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GIS based Model to optimize possible self sustaining regions in the context of a renewable energy supply

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Abstract:

During the last years an increasing energy demand, rising prices for fossil fuels, the challenge of meeting the objectives of the Kyoto protocol as well as a certain uncertainty of energy supply resulted in the two main aspects arising within the design of our future energy system, which are sustainability and security of supply.

To meet these challenges, the paper presents a modelling approach that handles information on geographically disaggregated data of renewable energy potentials as well as geographically disaggregated information on energy demand structures. The comparison of the identified energy potentials of the modelling process to the relative energy consumption structure results in a “balance grid” that represents the energy excess or shortage in every cell of the grid. The balance grid is the basis for modelling self-sustaining regions and allows a differentiated geographical consideration of energy production and consumption potentials.

Processing this information the model approach identifies optimized energy flows to balance all energy demand hot spots. This is applied for a special region of interest with the objective of finding one optimized setup for the whole prospected area. The final outcome of the model shows an ideally balanced energy flow structure for the whole examined region. In its simplest realization the energy flows only consider balanced flows for a full year timescale. Nevertheless these flows could also be treated on an arbitrary different timescale.

Based on these outcomes a possible sub-regionalisation in terms of energetic independency within the considered region of interest can be identified. This is reflected by clustering the region of interest into single self sustaining sub regions.

The model itself is a linear optimization model realised in the modelling language GAMS. There is an interface implemented to connect the model to common GIS software. In the current model all input and result data are administrated and visualised in ArcGIS.

Keywords: Renewable energy, regional energy systems, modelling

1. INTRODUCTION

A secure, efficient and environmentally conscious energy-supply is essential for a sustainable provision of goods and services. In the context of its international complexity the global energy industry has to cope with great challenges these days. This refers to aspects like the constantly increasing energy demand, insufficient energy conversion and transport capacities or geopolitical risks alongside others. Furthermore the possible long-time effects of CO₂ 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. Hence there are two keywords rising in decision making processes regarding our future energy system: Sustainability and Security of Supply.

Both aspects are of major interest and need to be treated carefully. Since an improvement of the current energy system towards sustainability and security of supply is also particularly determined by spatial questions, attention has to be paid to this spatial aspect when a modelling process of a possible future energy system is carried out. 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. To reduce the risks of energy dependency from politically instable countries it is necessary to meet the demand at the smallest possible scale with local and regional energy sources, which brings geographical information in the focus [Tegou et al., 2007].

2. SPATIALLY DISAGGREGATED ENERGY BALANCE

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.

2.1 Energy resources modelling

An adequate method for modelling renewable energy source (RES) potentials is presented by a top-down approach. GIS is especially useful in the RES modeling, which is also determined by the special geographical qualities of RES [Dominguez et al., 2007; Voivontas, 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).

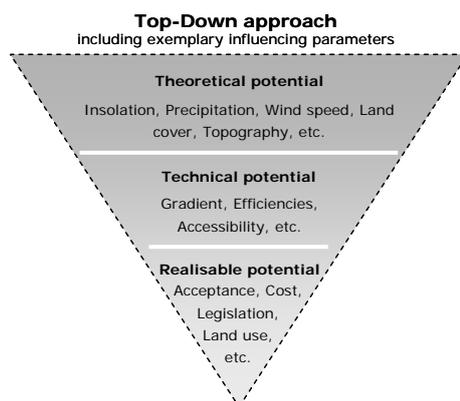


Figure 1: Top-down approach for the estimation of renewable energy potentials

forests and scrap wood) , non woody (grassland, cropland), liquid manure and organic waste, was estimated based mainly on land cover and land use data as well as annual

The estimation of the theoretical solar potential is based on topography and global radiation data for the region of interest [Ramachandra and Shruthi, 2007]. The available solar irradiation was calibrated by “solar radiation models” including the following assumptions for solar collector orientation: South 180°, gradient 39°, latitude of the study area. Additionally it was assumed that all roofs can be used for the installation of solar collectors. For the estimation of the technical potential an average efficiency factor for solar collectors is used.

The biomass potential, including woody (forestry plantations, natural

biomass growth rates for the respective biomass types and official statistics for organic waste. The average annual growth factors are based on Mittlböck [2006]. As not the total amount of annual increment can be used for energetic purposes due to topography, competitive use, sustainability and ecological factors, the theoretical potential has to be reduced [Smeets et al., 2007] by a predefined factor. It is assumed that 32% of the total forest potential can be used for energetic purposes. For agricultural biomass it is assumed that 25% of cropland can be used for the production of energy. Regarding grassland the part of fodder has to be excluded from energetic use, but a part is returned in form of liquid manure for biogas production.

