European conference of the Czech Presidency of the Council of the EU
TOWARDS eENVIRONMENT
Opportunities of SEIS and SISE: Integrating Environmental Knowledge in Europe
http:/www.e-envi2009.org/proceedings/
J. Hřebíček, J. Hradec, E. Pelikán, O. Mírovský, W. Pillmann, I.Holoubek, T. Bandholtz (eds.)
Masaryk University, 2009

Integrated energy spatial planning: "spatializing" policy decision support

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Abstract: One objective of a shared environmental information system for Europe (SEIS) is to organise the vast array of already collected environmental data and information and to integrate it for wide spectra of applications and user access. SEIS should pave the road to move away from paper-based reporting to a system where information is managed as close as possible to its source and made available to users in an open and transparent way. In this paper, we report on attempts to use GIS technology and geoportals as means to make spatial information on energy supply, energy potential and demand tangible for spatial planning beyond the provision of static maps. We demonstrate that GIS-based scalable and flexible information delivery sheds new light on the prevailing metaphor of GIS as a processing engine serving needs of users more on demand rather than through 'maps on stock'. We report briefly about several energy related projects in Europe and demonstrate that data will become available together with tools that allow experts to do their own analyses and to communicate their results in ways which policy makers and the public can readily understand and use as a basis for their own actions. Geoportals in combination with standardised geoprocessing today supports the older vision of an automated presentation of data on maps, and – if user privileges are given - facilities to interactively manipulate these maps.

Keywords: Energy modelling; energy region; GIS; spatial planning; GeoPortal; SEIS

1. INTRODUCTION

A reliable, secure, efficient and environmentally sound energy-supply is essential for a sustainable provision of goods and services [de Fries et al. 2007]. Policy is confronted with the challenge of security of supply which is of broad interest, which is a multi-faceted and multi-scaled issue and which needs long term solutions. Improvements of current energy systems concerning CO2 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. Blaschke et al. [2008] have pointed out the importance of spatial distribution of renewable energy carriers and possible utilization for the energy system. In addition, spatial planning in most European countries is – with exceptions at the local level - not explicitly dealing with "energy spaces", e.g. reserving space for future energy corridors and for "space-consuming" generation of renewable energies such as biomass production.

The problem faced in this context is the generally low energy density of renewable energy carriers which requests more emphasis on geographical deviations of renewable energy supply and energy demand. Although the utility providers are using GIS systems in a very severe manner at central locations within their business chains they are so far mainly thinking “along lines”. In order to reduce the increasingly problematic dependency on fossil fuels, national and regional policies need to take on responsibility for securing their energy supply. Master plans and decisions must be based on hard facts, many of which can and should be based on geographic footprints and on geospatial techniques. Renewable energy sources are characterised by their marked 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 renewable energy at almost every location, but this advantage of the broad spectrum of renewable sources compared to the conventional sources, also complicates the energy system. Conventional energy systems are characterised by a concentrated generation model and major consumption points situated far away from resources and power generation.

Renewable energy has a more heterogeneous spatial distribution and tends to be less ubiquitous. Consequently, regional aspects of energy distribution are reinforced today: regional planning will need to explicitly consider and account for various combinations of renewable energy generation, taking into account a region's characteristics and needs in relation to its energy potentials. Blaschke et al. [2008] claimed that only very few studies explicitly deal with geospatial relationships in modelling energy demand and supply [e.g. Hoogwijk et al. 2004, Dominguez & Amador 2007; de Vries et al. 2007, Ramachandra & Shruthi 2007; Pichugina et al. 2008] and hypothesized that this field of overlap between GIS/GIScience and energy research is not well developed yet. Only a few studies connect the supply or the potential supply with the demand side pattern of population [Blaschke et al. 2003] or with the locations of major industry as demand hot spots.

The variability and complexity of energy supply and demand systems necessitates the use of geospatial tools. In this paper we report on a national study in Austria, competed in November 2008, which analyses policy options for integrated energy planning: we elucidate preliminary results of this modelling and, finally, we point out that the internet as such and geoportals in particular enable mediation and facilitate communication for planners and decision makers.

