Comparative analysis of GIS in sight of view of renewable energy sources monitoring

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Abstract

At present there exists a great deal of GIS providing data on renewable energy on local and international level. In case of lack of field measurements the idea of using open source data along with field actinometrical measurements on the certain (or existing) sites seems to be efficient from the point of view of accuracy and costs. An overview of GIS commonly used in Russia and USA is given below. All the data used in the overview is available as project descriptions given on the web portal being discussed. All the systems have been analysed from the point of view of the data used on the portal, visualization tools and maps (wind, solar etc.).

Keywords:

renewable energy sources
monitoring
visualization tools
geospatial data

1 Introduction

Nowadays, the amount of data being produced and stored increases rapidly. Due to the rapid development and low cost of data transmission and storing tools the amount of stored data is steadily reaching enormous values. Naturally, in order to process all this data and process information 'usefully' it is necessary to develop more complicated methods and, in some cases, new fields of study. Moreover, from the point of view of processing speed more powerful calculation capacity is required.

Modern development of cloud computing allows to access, in the short period of time, almost unlimited resources for data processing and representation, and, in case of shortage, to broaden and deepen the needed data.

2 Data gathering and data processing used in modern GIS from the point of view of green energy monitoring

Data is the main valuable source of such systems. If certain data is confidential there exist several open source datasets providing correct data on renewable energy, and in some cases, with relatively high precision. Table 1 provides a brief overview of some datasets with information on solar energy.

Besides using these datasets it is also possible to use NASA SSE, open source datasets on solar energy, providing information about the whole Earth surface on the (1 x 1) grid. According to the researches held on the territory of Russia during several years, the NASA SSE data provides a sufficient accuracy level [1].

3 Visualization tools commonly applied in energy monitoring

The comparative analysis of different GIS is an essential part of defining proper functional parameters and requirements needed for creating a renewable energy monitoring system. The main issue in creating geographical information systems is finding the way of representing features being visualized (geographic parameters in this particular case) [2].

There exist several ways of describing geographical features.

Firstly it is necessary to recognize the data types. Normally two data types are defined:

- Spatial data (data describing the location)
- Attribute data (data specifying the characteristics of the spatial data i.e. what, when or how much) [3]

Secondly, it is needed to find the way of representation of the data in the GIS. Digitally it is possible to represent the data by grouping it into layers or by selecting appropriate data features.

Data grouping by layers is focused on finding similarities or relevant features in the target data (these features may be the source type as hydrography, elevation, water lines, sewer lines, grocery sales). In this case it is possible to use one of the following data models:

- vector (data model using coverage in ARC/INFO, shapefile in ArcView)
- raster data model (GRID or Image in ARC/INFO & ArcView) [4]

Selecting data properties should be done for for each layer separately [5]. Features are chosen with respect to projection, scale, accuracy and resolution

Finally it is necessary to find the means of data incorporation into a computer application system.

TABLE 1 Solar energy datasets

Charac-teristics	E.S.R.A. 1996	E.S.R.A. 2000	METEONORM 6,0	Climate 1	WRDC	S@tel-Light
Availableas	Book with CD	Two books with CD attached	CD and catalog	CD	Internet	Internet
Distribution	Paid	Paid	Paid	Paid	Free	Free
Web address	-	www.ensmp.fr/Fr/Services/ Presses ENS	www.meteotest.chl	www.climate-one.de	http://wrdc.mgo.rssi.ru	www.satellight.com
Application scale	Europe and North Africa	Europe and North Africa	Worldwide	Worldwide	Worldwide	Europe and North Africa
Supported parameters	S, D	Paid	S, D, T, V, W, P	S, T, V, W	S, D	S, D
Measure-ments period	1966-1975	www.ensmp.fr/Fr/Services/ Presses ENS	1961-1990 and 1996-2005	Different	1964-2009	1996-2000
Parameter extension	M	Europe and North Africa	m, h	m	M	h h
Number of observation sites	340	586	7756	>1200	1195	-
Spatial interpo-lation	No	No	Yes	No	No	Yes

S – total solar radiation, D – diffuse solar radiation, T – air temperature, P - atmospheric pressure, V – wind velocity, W - humidity in air, m – mean monthly parameters, h – mean hourly parameters, h h – half hourly parameters

It is needed to discuss each data type separately.

Spatial data types are represented as continuous, areas, networks and points.

Continuous data types are divided into elevation, rainfall and ocean salinity.

Areas are generally defined as:

- unbounded: land use, market areas, soils, rock type
- bounded: city/county/state boundaries, ownership parcels, zoning
- moving: air masses, animal herds, schools of fish

Networks may be classified as roads, transmission lines or streams.

