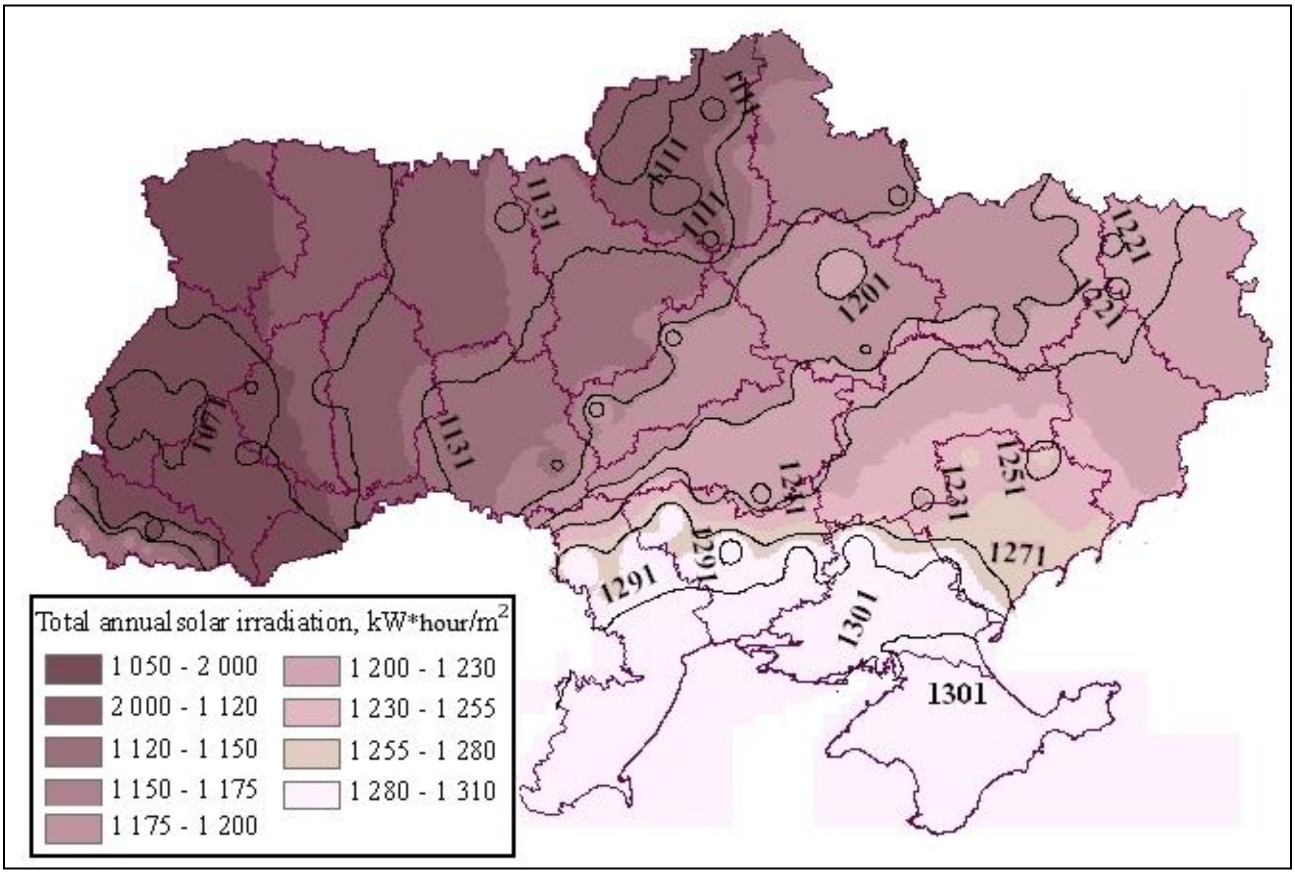


Figure 6. Total values of specific annual solar radiation

Harnessing of solar energy for household needs proves to be a remarkable means of saving power. With the mounting electricity consumption charges and the skyrocketing standards of living, there has been a constant search for power saving techniques that can help in monthly savings among many around the world.

In low geographical latitudes (below 40 degrees) from 60 to 70% of the domestic hot water, use with temperatures up to 60°C, can be provided by solar heating systems all year round. Nowadays the most common type of solar water heaters is evacuated tube collectors (44%).

The setup of the solar water heater is very simple. It necessitates the use of a tank, insulation materials and pipe fittings. The tank can be used to store the water to be heated and is usually kept on the roof top of building so that they get exposed to direct sunlight which in turn makes them hot. The insulation prevents the heat from getting out of the water with ease. The pipe fittings can further take the heated water to the kitchen and bathrooms depending on customized household requirements. In summer, spring and part of autumn the solar powered water heater would be able to cater to the hot water requirements at home [11].

Solar energy is environmentally friendly because it has virtually zero greenhouse emissions; because of this, more and more households are switching to solar energy products.

2.2 Assessing the potential contribution of solar energy to hot water supply in private rural settlements

In private rural settlements and suburban areas of Ukraine the problem of hot water supply is an urgent and important one, and the solution to this problem lies on the shoulders of residents [12].

From the time of Soviet Union, electricity supply of rural houses in Ukraine has been developed quite a lot. However, the same cannot be said for household gas supply and, so, for houses heating either. Thus, houses, which are not connected to the gas pipeline, are under the necessity to be heated by electricity. Such activity has its specific effects, including electrical network overloading and, as a consequence, accidents on substations. As a result, electricity supply system, constructed 20 years ago, was not originally designed to use electricity as a source for housing heating and hot water supply in private rural settlements.

Therefore, the alternative electric heating is especially important for owners of private houses and cottages. Solar water heating systems use free heat from the sun to warm domestic hot water. A conventional boiler or immersion heater can be used to make the water hotter, or to provide hot water when solar energy is unavailable.

Solar power for homes is becoming more popular every year. Today, solar power in Ukraine is already a bit developed through the introduction of solar collectors for hot water supply of some residential houses. Collectors are made in the Crimea, Kharkiv, Kiev, Dnepropetrovsk and other regions of Ukraine [13].

Based on above-mentioned points, USRIEP team has decided to consider this issue in detail and assess the potential contribution of solar energy to hot water supply in private rural settlements for the period of maximum solar activity (from March to October).

2.2.1 Housing facilities of Ukraine

In Ukraine urban and rural housing facilities area as of January 1, 2010, accounts for 1072,2 mln m2 of the total area (Figure 7). Total housing facility is about 10157,7 thousand buildings, of which 616,6 thousand are unpopulated [15].

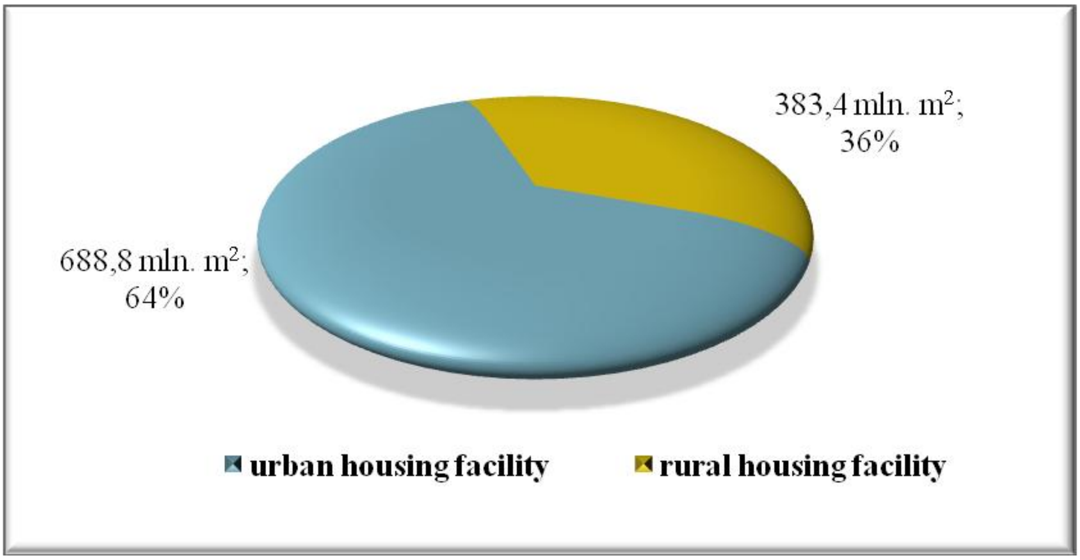


Figure 7. The structure of the housing stock in Ukraine

According to the statistical data [14], Ukraine's rural living area per capita reaches 26,1 square meters and the average family in Ukraine consists of 4 persons. It is assumed that non-living area of one private house is about 30% of its total area, which means that the area of an average private country house for 1 family (4 persons) may be expressed as: $S = (26{,}1 \cdot 4)+(26{,}1 \cdot 4 \cdot 0{,}3/0{,}7)=149{,}14 \approx 150$ m2. Thus, the number of private houses in each region of Ukraine is defined as follows:

$$N = \frac{A}{s}$$

where N - number of private houses; A - rural housing facility area in each region, m2 (Fig. 8); S – average area of a private rural house, m2.

