Realising energy potentials from wastewater by integrating spatial and energy planning

Wastewater treatment plants as regional energy and resource cells offer (thermal) energy from wastewater, which were so far used rarely, and can provide heating and cooling energy in the vicinity of the facility as well as energy for mobility purposes and, therefore, constitute interesting subjects in integrated spatial and energy planning on local and regional levels.

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Abstract

Wastewater treatment plants (WWTPs) demand electricity and thermal energy, but wastewater and sludge treatment also provides several energy outputs, e.g. thermal energy, which was almost unused so far. Via heat extraction from wastewater (effluent) and energy generation from digester gas, diverse existing or future energy supplies for heating and cooling in the surroundings of a WWTP as well as energy demands for mobility purposes can be satisfied. Due to this fact, taking into account spatial contexts will gain importance. Integrated spatial and energy planning enables enhanced utilisation of surplus (thermal) energy from WWTPs as can be derived from experiences in Switzerland with municipal energy structure plans.

Introduction

In addition to their main function, wastewater treatment plants (WWTPs) can be considered as regional energy and resource cells. On the one hand, wastewater and sludge treatment demand electricity and thermal energy (Lindtner 2008). On the other hand, treated wastewater and nutrient containing sludge are outputs of the wastewater and sludge treatment processes. WWTPs operating a digester can provide additional energy outputs (e.g. digester gas, electricity, waste heat). Furthermore, the treated wastewater represents a so far rarely used thermal energy resource (Kretschmer et al. 2014), that can be recovered via heat exchangers and heat pumps. For instance, a heat pump (with a coefficient of performance around 4) could provide 2,2 MW heating energy by cooling down the wastewater of a WWTP with 100 l/s effluent feed around 4 °C (Adelberger 2014).

With regard to an efficient operation of a WWTP, the optimisation of mass and energy flows is an essential precondition. The ratio between energy consumption and production illustrates the self-sufficiency of a WWTP. An estimation of the degree of self-sufficiency for Austrian WWTPs operating anaerobic sludge stabilisation comes to the conclusion that self-sufficiency regarding electric energy can be achieved under optimised conditions. Concerning thermal energy, surplus heat resulting from digester gas processing is available even under average conditions. Taking into account heat extraction from wastewater (effluent), WWTPs represent a significant thermal energy source to meet heat requirements also in the surroundings of the WWTP (Kretschmer et al. 2014).

Potential energy consumers in the vicinity of a WWTP

Generally, the distance to potential energy consumers in the surroundings of a WWTP and missing awareness

Key messages:

- Wastewater treatment plants (WWTPs) are considerable energy-consuming facilities, but also constitute essential sources of energy.
- Treated wastewater represents an up to now rarely used thermal energy resource.
- Surplus thermal energy from WWTPs can meet heating and/or cooling demands in the surroundings of the facility and besides heat and power generation digester gas can be used for mobility purposes.
- Taking into account spatial contexts can contribute to increased utilisation of thermal energy from WWTPs.

and knowledge about this new energy source constitute more important limiting factors for the use of thermal energy from wastewater than the availability of thermal energy at the plant itself (Zach et al. 2012). Therefore, the location of the WWTP determines to a large extent, how an energy surplus can be utilized.

With reference to their spatial contexts, three different types of WWTPs can be distinguished by means of distance between the site itself and surrounding settlement areas: (1) WWTPs within, (2) WWTPs near to and (3) WWTPs far from settlement areas. Depending on the location of the WWTP and the presence of existing or future potential energy consumers with heating and/or cooling demand the following options for the utilisation of surplus (thermal) energy can be determined: (1) of agricultural and forestry purposes and (2) for the purpose of climatisation in settlement areas as well as (3) for mobility purposes.

Heating and cooling demands in agriculture and forestry

According to examples of waste heat recovery documented in literature for other energy sources, thermal energy from wastewater can be applied in agriculture and forestry for dewatering as well as heating and cooling purposes (Gaderer et al. 2007, Schulz et al. 2007, Loibl et al. 2008):

- Dewatering of agricultural and forest products: Quality and suitability for storage of agricultural and forestry products can be raised by means of technical drying processes. Generally, dewatering of wood chips, crops, medicinal or spice plants can be considered. These processes represent heat sinks with heating requirements over varying periods. Whereas dewatering of wood chips can be carried out throughout the year, crops and medicinal or spice plant drying are limited in time depending on harvesting dates.
- Heating and cooling of barns: Climatisation of barns can be considered as another field of application of surplus thermal energy from wastewater. Heating demand exist e.g. in piglet breeding and poultry farming.
- Heating of greenhouses: Greenhouse cultivation of fruits, vegetables and ornamental plants requires heating energy subject to building techniques and different temperature levels for specific types of plants. Thermal energy from wastewater can provide the basic load for the heating system of greenhouses with a certain surplus of heat remaining during the summer.
- Aquaculture: Recirculation aquaculture systems feature heating demands depending on the kind of breeded species (e.g. fish, micro-algae) and their temperature requirements.

