DEVELOPMENT OF SETTLEMENT FRAGMENTATION INDICES FOR ENERGY INFRASTRUCTURE COST ASSESSMENT IN AUSTRIA

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ABSTRACT:

The European electricity directive of 1997 triggers the re-organization of the electricity market. This guideline obligated Austria to open gradually its electricity market for competition. In a demonstration study a methodology was developed which can support the national regulation authority to differentiate costs spatially in accordance to terrain and settlement structure. The methodology is applied to the whole territory of Austria. This paper describes the fragmentation measures based on remotely sensed data which distinguish areas with relative compact sealed surfaces and fragmented areas. The most relevant indices include three measures of fragmentation introduced by Jaeger (2000): degree of landscape division (D), splitting index (S), and effective mesh size (m). They characterize the anthropogenic penetration of landscapes from a geometric point of view and are calculated from the distribution function of the remaining patch sizes. The methodology will serve as a baseline for a fair energy delivery price based on spatially explicit infrastructure costs.

1. INTRODUCTION

The sprawl of settlements and roads with a significant increase of area consumption and fragmentation through any kind of infrastructural building activity is an ongoing challenge in many parts of Europe. Some processes are relatively well known. Anthropogenic fragmentation of landscapes, ecological consequences, their role in habitat decline and loss of species are investigated although fragmentation is still ongoing. The research results cannot directly influence policies and this process. Landscape fragmentation is caused by roads, railway lines, extension of settlement areas, etc. It further enhances the dispersion of pollutants and acoustic emissions and affects local climatic conditions, water balance, scenery, and land use. Less investigated are infrastructure costs directly and indirectly associated with dispersed settlements.

Triggered by the European-wide market liberalisation costs for formally national services such as telecommunication, electricity, water supply etc. are becoming more evident and are consequently attaining a spatial dimension. The former national providers have to open the markets to competitors and regulation authorities to guarantee a fair market have been established throughout Europe. The electricity directive, which entered into force in 1997 (‘Directive 96/92 on Common Provisions for the Electricity Markets on the other’), formed the European foundation for a fundamental re-organization of the electricity market. This guideline obligated Austria to open gradually its electricity market for competition. On the basis of this introduction, the transformation of the Austrian national electricity law (e.g. 'Elektrizitätswirtschafts- und -organisationsgesetz' and 'Energieliberalisierungsgesetz') was undertaken. The respective operator of transmission or distribution systems is obliged to allow access to its system to any system user (generator or consumer) of a certain size. Conditions to get access must not be in any way discriminatory and must not contain any unjustified provisions. To keep business entities that generate electricity and operate the supply system in Austria from taking prohibitive measures, general conditions and tariffs for the use of transmission and distribution systems are determined by the Austrian Minister for Economic Affairs.

These tariffs must be established according to the principle of equal treatment of all system users. The Minister of Economic Affairs calculated the tariff according to the so called gross method: the costs of operating the highest-voltage transmission systems are to be distributed between all consumers according to their consumption, irrespective of their purchase of electricity actually transferred via such transmission systems, the idea behind this calculation method being that all consumers are at least potentially in the same need of such a highest-voltage supply system.

Regional electricity transmitters and distributors that operate power stations of their own don't rely exclusively on the supply of electricity transferred via high-voltage lines. Therefore they don't want to be burdened with the

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full costs and oppose the calculation of tariffs after the gross method. On the other hand, eligible customers that are interested in taking advantage of a competitive electricity market by considering offers of electricity producers that are located in other EU member-states prefer the suggested gross method calculation, since this calculation method keeps costs for long-distance electricity-transfer low. Either way, the regulation authority has an interest for a fair pricing system which also takes into account the different terrain conditions and the spatial distribution of the population. Therefore, there is a need for a regionalization of the tariffs.

In a demonstration study a methodology for a regionalization of electricity infrastructure prices was developed and applied to the whole territory of Austria (about 84.000 km^2). This methodology aims to evaluate the costs for providing energy infrastructure in a spatially explicit manner. This paper focus on the fragmentation aspect which was regarded as the parameter with the least practical experiences and without standardized indices.

Beyond the application aspect a special methodological challenge of contemporary research can be seen in performing ‘object-based’ classification. We refer to the terminology of Blaschke and Strobl (2001) and we use an operational commercial software environment (Baatz and Schäpe, 2000). The software and the underlying multi-level image segmentation approach are increasingly used in image classification. The approach aims to minimise the overall heterogeneity in the image through heuristic optimisation of the boundaries of the resulting patches coincides with recent methodological achievements in landscape research. The idea of local homogenous patterns in a patch based landscape organisation recently triggered numerous studies, assuming the organisation of landscape patterns as a complex of local spectral distributions. The main reason to use this approach in this study is that the resulting pattern matter rather than statistical figures. It enables the user to integrate knowledge about the nature of boundaries between adjacent objects (sharp or fuzzy) and their specific properties (texture, neighbourhood, relationship) exists, even though at various degrees of certainty. The methodology of multi-resolution image segmentation offers the possibility to reproduce the boundaries across different data sets (e.g. medium and high resolution imagery, regional to local) and allow for a transparent inspection of results (Blaschke and Strobl, 2001).