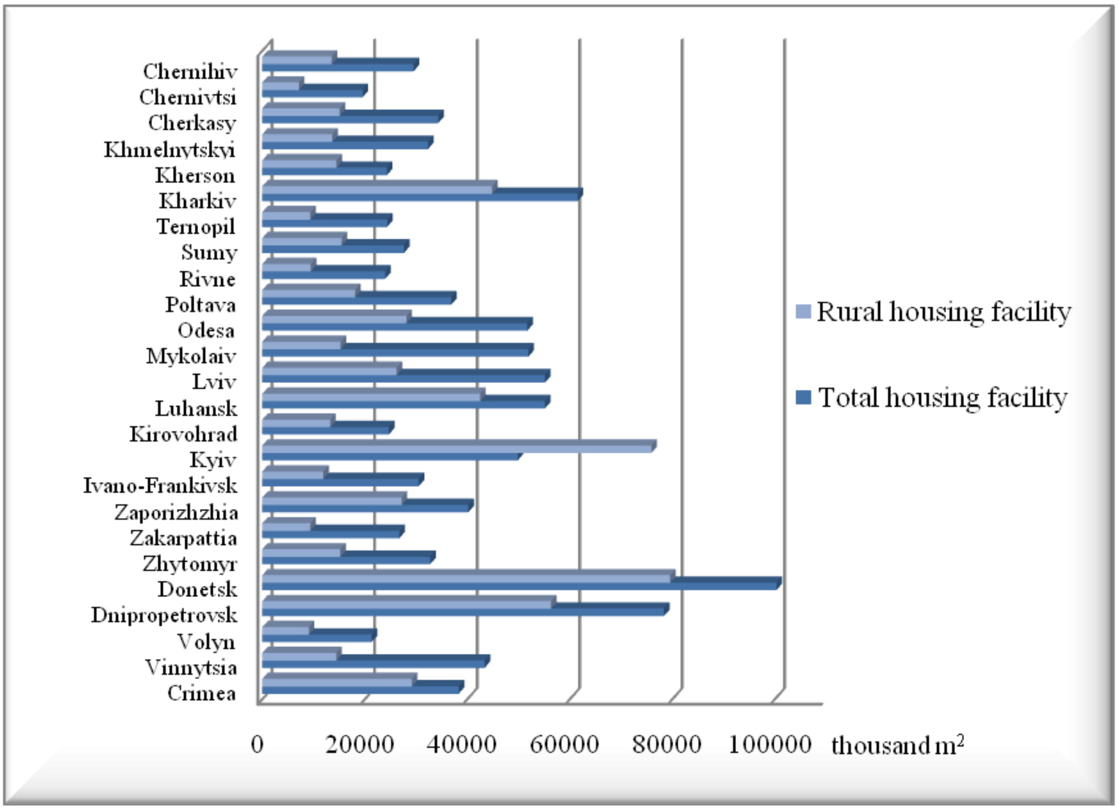


Figure 8. Regional housing facility

2.2.2 Daily hot water consumption

Daily hot water consumption varies widely depending upon a number of factors including how many people live in the house and the age of those people. As an approximation, 30 liters per day per person (at 60 °C) is about average for Ukrainian people. So, daily hot water volume needed for 1 house (4 persons) is:

$$V = 30 \cdot 4 = 120 \text{ liters}$$

where V is daily hot water consumption ,liters

2.2.3 Daily amount of energy required to heat water

Daily amount of energy needed to heat 120 liters of water from 10 °C to 60 °C can be expressed as:

$$Q = c \cdot m \cdot (t_2 - t_1)$$

where Q – amount of energy (W·hour); c - specific heat of water (W·hour / kg·°C); m – mass of water (kg); t_1 – initial water temperature (°C); t_2 – required water temperature (°C).

It is assumed that initial temperature of heated water on average is 10 °C (taken from the well, borehole or water pipeline for household use).

Thus, daily amount of energy to heat water from 10°C to 60°C for 1 house is:

$$Q = 1,16 \cdot 120 \cdot (60 - 10) = 6960 \text{ W•hour}$$

2.2.4 Minimum required volume of storage tank for 1 house (4 persons)

As it was mentioned, the initial water temperature is 10°C and about 7,0 kW·hour is needed to heat it up to 60°C. The heat lost in storage tank is almost 1,5 kW·hour and circulation in hot-water supply system is also 1,5 kW·hour. If so, amount of heat required for hot-water supply system is 7,0+1,5+1,5=10 kW·hour.

Minimum required volume of storage tank for 4 persons can be calculated as:

$$V_{tank} = \frac{Q_{total}}{c \cdot (t_2 - t_1)}$$

where V_{tank} - volume of storage (liters); Q_{total} – total amount of energy (W·hour); c - specific heat of water (W·hour / kg·°C); t_1 – initial water temperature (°C); t_2 – required water temperature (°C).

$$V_{tank} = \frac{10000}{1,16 \times (60 - 10)} = 172,41$$ liters

2.2.5 Estimation of solar collector efficiency

There are two important parameters to size solar collector surface area:

- solar irradiation;
- average system efficiency.

System efficiency depends on various factors such as type and tilt angle of solar collectors, insulation of pipes and storage tank, shading effect of nearby buildings or plants, etc. Since all these factors cannot be fully evaluated, system efficiency of solar collector could be approximately assessed as:

$$\eta = 0,8 \cdot \left\{\theta - \frac{9 \cdot U\left[\frac{(t_1 + t_2)}{2}\right] - t_e}{\sum_j g_j}\right\}$$

where η – estimated solar collector efficiency; θ – solar collector efficiency in accordance with registration certificate; U – heat lost coefficient; t1 – initial water temperature (°C); t2 – required water temperature (°C); t_e – seasonal average air temperature (°C); $\sum_j g_j$ – average seasonal insolation (W/m2).

2.2.6 Determination of solar collector size

The most common types of solar collectors are flat-plate and evacuated-tube. Compared to the flat-plate type collector, evacuated-tube collector is generally more expensive due to the more complex manufacturing process. However, it is more effective than flat-plate collector and requires a smaller installed area.

The size of solar collector is depended on two key factors:

- insolation level;
- energy requirements.

Energy requirement is usually take into account water volume and temperature rise needed. When these two factors are known, the required collector surface area can be estimated by the following equation:

$$S_{sc} = \frac{Q}{\sum_j g_j \cdot 0,9 \cdot \eta}$$

where S_{sc} – solar collector size (m2); Q - amount of energy needed to heat daily amount of water (W·hour); $\sum_j g_j$ – averaged seasonal insolation level (W/m2); η – estimated efficiency of a solar collector.

Due to the fact that insolation level is a major variable in different seasons, calculations on solar collector size should be done for each season in order to provide the full requirements for individual hot water supply in rural private house for the investigated period.

Estimated and recommended solar collector size for each region is shown in Table 4.

