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GIS-BASED ANALYSIS OF RENEWABLE ENERGY POTENTIALS IN URBAN SPACE

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GIS-based analysis of energy demand facilitates the planning and implementation of renewable energies in urban space. The process of preparing an urban energy concept concerns many actors and facilities, but increases also the acceptance of the energy transition in the proximity. A calculation of energy potentials in the city of Augsburg (Germany) illustrates an usual way of spatial energy planning.

Keywords: *energy planning, GIS-based analysis, energy potentials, urban space*

1. Introduction

Today's cities are responsible for 75 percent of the world's energy consumption and for 80 percent of the global carbon dioxide emissions [1]. Thus the need for innovative and nonpolluting forms of renewable energy production is particularly required in urban areas. But unlike the renewable energy production in rural regions, where there is no lack of space, cities face the challenge to produce clean energy in strictly limited space without any negative implications like noise and smell. Therefore the need of integrated energy planning is getting more significant, because it implements a lot of institutional players, professional responsibilities, and new technologies and increases the acceptance of nearby energy production in urban space.

2. GIS-based energy planning in urban space

2.1. Why using GIS

Geographic information systems (GIS) with its hardware and software can gather, transform and analyze information which is related to earth. For energy planning there are a lot of specific interrogations that need to be answered by GIS-based analysis. The system connects geographical, public or private statistics and data in order to put it in relation of space and time. For example, GIS can find structures in urban space and quantify its capacities to define locations for renewable energy use. The procedure of GIS-based energy planning can be divided into three basic steps [2].

2.2. Procedure of energy planning with GIS

2.2.1. Analysis of stock and potentials

At the very beginning of energy planning it is necessary to collect all data and information which are produced by public and private actors concerning energy issues in urban areas. On the one hand the condition and structure of urban space can be identified with digital maps, aerial images and plans of the city, in order to exclude non-qualified regions and mark particularly suitable locations for energy production in urban areas. On the other hand, data and information for example of population density, energy consumption and energy production lead to an overview of demand and supply of energy in urban space. The output of a GIS-based analysis will be the basis of an integrated energy concept.

2.2.2. Energy concept

An energy concept is not a sectoral issue, but its preparing is the task of engineers, urban planners, architects and actors of the energy sector. Therefore the coordination of both planning and managing is a long term process. The character of an energy concept is the evaluation of plausible scenarios and a forecast of energy consumption and supply, as well as the amount, local differences and the chronology. It also explores possibilities of energy savings and more efficient technologies. Furthermore an energy plan for a city also considers the needs of daily urban life, such as sustenance, mobility or environmental interests.

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2.2.3. Implementation of the concept

The energy plan is not a legal document, so it has to become obligatory. For example, in Germany the formal instrument of urban planning concerns the municipal authorities. In order to make the energy plan a binding law, it has to be implemented in a legal process. Therefore the local population has the right to participate on their issues, further contracts and agreements with responsible actors (e.g. companies, owner of buildings) have to be launched.

3. Potentials of renewable energies in the city of Augsburg

3.1. Near-surface geothermal energy – current situation

The energy contained in the top layers of the earth can be utilized with different techniques of exploitation like horizontal collectors expanded over a large area at a depth of about 1.5 meters, ground probes, groundwater heat exchangers or deep-reaching building elements connected to the earth. Generally near-surface geothermal energy is regarded to be the heat of approximately 5 to 18 degrees Celsius stored in rocks, soil or groundwater up to a depth of 400 meters.

In the city of Augsburg there are optimal conditions for the use of groundwater heat pumps due to geo-hydrological conditions like a low distance from the surface to the groundwater table and a porous aquifer which guarantees a high productivity of the heat pump. In the year of 2010 almost 360 groundwater heat pumps including nine facilities of cold production were installed. Figure 1 shows the allocation of the plants, classified by the water delivery rate. This parameter is useful as an indication for the capacity of the groundwater heat exchangers. A delivery rate of about a liter per second is necessary to generate an evaporation capacity of 14 kW which is enough to