2. METHODOLOGY

2.1 Study Area and Data Preperation

The study area is the territory of Austria. The first data processing steps include the preparation of 10 Landsat ETM scenes from the summer of 2002, its georectification into the UTM system and the mosaicing of the scenes. For pragmatic data handling reasons Austria is divided into three parts and the results are edgematched afterwards.

The main image processing step is a classification into two classes: sealed surfaces (mainly transportation, industry and settlements) and other surfaces. Although a binary classification is supposed to be a relatively straightforward image processing task the quality of the result depend on the definition of sealed surfaces, the underlying ontology and the classification methodology. Before the operational work a pixelwise maximum likelihood classification and a segmentation-based object oriented methodologies were compared in an internal benchmark. As expected, both approaches have advantages and disadvantages. But as explained before, pattern and shape characteristics of the resulting binary image are relevant; the object-based classification methodology was regarded to be the most appropriate one for this study.

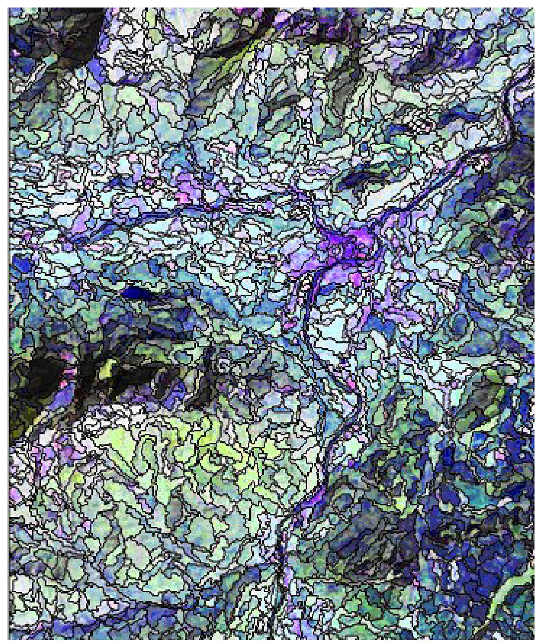

Figure 1: Example of an image segmentation for a small subset of the Landsat ETM data for Styria. The outlines of the resulting segments at a medium segmentation level are overlaid on the original Landsat data.

2.2 Object-based Classification

The fractal net evolution approach (FNEA, Baatz and Schäpe, 2000) is embedded in a commercial software environment. It utilizes fuzzy set theory to extract the objects of interest, at the scale of interest, segmenting images simultaneously at both fine and coarse scales. By operating on the relationships between networked, i.e., linked objects, it is possible to use local contextual information, which, in addition to the images’ spectral information, can be combined with image-object form and texture features to improve scene and to an

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imbalance between regions of high and low spectral variance. To overcome this, FNEA incorporates local mutual best fitting, which always performs the most homogeneous merge in the local vicinity following the gradient of best fitting. That is: each initial pixel or group of pixels grows together with its respective neighboring pixel(s), which results in the lowest heterogeneity of the respective join. To achieve this, an iterative heuristic optimization procedure aims to get the lowest possible overall heterogeneity.

We performed a classification of settlements and non-settlements. Major roads, parking areas and industrial complexes were included but due to the pre-segmentation most roads are not treated as separate object. This is already a generalisation step but the roads exist as a GIS layer and can be integrated if necessary. The preprocessed and segmented data sets were classified using extensive sampling of reference areas for all different geographical areas. The classification in eCognition™ software was performed within less than a weeks time. The fuzzy rules allowed for a certain flexibility. Figure 2 illustrates a typical rural situation with relatively little settlements and relatively dispersed pattern.