Table 4. Estimated and recommended solar collector size for each region

Region	Estimated solar collector size, m^2			Recommended solar collector size, m^2
	spring	*summer*	*autumn*	
Crimea	3,4	2,1	5,8	5,8
Vinnytsia	3,8	2,5	10,9	10,9
Volyn	3,9	2,7	13,0	13,0
Dnipropetrovsk	3,5	2,3	8,3	8,3
Donetsk	3,6	2,3	8,3	8,3
Zhytomyr	3,9	2,6	12,6	12,6
Zakarpattia	3,7	2,5	9,4	9,4
Zaporizhzhia	3,4	2,2	7,2	7,2
Ivano-Frankivsk	4,3	2,8	10,8	10,8
Kyiv	3,7	2,5	11,6	11,6
Kirovohrad	3,6	2,4	8,8	8,8
Luhansk	3,5	2,3	8,2	8,2
Lviv	4,2	2,8	12,6	12,6
Mykolaiv	3,3	2,1	6,7	6,7
Odesa	3,3	2,1	6,7	6,7
Poltava	3,6	2,4	9,8	9,8
Rivne	3,9	2,6	12,5	12,5
Sumy	3,7	2,5	11,4	11,4
Ternopil	4,1	2,7	11,9	11,9
Kharkiv	3,6	2,4	9,4	9,4
Kherson	3,3	2,2	6,6	6,6
Khmelnytskyi	3,9	2,6	11,2	11,2
Cherkasy	3,6	2,4	9,7	9,7
Chernivtsi	4,2	2,8	10,7	10,7
Chernihiv	3,8	2,6	13,1	13,1

2.3 Annual potential contribution of solar energy to hot water supply in private rural settlements

Annual potential contribution of solar energy to hot water supply in private rural settlements of each region is calculated by the following formula:

$$P_{annual} = \frac{\sum_j g_{j.av} \cdot S_{sc} \cdot \eta \cdot N_{reg} \cdot 0,9}{10^9}$$

where P_{annual} - potential contribution of solar energy to hot water supply of each region (GW); $\sum_j g_{j.av}$ – averaged regional solar radiation for the investigated period (W/m2); S_{sc} – solar collector size (m2); η – estimated efficiency of a solar collector; N_{reg} - number of houses in each region.

The results of calculations of solar power potential for hot water supply in private rural settlements were treated with GIS-technologies and presented in Table 5 and Figure 9.

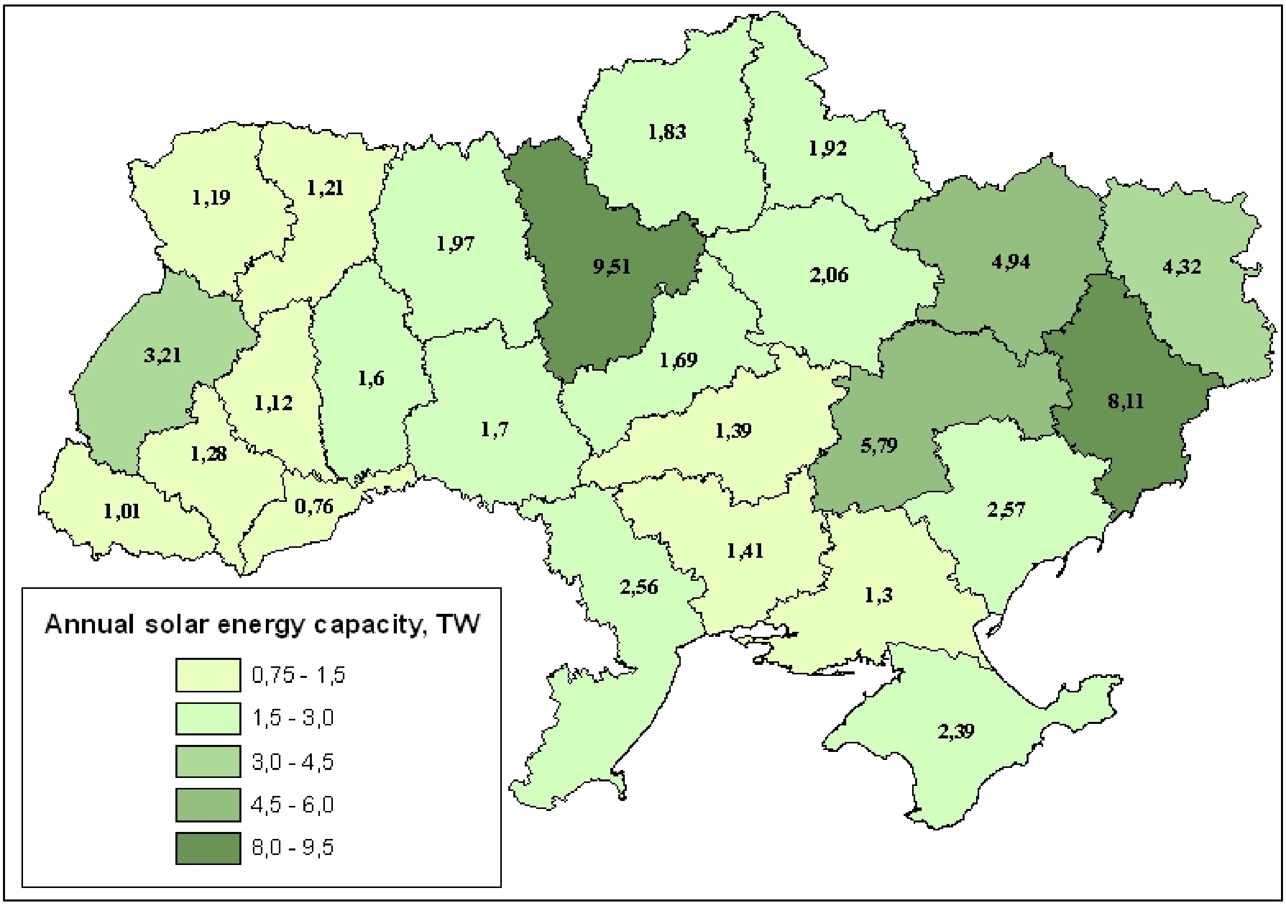


Figure 9. Solar power potential of Ukraine for hot water supply in private rural settlements

House builders generally have a resistance to new investments that increase the costs of building houses. The present low level of public awareness and the effectiveness of solar water heating in the Ukraine is such that there is not yet significant market demand for new houses incorporating solar water heating technology. Developers should be encouraged to design new houses with roofs having a southerly aspect. It is good energy design to build houses to obtain maximum benefit from solar water heating systems. The environmental benefits of using solar heating systems should be made clear in publicity and information material.

It is estimated that 20-30% of energy in every household is used to heat water. If it is coming from electricity or by burning fossil fuels then it better be generated by using solar panels. These panels, once installed, can last up to 25 years and there is almost no expenditure in maintaining them.

Ukraine has finalised construction of a new solar energy power station in Crimea. The newly built solar plant is part of Ukraine's National Projects and is capable of producing 25 gigawatt-hours (GWh) of environmentally clean electrical energy per year.

This achievement has been accomplished in accordance with the Nature Energy project. Such capacity will meet the needs of about 5000 households in the area and will help reduce carbon-dioxide (CO2) emissions by 20,000 tons per year.

Region	*Amount of private rural houses*	*Averaged daily insolation, W/m²*			**Averaged seasonal temperature, ºC**			**Estimated solar system efficiency**			**Annual potential contribution of solar energy to hot water supply in private rural settlements , GW**
		spring	*summer*	*autumn*	*spring*	*summer*	*autumn*	*spring*	*summer*	*autumn*	
Crimea	194633	4357,67	5921,56	2810,22	11,2	21,9	14,6	0,53	0,62	0,48	2,39
Vinnytsia	96347	4107,00	5156,00	2127,44	8,4	18,7	8,7	0,50	0,59	0,33	1,70
Volyn	60540	4017,56	4962,11	1995,33	8,3	18,1	7,8	0,49	0,58	0,30	1,19
Dnipropetrovsk	375660	4288,11	5569,78	2401,89	9,8	21,5	10,0	0,51	0,61	0,39	5,79
Donetsk	530520	4246,89	5552,78	2418,56	9,4	21,2	9,6	0,51	0,61	0,39	8,11
Zhytomyr	101533	4059,22	5071,11	2022,33	8,1	18,3	7,9	0,49	0,59	0,30	1,97
Zakarpattia	62487	4105,78	5238,56	2215,67	10,9	19,8	10,5	0,52	0,60	0,37	1,01
Zaporizhzhia	181353	4338,11	5716,22	2561,00	10,4	22,2	11,1	0,52	0,62	0,42	2,57
Ivano-Frankivsk	79467	3768,67	4738,44	2122,22	8,5	18,0	9,0	0,48	0,58	0,34	1,28
Kyiv	506133	4144,44	5156,89	2059,56	9,0	19,5	8,8	0,50	0,60	0,32	9,51
Kirovohrad	88467	4260,33	5443,22	2354,22	9,2	20,3	9,4	0,51	0,60	0,37	1,39
Luhansk	283360	4281,22	5521,56	2408,78	10,3	22,3	10,3	0,52	0,62	0,39	4,32
Lviv	174840	3839,89	4806,44	2002,33	8,1	17,4	8,3	0,48	0,58	0,31	3,21
Mykolaiv	101887	4463,56	5866,33	2646,44	10,8	22,5	11,8	0,53	0,62	0,43	1,41
Odesa	187460	4467,00	5866,33	2646,44	9,4	21,3	12,1	0,52	0,61	0,44	2,56
Poltava	120813	4243,89	5388,67	2262,89	8,9	20,4	8,2	0,51	0,60	0,35	2,06
Rivne	63200	4014,56	5016,22	2009,00	9,0	17,9	8,4	0,50	0,58	0,31	1,21
Sumy	103333	4192,44	5235,00	2124,22	8,3	19,6	7,8	0,50	0,60	0,32	1,92
Ternopil	62427	3932,11	4918,22	2060,00	7,7	17,6	8,2	0,49	0,58	0,31	1,12