2. RENEWABLE ENERGY MODELLING WITH GIS

2. 1 The general top-down modelling approach

Biberacher [2007] and Biberacher et al. [2008a,b] presented a top-down modelling approach for renewable energy source (RES) potentials. GIS is especially useful in the RES modelling, particularly because of the special geographical aspects of RES. As a first step, universally valid fundamentals are used to calculate the theoretical potentials. The estimation of spatial differentiated theoretical potentials is based on data on topography, climate, land use and many others. The estimated theoretical potentials are then reduced to a technical potential by taking into account technical limitations of state-of-the-art technology as well as factors concerning distribution or topography, e.g. steep slopes. For instance, certain land use classes or protected areas will typically be excluded. 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. Under expert-defined assumptions the development and deployment of the individual energy sources are integrated within this step (Figure 1).

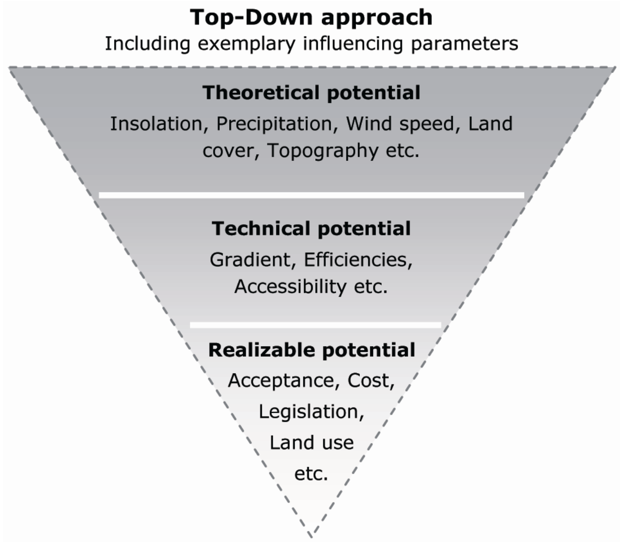

Figure 1. The Top-Down approach in spatially explicit energy modelling.

In addition to energy resources energy demand is assigned to specific locations and energy consumption is modelled at the same geographical resolution as the energy potentials. For the estimation of heat and electricity demand, characteristic values of demand structures are either used directly or are broken down into the appropriate spatial units through disaggregation. Some other statistical data for households in the area of interest are being used for the estimation of energy demand. By combing these data the spatial distribution of the energy demand can be identified and mapped. Figure 2 exemplifies three levels of energy demand presentation for a part of the city of Salzburg, Austria, reaching from address data to census information. The most flexible way to aggregate and disaggregate between the various levels is trough raster representations.

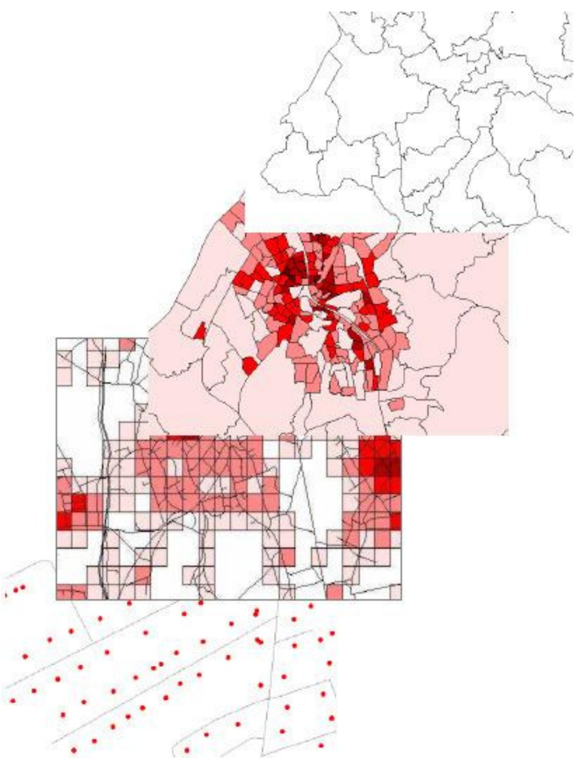

Figure 2. Various levels of representation of energy demand from household data to census information.

Biberacher [2008] optimized the model and further elaborated the framework incorporating location related temporal characteristics in energy supply and demand. These characteristics in mind an imaginable energy system setup can be explored using this framework. In this study the possible coverage of the global energy demand, by solar- and wind power in junction with a backup technology was treated.