For the modelling process of renewable energy potentials comparable spatial units have to be defined, which are the reference objects for the potential analysis. The modelling process is started by using rather small units, e.g. a geographical raster of a few hundred square meters. In a further step the results may be summed up to any larger spatial unit, to administrative units for instance [Mittlböck, 2006].

2.2 Energy consumption modelling

Besides energy resources also energy demand is generally 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 generally provided by public authorities or estimations are made in existing literature. In many cases they are only made available for larger administration units. If smaller units have been chosen for the modelling process the information on the energy demand has to be broken down into the appropriate spatial units. This process is called disaggregation. 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 [Schlomann et al., 2004] 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.

2.3 Energy balance

As the renewable energy potentials as well as the energy demand have been computed referring to the same spatial units they can be compared in a balancing way. Thereby it can be shown for each defined spatial unit if and to what extent the energy demand can be satisfied by the renewable energy potential of the spatial unit [Mittlböck, 2006].

The resulting energy balance does not state the realistic utilisable energy potential to satisfy the energy demand of a respective spatial unit. Nevertheless it provides the possibility to identify regions with a surplus energy potential or a demand excess (see Figure 2). This highly disaggregated energy balance is subject to a dynamic modelling approach. Different levels of valorisation for different energy potentials can be investigated and the resulting energy balances can be outlined and discussed.

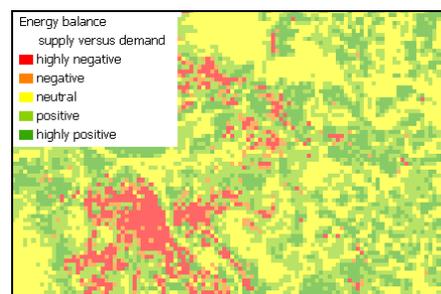


Figure 2: Energy balance – potential renewable energy sources versus given energy demand

3. MODELLING OF ENERGY FLOWS

As energy resources as well as the energy demand are commonly not distributed spatially equal, energy flows are necessary to satisfy all demands in a defined region. Of course these flows are dependent on the considered energy carriers but in general a flow can be determined by a starting unit A and a neighbouring unit B. The considered approach deals with arbitrary chosen spatial units for which energy potentials and demands are evaluated. In a real solution all demands need to be satisfied – either by energy potentials nearby or by energy flows from bordering spatial units, which is shown exemplarily in figure 3 [Mittlböck, 2006, Biberacher, 2007]. In this study only balancing energy flows are considered, energy flows based on a process chain are not included in the modelling approach developed so far.

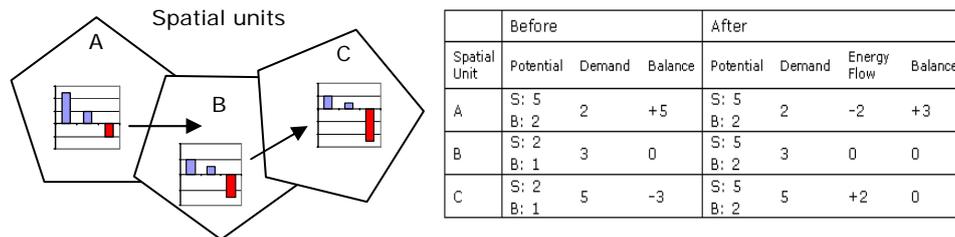


Figure 3: Scheme of Solar (S) & Biomass (B) potentials, demand and energy balance of spatial units with resulting balancing energy flows in arbitrary units.

The evaluation of balancing energy flows is influenced by numerous aspects. First and foremost it is influenced by the energy carrier itself. While electricity can be transported over large distances without suffering high losses, the technical efficiency and economic viability limits are reached quite fast in the case of heat transport [Söderman and Petterson, 2006]. Besides the energy carrier itself also natural conditions (topography, climate, etc.) and existing infrastructure as well as political aspects have an influence – either positive or negative - on the possible exchange of energy between spatial units.

Based on these aspects, energy flows between spatial units can be weighted. This weighting process is implemented as follows:

A norm weight is assigned to each single energy flow between neighbouring spatial units. This weight can be increased or decreased by the aspects already mentioned above. While natural barriers as well as political borders could have a negative influence on the energy transport, existing infrastructure like roads and electrical grids would support the transport of energy.