Kharkiv	298900	4210,33	5416,00	2296,56	9,0	20,6	8,6	0,51	0,61	0,36	4,94
Kherson	96620	4470,67	5808,78	2687,00	10,7	22,3	11,8	0,53	0,62	0,44	1,30
Khmelnytskyi	91140	4021,67	5050,22	2107,56	8,3	18,3	8,6	0,49	0,59	0,33	1,60
Cherkasy	100633	4216,44	5405,67	2242,44	9,1	20,2	9,2	0,51	0,60	0,36	1,69
Chernivtsi	47627	3768,67	4738,44	2122,22	8,9	18,5	9,3	0,49	0,58	0,34	0,76
Chernihiv	90400	4106,56	5057,33	1978,22	8,3	19,2	8,1	0,50	0,59	0,30	1,83
										TOTAL	**59,67**

Table 5. Potential contribution of solar energy to hot water supply in private rural settlements of each Ukrainian region

3 Legislative and regulatory framework

3.1 Legal Framework

Considerable attention has recently been paid to introduction of energy efficient technologies and accordingly to improvement of the current laws in Ukraine. Thence there can be observed an existing trend of legislative amendments aimed at promoting development and attraction of investments in the renewable (alternative) energy sector of Ukraine.

Nowadays adaptation of the Ukrainian laws to the EU laws is a priority component of the Ukrainian policy given Ukraine's aspirations to eventually gain full membership in the European Union. The Law of Ukraine "On the National Program of Adaptation of the Ukrainian Laws to the European Union Laws" provides for gradual adaptation of Ukraine's own laws to those of Europe, so in the alternative energy sector, Ukraine is governed specifically by the provisions of Directive 2001/77/EC of the European Parliament and Council on the Establishment of Favourable Conditions for Sales of the Electric Energy, as Generated by Renewable Energy Sources at the Domestic Electric Energy Market" dated September 27th, 2001 [15].

The principal legislative acts regulating the issues related to the introduction and development of the renewable energy industry in Ukraine are as follows:

- the Law of Ukraine "On Energy Saving" dated July 1st, 1994, as amended and modified by the Law of Ukraine "On Amendment of Certain Legislative Acts of Ukraine Concerning the Promotion of Energy Efficiency Measures" dated March 16th, 2007;
- the Law of Ukraine "On Electric Energy" dated October 16th, 1997, as amended and modified by the Law of Ukraine "On Amendment of Certain Legislative Acts of Ukraine Concerning the Establishment of "Green" Tariff" dated September 25th, 2008, and by the Law of Ukraine "On Amendment of the Law of Ukraine "On Electric Energy" in order Encourage the Use of Alternative Energy Sources" dated April 1st, 2009;
- the Law of Ukraine "On Alternative Fuels" dated January 14th, 2000;
- the Law of Ukraine "On Alternative Energy Sources" dated February 20th, 2003;
- the Law of Ukraine "On the Combined Generation of Heat and Electric Energy (Cogeneration) and the Use of Waste Energy Potential" dated April 5th, 2005, etc.

The main principles of the state policy of Ukraine in the electric energy sector consist particularly in promoting the alternative energy industry as an environmentally friendly and fuel free energy subsector. To date, there exist the following mechanisms to encourage the alternative energy sector development:

- establishment of a "Green" tariff – a special tariff rate – at which there is purchased the electric energy, as generated by power generation facilities using alternative energy sources (except for blast furnace and coke gases, and as regards the use of hydro power it only pertains to that generated by small hydro power plants of installed capacity not exceeding 10 MW);
- commitment by the Wholesale Electricity Market of Ukraine to purchase the electric energy, as generated by power generation facilities using alternative energy sources, at the "Green" tariff;
- establishment of the State Energy Conservation Fund in order to provide for funding of measures for the efficient use of fuel and energy resources (being of declarative nature);

3.1.1 Application of "Green" Tariff

In 2009 the Ukrainian parliament adopted a law on subsidized tariffs for electricity produced from non-conventional sources, i.e., green tariffs. The Wholesale Electricity Market of Ukraine has an explicit obligation to purchase all volumes of electricity produced from alternative energy sources at the green tariff.

The green tariff is established by the National Energy Regulation Commission for each generating company and will be effective until 1 January 2030. Business entities that have applied to the National Electricity Regulation Commission of Ukraine meet all the required conditions and have provided all the necessary information in full are entitled to have the "Green" tariff applicable thereto.

3.2 The New Energy Strategy for Ukraine Up To 2030

The New Energy Strategy for Ukraine to 2030, which was approved by the Ukrainian Government in spring 2006, estimates that Ukraine will nearly quadruple its use of non-conventional energy sources, which under Ukrainian legislation include renewable and waste energy sources - from 10,9 Mtoe to 40,4 Mtoe (Million Tones of Oil Equivalent) in 2030. The highest growth is expected in use of solar energy, wind farms and low-potential heat, although the growth will start from a very low base as currently the installed capacity in this sector (including small hydro power plants) amounts to 0,18 GW.

The Strategy envisages the development of renewables in accordance with the fundamental principles of the "Green Book: European Strategy for Secure, Competitive and Sustainable Energy". The Energy Strategy set out a number of incentives to stimulate renewable energy production and use, but most of them have yet to be implemented into the legislation [16].

3.2.1 Sources of funding

Ukrainian State agencies are cooperating and implementing energy saving projects and developing new and renewable sources of energy with foreign organizations such as NEFCO, ADEME, SIDA as well as international organizations such as EBRD, the World Bank, IFC, USTDA, OPIC, etc.

Ukraine has a program of state support for the development of non-traditional and renewable energy sources and small hydro power plants. The target set for renewables is 19% of generation by 2030. Current State budget financing is limited to wind energy only and is not enough to significantly boost the development of the sector. However, the EU has devoted UAH 319 million (EUR 27,7 million) to support implementation of the Energy Strategy for Ukraine in 2009. In Ukraine, major deals will experience some difficulties with debt financing due to the economic downturn and regardless will require more sophisticated approaches to structuring. International financial institutions are investing increasing amounts in Ukraine. The IFC declared its intention to invest about USD 500 million in the near future to support implementation of different projects. EBRD approved the allocation of USD 50 million to development of the alternative power sector in Ukraine. The World Bank also supports for implementation of the power projects in Ukraine [16].

3.3 Prognosis for 2050

Predicting the further development of economy and energy sector based on the most effective up-to-date technology the experts concluded that depending on the region a partial or complete replacement of nuclear and fossil fuels by renewable energy sources is possible. In the Renewable Energy Agency an estimate of the sustainable energy development in Ukraine was done. Thus it was concluded that it is necessary to develop the available renewable energy sources rapidly though the clauses of the Energy Strategy of Ukraine till 2030 say quite the other. So the power industry of Ukraine would develop on the same technological and technical base as the countries of EU do [17].