2. 2 Earlier studies

Within an Austrian nationally funded research project the concept of Virtual power plants has been implemented based on GIS-technology (Mittlböck et al., 2007). The objective was and still is to create energy self-sustaining regions based on the optimal combination of different renewable energy potentials into virtual power plants and their correlation with the relative energy demand structure. The Research Studio iSPACE has developed an operational method for spatial analyses based on *Regional Autarky Models for a Sustainable Energy Supply* (RAMSES). Biberacher et al. [2008a,b] describe a linear optimisation model and formulate the underlying optimisation problem in the algebraic modelling language GAMS – General Algebraic Modelling Systems and the cplex linear optimisation solver developed by ILOG. The output of an optimisation process yields the arising energy flows and their amount.

Several detailed studies on single energy carriers such as wind, biomass, photovoltaic, solar thermal, geothermic, water etc. have been carried out over the last years in the research studio iSPACE. The level of detail needed in modelling supply, demand and potentials shall hereafter be illustrated for biomass (for more details see Schardinger et al., 2008). In a first instance the biomass to energy service chain may be represented by biomass supply, intermediate storage, final storage, conversion of biomass into usable solid or liquid biofuel, delivery to the energy plant and, towards the end of the chain, energy production. Each link of this chain is more or less directly dependent on the geographical location of each process and will be represented by GIS data sets. They can be output to maps or input to further analyses steps. It is well known that if each step of the whole bio energy chain is not optimised, the final costs of the energy produced (both in terms of heat and electricity) will be high and will be outcompeted by energy from traditional fossil fuels [see, i.e. Perpina et al. 2008].

The cost of energy from biomass mainly results from biomass production, storage, transport from the production or collection area to the plant and plant costs. Moreover, in some cases mechanical, thermo chemical or bio-chemical processes are required to transform the original biomass into the desired more practical fuel after the collection. As a first step of the work the present biomass availability per territory has been determined on the basis of a GIS analysis performed on layers and associated databases based on land use and divided into agricultural resources, forestry potential, green garbage and deposits from food production. At the end of this process biomass potentials are localised, together with information on their typology and the accessibility of the production area.

The modelling of the energy demand follows a bottom-up approach as illustrated in Figure 1: GIS-derived information on settlement structures, population statistics and specific data on 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 (Figure 3).

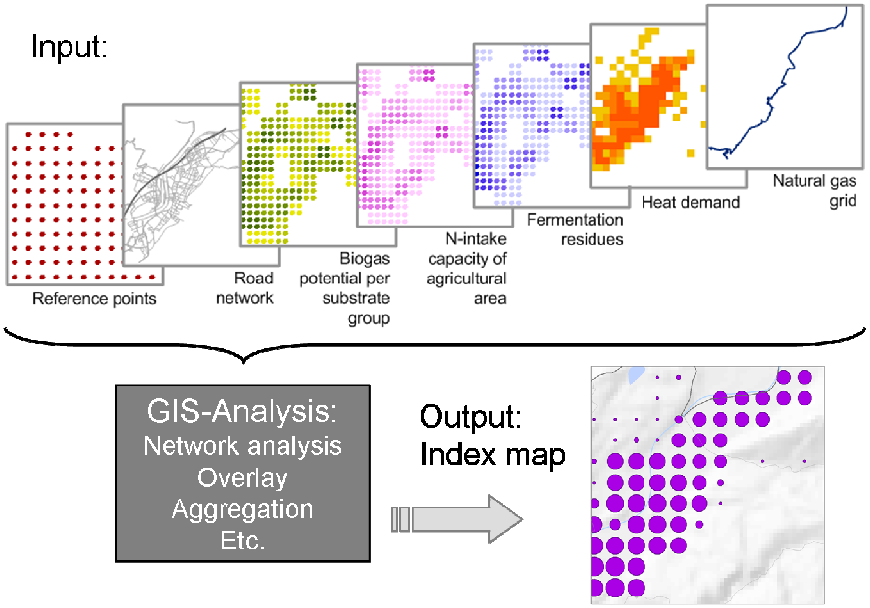

Figure 3. Model for province wide location evaluation for biogas plants

3. ENERGY REGIONS

As well known in scientific literature and in practical spatial planning has to be both top-down and bottom-up, both urban and rural. Basic concepts cannot be repeated herein. It should only be emphasized that spatial planning tools shall flexibly cater for different types of regions (administrative vs. functional e.g. concerning energy demand and supply). It is well know in various business fields that successful regions attract a mix of entrepreneurs, capital, facilities and workers, needed to drive the economy and provide the mix of amenities critical to living the good life. It seems to be less clear if such a combination can be naturally provided concerning energy demand and supply and if those can be usually provided by national and provincial jurisdictions. In spatial planning, the concept of a region is typically seen as a precondition for assessing spatial and regional reference of economic activities when trying to achieve sustainable effects. In the scientific and the political debates a broad variety of regional concepts are in use. The concepts used correspond with heterogeneous ways of a regionalization and its specific and different demands, methods and instruments used for working on regional challenges. The term ‘energy region’ is used pragmatically herein. It is not a question of small-scaled or relatively closed economy, but of a balanced combination of regional economic relationships and of over-regional one's.

