Virtual Power Plants: Spatial Energy Models in Times of Climate Change

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Introduction: The Energy Debate and Arising Research Needs

In 2006/07, energy supply and climate change moved to the top of the political agenda. Events such as the oil dispute between Russia and Belarus, coupled with the crises of oil supplier countries in the Middle East, have elucidated the importance of supply reliability. A reliable, secure, efficient and environmentally sound energy-supply is essential for a sustainable provision of goods and services, especially within the light of the global warming. Internationally complex, though, policy and the global energy industry has to cope with ever great challenges. This refers to aspects like the constantly increasing energy demand, insufficient energy conversion and transport capacities or geopolitical risks alongside others. Furthermore the possible longtime effects of CO_2 emissions in relation to global warming and the challenge to meet the obligations of the Kyoto protocol have lead to an enhanced problem awareness regarding energy supply systems.

For the Digital Earth research topic there are two major aspects to be dealt with using geospatial techniques: the CO_2 topic and security of supply. Both are of broad interest at several scales and both need long term solutions. Improvements of current energy system concerning CO_2 and security of supply are particularly determined by spatial questions. So far, the energy industry has paid only little attention to geospatial aspects in modelling possible future energy systems and solutions. This namely refers to the spatial distribution of renewable energy carriers and their possible utilization in the energy system. The problem faced in this context is the generally low energy density of renewable energy carriers. Therefore it is of major interest – especially in terms of “security of supply” – to pay attention to the geographical deviation of renewable energy supply and energy demand. Although the utility providers have been and still are using GIS systems in a very severe manner at central locations within their business chains GIScience did not emphasize energy significantly (BIBERACHER 2007, DOMINGUEZ & AMADOR 2007, RAMACHANDRA & SHRUTI 2007). Energy providers were so far mainly thinking “along lines”. Understandably, they concentrated on the cost-intensive digital conversion of grid systems including all their related assets. Two exceptions may be the biomass estimation from forestry and agriculture (VOIVANTAS et al. 2001, BERNDES et al. 2003, LIAO et al. 2004, SHI et al. 2008) and solar power availability (MYERS 2005). Although studies on other energy sources exist which include geospatial relations (e.g. HOOGWIJK et al. 2004, DE VRIES et al. 2007, PICHUGINA et al. 2008) we hypothesize that this field of overlap between GIS/GIScience and energy research is not well developed as yet. Only few studies connect the supply or the potential supply, respectively, with demand side pattern of population (BLASCHKE et al. 2003) or with locations of major industry as demand hot spots.

In order to reduce the increasingly problematic dependence on fossil fuels, national and regional policies need to take on responsibility for securing their energy supplies. Master plans and decisions have to be based on hard facts. Many of the necessary facts can and should be based on geospatial techniques. The vision of "Digital Earth" should include the vision of a severe reduction of the carbon released by electricity/energy generation.

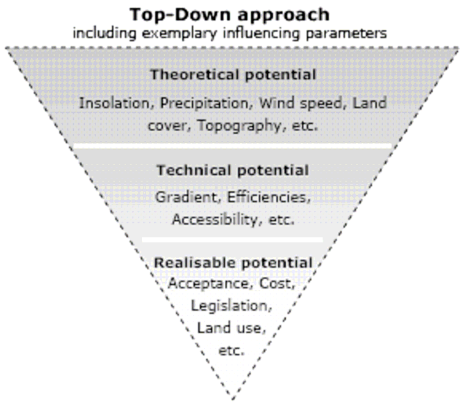
Spatial Disaggregation of Energy Supply, Demand and Potential

Renewable energy sources are characterised by its strong temporal and spatial variability, in contrast with the distribution of the so-called fossil fuels. Typically, one can find at least one local source of green energy in almost every location. Conversely, this advantage of the broad spectrum of renewable energy sources, compared to the conventional sources, bears the disadvantage of making the energy harvesting system more complex than the one using conventional fuels characterised by the specific distribution of supply and demand. Conventional energy systems are characterised by a concentrated generation model and huge consumption points situated far away from resources and power generation. Renewable energy is more spatially and temporally heterogeneously distributed. Consequently, regional aspects in energy distribution are (re-)enforced. Renewables are more a type of "near to demand sources" of energy in terms of spatial and temporal electricity production patterns. The variability and complexity of their supply and demand system necessitates the use of geospatial tools.

SHI et al. (2008) describe GIS as a powerful tool to integrate data of various factors and to perform spatial analyses for feasibility evaluation and location optimization for biomass plant locations. They describe Noon and Daly's BRAVO (The Biomass Resource Assessment Version One) might be the first GIS-based decision support system in the biomass energy sector (NOON & DALY 1996). The authors of BRAVO found that transportation accounted for a major part of the overall cost, and thus power plant location is crucial to the feasibility of converting coal-fired power plants into co-firing plants (plants using both coal and biomass as the fuel source).