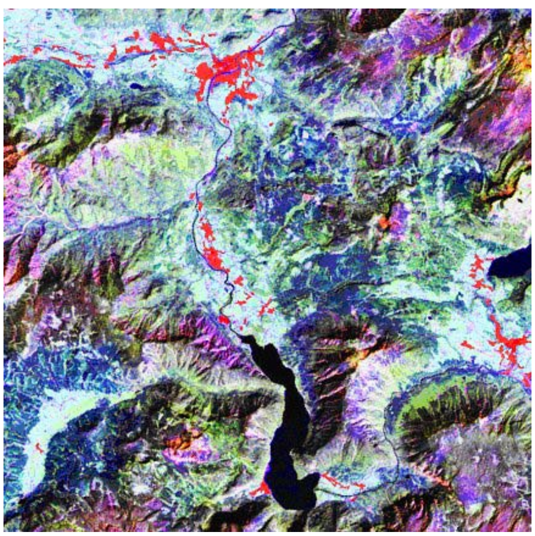

Figure 2: Example of the resulting settlement mask overlaid on a 6-band visual combination the Landsat ETM solar bands for the Hallstädter See/Salzkammergut area (Upper Austria).

2.3 Analysis of the settlement mask

In the second phase of the project, several fragmentation measures were applied to distinguish areas with relative compact sealed surfaces and fragmented areas. To achieve the required information about the structural difference of settlement in Austria (city vs. countryside, compact versus dispers settlement areas) we are using landscape metrics methods introduced by Jaeger, 2000).

Quantification of fragmentation through spatial indices is currently becoming a common practice in landscape ecology and related disciplines. These indices capture and summarise some of the spatial characteristics that have been found to be relevant for different ecological or physical processes. In particular, landscape fragmentation indices derived from remotely sensed data are being increasingly used for landscape condition assessment and land cover change characterization (e.g. Gulinck et al. 1993, Chuvieco 1999). Satellite images are used as the primary source of spatial information because they provide the digital mosaic of land cover classes and the corresponding spatial entities required for the computation of these indices

The number of potential landscape metrics is legion (Gustafson 1998). From the results of preliminary test runs it was concluded that only very few indices should be calculated to ensure acceptance of the endusers. These indices should a) be relatively simple and understandable, b) express fragmentation and complexity of settlements separately c) be mathematically robust against changes in the data set and against outliers or very special geometric situations along border polygons, d) interpretable concerning their absolute values.

According to these criteria, the most relevant indices include three measures of fragmentation introduced by Jaeger (2000): degree of landscape division (D), splitting index (S), and effective mesh size (m). They characterize the anthropogenic penetration of landscapes from a geometric point of view and are calculated from the distribution function of the remaining patch sizes.

The three new fragmentation measures degree of landscape division (D), splitting index (S), and effective mesh size (m), are based on the ability of two animals placed in different areas somewhere in a region to find each other within the landscape. This is equivalent to the probability that two randomly chosen places in a region will be found in the same undissected area.

For the sake of clarity, the measures are introduced via three auxiliary measures: coherence (C), splitting density (s), and net product (N). Jaeger introduced these measures mainly for the following reasons: a) the possibility of two individuals to meet is a precondition for the survival of a population. It takes into account the size of undissected areas and the accessibility of inhabitable places. b) the size of undissected areas and the accessibility of these areas are two of the most important factors influencing extinction. They are inversely correlated with, for example, the isolation of subhabitats and the separation of the subpopulations of a metapopulation.

To be able to use this information aggregated either on community provincial or other regions and want to compare the results we created a 3*3 km^2 raster that covers the whole of Austria. Because the indices rely on the area of investigation (what is fragmented to what degree) this is a necessary step to get comparable results at the end.

The initial settlement classification in eCognition, results in several georeferenced images. First post-processing step was to clip all Landsat Szenes to the Austrian border to avoid the classification of neighbouring territories without ground control data. For further processing these georeferenced images were converted into ESRI Grids and merged them together.

After Clipping with an Austrian Boundary Grid we got the Settlement area for Austria as one consistent grid. This settlement area grid was combined with the prior created 3*3 km Grid for Austria. To perform the landscape metrics analysis in Fragstats software about 10000 equally sized 3*3 km grids were created through GIS overlay techniques.

In the end we combined the result set with the 3*3 km Grid and performed zonal statistics for communities, provinces and network – operator areas. After subtracting all unsettled areas, we used the Mean of the Splitting and Division Index as well as the Mean of the Effective Mesh Size as Indicators for structural difference of the settlement in Austria. Finally, these results were integrated with other data sets including terrain information and socio-economic data.

3. RESULTS AND DISCUSSION

Using the chosen image analysis methodology we were able to classify the whole territory of Austria on basis of Landsat ETM data. The classification result was a binary data set of settlements and other areas. Then, an analysis of the fragmentation and some other characteristics of the settlements were performed. The classification process using on an object-based methodology was very successful and resulted in an operationally usable data layer for the whole territory of Austria.