Points are generally described as:

- Fixed ones: wells, street lamps, addresses
- Moving ones: cars, fish, deer

Attribute data types are generally defined as special data tables that contain locational information in the form of addresses, a set of longitude/latitude coordinates (or x/y) etc. Systems like ArcView consider these data tables as event tables [6]. However, the spatial data in the real system is described as a shape file. Thus, all the event tables are to be converted to the strict format. In order to convert data to a shape file format, it is possible to use geocoding, and later display the data as a map.

4 Maps categorization and comparative analysis of the existing representation models

In common case all the maps provided by renewable energy monitoring systems are classified with respect to the energy source they are representing. They are also classified concerning the means of their creation (i.e. raster and vector data model) [7].

Raster data is simple and faster to realize but in certain cases the map resolution may not be sufficient enough for proper analysis.

Vector data model requires more complicated and sophisticated tools but it is, in turn, a correct way of weather data representation. Thus, vector data model provides high quality resolution which may be extremely important in certain cases.

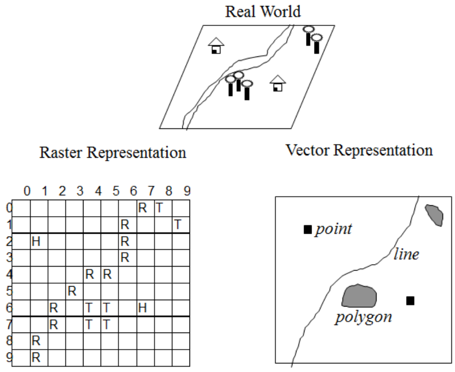

Figure 1 Differences in representation between raster and vector data models (http://www.utdallas.edu/~briggs/)

5 Comparative analysis of existing GIS

The analysis is carried out according to the defined parameters as data being represented, visualization tools and maps applied for data visualization.

5.1 RUSSIA'S RENEWABLE ENERGY SOURCES

According to the description provided on the "Renewable Energy Sources" GIS (RRES GIS) official website [8] the project is accomplished in cooperation with following scientific research centres:

- Moscow State University's Faculty of Geography
- Joint Institute for High Temperatures of the Russian Academy of Sciences, (research institute in the fields of high energy densities physics, shock wave physics, thermodynamics databases, numerical simulations and cluster computing, dusty plasma, applied electrodynamics, combustion, green power (JIHT))
- Renewable Energy Sources and Energy Conservation Laboratory.

Data provided on the website is based on the Global Atlas for Solar energy in Russia and climate databases (special datasets applied in renewable energy monitoring in Russia). Data provided by the GIS may also be used in constructing mathematical models, including dynamic ones, of power stations working on renewable energy.

The Global Atlas for Solar energy in Russia is a set of maps of total solar radiation on the whole surface of Russia. Mean values of solar radiation are calculated from radiation sums of different periods of time. It should be noticed that the data format is defined by heliotechnical equipment requirements [9]. Data for the Global Atlas is provided by Russian weather stations (multiyear solar radiation measurements), Meteonorm RetScreen and NASA SSE(NASA Surface meteorology and Solar Energy) databases. Data taken from NASA SSE, is satellites measurements values used to calculate the Earth's Radiation Energy Balance. Using these values solar radiation distribution models are developed. In these models the following weather parameters are considered:

- Earth's surface albedo
- Cloud coverage
- Humidity in air
- Atmospheric aerosols concentration

Together all these parameters allow determining mean solar radiation streams with a little inaccuracy. It still should be mentioned that these parameters have been calculated in accordance with USA surface specifications.

On the basis of NASA SSE datasets wind annual average velocities distribution maps have been constructed (50 and 10 m heights), which are also included in the Global Atlas. These are map are essential in calculating wind velocities in different regions of Russia. Data taken from the maps is later used in defining power stations' potential efficiency (including those ones that are integrated into combined solar and wind power stations). Nevertheless, due to the dependency of actual wind velocity and direction from the region's geographic conditions, it is obligatory to verify all the data, i.e. wind parameters are measured directly at the site of the planned power station. Multiyear data of the surrounding weather station may also be taken into consideration.

Thus, data used in 'Russia's Renewable Energy Sources' GIS is a special dataset that includes statistical information and results of processing this data.

Statistical data is obtained from weather stations all over the country and from the NASA SSE weather database, created on the basis of long-term surface observations with Earth satellites.

