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Implementation of a GEOdatabase to administrate global energy resources

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Abstract: The future development of our energy system is still unclear. This uncertainty is based on numerous aspects. In addition to the currently most relevant climate debate this will also be a question of available technologies as well as of available resources. Hence the global energy resources and their distribution will be one of the most influencing factors in the design of our future energy system. To model and administrate global energy potentials a geographical (GEO) database has been implemented. The intention to implement such a global GEO database is based on the fact that numerous aspects describing our energy system rely on spatial characteristics. Particularly renewable energy resources depend on numerous datasets, the most important ones are topography, land cover, climate, population distribution and precipitation. With respect to these datasets the theoretical and furthermore useable global potentials of renewable energy carriers were estimated, in this paper the computation of wind power is shown exemplarily. When modelling renewable energy potentials special attention has to be paid to the fact that renewable energy potentials are often not additive, what means that the land surface is only available once and therefore several potentials exclude the option to yield another potential on the same area. For the estimation of the highest possible energy potential on a certain area, a competition analysis regarding the utilization of the land surface was carried out.

Keywords: Energy resources, GIS, Global Database, modelling.

1. INTRODUCTION

Numerous statistics give numbers on energy potentials on country level (IAEA 2005, BP 2006, EIA 2005, WEC 2004) but only few studies reflect the real spatial and temporal distribution of - especially renewable - energy carriers. One work treating this issue quite fundamentally has been done by Hoogwijk [2004]. Nevertheless also in this work the chosen spatial resolution is quite rough (0.5°). Since primary geographic information like topography, land cover, climate are available in a quite high spatial resolution for the whole globe (up to 1km), an estimate on the related renewable energy potentials can be evolved in the same high spatial resolution. That issue is treated in the current paper and a global GEOdatabase including conventional and renewable energy potentials is developed.

The GEOdatabase not only includes the consideration of the global spatial distribution of single conventional and renewable energy resources but also the influence of their spatial distribution in the context of the complete energy system and the coupling with spatial energy demand structures.

2. BASIC FRAMEWORK

The intention of the GEOdatabase is to consider all relevant energy resources with their geographical distribution in one common database. As the input all relevant raw data like solar insolation, wind speed, precipitation, topography, land cover, etc. are used on a global scale. These datasets are included in the database, each describing one aspect of the energy...
The datasets are linked via the common geographical reference, whereby mainly renewable energy resources have been investigated. Therefore general data – describing land cover issues, climate conditions or population distribution and statistical datasets – are utilized to generate spatial estimates on harvestable renewable energy potentials as well as conventional resources. A scheme of the Geodatabase is shown in figure 1.

The challenge for the integration of raw data and the modelling process is the dynamical spatial resolution. For the renewable energy resources the data are proceeded and included into the database on a raster basis of different resolution up to 1 km, whereas other energy sources like nuclear or fossil energy are handled on a country or regional level. A further crucial point within the modelling of renewable energy potentials is the temporal resolution of their availability, which could be hourly, daily, seasonal or annual, depending on the considered energy carrier.

Hence the GEOdatabase includes a 3D data framework that enables the administration and treatment of two space and one time dimension.

3. GENERAL MODELLING APPROACH

3.1 Relevant Data

The global energy resources depend on numerous datasets which represent physical, ecological and economical restrictions on the available potential. Non-renewable resources are mainly determined by their global spatial distribution by type of resource (conventional/non-conventional), level of confidence that the respective resource exists as well as by recovery costs. Regarding renewable energy potentials the most significant general influencing factors - next to specific data like solar insolation or wind speed - are topography, land cover, climate and population distribution. Although these restricted data are not sufficient to provide an accurate description of the real situation, they offer a good basis to estimate the renewable energy potentials. By implementing and interlinking these datasets on a global scale, the potential energy harvest of a respective energy resource in different areas of the globe can be estimated in a proper way with respect to local/regional conditions and included in one common database.

