A Decision Support System for the Planning of Hybrid Renewable Energy Technologies

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Abstract. Implementation of renewable energy resources (RES) with the use of knowledge-based approach requires systems which enable to combine data from different databases in order to multidimensional character of analysed factors. Therefore, this study provides the decision support system for the planning of hybrid renewable energy technologies designed for regional authorities. The system in this research integrates two RES: solar and wind. Moreover, it combines energy potential data with administrative division and data on land cover. Presented functionality shows the ability of single-element filtering as well as multi-element filtering which gives the opportunity visual data discovery. The novel decision support system designed in this research can constitute an effective instrument, which can help regional decision-makers to locate single-source as well as hybrid RES installations to meet the requirements of renewable energy production. The systems were designed for the case of Lubuskie Voivodeship (Poland). However, besides the fact of customized system for one region, the use of universal databases allows to prepare similar tool for any other region in European Union.

1. Introduction

The world economy is constantly increasing its demand for heat and electricity, which increases the demand for raw materials used in conventional energy sources [1,2]. The shrinking resources of energy resources make it necessary to search for new alternative solutions based on energy sources [3–5]. In the European Union (EU), of which Poland is a member, it was assumed that by the end of 2020, 20% of energy will come from renewable sources [6]. In 2016 The European Commission has published a 'Clean energy for all Europeans' (COM (2016) 0860) legislative package. That document was a part of a holistic strategy of the energy union (COM (2015) 0080). According to this document it was proposed to redesign the Directive on the promotion of renewable energy sources to make the EU a world leader in renewable energy and ensure that by 2030 the target of at least 27% of energy from renewable sources in total EU energy consumption is met. In the transport sector, a 14% renewables target has been set, with advanced biofuels and biogas accounting for 3.5% (1% by 2025). In addition, the certification scheme introduced a 7% reduction in the share of first generation biofuels in road and rail transport and plans to phase out palm oil (and other biofuels from food crops that increase CO₂ emissions) by 2030.
The rights of consumers to consume their own energy from renewable sources have been strengthened, the principle of "energy efficiency in the first place" has been introduced as a guiding principle and an indicative annual increase of 1.3% in the share of renewable energy sources in heating and cooling has been set [7].

The production of energy from renewable sources enables diversification of the energy production structure, reduces the country's dependence on fuel imports and contributes to the reduction of the environmental impact of the energy sector, thanks to low or zero emissions of pollutants. The use of renewable energy sources (RES) limit the import of fuels and provides the possibility of lower intensity of the use of fossil fuels, which improves energy security [8,9]. The current state energy policy, implemented on the basis of the objectives adopted in 2009, had to be updated in terms of its directions. The current state and forecasts of energy consumption based largely on the share of industry in the national economy are of key importance for the energy sector. Independently, it is necessary to meet international obligations [10]. It should be noted that Poland has been contributing to the reduction of the environmental impact of the energy sector in the last dozen or so years. However, this does not change the fact that the country's dependence on coal fuels is much higher than that of the other EU countries. Poland consumes about 4 500 PJ of primary energy. Most of it is coal and oil, followed by natural gas, lignite and renewable sources. PEP2040 adopts a further reduction of pollutant emissions from the energy sector, inter alia, through the implementation of nuclear energy, and thus an increase in the use of renewable energy sources. The adopted target of a 32% share of RES in net electricity generation is based primarily on the development of photovoltaics (especially until 2022), mainly due to the cost-effectiveness of such solutions and the expected increase in market flexibility required by RES development.