Using this statistical data direct (beam), diffuse and reflected solar radiation indices have been calculated for multidirectional horizon degrees and different time periods (including the daily distribution indices of the total amount of solar radiation striking the horizontal surface on the earth) [10].

All these indices may be used afterwards to evaluate the efficiency of solar power stations working on luminescent solar concentrators.

As the studied GIS uses raster map representation the following features fully describe the system visualization policy. Firstly, the whole area is covered by grid with equal-size cells. Location of every cell is calculated simultaneously relatively to the origin of the matrix. The majority feature is an attribute. Every cell on the grid is assigned a single value in the cell (e.g. land use type) in accordance with its majority attribute. This is how the attributes are recorded. Among the advantages it is possible to mention its simplicity. The system is relatively easy and fast to implement. All the calculations overlay and analysis are done fast because of the grid structure. Thus, in order to calculate certain value it is only needed to combine the corresponding cells.

The upper left of the grid is commonly defined as its origin, but there are certain features to be mentioned:

- State Plane and Universal Transverse Mercator UTM have their orign at the lower left
- Latitude/longitude and Cartesian coordinates are defined to have an origin at the center

There are certain notations that are commonly applied while constructing the raster model, as class, zone and neighbourhood:

- class is a combination of cells with the similar value (values may be defined by the object type, as for example the cells defining sandy soil, i.e. having the same type)
- unlike the class a zone is a combination of contiguous cells having the similar value
- neighbourhood is a combination of cells adjacent to a target cell(cells may be adjacent in a certain systematic manner)

All the maps provided by the system may be divided into several categories.

Maps are also divided with the respect to the energy sources they are representing. Thus, all the maps are divided into solar, wind, hydro and bio energy. The division is provided explicitly and is highly understandable.

From the point of view of representation concepts the majority of the maps are raster with a certain number of vector maps. It should be mentioned that this division is not unequivocal (i.e. there is no separation evident to the user). Yet, it is possible to find these categories as subdivisions. Thus, there are raster, resource and object maps.

FIGURE 2 Explicit map classification of RRES GIS

FIGURE 3 Inexplicit map categorization in the RRES GIS subcategories

5.2 NATIONAL RENEWABLE ENERGY LABORATORY, NREL

The National Renewable Energy Laboratory (NREL) is the main USA scientific laboratory center implementing researches on renewable energy, efficient energy use (or energy efficiency) and sustainable development.

All the data obtained during the researches is freely available on www.nrel.gov. The data has been visualized, but especially for the power station engineers, it is also available in a table format. All the information presented on the official website has been obtained from one of three research centers:

- The National Center for Photovoltaics
- The National Bioenergy Center
- The National Wind Technology Center - NWTC

All the data obtained during field and indoor measurement is published at Renewable Resource Data Center. For instance, 10 km data maps show hourly solar activity data obtained from field weather stations, daily data on snow coverage, monthly air humidity data, data on greenhouse gases, and a total amount of aerosols in atmosphere in order to let calculate daily surface insolation level [11]. The same maps, but with 40 km data provide information on cloud coverage, atmosphere higher levels humidity, greenhouse gases concentration and a total amount of aerosols in atmosphere in order to allow calculation of the total insolation level. It is still should be mentioned that satellite data is to be verified by field measurements whenever it is possible. For example, a cloud map is a height year histogram of satellite data taken in a 40 x 40 km resolution. Thus, the accuracy and the space map resolution are defined by the database itself.

Besides providing raster maps the NREL represents some data by means of vector model. To create its raster model NREL commonly applies square or rectangular grid. Naturally, that square grid (creating each cell with equal length sides) is conceptually much simpler than any other. In this case, it is possible to divide cells recursively into squares (cells) of same shape. The location is defined by neighborhood, i.e. left/right, above/below directions. This is commonly referred as rook's case. As all the cells (at least neighborhood ones) are equidistant, the calculation may be simplified. It is also possible to apply a queen's case, meaning that neighborhood includes 8 connections (including diagonals), But in this case all the cells may not be equidistant. Diagonal cells are 1.41 points away from the cell center (square root of 2).

For example NREL wind data (50 meter height above ground/surface) is obtained from original raster data that varied in resolution from 200-meter to 1000-meter cell sizes. Then, this data have been modified to produce geographic shapefiles. Thus, these shapefiles have been applied to create 50 meter wind maps. There are two distinct groups of data provided in this section: data produced by NREL and data produced by AWS Truepower but validated by NREL.