- **Topography**
  
  Topography is considered as one of the main influencing factors regarding the spatial distribution of energy resources. The physical availability of resources is influenced by topography as well as a possible harvest or depletion of energy resources. That affects all forms of renewable energy carriers as well as the depletion of conventional energy resources. Hence the topography has to be included in the modelling approach.

- **Land cover**
  
  A land cover classification which distinguishes 13 land cover classes – representing the generalised main land use categories - was used [Hansen et al, 1998]. These land cover classes are a major input to extrapolate available renewable energy resources as they are
correlated to the possible energy potential for the decision where an energy potential could be harvested.

- Population density

The global population is also considered as relevant for the estimation of energy potentials. Next to the factor of reachability also the aspect of land use competition is an aspect that is mainly influenced by the distribution and density of the population. Data on population distribution were derived from the Center for International Earth Science Information Network (CIESIN) [2005].

- Accessibility

Derived from the mentioned primary datasets the so called "accessibility" can be identified as a secondary dataset. This variable is determined by the global spatial distribution of demand pattern that has to be satisfied by the spatial distribution of supply pattern. On a global scale, some regions might be identified with a high theoretical renewable energy potential, but are far away from already built or economically feasible infrastructure. To estimate such effects a sensitivity analysis is carried out. This analysis deals with the spatial distribution of regions which enclose a certain threshold of inhabitants within a certain area as shown in table 1. Although “accessibility” is defined by several aspects, whereas population density can be identified as the most significant one. Therefore accessibility was modelled under the simplified assumption that only population density affects the accessibility of renewable energy potentials. This approach to define accessibility is applied to categorise the different energy resources.

Table 1: Distribution of accessible areas depending on inhabitants within a certain area

<table>
<thead>
<tr>
<th>Inhabitants in area</th>
<th>Radius of 100 km</th>
<th>Radius of 200 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10^2 * radius^2</td>
<td>![Map 100 km]</td>
<td>![Map 200 km]</td>
</tr>
<tr>
<td>&gt; 100^2 * radius^2</td>
<td>![Map 100 km]</td>
<td>![Map 200 km]</td>
</tr>
</tbody>
</table>

3.2 Estimation of global energy resources

The estimation of the energy potentials is accomplished in a top-down approach. This means that in a first step the physically available energy potential of the respective energy carrier is calculated, which is then reduced to a realisable potential by further constraints like technical efficiency factors or politically and economically influenced aspects. So far solar, wind and hydro power, biomass, fossil and nuclear resources have been included in the database. While the renewable resources are modelled on a spatial resolution of 1 km² for the whole globe and a time resolution varying from hourly to yearly cumulated values, the conventional resources are treated on a national cumulated level reflecting the known remaining recoverable resources.

3.3 Global Wind Power Potential - Case study

3.3.1 Methodology

The calculation of the global wind power potential is based on the average wind speed, topography, land cover, population and the energy harvest of a typical wind turbine. Therefore the physically available potential of wind power is computed in the first step, which is done by calculating the energy harvest gained from a 2.3 MW turbine depending on the average wind speed [wind data from NASA, 2007]. This is accomplished on a
temporal basis of 3 hours because the diversification of the wind supply is quite high as can be seen in figure 2 and a high temporal resolution has to be used for further investigations in terms of suitability for covering the energy demand on time.