The estimation of energy resource potentials and energy demand in a spatially high resolution, which are based on geographical methods and data, allow a discrete valorisation in the modelling process. Especially the treatment of renewable energy carriers with their relatively low energy density and small-scale variance in supply require a spatially high disaggregated modelling of the energy flows. Until now energy potentials and demand were mostly included into modelling schemes in a cumulative way (BIBERACHER et al. 2008a).

An adequate method for modelling renewable energy source (RES) potentials is presented by a top-down approach. GIS is especially useful in the RES modelling, which is also determined by the special geographical qualities of RES (DOMINGUEZ et al. 2007; VOIVONTAS et al. 1998). In a first step universally valid fundamentals are used to calculate the theoretical potentials. The estimated theoretical potentials are then reduced to a technical potential by including technical limitations taking into account the state-of-the-art as well as factors concerning natural space. By using rather soft factors which may be modified over time and may vary regionally the potential can be further reduced to a realisable one (Figure 1). For details see BIBERACHER 2007 and BIBERACHER et al. 2008a.



The model-based estimation of regionally available energy potentials is based on a top-down approach: data on topography, climate and land use amongst others are incorporated to model the theoretical potentials of the relevant energy sources. Thereafter these potentials are reduced to the effective potentials by the consideration of technical, legal and ecological constraints. At last the technical potential is modelled under realistic – usually expert-defined – assumptions regarding the development and deployment of the single energy sources.

Fig. 1: Top-Down approach including exemplary influencing parameters

In addition to energy resources also energy demand is assigned to specific locations. Seeing that energy flows, especially in the case of low dense energy carriers play an important role not only on a global scale but also on a regional scale distances between supply and demand are of major interest. Hence it is essential to model the energy consumption on the same geographical resolution as the energy potentials to ensure their comparability. For the estimation of the heat and electricity demand characteristic values of demand structures are used, which are then assigned and located to the requested spatial resolution. The data sources for the calculation of the energy demand are provided by public authorities. In many cases they are only available for larger administration units and the energy demand information has to be dis-aggregated. To accomplish the disaggregation of the information, established factors such as settlement areas or buildings are used. The resulting allocation is based on probabilities not on exact census information which is a matter of privacy protection. Specific data on energy demand and statistic data of households in the specific region are used for the estimation of energy demand. By joining these data the spatial distribution of the energy demand can be identified.

Virtual power plants

Within an Austrian nationally funded research project (MITTLBOECK et al. 2007) the concept of Virtual power plants has been implemented based on GIS-technology. The aim was and still is to create energy selfsustaining regions based on the optimal combination of different renewable energy potentials into virtual power plants and their correlation with the relative energy demand structure. Assigning costs to energy flows enables the following modelling approach with three underlying assumptions (BIBERACHER et al. 2008a).

Assumption 1: The energy demand (*di*) in each single spatial unit has to be satisfied by the sum of incoming energy streams (*inx*) from neighbouring spatial units (*ni*), added to the already available energy potential within this spatial unit (*pi*), minus the sum of outgoing energy streams (*outx*) to neighbouring spatial units (*ni*).

$$d_i \leq p_i + \sum_{x=0}^{n_i} in_x - \sum_{x=0}^{n_i} out_x \quad \text{for all } i = 0..u; \text{ while } u = \text{number of units} \tag{1}$$

Assumption 2: The arising cumulated fictive costs (C) from all single energy flows (*flowi*) between spatial units (each flow is identified once as *in*-flow and once as *out*-flow) should be smallest for the considered region. Each single energy flow accounts with its individual specific cost assignment (*ki*).

$$\text{Minimise}\left(C = \sum_{i=0}^{f} \left(k_i \cdot flow_i \right) \right) \text{while } f = \text{number of individual flows} \tag{2}$$

Assumption 3: The individual specific costs (*ki*) are identified by a fixed basic cost (c) plus the sum of distinguished specific influences factors (related to the following figure, number of factors is determined by r) interpreted as increasing or decreasing cost assignments (*aix*).

$$k_i = c + \sum_{x=0}^{r} a_{ix} \quad \text{for all } i = 0..u; \text{ while } u = \text{number of units} \tag{3}$$

BIBERACHER et al. (2008) describe a linear optimisation model and formulate the optimisation problem in the algebraic modelling language *GAMS* – General Algebraic Modelling Systems and solved with the *cplex* linear optimisation solver developed by ILOG. The output of an optimisation process yields the arising energy flows and their size.