Based on international obligations, Poland should produce 15% of energy from RES in gross final energy consumption by 2020 [11]. In Poland the share of electricity from RES in domestic energy sales to end users was 13.06%. Around 67% of renewable energy in Poland comes from wind, 17% from biomass, 11% from hydroelectric power plants and 3% each from biogas and solar radiation [12]. The potential of renewable energy in Poland varies depending on natural conditions, infrastructure, economic development [13], as well as soft factors such as political willingness of the region's authorities and social perception of investments in RES [14]. So far, due to the existing conditions, solar energy has been of little importance (less than 1 per mile in 2009), but the current measures taken to stimulate the increased use of solar energy (co-financing of investments from government funds, loans on preferential terms, repurchase of energy generated by individual producers) make this method of energy generation increasingly important (0.5% in 2018) [12]. The total potential of thermal solar energy is over 19,000 TJ and requires the installation of about 14.7 million m² of solar collectors [15], and only 99 TJ (27,514 MWh) is produced in the current installations [12]. Besides solar energy, due to political decision onshore wind energy production is now decreasing and direction of the wind energy development is focused on offshore installations [16]. However, changes in political situation, like for instance the European Green Deal introduced in December 2019 [17], may occur in the need of boosting investments in variety of RES branches. Therefore, especially in those RES which are underdeveloped, there is a need to propose a system that will be able to optimize decision making process for more effective RES development. The aim of the paper is to develop a decision support system for the planning of solar and wind renewable energy technologies. The developed tool would be presented on the case of one selected region in Poland, as a suitable decision making authorities in terms of RES development are at this level (Polish voivodeship).

2. Data and methods
The decision support system developed in this study integrates solar and wind energy potential for the planning of hybrid renewable energy technologies at the regional level. The RES potentials used in this research come from outsource datasets. Such approach allows to prepare similar decision support system for any other region in the world due to the full coverage of the globe by these databases: Global Wind
Atlas and Global Solar Atlas. The RES potential was combined with the information about the land cover (CORINE Land Cover 2018), the administrative division of the country.

Wind energy potential was obtained from opensource, web-based database, namely the Global Wind Atlas (GWA). GWA presents the potential of energy of wind as wind power density reflected in W/m². This value for each area is assessed by downscaling from large-scale to the microscale wind climate data. The approach of generalization is a key element developed by the Technical University of Denmark in GWA database. It incorporates data on global circulation, orography, topography, position of the coastline as well as a surface roughness [18].

Solar energy potential was obtained from the Global Solar Atlas (GSA). Similarly to GWA, GSA is an opensource, web-based database with similar interface allowing the user to use both tools in intuitive way. Solar energy potential is assessed as amount of energy that theoretically can be converted by a photovoltaic (PV) system into electricity according to local geographical conditions of a site and a configuration of the PV system. Values of solar energy (PVOUT) is originally provided in kWh/kWp unit. PVOUT is calculated according to variety of natural factors covering: solar resources, air temperature, terrain elevation and the height to the sea level. The evaluation approach used in order to estimate that factor takes into account three commonly used PV systems. That includes (1) small residential rooftop systems, (2) distributed, or medium-size commercial roof-mounted systems, and (3) large or utility-scale PV power plants. Due to the generalization of available data, GSA is suitable for initial screening of regions suitable for solar energy production, however, more detailed location requires data with higher precision [19].

Information on land cover comes from CORINE Land Cover 2018 (CLC2018). CLC2018 project was implemented as part of the European Earth monitoring program – Copernicus Land Monitoring. The CLC2018 demonstrate the changes in land cover/land use that occurred in 2012-2018 and the construction of a uniform and opensource CLC2018 database. In addition, as part of the European service Copernicus Land Monitoring, High Resolution Layers have been developed including: impermeable areas, forests (crowns and forest types), permanent grasslands, water reservoirs and wetlands and local products, i.e. Urban Atlas, detailed land cover/land use along the largest rivers (Riperian zones) and selected nature protection areas NATURA2000 [20]. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The time series are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha [21].

Data from the state register of borders and area of territorial division units of the country was obtained from the Head Office of Geodesy and Cartography. Three levels of the national division of the country were used in the research. All of these levels are complimentary to the Nomenclature of Territorial Units for Statistics (NUTS) and Local Administrative Units (LAU) used in the European Union. These three administrative levels are: borders of regions (NUTS 2), borders of counties (LAU 1, formerly NUTS 4), borders of municipalities (LAU 2, formerly NUTS 5) [22]. Administrative units data and CLC2018 were intersected to enable analysing land cover patches in specific municipalities and counties separately for more detailed information.