![Figure 2: Temporal diversification of wind potential](image)

The size of a 2.3 MW turbine is chosen because it is considered as state of the art. Regarding the size of a turbine and resulting wind shadow effects, a 2.3 MW turbine and resulting distances between two turbines could be accepted as reference to estimate a harvestable wind power potential per area. The power curve of the wind turbine as a function of wind speed is shown in figure 3 [Danish Wind Industry Association, 2007]. In sequence the energy output for the physically available global potential from wind power per surface area can be generated. For this the real surface area is considered. A further restriction that has to be taken into account is land cover. It is assumed that for an intensive utilization of wind power the average power density sticks out to be 4.6 MW/km² [Hoogwijk, 2004]. The estimation of the average upper limit of installable wind turbines depending on the designation of the surface was performed on the basis of land cover categorisation. With the combination of the upper limit of wind turbines per area and the energy harvest of a 2.3 MW turbine a global theoretical potential is identified. This potential is then further restricted by neglecting single quadrants, depending on topography. An upper threshold of 2000 m refers to high mountain areas that are not reasonable for wind turbine installations. A lower threshold of – 40 m refers to offshore regions, which will be too deep for turbine installations [Hoogwijk, 2004].

![Figure 3: Power curve of a 2,3 MW wind turbine](image)

### 3.3.2 Categorisation of wind potentials

Limiting the global wind power potential to the restricted usable potential for energy issues provides the upper limit of the usable global wind power potential. This potential has to be categorised, which is carried out by the assumption of two attributes for the global wind power potential: availability and distance to population.

The availability is defined as the annual average energy harvest of single wind turbines, translated to corresponding full load hours. Three levels are distinguished: low (<800 full load hours / year), mean (800 - 3000 full load hours / year) and high availability (>3000 full load hours / year).

The attribute distance to population is chosen as the cumulated population higher than 100000 within a circle of 200 km diameter. Four categories are distinguished: offshore
short distance, offshore large distance, onshore short distance and onshore large distance. The categorisation is based on the global population grid and the elevation.

That leads to four different categorisation classes, based on the permutation of on-/ and off-shore with two accessibility classes.

Dividing these categories further on into three natural availability classes low, average and high, 12 individual categories could be distinguished. Each single geographic location is assigned to one of these categories [Biberacher et al., 2007]. Four of these categories are shown exemplarily in table 2.

<table>
<thead>
<tr>
<th>Table 2: Categorisation of wind potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability of wind power potential</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>mean</td>
</tr>
<tr>
<td>low</td>
</tr>
<tr>
<td>Off shore potential far away from populated areas</td>
</tr>
<tr>
<td>On shore potential far away from populated areas</td>
</tr>
</tbody>
</table>

As exemplarily outlined for the global wind power potential also the other mentioned potentials are investigated.

3.4 Hydro power

For the estimation of the hydro power potential datasets of the global distribution of precipitation and topography [Worldclim database, 2007] of the globe were used. The description of topography allows the calculation of the drainage system for drain water, while the precipitation data provide the base for the quantitative estimation of drain water. By interlinking both datasets it is possible to calculate the gravity potentials of cumulated rain runoffs over different terrains. This potential is then further reduced by several constraints, for example the restriction that only potentials beyond a certain threshold are considered. Further restrictions are caused by issues like water back hold.

3.5 Biomass

Regarding biomass, woody (forestry plantations, natural forests and natural woodlands) and non woody biomass resources (grassland and cropland) were taken into account. Processed waste or by-products of agro-industrial activities are not considered. For the estimation of the biomass potential the most relevant datasets are land cover, climate data and population data. For the different land cover classes a mean net production of biomass following Heinloth [2003] was set as well as a factor of possible energetic use, also depending on population density. As far as the net production of biomass is concerned the climatic parameters precipitation and annual mean temperature are considered as the main influencing factors [Lieth, 1972; Grieser, 2006] and are
therefore included in the modelling process. The biomass production - restricted by the accessibility - in energetic units is shown in figure 5. The possible share of biomass that can be used for energy production was based on Heinloth [2003] and own assumptions. As a last step an energy conversion factor was included to estimate the global biomass potential.

3.6 Solar power

Solar energy potentials were calculated mainly based on global irradiation [Ramachandra and Shruthi, 2007] taken from NASA [2007], topography and land cover. It is estimated that the upper limit of available surface share for solar collectors is determined by the real land cover. For example is assumed that 1% of the urban and built up area can be used for the installation of solar collectors following Sörensen [2001]. Furthermore two constraints were included in the computation to generate different categories of potentials, availability – depending on the annual global insolation per m² - and accessibility.