Figure 4 outlines how these aspects could look like for a certain region of interest. For this region the single spatial units (e.g. raster cells) are analysed whether they are connected to a certain infrastructure (e.g. roads), represent a certain borderline or represent a region with certain natural conditions.

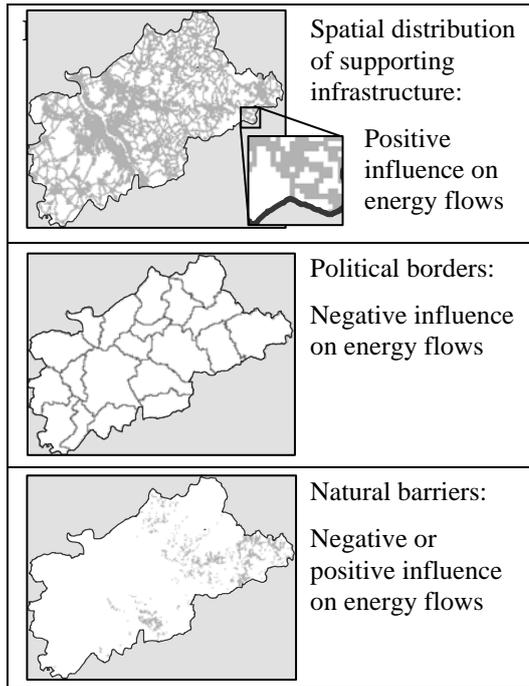


Figure 4: Influences on energy flow related costs depending on spatial factors.

This listing does not claim to be sufficient in terms of describing reality. But it can represent the range of differing aspects that have to be considered in terms of weighting energy flows between single spatial units.

However this example should provide a suitable insight in the idea of weighting energy flows.

After identifying different weighting categories these categories have to be quantified due to their influence on the energy transport. One possibility could be the interpretation of the single weighting categories as fictive costs. Based on this interpretation the single flows become quantifiable regarding their suitability (see equation 2 in section 4).

4. SPATIAL REGIONALISATION

The interpretation of energy flows by assigned fictive costs enables the following modelling approach:

Assumption 1: The energy demand (d_i) in each single spatial unit has to be satisfied by the sum of incoming energy streams (in_x) from neighbouring spatial units (n_i), added to the already available energy potential within this spatial unit (p_i), minus the sum of outgoing energy streams (out_x) to neighbouring spatial units (n_i).

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

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

Assumption 3: The individual specific costs (k_i) are identified by a fixed basic cost (c) plus the sum of distinguished specific influences factors (related to figure 4, number of factors is determined by r) interpreted as increasing or decreasing cost assignments (a_{ix}).

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

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

Therefore the whole model can be described as a linear optimisation problem. This optimisation problem was formulated in the algebraic modelling language *GAMS* – General Algebraic Modelling Systems [GAMS, 2007] and solved with the *cplex* linear optimisation solver developed by ILOG [ILOG, 2007].

The output of an optimisation process shows the arising energy flows and their size. In case of single spatial raster units figure 5 shows a possible solution.

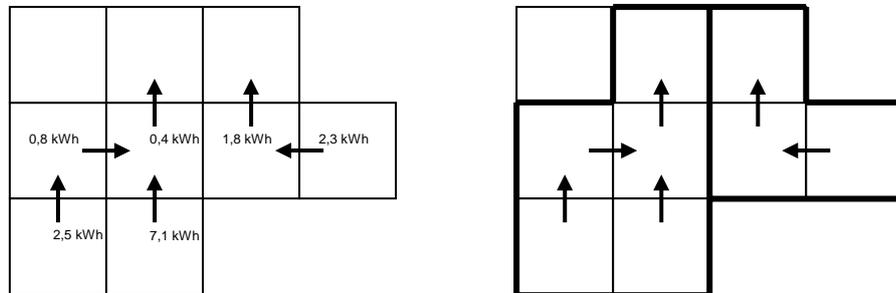


Figure 5: Calculated energy flows between neighbouring spatial units.

The solution shown in figure 5 outlines which energy flows are necessary at the minimum (in terms of the cumulated amount of the renewable energy potentials) to satisfy all arising energy needs of the considered region regarding balancing energy flows. Based on this flow chart, borders can be identified, that are not part of an energy exchange flow. That finally leads to enclosed regions, which are - in terms of energy flows - decoupled islands within the whole considered region.