In order to integrate GWA and GSA, geographic information system (GIS) with business intelligence (BI) software were used. In particular, we configured and operated ArcGIS 10.4 and Tableau 2019.4.1 in live connection mode. Therefore GIS and BI software had a concurrent access to spatial data stored in geodatabase file [15]. The GIS component was applied for data blending and pre-processing as well as advanced geoprocessing and geostatistical operations. Tableau was used as visual analytics environment and geodata-based decision-making support tool [16,17]. Visual data exploration was carried out within the dashboards, which allow to drill and filter location-based information, to perform data grouping and clustering as well as to calculate basic statistics and to assess the trends and correlations between dimensions. The workflow of the designed solution is presented in the diagram (figure 1).
In this study presents the applicability of the developed decision support system based on the example of the Lubuskie Voivodeship (Poland). The climatic region, to which the Lubuskie Voivodeship belongs, is characterized by the type of warm moderate weather [23]. In terms of thermal conditions, the region belongs to the privileged regions in Poland. The average annual temperature recorded in its area is one of the highest in Poland. Due to the goal of location of wind and solar hybrid installations, conditions of these two RES are presented.

In the Lubuskie Voivodship, landform and land cover only locally and to a limited extent modify wind direction and speed. In connection with the above, it can be assumed that the observed wind directions mainly refer to the directions of air mass inflow. The average annual wind speed in the voivodship is 2.5-3.5 m/s. The wind with the highest average speeds during the year (3.5 to 4.0 m/s) is most common from the west. The smallest average speeds of about 2.5 m/s are characterized by wind from the S and SE directions. The highest average wind speeds are recorded in winter and spring from November to March inclusive, and the lowest in August and September [24]. The figure below presents the range of wind speed measured on 10 m and 80 m above land surface (together with the major wind direction) in the last decade for the capital city of the region (figure 2).

In terms of geographical location, the Lubuskie Voivodship has an average solar density up to 1,022 kWh/m²/year (in Poland: 950 – 1,250 kWh/m²/year), and the average sunshine in the region is about 1,600 hours a year, while almost 80 % of the total amount of annual sunshine falls on 6 months of spring and summer [25]. The average potential of solar energy that can be obtained with a solar collector in the voivodship is 1025.8 MJ/m²/year. The highest solar energy potential can be observed in
the southern part of the voivodship as well as in few municipalities in the north-east part of the region [26]. The figure below presents the variation of sunshine duration and shortwave radiation in the last decade for the capital city of the region (figure 3).

Figure 3. Solar conditions in the capital city of the region (source: source: www.meteoblue.com)

Considering the structure of wind and solar potentials presented above, the development of hybrid solutions combining these two RES might compensate periods of low energy production from one source by the other one. That may increase the stability of the energy system in the region.

3. Results

The developed decision support system presents to the decision-makers six integrated elements which are dynamically connected in one dashboard. These elements are: (1) map of the region, (2) pie chart presenting shares of analysed land cover categories, (3) scatter plot representing RES potential of each municipality in relation to administrative units, where shape describes a county of each municipality and size presents the area of each municipality, (4) bubble scatter plot representing RES potential of each municipality in land cover, divided into specific land cover categories, where colour describes a land cover within each municipality and size presents the area of each land cover class, (5) land cover legend and (6) administrative unit legend (figure 4).

Figure 4. Interactive dashboard for hybrid renewable energy location.
As all maps, charts, plots and legends are connected dynamically, action at any of these elements cause the reaction at all other elements. Selection can refer to any object as well as to the group of objects. The user is enabled to choose the range of selected objects by using regular patterns like objects within a certain distance from any point or self-define irregular shape of objects that should be analysed. Every selection results in filtering other elements of the dashboard in the real time. Below three examples of single-element filtering are presented: selection from map (figure 5), selection from legend (figure 6), selection from scatter plot (figure 7).

Figure 5. Single-element filtering – selection from map.

Figure 6. Single-element filtering – selection from legend.
Besides single-element filtering, the designed dashboard allows also to perform multi-element filtering. That allows the decision-makers to take into account variety of factors influencing effective implementation of hybrid RES. For instance such factors could be financial situation of limited group of administrative units and the focus of RES technologies which cannot be implemented easily in every kind of area due to physical limitations. In order to present the applicability of such multi-element filtering the example is presented below (figure 8).
be used. Such functionality of the designed solution presents the practical aspect of the research, which may influence the promotion of RES.