3.7 Nuclear resources

Uranium, Lithium and Thorium resources are included in the database on a national level. These resources were categorised regarding the level of confidence that the resource exists, given how much exploitation has been done as well as by recovery costs [IAEA, 2006]. Regarding Uranium only conventional uranium resources, where uranium is the main product of extraction processes are considered. As far as Thorium and Lithium are concerned all currently known resources were included in the database according to IAEA [2006].

3.8 Fossil resources

All currently known and proved recoverable resources of crude oil, gas and coal were added to the database. These data were estimated based on a literature research [BP, 2006; WEC, 2002; EIA, 2004]. The preserved data were evaluated and thereafter the fossil resources were defined.

3.9 Competitive land use

Special attention has to be paid to the fact that renewable energy potentials are often NOT additive potentials. This means that land surface is only available once and therefore several potentials exclude the option to use another potential on the same area.

To estimate the highest possible energy potential derived from a certain area a competition analysis – regarding the utilization of the surface – has to be carried out. That means that land surface dedication is NOT considered to be changed in order to increase the utilisable energy potential (otherwise in most cases solar power would be the most competitive energy carrier). The challenge of a competition analysis is to identify the maximum renewable energy potential for each location on the globe.

To simplify the analysis a possible double usage per raster cell is neglected and only the most promising renewable energy carrier – depending on land cover classes (GLCF - Global Land Cover Facility) [Hansen et al., 1998] - is considered to determine the upper bound of utilisable energy potential per raster cell.

This analysis refers to primary energy units and therefore lines out which energy density per location could possibly be harvested if a technology without efficiency losses would be available. This could also refer to an energy carrier that is not the most competitive one at this location regarding current available technologies. Based on this approach a maximum upper limit of the renewable energy potential derived from the competition of biomass, solar energy and wind energy is determined on a global scale (see figure 6).
Figure 5: Geographic distribution of competitive renewable energy source (referring to primary energy units). Each grey value identifies one resource as the most competitive one.

This competitive land use calculation can be part of a dynamic parameterisation, in terms of regional deviations, land use adaptations and further aspects. Table 3 outlines numbers derived for the different potentials within single world regions. These numbers are subject to an individual parameterisation and have to be evaluated under these assumptions made.

Table 3: Land use competition regarding a parallel utilization of dedicated area.