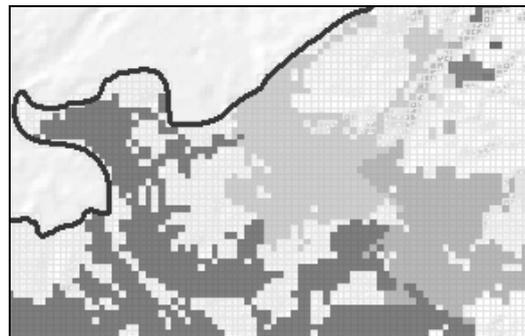


Figure 6: Optimised self sustaining energy regions (individual grey scales).

Ultimately this approach leads to a clustering of single spatial units as shown in figure 6. These clusters represent spatial areas, which can be identified as regions with a positive energy balance - related to all cumulated potentials and needs within the cluster (for clustering techniques see also Murray and Estivill-Castro, 1998). Spatial units that are not connected to a cluster of at least two single units, represent a positive energy balance by their own that is neither influenced by in-flows from neighbouring units nor by out-flows to neighbouring units.

5. SENSITIVITY ANALYSIS

The resulting clusters could be interpreted as possible self sustaining regions in terms of renewable energy supply. The distinctiveness of this approach to calculate possible self sustaining regions is that single clusters are not calculated individually. That means that the surplus of energy is not optimized for each single cluster but for the whole region of interest. Especially in the case of concentrated demand hot spots (like cities) within the examined region a huge neighbourhood will be affected by providing the counterbalance to

satisfy all needs. That also influences areas which would be self sustaining if they are considered individually.

The forming of energy clusters by the indicated model is shown in figure 7. The three scenarios are based on the different valorisation of renewable energy carriers to satisfy the heat demand of each spatial unit. Although the energy balance grid does not seem to be very different in these scenarios there is a noticeable effect on the cluster building process resulting from varying energy flows between neighbouring units

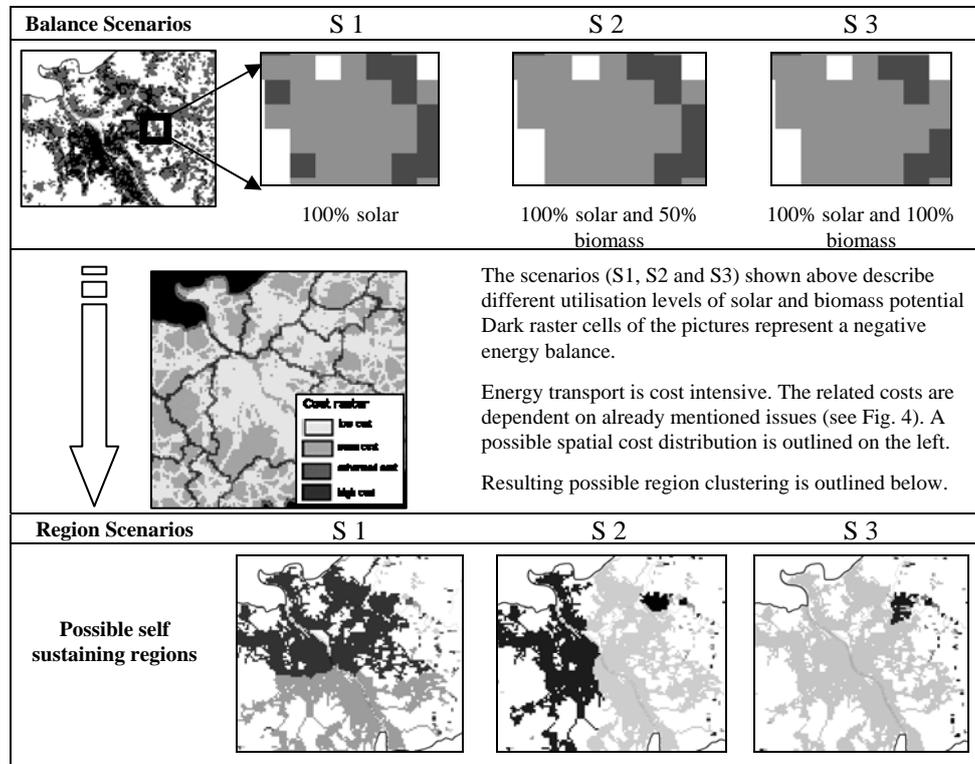


Figure 7: Different scenarios regarding the valorisation of renewable energy carriers to satisfy the heat demand lead to different optimised self sustaining energy regions (identified by individual grey scales).