An energy region is a hybrid concept, catering for different intentions, partially moving in opposite directions. It includes endogenous regional potentials and it could also be debated in the light of "new regionalism". In spatial planning, these discourses are the departing points of conceptions of "sustainable regional development". Views and findings corresponding with "sustainable regional development" support a conceptual basis for regional approaches to sustainable economy, especially when its spatial relations and effects are regarded. Ultimately, direct connection of the socio-economic actors to regulating subjects on the regional level (e.g. a regional government) will assure regional and sustainable effects of their economical activities. In general, regions are often the most local level for delivering cost-effective water, sewer, transit, and other public services. They have also become the most appropriate level for addressing various challenges. “Energy regions” seem to be a new dimension in defining regions functionally. Generally, they should be large enough to encompass locally/regionally important economic marketplaces and environmental watersheds/airsheds, as well as relatively (!) homogeneous living conditions. Yet energy regions should be small enough to engage community leaders and citizens in pursuing practical strategies to provide affordable infrastructure and services, protect threatened environments, and foster robust economic development aiming to care for local resources without necessarily being fully autarchic.

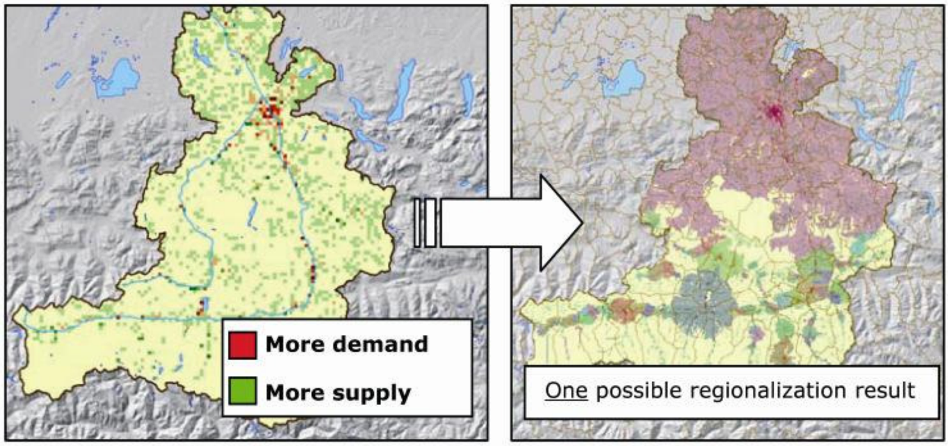

Figure 4. Delineation of energy regions (adapted from: Mittlboeck et al. 2007)

4. RESULTS

For the renewable energy sources hydropower, wind, biomass, solar and geothermal energy, the described general model has successfully been instantiated and applied to regional systems in Austria (Salzburg province and German parts of the Salzach river catchment) and to parts of North-Rhine Westphalia. Through an assessment of spatial interrelations RAMSES supports the decision-making for the adaptation of energy systems. A third study for the whole territory of Austria on behalf of the ÖROK (Austrian Conference on Spatial Planning, an organisation coordinating spatial planning between the federal, province and municipality levels) is a first consensus based process strongly building on GIS-functionality for an integrated spatial planning by outlining renewable energy potentials with their spatial distribution and taking into account spatial planning aspects. (Figure 5).