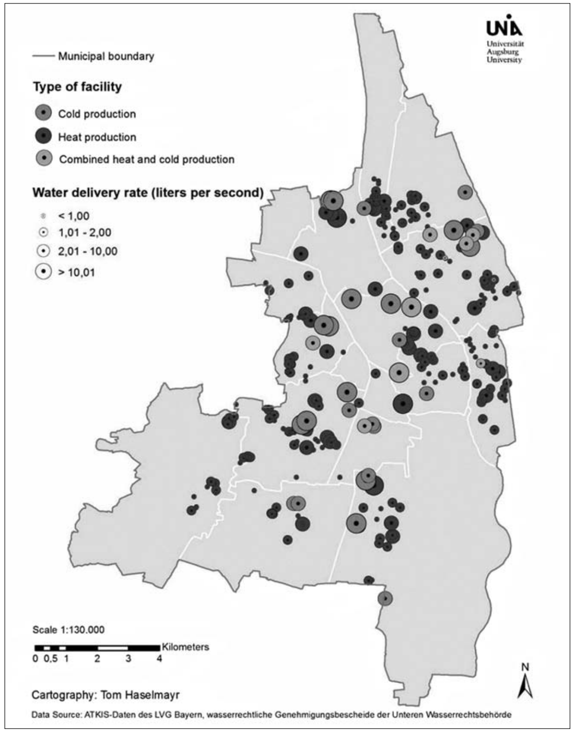

Fig. 1. Groundwater heat pumps in Augsburg [3]

provide heat for an average four-person household. Plants with delivery rates higher than five liters per seconds are likely to supply a whole block of flats or an industrial enterprise with a huge heat demand. The map also shows areas of possible mutual interferences of the plants as a result of the high concentration [3].

3.2. Near-surface geothermal energy – potential analysis

The first step of the GIS-based potential analysis of near-surface geothermal energy is to determine those areas that have to be excluded because of nature conservation issues, legal restrictions or improper natural conditions. In Augsburg there is a huge water conservation area, where geothermal activities are prohibited. In the case of a leakage, refrigeration fluid that is necessary to run the heat pump could contaminate groundwater used for municipal drinking water supply. Some smaller areas are also excluded due to impermeable aquifers or a distance too far from the surface to the groundwater table. Now the areas that come into consideration are identified and quantified.

In the next step a GIS-based spatial intersection analysis has to be executed to find out the total heated living space located in the suitable area. The result shows that about 85 percent of the entire living space in Augsburg is suitable for near-surface geothermal heat supply. Now the heat demand for that area can be calculated based on the average heat demand of urban residential buildings in Augsburg of 90 W per square meter. After that it's necessary to determine a limit of the potential heat pump coverage which is about 36 percent according to the German Heat Pump Association (BWP). The overall result shows that approximately 430.000 MWh can be generated with heat pumps using near-surface geothermal energy [3].

3.3. Total renewable energy potential in Augsburg

Besides near-surface geothermal energy the development potential of wind power, water power, biomass, photovoltaics and deep geothermal energy has also been calculated for Augsburg with the help of GIS methods. Table 1 shows the results of the analysis in MWh per anno.

The enormous potential of deep geothermal energy is grayed out and not included in the sum because it is uncertain yet if technological progress will make it possible to gain that energy profitably.

Wind power plays a minor role in Augsburg as the area is densely populated and the average wind speed

Table 1. Summary of energy potentials depending on technology [3]

Renewable energy resource	Electricity (MWh)	Heat (MWh)
Wind power	10.718	–
Water power	89.164	–
Biomass	89.399	127.714
Photovoltaics	288.383	–
Near-surface geothermal energy	–	428.342
Deep geothermal energy	$2,80 \cdot 10^8$	$4,17 \cdot 10^8$
Sum	477.664	556.056

