The GEOSS - ENERGEO portal: towards an interactive platform to calculate, forecast and monitor the environmental impact of energy carriers

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Abstract

The EU FP7 project ENERGEO is the official EU contribution to the worldwide Global Earth Observation System of Systems (GEOSS) and develops a strategy for a global assessment of the current and future impact of the exploitation of energy resources on the environment. It contributes to the GEO-tasks EN-07-02 and EN-07-03. In this four years project, a global observation strategy will be developed until mid 2013 to appropriately assess the impacts of the current and future transitions in energy-use on the environment by a combination of existing models, existing global datasets from which environmental indicators as well as existing and currently developed models capable of assessing and forecasting environmental impacts and costs of energy exploitation. This paper focuses on developing a distributed system following the GEOSS architecture recommendations. Standardized interfaces for information access (OGC/ISO Web-Map-Service, Web Feature Service and Web Coverage Service) and OGC web processing are utilized for the specific needs of stakeholders which will be incorporated through the GEOSS ‘Energy Community of Practice’.

Keywords: GEOSS; Energy modelling; GIS; Service Oriented Architecture; Geo-Portal; Energy portal

1. Background, justification and concepts

Most societies experience an increasingly problematic dependence on fossil fuels. For the justification of the necessity of an increased use of renewable sources we point to the scientific literature (overview article in: Nature, 14 August 2008) and to policy actions in many parts of the world, most notably the European Union and Japan. Electricity generation provides 18,000 terawatt-hours of energy a year, around 40% of humanity’s total energy use. In doing so it produces more than 10 Gigatonnes of carbon dioxide every year, the largest sectoral contribution of humanity’s fossil-fuel derived emissions (ibid.). There is a wide range of technologies — from solar and wind to nuclear and geothermal — that can generate electricity without net carbon emissions from fuel. The potential benefits of renewable energy are repeatedly emphasised in literature and include: a decrease in external energy dependence; a boost to local and regional component manufacturing industries; promotion of regional engineering and consultancy services specializing in the utilization of RE; increased R&D, decrease in impact of electricity production and transformation; increase in the level of services for the rural population; creation of employment, etc. (Migueza et al. 2006; Beccali et al. 2007; Hepbasli 2008).

While the quest for Renewable energy is not doubted it must be stated that complete assessments of the sustainability including energy production, transportation and consumption is less understood at the moment. Several consequences of transportation and substitution of fossil fuels may put considerable pressures on the environment, too, and there is some concern regarding the sustainability of the current as well
as the future pattern of energy consumption. For the full paper, we have here to discuss the exergy concept. When, for instance, evaluating the performance of solar energy systems using an exergy analysis method, calculation of the exergy of radiation is crucial but problematic, since exergy represents the maximum quantity of work that can be produced in some given environment - within the terrestrial environment, considered as an infinite heat source or sink – (Petela 2003; Hepbatli 2008).

Both from a viewpoint of abating environmental pressures caused by the use of energy as from the perspective of a secured and sustainable availability of energy, there is a need of:

- Information to help assessing current environmental impact of the production, transport and use of energy on a global scale in order to make balanced decision towards energy diversification
- Information to assess spatially and temporally explicit opportunities to diversify the energy portfolio towards a mix of energy resources which reduces pressure on the environment
- Monitoring of the geographical and temporal trends in the impact of the production, transport and use of energy to support policies and decisions aimed at energy security and energy diversification.

Policy is confronted with the challenge of security of supply which is of broad interest, which is a multifaceted 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 intensively within their business chains they have so far mainly been thinking “along lines” which means they concentrated on the existing grid structure and less so on potential areas. Still, 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. This is also the main approach in the GEOSS Energy portal, namely to provide the information needed for evaluating the potential for producing renewable energy and assessing the risks and potential of carbon capture and storage systems designed to reduce greenhouse gas emissions.

Renewable energy sources are characterized by their temporal and spatial variability, in contrast to the distribution of the fossil fuels. Typically, one can find at least one local source of renewable energy at almost every location. This advantage of the broad spectrum of renewable sources compared to conventional sources complicates the energy system.

2. **Energy modelling: spatial and temporal availability of Renewables vs. demand**

Conventional energy systems are characterized 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. Dominguez & Amador 2007; de Vries et al. 2007; Ramachandra & Shruthi 2007) and hypothesized that this field of overlap between GIS and energy research is not well developed. Even less studies connect the supply or the potential supply with the demand side pattern of population (Blaschke et al. 2003) or with the industry as demand pattern. Still, the variability and complexity of energy supply and demand systems necessitates the use of geospatial tools (Blaschke et al. 2009).