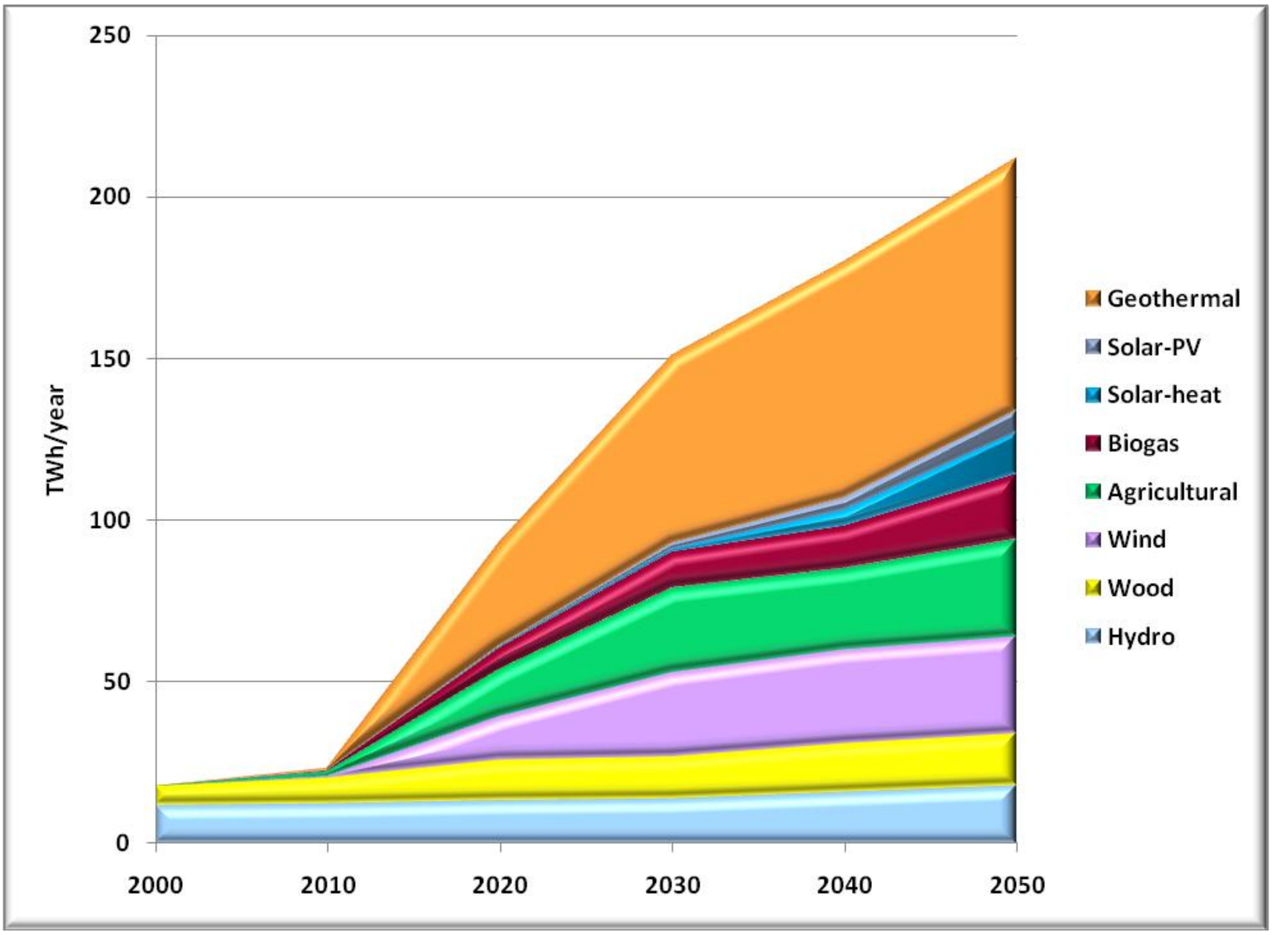


Figure 10. Forecast of renewable energy utilization in Ukraine, the path to 2050

3.3.1 Wind power

The possible capacity of a wind farms in the centralized energy system of Ukraine is estimated to be 16 000 MW. The capacity factor is assumed to be 30% (2630 h / year) – it is quite feasible for the climatic conditions of our country if the modern wind power plants are used. In this case the potential of wind energy use is 42 TW•h/year. It is planned to build wind power plants with total capacity of 11,290 MW with an annual electricity production of about 25 TW•h/year by 2030. From 2030 to 2050 the modernization of wind power plants built by then will prevail. Thus, by 2050 the technical potential of wind power plants building will be practically implemented and the amount of electricity they produce may reach 34 TW•h/year.

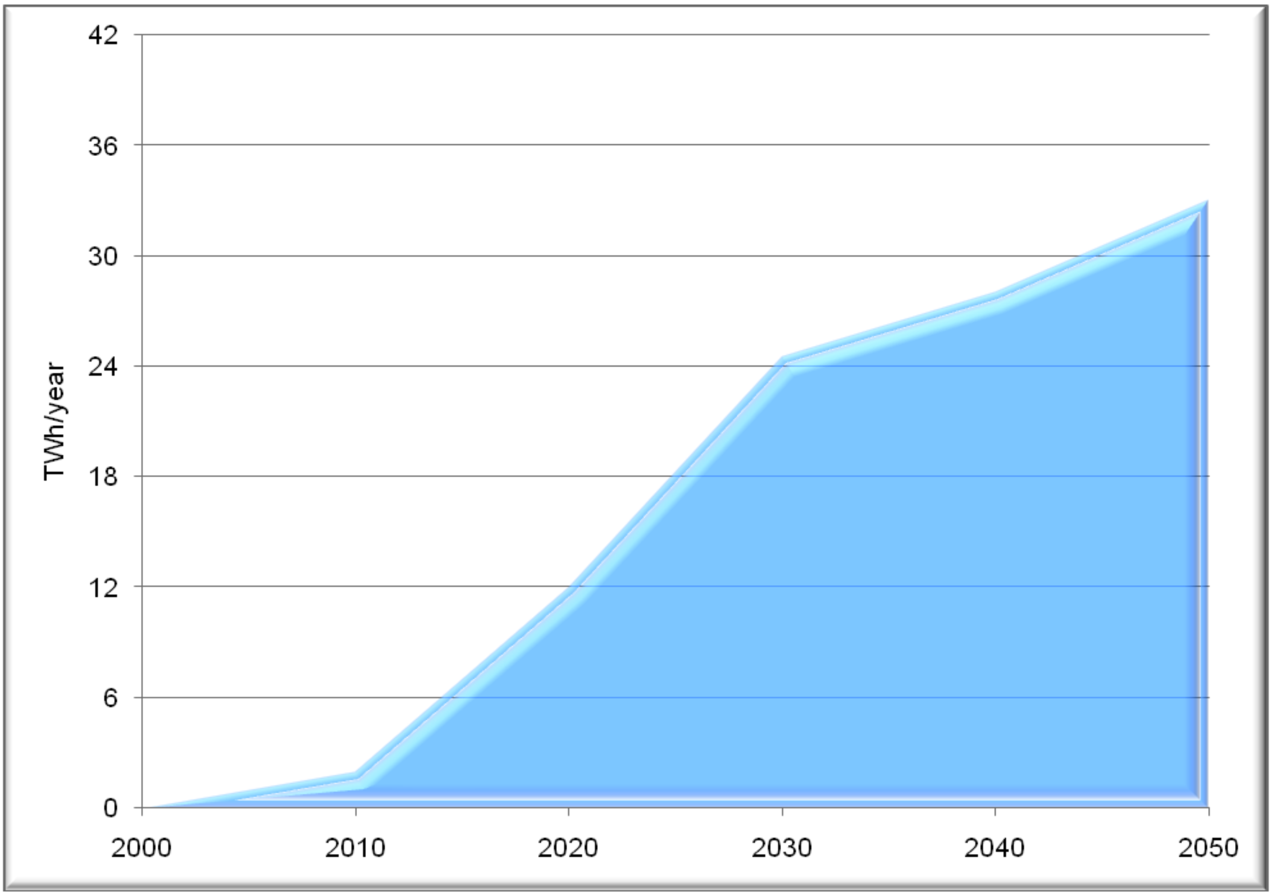


Figure 11. Forecast of wind power generation in Ukraine

3.3.2 Solar power

In the climatic conditions of Ukraine it is possible to use solar energy to create a twenty-four-hour heat supply system. Such projects are implemented in many countries northward of Ukraine. The potential of solar energy use will be almost 75 TW•h/year if solar panels are used at a rate of 3,9 m2 per person and with an annual production of 400 kW/h per 1 m2 of solar collector. The forecast of solar collector implementation rate by 2030 is made taking into consideration the acceleration in 2030-2050's. Solar collectors are expected to produce 7 TW•h/year of thermal energy by 2050, which is only a small part of the technically available capacity.