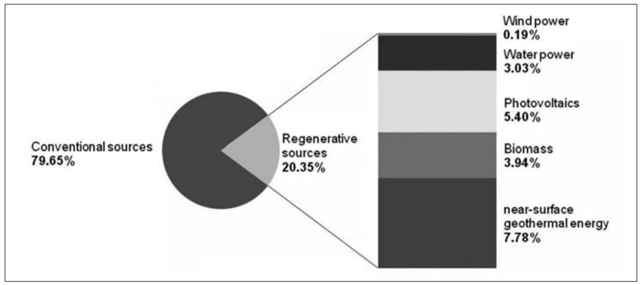

Fig. 2. Share of renewable energies [3]

is quite low. There is only one suitable area where two wind energy plants can be installed. With a supposed hub height of 140 meters the 3 MW generators can produce energy for 3.000 average households. The natural water power potential in Augsburg is huge and has contributed to the economic development of the city since the Middle Ages. Today most of the fitting locations for hydropower plants are already occupied and only critical sites e.g. in conservation areas still remain. In the municipal area of Augsburg there are about 8.500 acres of wood land and about 10.000 acres of farming and grass land. This leads to a huge biomass potential that can be fired in the already existing combined heat and power plant. Within Germany Augsburg is one of the best locations for the utilization of solar energy because of an average global solar radiation of 1.165 kWh per square meter. The potential on the entire roof area together with ground-mounted systems is the most significant entry under the electricity column (Fig. 2).

When adding the development potential to the renewable energies that have already been installed a coverage rate of over 20 percent can be reached in grid-based heat and electricity supply. For a city this is quite a good result considering that the whole potential derives from the densely populated municipal area with so many competing uses. Therefore the need to exploit new technologies for urban energy supply is obvious; the challenge is their integration into urban landscape.

4. New technologies of regenerative urban energy production

4.1. Urban wind turbines

Modern multi-megawatt wind turbines can hardly be integrated in cities because of noise emissions, shadow flicker and security restrictions. But small scale turbines especially designed for urban conditions make it possible to use the city's wind potential on exposed locations. Mostly systems with vertical rotation axes are used for urban wind turbines because they offer a few advantages in comparison to conventional horizontal systems: they can be used under weak wind conditions due to a low start-up speed; tracking the wind direction is not necessary; they produce very little noise emissions and shadow flicker [4]. The most difficult part for urban wind power is to find a suitable installation site that is high enough to reach strong and constant winds and simultaneously offers a bearing roof construction. Historical and heterogeneous roofs should be avoided to prevent a negative effect on the cityscape.

The British company Quiet Revolution has already proved practical feasibility with a six kW vertical wind turbine with an overall height of five meters. The rotor blades are made of carbon fibre and all moving parts are designed to minimize maintenance. The technology is used for example on top of the ANZ Center in Melbourne. A new approach is pursued in Guangzhou, China, where the US-architects Skidmore, Owings and Merill developed a skyscraper with integrated wind turbines. The Pearl River Tower incorporates four funnel shaped openings that catch the wind and increase its speed due to the reducing diameter leading to the turbines. By the use of wind power the skyscraper produces approximately one million kWh per anno [5].

4.2. Asphalt solar collectors

It is a well-known everyday phenomenon that asphalt surfaces are heated up on sunny days. The dark and rough structure leads to an almost complete absorption of the incoming sunlight. Especially cities with a multitude of tarred streets and places could use this potential to increase the urban energy production. The British-Dutch company Invisible Heating Systems (IHS) developed a system for heating and cooling buildings. It works with two separated natural aquifers, one used as a cold reservoir in summer and the other as a warm reservoir in winter. In wintermode a heat pump brings the temperature of the warm source up to a level that can be used for heating the building. After the water passed the heat pump and leaves the building it is still warm enough to keep the road free of ice and snow. During that process it cools down and feeds the cold source used in summertime for air conditioning. Referring to IHS 270 kWh can be gained out of one square meter of asphalt per anno [6]. At the Worcester Polytechnic Institute in the United States the technology is brought one step further. With the help of a thermoelectric generator it is possible to generate electricity on streets and places. The generator uses the Seebeck effect that explains the formation of voltage between two contacts of conductive materials when they differ in temperature. A major benefit of the systems is that it can produce energy even after sunset because of the characteristic of asphalt to store heat very well. As a positive side effect the technology helps to reduce the urban heat island effect by reducing the temperature of asphalt surfaces [7].