4. Discussion and conclusions
Analyses of big data stored in many diffused datasets may constitute a significant barrier for decision-makers to take into account selected, proper information useful for final decision. Besides the fact that decision support systems are designed in recent years, still 92% of managers are not using them due to their level of complexity [27]. Among others, it is connected with the fact that from the point of view of the users they seem to be too complicated. Therefore, decision support systems should be based on the most simples as possible dashboards that are going to be used by layman. Such opportunity gives visual data discovery, which seems to be more natural for human cognition. The advantage of the visual approach in data analytics is an opportunity to replace some complex cognitive tasks by easier perceptual tasks [28]. The decision support system designed for the purpose of this study is based on few basic elements that are taken into account in the process of RES installations location. The selection of key factors used in the system was based on the discussion with representatives of local administration. Based on the approach of customizing decision support systems [29], we have presented an interactive dashboard enabling selection of possible RES investments location based on the energy potential, administrative division of the country and land cover. The dashboard would be presented to the administration at the regional level for consideration of using it in the process of RES development in the Lubuskie Voivodeship.

Overcoming high complexity of the system was possible due to the technological innovation that was used while constructing the dashboard – the use of the Visual Query Language (VizQL). As Lloret-Gazo stated, the main advantage of these systems is that data are becoming available to everyone, as non-expert users demand easy ways to retrieve data from big data sets. Queries in VizQL are represented visually and users do not have to understand query languages such as SQL or XQuery [30]. Comparing the system designed in this study to other systems used in the domain of RES [31–33], the functionality of filtering and dynamic selections of analysed data is not possible, unlike in this study. Feedback on other systems is stable and does not allow for visual discovery of possible options so easily. Moreover, solution applied in this study solves one of the most common problems in Polish practice of regional planning which is connected with credibility of data. In many cases supra-local data is prepared in the bottom-up approach which result in merging information prepared on municipal level. Due to different methods as well as human factors, it can be seen that at the connection of different units there is a problem of data continuity and sharp changes of values are noticeable. That does not relate to the character of natural phenomena. This problem was solved by integrating four different data sets (two representing energy potential, one – land cover, one – administrative division), which were obtained from databases at European or global levels.

Depending on the changing political context of RES implementation the activity of local authorities in this domain may vary like it happens in other fields of their activity [34]. However, undertaking strategic and horizontal decisions at the state level significantly impact changes in at the local scale [35], which result in the sustainable development level of regions [36]. In order to face environmental challenges [37–39] there is an urgent need to support local stakeholders with tools which would enable them to make knowledge-based decisions [40]. The application of the decisions support system may result in limiting inappropriate energy location selection [41] and lead to decreasing problems connected with social conflicts which sometimes are connected with RES implementation [42]. That may enhance participatory approach in environmental management [43–45].

A limitation of this study in more detailed local analyses could be the use of GWA and GSA. These databases give suitable information for the purpose of this study, which is a screening of approximate conditions for RES location at the regional level. However, in order to avoid misleading interpretation, once the local unit is selected to concentrate their activities in RES promotion, more detailed, local analysis of suitability conditions should be prepared. Due to recently developed solutions for the free access to in-situ meteorological and hydrological datasets [46] it becomes easier to perform
environmental assessment which would allow to answer the question if local conditions are also suitable for the RES investments. On the other hand, the GWA and GSA datasets used in this study give the opportunity to apply similar system for any other region, which is an advantage of this study. In terms of NUTS and LAU that were used in this study, it has to be highlighted that size of these administrative units vary between member states of European Union [47], which should be taken into account while considering similar research for other areas.

Acknowledgements
This research is a result of scientific activity conducted within the Leading Research Group: Sustainable Cities and Regions and was financially supported by Wroclaw University of Environmental and Life Sciences.

Geodata and indicators have been collected from the following repositories:
- Potential of solar energy production - https://globalsolaratlas.info;
- Potential of wind energy production - https://globalwindatlas.info;
- Land cover - https://land.copernicus.eu/;
- Map of administrative divisions of Poland - http://www.gugik.gov.pl;
- Wind and solar conditions – http://www.meteoblue.com.

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