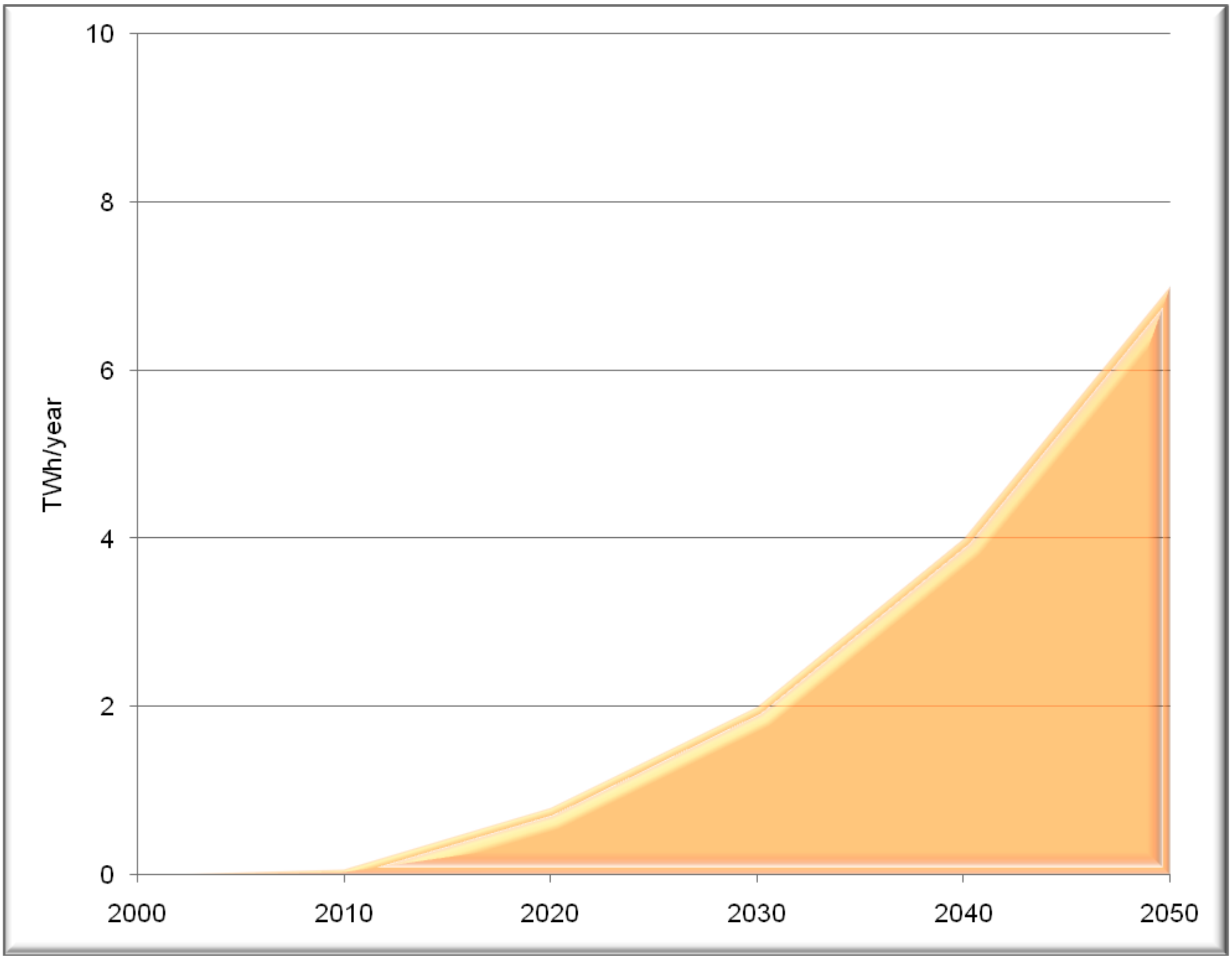


Figure 12. Forecast of solar heat supply in Ukraine

In accordance with key principles of the EU green paper, the long-term renewable energy development in Ukraine should be based on economic competition with other energy sources, with the state providing support to renewable energy sources advanced technologies which reflect public interest as regards enhancing the energy security level, environmental cleanness and combating global climate change. At present only 0,8% of the energy in Ukraine is provided by renewable energy sources. The EU countries have agreed to generate 20% renewable energy in 2020.

Several stakeholders have presented alternative targets, showing a faster growth path and higher final targets, especially in the field of biomass and wind energy. In order to develop an effective and efficient renewable energy support framework, it is necessary to develop a clear view on future targets, which are both challenging and realistic.

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18. Climatic cadastre of Ukraine

D. Annex I: Assessment of the wind and solar energy potential in Bulgaria and policy recommendations for their promotion

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1 Introduction

One of the most important aims of the EnviroGRIDS project is to contribute Global Earth Observation Systems of Systems (GEOSS), which is being built by the Group on Earth Observations (GEO) on the basis of a 10-Year Implementation Plan running from 2005 to 2015, by providing data/information available at Black Sea Catchment.[53] GEOSS is building a data-driven view of Earth that feeds into models and scenarios to explore past, present and future. The Fifth Work Package of the EnviroGRIDS Project mainly works on providing data/information to GEOSS system in terms of Societal Benefit Areas (SBAs) already considered by GEO. Partners contributing the Task 5.4 directly deal with Energy SBA. Task 5.4 does not only provide the results of the Renewable energy potential and forecasting in contributing countries as a report but it also contributes to GEOSS by providing maps of the result of the studies executed within this task.

Temperature, humidity, wind speed, global solar radiation, and etc. are considered as the data measured at a specific location that is mostly a meteorological monitoring station. Such data are widely used for monitoring meteorological conditions in a region. However, point source data should be represented by surfaces as grid, contours, triangulated irregular networks or points for covering the regions that they belong to.[54,55] A variety of spatial interpolation methods are used to estimate unsampled locations of a region by using sampled points in order to represent point source data by raster surfaces. Raster data derived by using suitable spatial interpolation method is the main component of the meteorological maps. Therefore spatial interpolation can be considered as one of the important step of the mapping process of the point source data.

There are several spatial interpolation methods such as Kriging, Inverse Distance Weighted, Natural Neighbour, Spline, Multiquadric, and etc. However the main problem is to determine the interpolation method which gives the best estimations of unsampled points for each specific case, because accuracies vary widely among applied spatial interpolation methods depending on the spatial attributes of the data, total number of point sources, their locations, and distribution.

This part of Deliverable 5.6 is prepared to explain and discuss the studies conducted to determine spatial interpolation method that will be used mapping the point source data for Bulgaria and North part of the Turkey, the region located along the Black Sea cost in Turkey. In this context, Inverse Distance Weighted (IDW), Multiquadric (MQ), Natural Neighbour (NN) and Kriging. interpolation methods, which are extensively used and suggested by implemented studies[56,57,58], were selected for comparisons executed in the study. Accuracies of these methods were examined by using different methods mainly based on cross validation. Root Mean Square Errors were used as basic criteria to decide on performances of the methods.

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2 Spatial Interpolation Methods

In this part of the report, spatial interpolation methods compared while determining the mapping methodology of the point source data are briefly explained.

2.1 Multiquadric Transformation Method

Multiquadric function proposed by Hardy[59] has been widely used in Digital Terrain Modelling (DTM). Hardy gives a detailed overview of applications in different applied earth sciences.[60]

Hardy's multiquadric function is given by the following equation.

$$f(x,y) = \sum_{i=1}^{n} c_i \sqrt{(x-x_i)^2 + (y-y_i)^2 + \Delta^2} \tag{1}$$

In this function, n denotes the number of control points. c_i are the coefficients to be determined. Δ^2 can be taken as zero. A linear equation system has been established with the elements.

2.2 Kriging

Kriging is a group of geostatistical techniques to interpolate the value of a random field (e.g., the elevation, z, of the landscape as a function of the geographic location) at an unobserved location from observations of its value at nearby locations.

The background theory of interpolation and extrapolation by Kriging was developed by the French mathematician Georges Matheron based on the Master's thesis of Daniel Gerhardus Krige, the pioneering plotter of distance-weighted average gold grades at the Witwatersrand reef complex in South Africa.

It uses linear combinations of weights at known points to estimate the value at an unknown point[61]. However in this method the spatial correlation is taken in to account while estimating the surface. This correlation is determined by using semi-variance function as stated in Equation 2 where *N(h)* denotes the number of pairs of sampled points with a distance of *h*. The complete formulation of Kriging methodology is provided by several literatures[62].

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(s_i) - Z(s_i + h)\right]^2 \tag{2}$$

There are several types of Kriging such as Ordinary Kriging, Universal Kriging and Cokriging. Ordinary Kriging is the most common method which assumes that here is no constant mean for the data over an area mean while Universal Kriging assumes that an overriding trend exists in the data and that it can be modelled. Ordinary Kriging is used in this study as one of the spatial interpolation method to be compared with other spatial interpolation methods.

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59 Hardy, R.L., (1971) Multiquadric equations of topography and other irregular surfaces. Journal of Geophysical Research, 76(8):1905–1915.

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62 Goovaerts, P., (2000) Performance comparison of geostatistical algorithms for incorporating elevation into the mapping of precipitation. Journal of Hydrology 228:113-129.