<table>
<thead>
<tr>
<th>Region</th>
<th>Solar total</th>
<th>Solar under competition constraints</th>
<th>Wind on-shore total</th>
<th>Wind under competition constraints</th>
<th>Biomass total</th>
<th>Biomass under competition constraints</th>
<th>Single additive total Potentials</th>
<th>Maximal additive potential under competition constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Asia</td>
<td>484128</td>
<td>482656</td>
<td>166</td>
<td>53345</td>
<td>38311</td>
<td>619004</td>
<td>528160</td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>462148</td>
<td>462207</td>
<td>166</td>
<td>52701</td>
<td>33304</td>
<td>519680</td>
<td>4717993</td>
<td></td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>816120</td>
<td>811217</td>
<td>240451</td>
<td>74840</td>
<td>19120</td>
<td>1104412</td>
<td>865202</td>
<td></td>
</tr>
<tr>
<td>East Europe</td>
<td>40302</td>
<td>398550</td>
<td>12496</td>
<td>7034</td>
<td>1703</td>
<td>59562</td>
<td>43560</td>
<td></td>
</tr>
<tr>
<td>West Europe</td>
<td>119232</td>
<td>114650</td>
<td>569882</td>
<td>15433</td>
<td>40540</td>
<td>193583</td>
<td>138664</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>457632</td>
<td>456232</td>
<td>157889</td>
<td>1946</td>
<td>5033</td>
<td>631570</td>
<td>458816</td>
<td></td>
</tr>
<tr>
<td>Middle East</td>
<td>1566784</td>
<td>1556010</td>
<td>47834</td>
<td>4468</td>
<td>392</td>
<td>1703086</td>
<td>1557904</td>
<td></td>
</tr>
<tr>
<td>Central &amp; South America</td>
<td>393336</td>
<td>381989</td>
<td>100872</td>
<td>40338</td>
<td>142852</td>
<td>637060</td>
<td>538427</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>288036</td>
<td>284818</td>
<td>97542</td>
<td>15890</td>
<td>110145</td>
<td>401468</td>
<td>307764</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>790740</td>
<td>790542</td>
<td>90547</td>
<td>31777</td>
<td>122244</td>
<td>922084</td>
<td>803705</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>139428</td>
<td>137182</td>
<td>18792</td>
<td>5152</td>
<td>5702</td>
<td>174182</td>
<td>148061</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>7277</td>
<td>7142</td>
<td>4219</td>
<td>1775</td>
<td>1084</td>
<td>13266</td>
<td>10152</td>
<td></td>
</tr>
<tr>
<td>South Korea</td>
<td>1584</td>
<td>1548</td>
<td>870</td>
<td>558</td>
<td>331</td>
<td>2812</td>
<td>2117</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>78490</td>
<td>78145</td>
<td>5598</td>
<td>1095</td>
<td>4028</td>
<td>109063</td>
<td>85745</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>432286</td>
<td>429634</td>
<td>127055</td>
<td>8366</td>
<td>41036</td>
<td>593906</td>
<td>461038</td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>464128</td>
<td>462656</td>
<td>166</td>
<td>53345</td>
<td>38311</td>
<td>619004</td>
<td>528160</td>
<td></td>
</tr>
</tbody>
</table>

Since the database forms one common platform to model and administrate all energy potentials and accompanied influencing factors, the comparison, regarding differences and interactions between single potentials can be investigated in a convenient way.

4. CONCLUSIONS

The database provides a suitable and flexible platform for the standardized administration of data on renewable, fossil and nuclear energy resources. Some data, especially those referring to renewable energy potentials are included on a raster basis, others - mainly nuclear and fossil energy resources - are provided on a country or regional basis. Also a dynamic temporal resolution is included in the database to illustrate if and how the possible energy potential might alternate in an annual, seasonal or even hourly period.

One influencing factor for the future energy supply is the accessibility of energy carriers. Especially for renewable energy carriers their vicinity to demand is important, as their energy density is not very high. Accessibility also refers to the distance to existing or economically feasible infrastructure and therefore the inclusion of all relevant data on energy potentials in the database can show preferable areas for locations of energy supply. Although the data included do not provide an accurate description of the real situation, they offer a good basis to approximate the global energy potentials. Since primarily global datasets are utilized in the approach shown, a good reliability regarding comparisons of
different world regions is ensured. A possible adjustment to regional datasets will be investigated in further steps.

The innovation of this approach lies in the model based correlation of single datasets in order to estimate utilizable potentials dynamically - dependent on differing input assumptions. Furthermore this dynamic treatment of single energy resources enables their investigation regarding different land use competition aspects by joining the single results. On a global scale the model based estimations on energy potentials - depending on dynamic constraint assumptions - reflect stated numbers in common literature, e.g. WEC [2004]. Statements on a subregional or even local scale are accompanied by a high uncertainty. This uncertainty is based on the fact that primarily global datasets are investigated. Furthermore the location dependent variance of datasets, also linked to the spatial resolution, is quite high. Strategies for an optimal interaction of different energy resources for the satisfaction of the still globally rising energy demand can be derived from these data. Further investigations will also treat ecological and economical impacts on the exploitation of resources, namely referring to learning curves of technologies and therefore possible deviations in future estimates of utilizable potentials.

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