Difficulties and misclassifications were problematic only in certain areas, e.g. in some vineyards in Eastern Austria (Lower Austria, Burgenland) and garden allotments around the big cities. The accuracy of the binary mask is supposed to be significant above 95%. This accuracy assessment with external GIS data sets was performed for some provinces only but with very promising results, e.g. 96.5% for the province of Salzburg. Figure 2 illustrates a typical rural situation with relatively little settlements and relatively dispersed pattern.

4. CONCLUSION

To analyse large areas or whole countries it is obvious to utilize earth observation techniques and geographic information systems, enabling a small-scale view of landscape mosaics. In terms of image classification it is concluded that the methodology is relatively well transferable between scenes. It turned out, that although satellite remote sensing is still regarded as not being a rapidly available source of information and not achievable for ordinary users, this data source was the most consistent layer of information and could be utilized to further distinguish different types of settlements, specifically urban structures and village structures. The costs of a Landsat ETM mosaic are relatively moderate and the methodology will serve as a baseline for a fair energy delivery price based on spatially explicit infrastructure costs.

According to the aims of the project, namely to explore and to characterise settlement patter, the object-based classification worked better than the ‘classical’ pixel-based maximum likelihood classification technique. While for the text areas not many statistical differences could be reported more realistic settlement pattern resulted. This was important for the overarching methodology where the fragmentation pattern is evaluated and single pixels are of little interest. As stated above, a large number of indices has been used to quantify the structure of categorical maps as a surrogate of actual landscapes and correlate them to ecological processes and new indices are created permanently. The main objective concerning the pattern analysis in this project was therefore to describe the relevant aspect of pattern, namely the fragmentation degree of the settlements with very few indices.

The fragmentation was reduced to the three indices developed by Jaeger (2000). Further measures used for quantifying fragmentation are proximity, lacunarity, and contagion (Riitters et al. 1995, 1996; Haines-Young and Chopping 1996; Gustafson 1998). Hargis et al. (1998) further include nearest neighbor distance and fractal dimension. These measures are not investigated since they contain more aspects of spatial heterogeneity than fragmentation and relative more to the texture of a landscape which can on the other hand be interesting e.g. in ecological studies. Since the indices are implemented in software programmes such as Fragstats 3.3, no software programming was necessary but a lot of batch programming to perform analysis based on 10000 3 by 3 km grids. The next research steps are to evaluate the influence of the chosen grid size on the results. The application is currently presented expert users to the electricity companies and to the electricity control authority.

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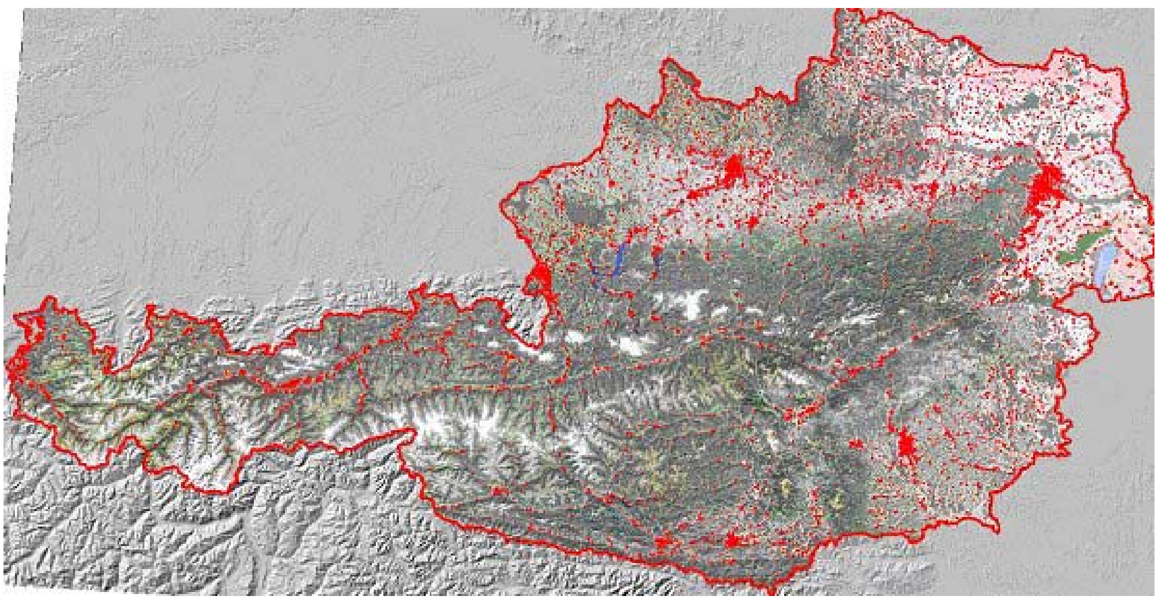

Figure 3: Resulting settlement masks for Austria.