In general this approach provides the possibility of sensitivity case studies regarding different input settings concerning energy needs, suitable potentials, infrastructure, etc. by this individual single location based studies as well as the "big picture" overview of an entire region of interest are enabled.

6. CONCLUSION

The outlined approach combines a spatially high disaggregated insight in energy resource-, supply- and demand structures, while other current studies work with the cumulative inclusion of energy potentials and demand.

As the approach is not fixed on one spatial scale global as well as regional or sub-regional questions on possible energy flows could be quantified. Spatial units can be chosen individually and influencing parameters on energy flows can be treated.

Hence the modelling approach supports a decision making process on different spatial scales with quantifiable numbers and system setups. Furthermore the integrated model workflow enables a sensitivity analysis. Variations in the input assumptions and their consequences on the results can be treated in a quite flexible way.

By visualising energy flows and the resulting possible energy clusters, cooperation projects between affected administrative units on the use of renewable energies could be motivated. To give a full picture of the possibilities regarding the use of renewable energy to satisfy

the heat and electricity demand also a detailed registration of already utilised renewable energy resources, especially regarding energy flows between neighbouring cells of the balance grid is necessary.

Within the discussed energy flow model a quite simple approach regarding the timescale of the balanced energy flows between the spatial units of the region of interest was used. As the energy demand as well as the supply with renewable energy carriers is not temporarily constant e.g. solar insolation the energy flows should also be treated in a flexible timescale. That will be part of future investigations.

Within the part of energy flow modelling future investigations will also regard the inclusion of more detailed factors of cost estimation, as well as for the different renewable energy carriers. Until now only balancing energy flows to reach a balanced energy balance for a whole region of interest has been included in the considerations. Future developments will also include energy flows based on process chains.

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REFERENCES

- Biberacher, M., Modelling and optimisation of future energy systems using spatial and temporal methods, VDM Verlag, ISBN 978-3836424356, Germany, 2007
- Dominguez, J., Amador, J., Geographical information systems applied in the field of renewable energy resources, *Computers and Industrial Engineering*, 52(3), 322 – 326, 2007
- Estivill-Castro, V. and Murray, A.T., Cluster discovery techniques for exploratory spatial data analysis; *International Journal of Geographical Information Science*, 12(5), 431 - 443, 1998
- GAMS, General algebraic modeling system, <http://www.gams.com/>, (online 18.5.2007)
- ILOG, <http://www.ilog.com/products/cplex/>, (online 2.3.2007)
- Mittlböck, M. et. al., Virtuelle Kraftwerke für Autarke Regionen, BMvit, Hrsg., Berichte aus Energie- und Umweltforschung 58/2006, Austria, 2007.
- Ramachandra, T.V., Shruthi, B.V., Spatial mapping of renewable energy potential; *Renewable and Sustainable Energy Reviews*, Volume 11(7), 1460–1480, 2007
- Schlomann, B.; Gruber, E.; Eichhammer, W.; Diekmann, J.; Ziesing, H.-J.; Rieke, H.; Wittke, F.; Herzog, T.; Barbosa, M.; Lutz, S.; Broeske, U.; Merten, D.; Falkenberg, D.; Nill, M.; Kaltschmitt, M.; Geiger, B.; Kleeberger, H.; Eckl, R., Energieverbrauch der privaten Haushalte und des Sektors Gewerbe, Handel, Dienstleistungen (GHD), Abschlussbericht and das Bundesministerium für Wirtschaft und Arbeit, Karlsruhe: Fraunhofer ISI, 2004
- Smeets, E., Faaij, A., Lewandowski, I., Turkenburg, W., A bottom-up assessment and review of global bio-energy potentials to 2050, *Progress in Energy and Combustion Science*, 33(1), 56–106, 2007
- Söderman, J., Pettersson, F., Structural and operational optimisation of distributed energy systems, *Applied Thermal Engineering* 26(13) 1400-1408, 2006
- Tegou, Leda-Ioanna, Polatidis, Heracles, Haralambopoulos, Dias A., Distributed Generation with Renewable Energy Systems: The spatial dimension for an autonomous Grid, Paper presented at the 47th conference of the European Regional Science Association “Local governance and sustainable development, Thematic stream M: Environment, natural resources and sustainability”, ERSAs 2007, Paris, France, August 29th – September 2nd 2007
- Voivontas, D., Assimacopoulos, D., Mourelatos, A. and Corominas, J.; Evaluation of Renewable Energy potential using a GIS decision support system; *Renewable Energy*, 13(3), 333-344, 1998