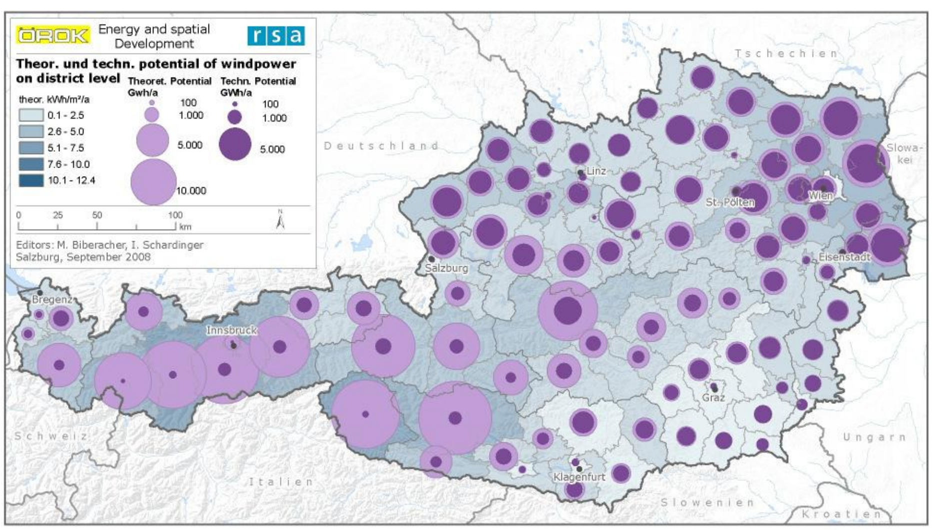

Figure 5. Map of theoretical and technical potential of wind power as one preliminary result from the ÖROK study

The GIS based models serve as the core functionality. The main innovation in the context of integrated systems such as SEIS and geoportals are automated mapping procedures coupled with scenario techniques. The GIS-derived results are typically stored in raster formats and are to be combined further based on the rule sets of the respective user. This way, we incorporate some generic combination functionality (e.g.: potential per cell: {energy carrier

1: 70% realized} + {energy carrier 2: 60% realized} + {energy carrier 3: status quo extrapolated minus estimated demand for time z1}) into a geographically enabled system.

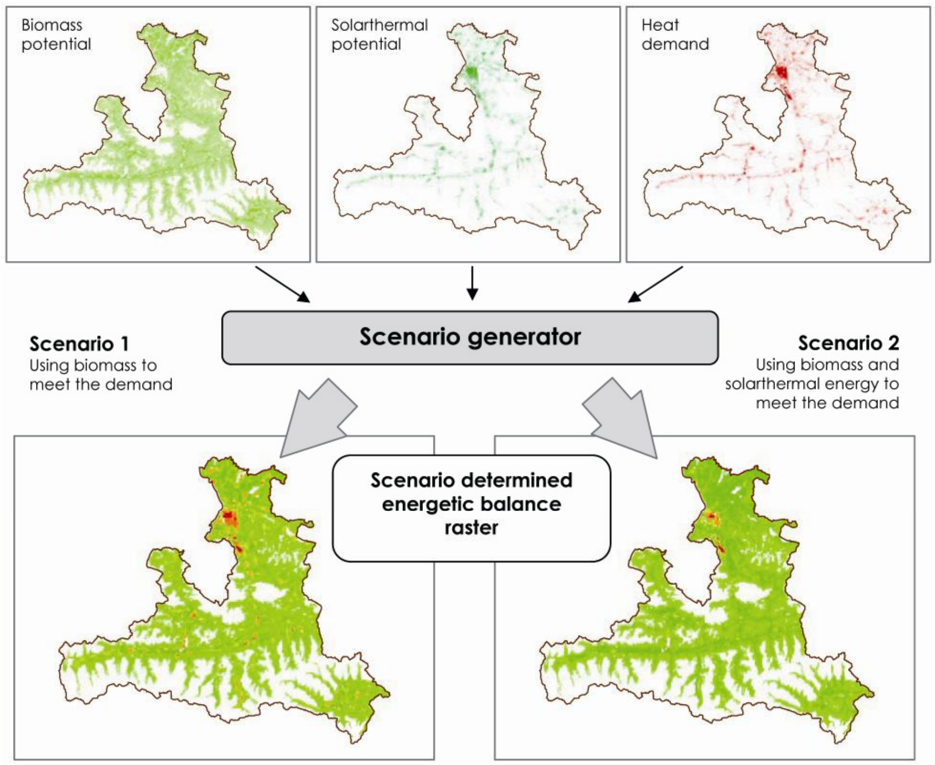

Figure 6. Outlook on further use of results from the ÖROK study for the province of Salzburg. The GIS model shown serves as a scenario generator and communication tool.