2.3 Inverse Distance Weighted

IDW is a method for multivariate interpolation, a process of assigning values to unknown points by using values from usually scattered set of known points. Here, the value at the unknown point is a weighted sum of the values of N known points. A general form of finding an interpolated value u at a given point x based on samples ui = u(xi) for i = 0,1,...,N using IDW is an interpolating function:

$$u(\mathbf{x}) = \sum_{i=0}^{N} \frac{w_i(\mathbf{x}) u_i}{\sum_{j=0}^{N} w_j(\mathbf{x})}, \qquad (3)$$

where

$$w_i(\mathbf{x}) = \frac{1}{d(\mathbf{x}, \mathbf{x}_i)^p} \qquad (4)$$

is a simple IDW weighting function, as defined by Shepard[63], x denotes an interpolated (arbitrary) point, x_i is an interpolating (known) point, d is a given distance from the known point xi to the unknown point x, N is the total number of known points used in interpolation and p is a positive real number, called the power parameter. In this study power number is considered as 2 in practice so applied methodology is abbreviated as IDW2.

2.4 Natural Neighbour

Natural neighbour interpolation is a method of spatial interpolation, developed by Robin Sibson. The method is based on Voronoi tessellation of a discrete set of spatial points. This has advantages over simpler methods of interpolation, such as nearest neighbour, in that it provides a more smooth approximation to the underlying "true" function.[64]

The basic equation in 2D is:

$$G(x,y) = \sum_{i=1}^{n} w_i f(x_i, y_i) \qquad (5)$$

In this equation $G(x,y)$ denotes the estimate at (x,y), w_i denotes the weights and $f(x_i,y_i)$ denotes the known data at (x_i,y_i). The natural neighbour method proposes a measure for the computation of the weights, and the selection of the interpolating neighbours. The natural neighbour method utilises the change to the Voronoi tessellation to compute weights. The weights, w_i, are by utilisation of the area "stolen" from the surrounding points when inserting a new point into the tessellation. Each weight may be computed by dividing the section of the new tessellated region that lies within the tessellated region of each original neighbouring tessellated polygon.

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3 Methodology

As the methodology of this study, above stated spatial interpolation techniques were implemented by using wind speed data recorded in Bulgaria and Turkey separately by using Surfer and ArcGIS software. Mainly default settings were accepted as the parameters of each interpolation methods. Performances of the applied methods were assessed in terms of three different extents mainly considering the assessment of the root mean square errors (RMSE) of estimated values. In this context firstly, inertial overall accuracy assessment results were considered to compare the accuracies of the applied interpolation methods. Secondly, cross validation technique was used and four monitoring stations were selected as control station in Turkey and Bulgaria. Interpolation methods were applied for both of the study areas separately by using the data of remaining monitoring stations. Locations of monitoring station and measured wind speed values at these stations were considered while selecting control stations. Estimated values for control stations were compared with measured data and RMSEs were calculated depending on errors at each control station. As the final accuracy assessment process, cross validation technique were applied. However this time all of the monitoring station was selected as control station successively and value of each control station was estimated by interpolating the wind speed values measured at the remaining monitoring stations. Performances of the spatial interpolation methods in terms of accuracy were determined by calculating the RMSE regarding the errors obtained at each control station.

4 Case Studies

Two separate case studies implemented in this study. Although both of the case studies used the same methodology in practice, study areas and the data recorded at that areas are different from each other. The country of Bulgaria is selected as the study area in the first case study while the only northern part of the Turkey (the region included in the coverage of EnviroGIRDS Project) is examined in the second case study. 41 of 81 provinces in Turkey are included in the study area. Study areas are indicated in Figure 1.

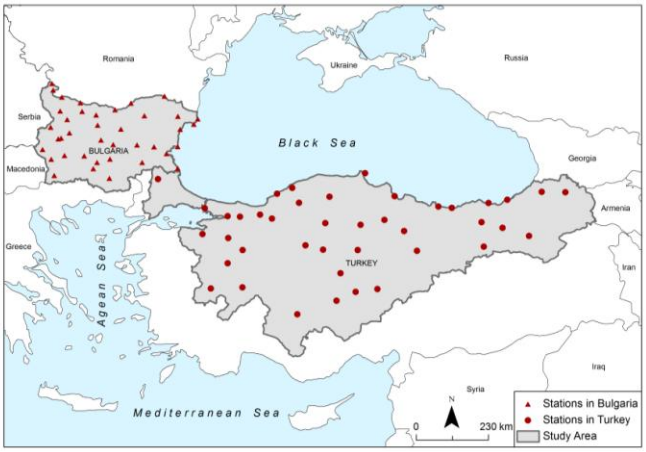

Figure 54. Distribution of meteorological monitoring stations in study area

4.1 Determination of the Spatial Interpolation Method for Bulgaria

4.1.1 Data Used in Application

In this study point sourced wind speed data recorded at 39 meteorological monitoring stations distributed in Bulgaria were used to compare the performances of spatial interpolation methods in terms of accuracy. Wind speed data recorded at 10 m of Bulgaria were provided by The Black Sea Regional Energy Centre (BSREC). Figure 2 indicates the geographical distribution of monitoring stations. The detailed information on these stations is available in the Table 1 together with the data recorded at each station.

Figure 55. Distribution of meteorological monitoring stations in Bulgaria

Table 16. The List of Monitoring Stations and Data

Station Name	Latitude	Longitude	Elevation (m)	Wind speed at 10m (m/s)
Ahtopol	42.08	27.95	31	4.63
Emine	42.70	27.90	55	7.44
Burgas	42.48	27.48	21	6.46
Karnobat	42.65	26.98	194	4.79
Blagoevgrad	42.02	23.10	416	5.39
Sandanski	41.57	23.28	206	4.93
Dobrich	43.57	27.83	251	4.38
Kaliakra	43.37	28.47	60	6.88
Shabla	43.53	28.62	6	6.09
Sofia	42.65	23.38	586	4.04
Dragoman	42.93	22.93	715	4.98
Chernivryh	42.62	23.27	2286	9.41
Murgash	42.83	23.67	1687	8.99
Musala	42.17	23.58	2925	7.96
Elhovo	42.18	26.57	139	4.90
Chirpan	42.20	25.33	173	4.58
Kazanlyk	42.62	25.40	392	4.98
Kjustendil	42.27	22.72	520	4.54
Kyrdjali	41.65	25.37	331	6.14
Lom	43.82	23.22	32	5.30
Montana	43.42	23.22	202	5.04
Lovech	43.13	24.73	220	4.84
Botev	42.72	24.92	2376	9.61
Plovdiv	42.07	24.85	154	5.09
Pazardjik	42.22	24.33	212	5.40
Kneja	43.48	24.07	117	5.26
Pleven	43.42	24.63	160	5.18
Razgrad	43.52	26.52	345	4.74
Rojen	41.88	24.73	1750	4.36
Ruse	43.85	25.95	46	5.80
Silistra	44.12	27.25	16	5.26
Sliven	42.67	26.32	259	5.69
Varna	43.20	27.95	39	5.75
Svishtov	43.62	25.35	24	5.96
Veliko tarnovo	43.08	25.65	195	4.48
Novoselo	44.17	22.77	36	5.43
Vidin	43.99	22.85	31	4.11
Orjahovo	43.72	23.97	29	5.74
Vraca	43.20	23.53	309	4.92

While applying second comparison method, Lovech, Plovdiv, Razgrad, and Sliven monitoring stations were considered as control stations that will be used in cross validation.

Geometric data used for mapping meteorological data is vector data including provinces in Bulgaria. Vector data of neighbouring countries to Bulgaria were also used as the complementary data for communicating the reference information about the location of study area in thematic maps. ESRI World Vector Dataset was used for this purpose. Geographic Coordinate System WGS 84 (World Geodetic System 1984) was used geographic reference and WGS 84 was selected as the datum of the vector data.

4.1.2 Results for Bulgaria

For assessing the accuracies of the applied interpolation methods firstly statistical reports provided by Surfer Software for each method were compared. As it is represented in the Table 2, accuracy assessment statistics points out that IDW 2 has the best performance with the lowest RMSE which is ±0.23 for Bulgaria.

Table 17. Accuracy Assessment Statistics of each method

	IDW 2	Kriging	MQ	NN
Mean	5.27	5.50	5.33	5.29
RMSE (±)	0.23	0.76	0.42	0.26
Variance	0.05	0.58	0.18	0.07

In the second accuracy assessment method 4 monitoring stations are considered as control stations and their values are estimated by interpolating the values of remaining 35 monitoring stations. Results of the second accuracy assessment method which are obtained by comparing estimated and measured wind speed values at four control stations are indicated in Table 3. As it presented in the table IDW 2 method has the lowest RMSE value for Bulgaria in cross validation. These results are consistent with the results of first accuracy assessment method.