Renewable energy sources are manifold and vary very much regarding their spatial and temporal availability. Next to the typical listing of the energy carriers as media (wind, water, biomass …) the supply options may be divided into broad divisions based on the nature of the underlying energy transformation process (Twidell & Weir 2006).

- Mechanical supplies, such as hydro, wind, wave and tidal power. The mechanical source of power is usually transformed into electricity at high efficiency rates, e.g. 35% for wind or 70 to 90% for hydro power.
- Heat supplies, such as biomass combustion and solar collectors, provide heat with transition rates of 20 to 35%.
- Photosynthesis and photochemistry and direct photovoltaic conversion may only reach conversion efficiencies of 15 to 30%.

To illustrate the world wide potential, we use the example of biomass. De Fries et al. (2007) calculate a potential for liquid biofuels in the order of 75–300 EJ year$^{-1}$ and for electricity from WSB options at production costs below 10 ¢ (US) kWh$^{-1}$ of 200–300 PWh year$^{-1}$.

Biberacher (2007) and Biberacher et al. (2008a,b) presented a top-down modelling approach for renewable energy source potentials and proofed GIS to be especially useful because of the special spatio-temporal aspects of the Renewables. Theoretical potentials are based on topography, climate, land use and many others. The estimated theoretical potentials are reduced to technical potentials 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.

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. 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.

Biberacher and Gadocha (2009) presented a modelling approach for the optimization of the fulfilment of the heating demand within a defined region of interest, favouring renewable energy carriers - with a particular focus on spatial differentiation. The modelling approach presented handles information on geographically disaggregated data describing renewable energy potentials (biomass, solar energy, geothermal energy, ambient heat) on the one hand and geographically disaggregated information on the heating demand on the other hand. This spatial balance is the basis for modelling an optimum spatial utilization of identified renewable energy resources to satisfy the heating demand with respect to the objective function of the model, which is defined as highest economic efficiency with respect to greenhouse gas emissions constraints in the region. All relevant spatial data are disaggregated to a consistent spatial resolution. This includes the energy potentials, the demand structure as well as some infrastructure data. The region of in-
terest is segmented into a collection of raster cells, which present the smallest spatial unit in the model. The smallest size of raster cells is 250 m x 250 m. In recent studies, the modelling approach is extended to a more holistic analysis of a region and to spatial scenario techniques (e.g. Schardinger et al. 2010).

3. The concept for a GEOSS Energy portal

The Group on Earth Observations is coordinating efforts to build a Global Earth Observation System of Systems, or GEOSS. GEO was launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight) leading industrialized countries. These high-level meetings recognized that international collaboration is essential for exploiting the growing potential of Earth observations to support decision making in an increasingly complex and environmentally stressed world. GEO is a voluntary partnership of governments and international organizations. It provides a framework within which these partners can develop new projects and coordinate their strategies and investments. As of June 2010, GEO’s Members include 81 Governments and the European Commission. In addition, 58 intergovernmental, international, and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations.

GEOSS shall be a global and flexible network of content providers allowing decision makers to access information at their desk. This ‘system of systems’ will ultimately (operational: 2015) proactively link together existing and planned observing systems around the world and support the development of new systems where gaps currently exist. It will promote common technical standards so that data from the thousands of different instruments can be combined into coherent data sets. The ‘GEOPortal’ offers a single Internet access point for users seeking data, imagery and analytical software packages relevant to all parts of the globe. It connects users to existing data bases and portals and provides reliable, up-to-date and user friendly information – vital for the work of decision makers, planners and emergency managers.

The goal of GEOSS task EN-07-01: “Management of Energy Sources” is to support the development of Earth observation products and services for the resource assessment, monitoring and forecasting of fluctuating energy sources (e.g. hydro, solar, wind, ocean). In various projects around the world potentials and demand for renewable energy have been analysed and quantified, only sometimes in a spatially explicit manner and – even more rarely – leading to web-based information and analysis services. Frontrunner concerning energy related web-based services in a Service Oriented Architecture (SOA) are the European SODA and MESOR projects (Gschwind et al. 2006; Ménard et al. 2009).