We have been reluctant to call this application a 'spatial decision support system' since it has not been tested operationally. If the user has a sound hypothesis and provides logic combinations of expected future energy use the results will be scenarios rather than maps in a more classical sense (see next section). Geographic information based combination allow non-experts to receive proper data presentations, and the automation of map construction saves time. At present, it is not interactive exploratory data analysis with hundreds try and error map generation steps, mainly due to the amount of data and processing steps behind. But the provided interactive, dynamic data displays allow for some degree of interactivity that could enhance the expressiveness of maps and thus promote data exploration.

5. DISCUSSION

As stated at the EC SEIS homepage (http://ec.europa.eu/environment/seis/how.htm), SEIS seeks to take advantage of the opportunities offered by the latest developments in information and communication (ICT) and geographic information (GIS) technologies. The European INSPIRE Directive (2007/2/EC) establishes an infrastructure for spatial information in Europe entered into force in May 2007. It is the first supra-national legal framework building on Geographic Information. It contains provisions aiming to improve the accessibility and interoperability of spatial data. Both, the implementation of INSPIRE and SEIS implementation aim to overcome existing inefficiencies relating to the usability and use of spatial data stored by public authorities.

Since one of the main ideas behind SEIS and legislations like INSPIRE is that data should be collected once and then re-used in different contexts some research questions of Geographic Information Science, or GIScience in short, are tackled. GIScience more and more moves hundreds of applications onto a bigger agenda. The term *GIScience* was coined or at least introduced in the scientific literature by Goodchild [1992], who described it to deal with the basics of GIS-technology, concentrating on those issues that are an impediment to a successful implementation. Duckham et al. [2003] stated in a book on GIScience that GIScience addresses the fundamental research principles on which Geographical Information Systems are based (e.g. research on GIS) or that it refers simply to the use of GIS in scientific applications (e.g. research with GIS). Following the GIScience research agendas discussed by Mark [2003], the authors conclude that concepts of energy regions can be directly or indirectly seen as an important topic for future GIScience research. As Blaschke et al. [2008] claimed energy is at the moment not playing a particular role towards a broader conceptual grounding of successful applications. While early GIS are said to be successful in routine and blunt-edged senses [Longley et al. 2005] they may have shied away from many of the bigger questions concerning how the world works. In tendency, GIS has always been an applications-led technology, and many applications have had quite modest goals in terms of the science of problem-solving. Longley et al. [2005] point out that the test of good science and technology lies in its usefulness for exploring the world around us. Future integrated systems such as SEIS and portals such as GEOSS need to consider that no scientific and technological ingenuity can salvage a representation that is too inaccurate, expensive, cumbersome, or opaque to reveal anything new about the world. Yet GIS applications need also to be grounded in sound concepts and theory if they are to resolve any but the most trivial questions. Kraak [2006] argues that although the traditional paper map allowed geographers to use it to synthesize, analyse and explore, it is obvious that the rise of Geographical Information Systems have stimulated these functions. Maps that used to be produced in an elaborated way can now be created in many alternative views by a single click of the mouse. Additionally, many more maps are produced and used, a trend multiplied by the development of the Internet, and, increasingly, mobile applications.

GIScience is said to be a legitimate subfield of information science and particularly attractive to information scientists because of the well-defined nature of geographic information and the comparatively advanced state of knowledge about this information type [Goodchild 2004]. What are energy regions, then? For renewable energy we have pointed out coarsely how powerful GIS technology is in the modelling part and how important the GIScience research agenda will be in the future in asking the right questions: how can geographic knowledge and skills be acquired and how can concepts of (energy) regions be made more readily understood and usable by humans? It also leads to the question whether or not spatial arrangements of land use types add specific qualities beyond statistical measures of their existence and quantity. For instance, can a landscape be sustainable, as long as 20% of the land use is extensive, 10% is protection area, etc., no matter where the respective patches are, which typical size and shape they have, how connected patches are and how often incompatible land use types are adjacent? [Blaschke 2006]. These questions have to be addressed to energy regions and have to be examined empirically. Translating them into the GIScience world we may follow Gahagen's [2005] dichotomy when developing visually centred methods and techniques and/or tools to present, analyse, synthesize and explore geospatial data but being at the same time interested it their effect on problem-solving (efficiency, effectiveness). Gahagen described the GIScience process, and projected possible maps and graphics, as well as computational methods on each of the process steps. ''To better support the entire science process, we must provide mechanisms that can visualize the connections between the various stages of analysis, and show how concepts relate to data, how models relate to concepts, and so forth'' Gahegan, 2005, p. 85. That is so far not the core vision of worldwide integrating information systems such as SEIS but these are maybe the research questions of tomorrow.

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