The accuracy assessment process applied by selecting limited number of control stations can be affected by several parameters. Two significant parameters affecting these results are distribution of the control stations on the study area and the measurement value at each control station. For increasing the results of the accuracy assessment, control points located at centralized positions in study area should be selected. Additionally, measurements recorded at selected control stations should be close to mean value of all records. In conclusion, cross validation technique may not give reliable results when it is applied with limited number of control station. For obtaining more respectable results another accuracy assessment method was applied by using cross validation technique with larger extent. Differently from the other method, each monitoring station was considered as control station and its value was estimated by interpolating remaining monitoring station successively. Table 4 indicates the overall RMSEs obtained by applying the final accuracy assessment method. As it is clearly indicated in the Table 4, IDW2 spatial interpolation method has the lowest overall RMSE for Bulgaria.

Table 18. Accuracy Assessment Statistics of each method at control stations

Station Name	Measured Wind Speed at 10m (m/s)	Estimated Values and Errors							
		IDW2	Error	Kriging	Error	MQ	Error	NN	Error
Lovech	4.84	5.99	-1.15	6.78	-1.94	7.03	-2.18	6.97	-2.13
Plovdiv	5.09	5.08	0.01	5.30	-0.21	5.10	-0.01	5.13	-0.04
Razgrad	4.74	5.45	-0.71	5.05	-0.31	4.88	-0.14	5.26	-0.52
Sliven	5.69	5.26	0.43	4.54	1.15	4.11	1.58	4.79	0.90
RMSE			**±0.71**		**±1.26**		**±1.26**		**±1.27**

Table 19. Overall RMSE of each method

	IDW2	Kriging	NN	MQ
RMSE	±1.66	±1.87	±2.33	±1.87

4.2 Determination of the Spatial Interpolation Method for Turkey

4.2.1 Data Used in Application

In this study performances of the spatial interpolation methods were compared by interpolating the point sourced wind speed data recorded at 41 meteorological monitoring stations selected from one station in each province within the study area in Turkey. Study area coverage and spatial distributions of the 41 meteorological stations in Turkey are indicated in Figure 3. Wind speed data recorded at 10m at 41 meteorological monitoring stations in the study area was calculated as the average of 10 year wind speed data, which cover the period from the year of 2000 to 2010, provided by The State Meteorological Institute of Turkey.

Figure 56. Distribution of meteorological monitoring stations in Turkey

Table 20. Monitoring stations located in the study area and data

Station Name	Latitude	Longitude	Elevation (m)	Wind speed at 10m (m/s)
Afyon	38.7380	30.5604	1034	2.06
Aksaray	38.3705	33.9987	970	2.66
Amasya	40.6668	35.8353	409	1.21
Ankara	39.9727	32.8637	891	2.38
Ardahan	41.0922	42.7035	1827	1.95
Artvin	41.1752	41.8187	625	1.95
Bartın	41.6248	32.3569	33	1.45
Bayburt	40.2500	40.2333	1584	1.59
Bilecik	40.1414	29.9772	539	2.15
Bolu	40.7329	31.6022	743	1.39
Bursa	40.2308	29.0133	100	1.96
Çankırı	40.6086	33.6102	751	1.12
Çorum	40.5461	34.9362	776	1.91
Düzce	40.8437	31.1488	146	0.91
Erzincan	39.7523	39.4868	1216	1.45
Erzurum	39.9529	41.1897	1758	2.56
Eskişehir Anadolu	39.8119	30.5287	787	3.02
Giresun	40.9227	38.3878	38	1.31
Gümüşhane	40.4598	39.4653	16	1.79
Karabük	41.1963	32.6216	1216	0.71
Kartal	40.54	29.06	259	2.03
Kastamonu	41.3710	33.7756	800	1.35
Kayseri	38.6870	35.5000	1094	1.58
Kırıkkale	39.8433	33.5181	751	2.25
Kırklareli	41.7382	27.2178	232	1.28
Kırşehir	39.1639	34.1561	1007	2.71
Kocaeli	40.7700	29.9300	76	1.47
Konya	37.9837	32.5740	1031	2.08
Kütahya	39.4171	29.9891	969	1.53
Nevşehir	38.6163	34.7025	1260	1.96
Ordu	40.9838	37.8858	5	1.53
Rize	41.0400	40.5013	3	1.29
Sakarya	40.7676	30.3934	30	1.44
Samsun	41.3435	36.2553	4	2.13
Sinop	42.0299	35.1545	32	3.03
Sivas	39.7437	37.0020	1294	1.23
Tokat	40.3312	36.5577	611	2.15

Trabzon	40.9950	39.7830	39	2.36
Uşak	38.6712	29.4040	919	1.95
Yozgat	39.8213	34.8095	1301	1.88
Zonguldak	41.4492	31.7779	135	2.48

Four monitoring stations named as Bayburt, Bilecik, Çorum, and Tokat are considered as control stations that will be used in cross validation, while applying second comparison method.

4.2.2 Results for Turkey

For assessing the accuracies of the applied interpolation methods firstly statistical reports provided by Surfer Software for each method were compared. As it is represented in the Table 6, accuracy assessment statistics points out that IDW 2 has the best performance with the lowest RMSE which is ±0.24 for Turkey

Table 21. Accuracy assessment statistics calculated for each method

	IDW 2	Kriging	Radial Basis (Multiquadratic)	Natural Neighbour
Mean	1.830	1.830	1.861	1.878
RMSE (±)	0.235	0.364	0.496	0.372
Variance	0.055	0.132	0.246	0.138

In the second method 4 monitoring station are determined as control stations to used for applying cross validation. Estimations were obtained via applying each interpolation method by using data of remaining 37 monitoring stations. Results of the second accuracy assessment method which are obtained by comparing estimated and measured wind speed values at four control stations are indicated in Table 7. As it presented in the table, IDW 2 method has the lowest RMSE value, ±0.33, for the study area in Turkey as a result of the use of cross validation technique. These results are consistent with the results of first accuracy assessment method indicated in Table 6.

Table 22. RMSE for each of the method

Station Name	Measured Wind Speed at 10m (m/s)	Estimated Values and Errors							
		IDW2	Error	Kriging	Error	MQ	Error	NN	Error
Bayburt	1.59	1.83	-0.24	1.88	-0.29	1.85	-0.26	1.69	-0.10
Bilecik	2.15	1.87	0.27	1.97	0.18	2.00	0.15	1.90	0.25
Çorum	1.91	1.79	0.12	1.66	0.24	1.57	0.34	1.66	0.25
Tokat	2.15	1.59	0.56	1.33	0.83	1.23	0.92	1.37	0.78
RMSE			**±0.33**		**±0.46**		**±0.49**		**±0.36**

Third accuracy assessment method based on cross validation of the each monitoring station successively is also applied to wind speed data used in the project. Table 8 indicates the overall RMSEs obtained by applying the final accuracy assessment method. As it is clearly indicated in the Table 4, IDW2 spatial interpolation method has the lowest overall RMSE for Turkey with the value of ±0.56.

Table 23. Overall RMSE of each method

	IDW2	Kriging	NN	MQ
RMSE	±0.56	±0.59	±0.64	±0.62

5 Conclusion

This study was conducted to evaluate the performances of IDW2, Kriging, MQ and NN spatial interpolation methods which are widely used in GIS software for presenting the point source data as raster surfaces. The default settings of each interpolation method were considered in the study implemented by using data collected at monitoring stations distributed over Bulgaria and study area in Turkey. Accuracy assessment studies present that IDW2 interpolation has the most accurate estimations for both data sets of Bulgaria and Turkey. However, since there are several parameters such as distribution of the monitoring stations, the characteristics of the data recorded each station, and etc. affecting the performances of the spatial interpolation methods, it is possible to obtain different results by applying the same methods to data sets with different values or density and distribution. As a result, since the efficiency of interpolation has unsteady characteristic, accuracies of different interpolation methods should be examined before mapping point source data set obtained for each case, although point sources have the same similar distribution over study area.

6 Abbreviations and Acronyms

GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
IDW	Inverse Distance Weighted
MQ	Multiquadric
NN	Natural Neighbour
RMSE	Root Mean Square Error
SBA	Societial Benefit Area
WGS 84	World Geodetic System 1984