The ENERGEO project is ambitious and has multiple objectives including to assessing regional and global data sets of energy and environmental indicators by exploiting earth observation data, legacy GIS resources and in-situ monitoring networks in order to support the objective of regional to global monitoring of environmental impacts of energy use. This chapter concentrates on the GIS-based SOA-architecture of the energy portal currently designed. An energy portal is one mean to communicating the results (Blaschke et al. 2008; 2009) but shall be developed into a two-way interactive platform where users can access metadata, partially data and some models to run the data.

The ENERGEO project tests and demonstrates the observing system and developed scenarios through the execution of dedicated pilots which focus on some of the most important issues relating to atmospheric composition and food security, sustainable integration of solar energy in current grids as well as its visual impact and relating to the impact of wind energy on marine ecosystems. At the end of 2012, the results of the pilots shall feed into an integrated platform that will run for known scenarios in order to assess energy strategies. As for now, one important task is the overall system design which will be described in detail in the full paper. Here, only a brief description is provided:
ENERGEO establishes a distributed system based on GEOSS architecture and international standards, namely four main elements: 1) the GEO Portal allowing the user to search for information and services available in GEOSS; 2) the GEOSS discovery is the element that collects search and presents the various existing GEOSS components to the users via the GEO Portal; 3) the GEOSS Component and Service Registry allowing GEOSS organizations to contribute components and services to the community; 4) the Standards Registry which enables contributors to GEOSS to configure their own systems to be compatible and interoperable with others systems.

Figure 1: Architecture of the EnerGEO GEOSS Geoportal.

A community portal with search facilities is currently designed and implemented based on international standards for catalogue discovery (OGC Catalogue Services CSW 2.0.2). The current state of a community-adopted metadata editor for ENERGEO is shown in Figure 2. One first and obvious mission of such a portal is the ‘find’ task which is ideally planned to be intrinsically linked to the ‘bind’ task referring to the OGC “publish-find-bind” logic (see OGC reference model ORM: www.opengeospatial.org/standards/orm). The first logic step for the user is referred to as discovery services and is intrinsically linked to the definition of metadata. Currently a questionnaire about the energy community’s needs regarding metadata information is being prepared. “How-To”-documents are developed to help users with specific tasks (e.g. how to document metadata information, how to convert ASCII to raster files,…).

ENERGEO enables users to register and publish data and services to a directory (such as a registry or catalogue). Initially, ENERGEO allows to publishing service metadata describing the capabilities of the services and the network address. OGC has developed a framework for defining specialized catalogues that support registration processes such as those described in ISO 19135: establishing, maintaining, and publishing registers of identifiers and meanings that are assigned to items of geographic information. The Catalog Service for the Web (CSW) - as defined in the OGC Catalogue Specification (CAT) - has been augmented by an ebRIM Information Model to establish an OGC framework for registration of geospatial information.
For GEOSS and in particular for the ENERGEO project standardized interfaces for information access (OGC/ISO Web-Map-Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS)) are currently implemented as part of the framework. Regarding web processing services, several studies are currently ongoing which shall unravel some problems with the current version of the OGC Web Processing Services (WPS) and processing via the web is still the most crucial step in most implementations.

In principle, the WPS standard (Schut 2007) provides web-processing functionality in a workflow-oriented infrastructure. WPS defines an open interface that enables publishing of geospatial processes and allows for the development of software clients that discover and bind to those processes. As typical for a geo-processing workflow between a Client and a Web GIS Engine WPS uses request-response pattern (GetCapabilities, DescribeProcess, and Execute). In regard to the usability of WPS for this purpose ongoing research (Resch et al. 2009; Resch & Mittlböck 2010, Resch et al. in press) analyses concerning the performance of Data-Access through catalogue discovery using distributed search architectures, the utilization of existing GEOSS Catalogue Services in the EnerGEO Web Portal and embedding not fully OGC conform existing important services in the energy domain such as SODA and MESOR (Gschwind et al. 2006; Ménard et al. 2009).

Other ongoing research tackles technical implementation aspects includes the evaluation of open-source versus commercial GIS software with a strong focus on scalability and performance of different geoproc-
essing and analysis tools. Due to the exponential increase of (real-time) data source available and, consequently, the enormous amount of spatial-temporal data provided, comprehensive architectures in terms of distributed and cloud processing tasks will be required (Schaeffer et al. 2009; Friis-Christensen et al. 2007).

4. Literature