NREL provides datasets that may be later modified by other tools. For example solar data of Colorado is provided as a shape file that is later possible to be used in such tools as QGIS. In QGIS this shape file may be added as vector layer. These shapefiles are geometry records and attributes corresponding to each record. The information about records/columns and their explication are provided in the metadata. In order to visualize dataset provided by NREL it is necessary to use data based on attributes.

It should be also mentioned that points are commonly referenced as nodes (and arcs as lines). To sum up, it is possible to define key features common to different representation tools.

As it has been mentioned above the polygon edges are described by listing ID numbers like walking around the outside boundary of the area. There is also another file that contains information of all the points and their respective coordinates (an array of IDs). The second file's efficiency is proved by the following reasons:

- there is a problem with the duplicate coordinates and double borders; using the second file helps to solve this problem
- as there is a list of IDs in the second file lines can be manipulated directly as polygons, but still there is a problem with networks representation
- even if the second data file gives sufficient information there is still lack of topological data
- the second generation mapping package, from the Laboratory for Computer Graphics and Spatial Analysis at Harvard, called CALFORM was the first to apply second data file in their vector model.

Unlike 'Russia's Renewable Energy Sources' GIS the maps provided by NREL are explicitly divided into several categories.

The team responsible for map development is NREL's Geospatial Data Science Team that creates tools for various renewable energy sources and for certain specific tasks (e.g. certain projects). As a benefit to the public, a majority of static maps are offered and Google Map (KML/KMZ) files on a tool called MapSearch To be beneficial for the public a majority of static maps and Google Map files (KML/KMZ) are available on a special tool created by NREL and called MapSearch. The main categories of maps in a public access are:

Biomass Maps

The biomass resources in the United States data provided in the map form shows the information throughout the county. [12].

Federal Energy Management Program

The main goal of the Federal Energy Management Program (FEMP) in cooperation with with Geospatial Analysis staff at NREL was to update the analysis for the development project. Working together they have finally composed an interactive FEMP Screening Map application [13]. Nevertheless, the earlier map versions have been saved and archived. Thus all of them are still available and may be accessed by contacting the NREL's Webmaster.

Geothermal maps

There are available maps showing not only favorable resources for enhanced geothermal systems, but also identified hydrothermal sites. Besides providing data on currently developed projects there are also sites on the map showing the planned geothermal power plant projects.

Hydrogen Maps

A tool known as GIS modeling is applied in analyzing and visualizing the spatial relationship between supply and demand. For instance, supply in the form of resources (renewable and traditional), hydrogen production facileties, and transportation infrastructure, from one side and hydrogen demand centers from another [14]. This tool is a powerful facility allowing processing large and complex datasets, siting hydrogen production facilities and refueling stations on the map, and analyzing diversity of resources for hydrogen production throughout the United States.

International Maps

NREL provide powerful analysis Geospatial Toolkits and maps created in collaboration with with various countries. The maps are available through the MapSearch tool and as a separate category on the official web site (international maps).

Marine and Hydrokinetic Maps

There are several viable sites of marine and hydrokinetic resources in the United States. Maps of marine and hydrokinetic (MHK) resources are available on the NREL's website. Some of them are: Nonpowered Dams Assessment, Wave Resource Assessment, Tidal Streams Resource Assessment, Wave Energy Resource Atlas, and Tidal Streams Resource Maps [15].

Solar Maps

Data for solar maps (solar radiation resources) has been obtained via several photovoltaic collector orientations in the United States [16]. Among the available maps are: PV Solar Radiation Maps, Direct Normal Solar Radiation Maps, Map of U.S. Solar Measurement Station Locations, and the United States Solar Atlas.

Wind Maps

The wind power density is the main factor determining the wind resource potential [17]. Thus, wind maps are based on these calculations. The wind energy resources are estimated for the maps and are represented as maps. The data is available only for the United States and its territories. It should be mentioned that these maps indicate general areas where a high wind resource may exist [18].

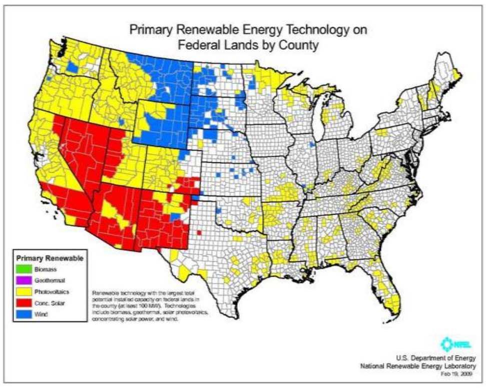

FIGURE 4 NREL renewable energy technology visualization sample

5.3 INTERNATIONAL RENEWABLE ENERGY AGENCY, IRENA

Created in 2009 the organization's main goal is to develop and support the renewable energy sources utilization. The organization is aimed to provide a free access to the renewable energy sources data for public and for potential power station developers. IRENA was established on the 26-th of January, 2009 in Bonn, Germany, when 75 states signed an IRENA official statute, which entered into force on the 8-th of July, 2010. IRENA is promoting sustainable development, usage of renewable energy and distributes all the obtained knowledge in order to increase the interest rate in this particular field [19].