4.3. Drain-water heat recovery

Using warm drain-water for energy recovery is a method that suits perfectly to the urban space. Waste waters from households and industrial enterprises such as the food industry or laundries are available in huge amounts and heat consumers are in the immediate environment. The potential of drain-water recovery can be realized at three different places. Firstly inside the building before the water is discharged into the sewage system, secondly inside the canalization and thirdly at the outlet of a sewage plant. The use inside the canalization has been proven as the most practicable method due to a relative high temperature level and a constant water flow rate. Based on experiences gained through the past years the following minimal requirements emerged: an average water discharge of 15 liters per second, a heat consumer with a demand of 150 kW, a distance less than 300 meters between the source and the consumer [8].

In Straubing, Germany a facility was built that can supply more than 100 apartments with heat from the sewage system. It works with a new procedure using a bypass cycle that separates drain water from process water. A downstream heat exchanger and an electrical compression heat pump ensure that a seasonal performance factor of 4 can be realized which represents a ratio of 4 (gained thermal energy) to 1 (electrical input energy). The energy that drives the heat pump comes from a cogeneration power station located at the local sewage plant, so the whole system is powered by renewable sources. The system easily exceeds the annual demand for heat of the apartments which is about 540.000 MWh. Regarding the economic efficiency it is assumed that the facility will be amortized within 20 years [9].

5. Acceptance of renewable energies in urban space

Public acceptance of renewable energies is particularly required in urban areas because negative side effects concern much more people than in a rural environment. Referring to a survey of TNS Infratest 94 percent of the German population support the expansion of renewable energies [10]. This is contradictory to the fact that almost every renewable energy project is confronted with lawsuits or citizens' initiatives against it. This phenomenon of general acceptance on the one hand and individual animosity on the other hand is described to the point by the word NIMBY – Not In My Backyard. It turned out that the attitude to renewable energies depends highly on the technology that is used. While solar energy is widely accepted, wind and water power were looked at more critically. The lowest level of acceptance is given to biomass, possibly caused by malodor and engine noises. Concepts like heat recovery, near-surface geothermal energy and asphalt solar collectors are almost invisible what makes the integration into the cityscape easier and increases public acceptance.

The most determining fact for the acceptance of renewable energies in the urban space is a harmonious integration into the cityscape. In particular solar energy shapes and reforms significantly the image of many German cities today. So far aesthetic aspects play a minor role when solar rooftops are being planned. As a result the roofscape often appears to be fragmented and arbitrary due to large mounting frames and heterogeneous module types. Building integrated photovoltaics (BIPV) are a solution for that problem. They can be integrated frameless in roofs and facades and take over the function of the buildings' shell like weather protection, fire protection and noise protection. They can be combined with wood, glass or metal whereby they cover a wide range of complex construction projects. Mainly thin film modules are used with BIPV technology. They offer a few advantages like better energy conversion under poor light conditions and lower acquisition costs compared to conventional modules. As a disadvantage they only reach efficiency factors of eight to twelve percent while monocrystalline modules reach efficiency factors up to 20 percent. Thin film modules offer architects and city planners new ways of implementing solar energy into buildings. Used as semi transparent modules they can substitute huge glass facades where they contribute to the energy production as wells as to a sustainable heat and light management.

6. Conclusion

With the help of GIS applications renewable energy potentials can be analysed based on a spatial approach. This is especially advantageous in urban areas where many competing extensive sectors try to find a place of location. GIS provides methods and tools like intersection analysis, weighted overlays, buffer zones and many more that help balance between those competing uses. In addition to that it is possible to locate concrete areas where unoccupied space meets the best natural conditions for renewable energies such as a strong solar radiation, a high wind speed or a constant water flow rate. Combined with mathematical formulas the potential energy production can be quantified and an outlook of urban energy independence can be given as the example of Augsburg shows. It should be underlined that the informative value of a GIS analysis depends strongly on the quality and validity of the input data.

Especially because planning an energy concept is a multi-step, integrated process, a precise analysis is the basis for prospective energy supply in urban space. The realization of those urban energy concepts combines the specific requirements of both geographical and technical approaches. Finally a reliable, well accepted nearby energy production depends on the intelligent use of rare urban space.

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