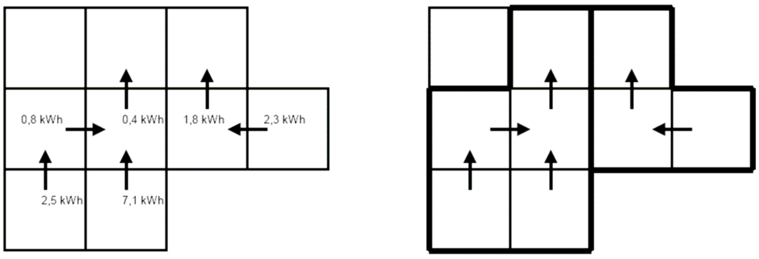


Fig. 2: Energy flows between neighbouring spatial units

Digital Earth, GIScience and Energy: Future Research Needs

Based on conceptual and methodological first steps jointly elaborated by the University of Salzburg (Z_GIS, Centre for Geoinformatics), the Salzburg AG, a regional utility provider and the Research Studio iSPACE have developed a framework for modelling regional energy potential and demand. This spatial analyses based framework is called *Regional Autarky Models for a Sustainable Energy Supply* (RAMSES). For two regional systems (a: Salzburg province and neighbouring German parts of the Salzach river catchment, b: North-Rhine Westphalia "Bonn-Rhein-Sieg") and for the whole of Austria this framework has been applied to the renewable energy sources hydropower, wind, biomass, solar and geothermal energy. As touched very briefly, the increasing energy demand and climate change are confronting the energy system with new challenges. Therefore, spatially explicit concepts are needed (BIBERACHER 2007). Through a methodological assessment of spatial interrelations in the energy industry RAMSES supports the decision-making for the adaptation of energy systems.

The energy consumption is modelled bottom-up: GIS-derived information on settlement structures, population statistics and consumption patterns of households and economic sectors renders possible to assess the spatial allocation of the energy demand. The comparison of the estimated energy potentials with the existing energy consumption structure results in an ‘energy balance map’, representing the energy excess or shortage for every sub-unit. An additional step is the generation of energy balance maps for further considerations of the level of self-sustenance of a specified region. Recently, collaborations with power supply companies are started to really put regional autarky in practice and to therefore realizing the vision of virtual power plants (MITTLBÖCK et al. 2007; BIBERACHER et al. 2008b). Fig. 3 illustrates the potential of Digital Earth to communicate energy potentials and demands and enables fresh thinking about the balancing price of carbon, new transmission systems and smarter grids (NATURE 14. Aug 2008, p. 816).

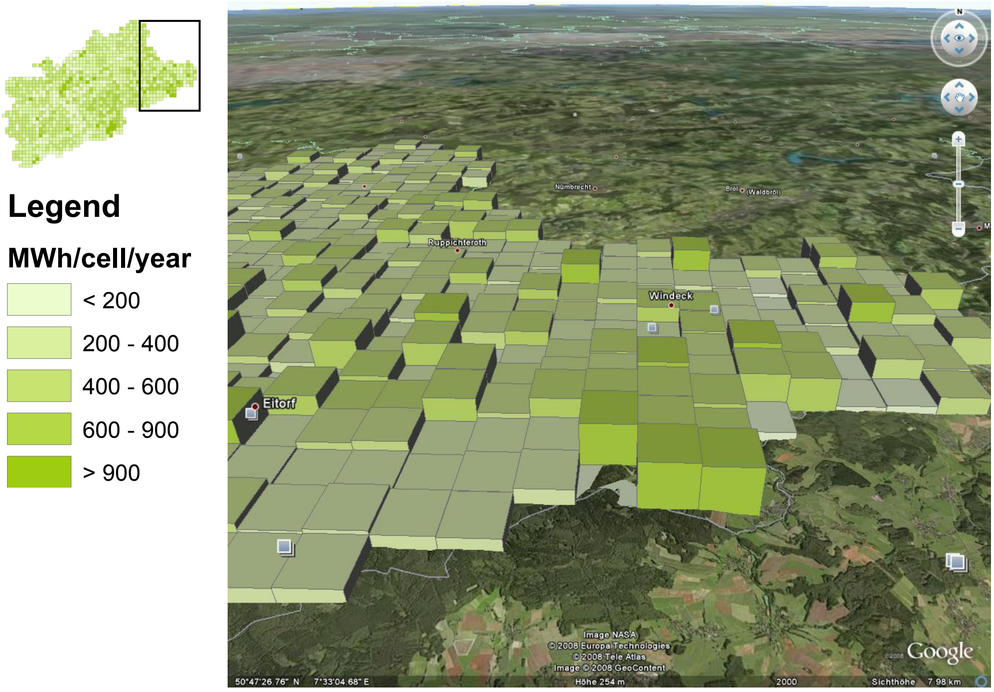


Fig. 3: Biomass energy potential for 250m raster cells for a part of Rhein-Sieg

The Digital Earth technology renders new grass-root movements possible as some spectacular examples of Darfur have proven. From a geospatial perspective as well as from a methods, techniques and software technology perspective, energy certainly is a globalized phenomenon. While the GIS industry is mainly based on some global players, with only regional differences in societal frameworks, and thus policies and operational practice (STROBL 2008), there is enormous future potential in the amalgamation of the GIS industry and the Energy industry aiming for an IT-based decision support for a sustainable planning. The latter only seems to be achievable when disciplinary borders are further wiped out and technical achievements as described in industry related journals are recognized by political scientists and planners in their media and vice versa.

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