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'Energy landscapes': Meeting energy demands and human aspirations

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ABSTRACT

Renewable energy will play a crucial role in the future society of the 21st century. The various renewable energy sources need to be balanced and their use carefully planned since they are characterized by high temporal and spatial variability that will pose challenges to maintaining a well balanced supply and to the stability of the grid. This article examines the ways that future 'energy landscapes' can be modelled in time and space. Biomass needs a great deal of space per unit of energy produced but it is an energy carrier that may be strategically useful in circumstances where other renewable energy carriers are likely to deliver less. A critical question considered in this article is whether a massive expansion in the use of biomass will allow us to construct future scenarios while repositioning the 'energy landscape' as an object of study. A second important issue is the utilization of heat from biomass energy plants. Biomass energy also has a larger spatial footprint than other carriers such as, for example, solar energy. This article seeks to provide a bridge between energy modelling and spatial planning while integrating research and techniques in energy modelling with Geographic Information Science. This encompasses GIS, remote sensing, spatial disaggregation techniques and geovisualization. Several case studies in Austria and Germany demonstrate a top-down methodology and some results while stepwise calculating potentials from theoretical to technically feasible potentials and setting the scene for the definition of economic potentials based on scenarios and assumptions.

1. Problem statement

1.1. *The demand for renewable energy sources*

Most societies are experiencing a dependence on fossil fuels that is increasingly problematic. The need to make increasing use of renewable energy sources is discussed in published scientific literature [1] and reflected by policies in many parts of the world, most notably the European Union and Japan. Electricity generation currently supplies about 18,000 TW-hours of energy per year, which is around 40% of humanity's total energy use. In doing so it produces more than 10 Gt of carbon dioxide every year, the largest sectoral contribution to humanity's fossil fuel derived emissions [1]. There is a wide range of technologies using, for example, solar, wind, nuclear, and geothermal energy, that can generate electricity with no net carbon emissions. The potential benefits of using renewable energy are repeatedly emphasised in the literature and include a decrease in external energy dependence, a boost to local and regional

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component manufacturing industries, the promotion of regional engineering and consultancy services specializing in the utilization of renewable energy, an increase in R & D, a decrease in the environmental impact of electricity production and transformation, an increase in the level of services available to rural populations, and the creation of employment, etc. [2–4].

While the desirability of renewable energy is not in doubt, comprehensive assessments of its sustainability that include energy production, transportation, and consumption are, at present, not generally carried out. Several consequences resulting from the use of these substitutes for fossil fuels, and from their transportation, may place considerable pressures on the environment, and there is also some concern regarding the sustainability of present and future patterns of energy consumption. For instance, when evaluating the performance of solar energy systems using exergy analysis, calculation of the exergy of radiation is crucial but can be problematic, since exergy represents the maximum quantity of work that can be produced in a given environment, and the terrestrial environment is considered to be an infinite heat source or sink [4,5]. Renewable energy sources are characterized by their temporal and spatial variability, which is in contrast to fossil fuels. At least one local source of renewable energy can typically be found at almost any location on the Earth's surface. Only recently electrical engineering and planning have begun embracing 'second-law thinking' to reduce energy consumption in the built environment [6].

The broad spectrum of renewable energy resources available compared to conventional resources also complicates the energy system and challenges the stability of an energy grid. Although there is a growing body of literature dealing with the transition of socio-technical systems towards sustainability and the system innovations that this requires (e.g. [7,8]), most of these publications do not include a single map.

1.2. Bioenergy

Timber, crop residues, and other biological energy sources are important for more than two billion people [1]. These fuels are mostly burned in fires and cooking stoves, but in recent years biomass has also become a source of fossil-fuel-free electricity. Bioenergy promises to bring a shift in the geopolitics of energy. Many regions with a high production potential want to become oil and gas independent, and green fuel exporters [1]. The assessment of projected global biomass and bioenergy production potentials for 2050, originally published by the IEA Bioenergy Task 40 and summarised by Junginger et al. [9], highlighted some regional potentials and identified sub-Saharan Africa as holding the greatest bioenergy production potential, followed closely by Latin America and Russia. The EU and the US ranked somewhere in the middle and could become biofuel importers. In Asia the situation was more complex: eastern Asia, together with China, was seen to hold considerable potential, but not Japan. Southeast Asia, together with India, would not be able to produce enough bioenergy given their rapidly increasing populations. Australia and the Pacific Islands could become big exporters, since they would be able to produce nearly six times more bioenergy than their future requirements. Low production figures were estimated for the Middle East, with its sandy deserts. The report concluded by saying that Africa and Latin America will find that the global shift towards biofuels and bioenergy offers an opportunity to produce for a global market and to derive power from this trade, while bioenergy-deprived countries such as Japan will have to choose between competing for increasingly scarce hydrocarbon reserves, or making energy deals with green superpowers.

In 2009 the European Union (EU) introduced the Renewable Energy Directive [10] with the overall objectives of increasing the security of energy supplies and reducing greenhouse gas emissions, and with practical goals of 20% renewable energy by 2020 accompanied by sustainability schemes (*EU Sustainable Development Strategy*). The targets not only include a 12% renewable energy share of the total electricity consumption, but also a 5.75% bio-fuel share of the total fuel consumption. These targets can be fulfilled by a supply of about 300 million wet tonnes of biomass. At the same time the EU agreed to try and halt the loss of biodiversity within its member states. One measure adopted involved the creation of the Natura2000 network of important nature sites, covering about 20% of the EU land surface. However, additional nature conservation and restoration sites will need to be designated if the biodiversity target is to be met. There are concerns that an increased cultivation of bioenergy crops will decrease the land available for nature reserves and for traditional agriculture or forestry. Various projects have been initiated at an operational level; for instance, to assess possible negative impacts of bioenergy on ecosystems, the European Forest and Agricultural Sector Optimization Model (EUFASOM) simultaneously assesses economic and environmental aspects of land use. Other authors analyse the potential effects of bioenergy production on European wetlands by integrating a spatial wetland distribution model with EUFASOM [10] while considering the costs and benefits of measures as well as their consequences for agriculture and forestry. According to [11] bioenergy targets have measurable effects on conservation planning and nature conservation. These authors exhibit that wetland targets in one place stimulate land use identification elsewhere due to market linkages. In particular, conservation and restoration of large wetland areas impact food production, consumption, and market prices.

About 6–7% of the total energy consumption within the EU currently comes from renewable energy, with biofuels accounting for 1–2% of the total fuel consumption. It is estimated that about 17.5 million hectares would be needed to meet the short term 10% biofuel target [10], which would account for roughly 10% of utilised agricultural area (UAA) within the EU. Furthermore, to reach the EU targets for 2020, 30 to 45 million hectares would be needed (45 million if only 1st generation biofuel technologies are used, according to a study by the OECD – see ref. [9]). This is clearly likely to have significant effects on land use and biodiversity, as well as on other ecosystem services. Problems include the conversion of cropland (especially that with perennial crops) to biomass crops, which may lead to increased diversity in cropping patterns and lower input uses, but on the other hand higher landscape structural diversity, which may have positive direct or indirect effects on biodiversity. For forestry, the harvesting of logging residues in a sustainable way is possible if properly