Data visualized on the IRENA is taken from different international sources the majority of which belong to NREL and Global Geographic catalogues as Wind resource maps of the Global Atlas, USA bioenergy data, Full Merra dataset, Spanish National Renewable Energy Centre (CENER) - www.cener.com,World Data base on Protected Areas, WDPA http://www.protectedplanet.net/country/KZ) [20].

Certain generic models used inn IRENA are implemented by several software vendors in specific computer file formats As IRENA represents data in raster and vector format (including data provided by NREL), there is a set of specific file formats commonly applied during data representation.

Coverage: specific vector data format developed in 1981 by ArcInfo

- coverage format supports multiple physical files (approximately 12) in a single folder [21]
- this data format is proprietary, thus there are published specifications allowed and for any change ArcInfo is required

Shape 'file': specific vector data format developed in 1993 by ArcView

- extensions supported: .shp, .shx, .dbf; shape file data format comprises several physical disk files (3 and more); it is required for all of the files to be present
- open-source, thus it is allowed to publish own specifications; commonly used by other vendors
- Geodatabase: specific vector data format created in 2000 by ArcGIS 8.0
- geodatabase supports multiple layers saved in a single file with .mdb extension (similar to MS Access)
- geodatabase format is proprietary; being a recently introduced data format, it is commonly referred as the next generation spatial data file format

The following map systems are used for data representation:

- Google Hybrid Map
- Google Satellite Map
- Google Street Map
- Google Terrain Map
- Bing Hybrid
- Bing Satellite Map
- Bing Street Map
- Open Street Map

7 Conclusions

The comparative analysis of different GIS is an essential part of defining proper functional parameters and requirements needed for creating a renewable energy monitoring system. A brief overview of existing GIS and their comparative analysis allow determining the following requirements list:

1. Data gathering. As it has been mentioned above the NASA SSE datasets prove to be sufficiently accurate and satisfy all the requirements. But still, all the GIS have their own weather stations (or at least data of field actinometrical measurements) to verify the NASA data. Thus, it is strongly recommended to obtain local weather data along with using open source information.
2. Data visualization and shape files. It has been mentioned that certain GIS provide their own shape files to be later used in other visualization platforms. In this case the data on local renewable energy sources is platform independent and allows the information to be later used for further researches. As the renewable energy monitoring system is used both for public and professional usage it is necessary to provide raster data for public (for easier access) and vector data for developers and researchers (for more accurate calculations).
3. Maps. During the overview the problem of inexplicit map categorization has been revealed as it is quite possible for user to be confused. Consequently, the maps are to be explicitly divided by quality and by energy types (as on the NREL website).

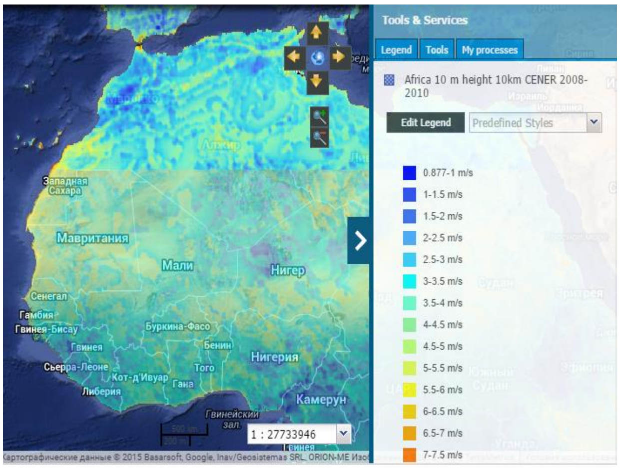

FIGURE 5 CENER data visualization sample on the IRENA portal

To sum up, it is possible to claim that for regions with high renewable energy potential the problem of energy monitoring is considered as an essential part of further development. In case of lack of field measurements the idea of using open source along with field actinometrical measurements on the certain (or existing) sites seems to be efficient from the point of view of accuracy and costs. In this case, the renewable energy monitoring systems may be considered as the strong foundation for alter development of alternative energy in the regions with high potential and high energy demands.

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