Heating and cooling demands in settlement areas

Thermal energy from wastewater can meet residential, commercial and industrial needs for heating (e.g. space heating, hot water) and cooling energy (e.g. air-conditioning). With regard to the provision of heat, between two supply systems can be distinguished (Figure 1). In the first case, the heat pump is located near to the heat exchanger so that the heating medium flows on high temperature level to the energy consumers. In

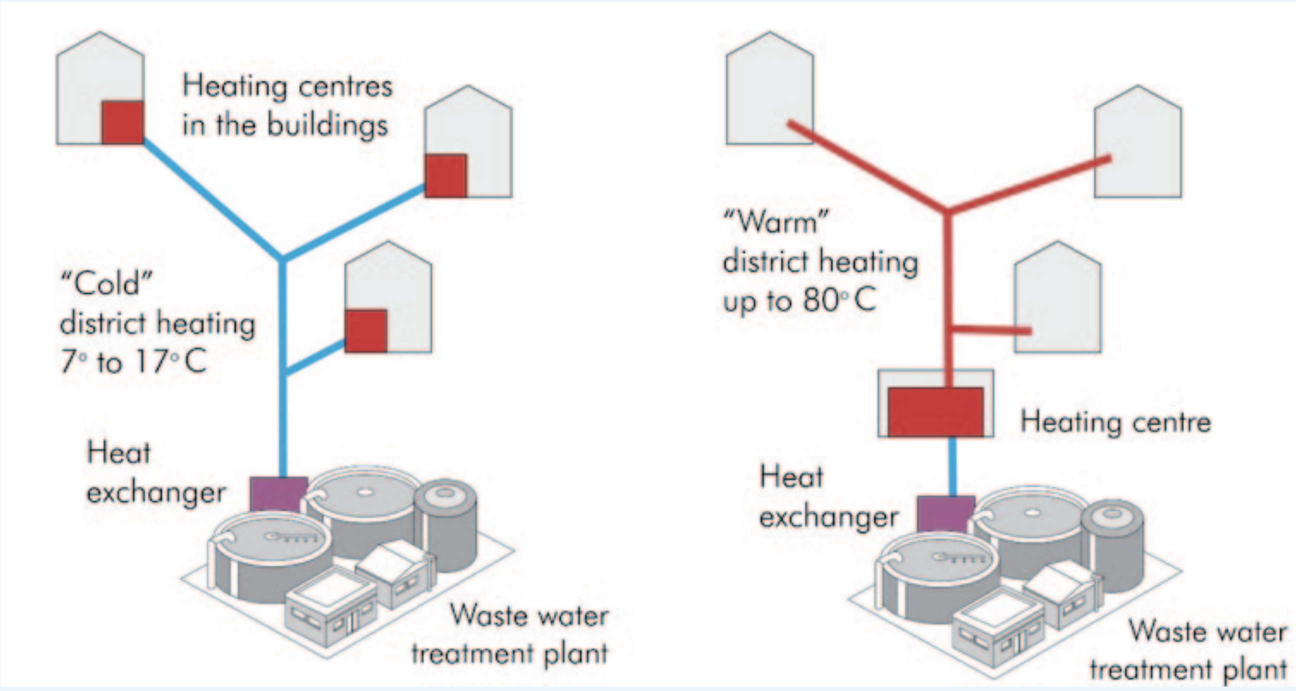

Figure 1: Principle of „cold“ (left) and „warm“ (right) district heating
(DBU, BWP, IEIA 2009; Tracey Saxby, IAN Image Library (http://ian.umces.edu/imagelibrary/),own adaptation)

the second case, the temperature increase is carried out at the location of the energy consumption (Müller et al. 2009, Zach et al. 2012).

- "Warm" district heating: In a "warm" district heating system the heat is produced in a central facility (e.g. heat exchanger and heat pump at the WWTP) and distributed to energy consumers on high temperature level via a district heating grid (Figure 1, right). Therefore, sufficient thermal insulation of the pipes is necessary that results in higher investments in the heat distribution network. Accordingly, warm district heating systems are applied in situations with short distances between heat generation and consumption. At the location of the heat consumption, space savings can be gained as the district heating transfer station features lower space requirements than other heat supply systems (Müller et al. 2009, Zach et al. 2012).
- "Cold" district heating: A "cold" district heating system combines advantages of a conventional district heating system with low heat losses of the pipes as the energy transport is carried out on a low temperature level. Heat is provided decentralized at the location of the consumers via several heat pump units (see figure 1, left). Low temperature differences between heating medium and surroundings minimise heat losses and allow cost-saving pipe networks with little thermal insulation. Therefore, cold district heating is suitable to bridge long distances between energy generation (e.g. via heat exchanger at the WWTP) and heat consumption. Possible extensions of the district heating system can be realised without the need for adaptations of the central heating facility. In addition, cold district heating systems allow for heating demands on different temperature levels within the same grid. (Müller et al. 2009, Zach et al. 2012)
- District cooling: Finally, thermal energy from wastewater can be applied in a district cooling system that distributes chilled water through a pipe network to buildings with cooling demand (e.g. air-conditioning systems). A district cooling system can also be combined with a district heating system. This combination is especially advantageous during the summer with thermal demand merely for domestic hot water (EC 2012).

Digester gas utilisation

In the case of WWTPs operating a digester, the biogas produced at the WWTP offers further possibilities to meet external energy demands. Normally, the energy is primarily used to supply the WWTP with electricity and heat, but surplus energy can also cover external demands. On the one hand, the digester gas can be burned in order to generate (power and) heat. Therefore, combined heat and power plants (CHPP) operate the energy transformation either directly at the WWTP, or the gas can be transported in a pipe to the location of the energy demand, where a CHPP can be operated close to he consumers. On the other hand, the digester gas can be used for mobility purposes as a substitute for natural gas after several treatment steps, e.g. dehumidification, cleaning (mainly hydrogen sulphide removal) and methane enrichment (Kollmann et al. 2014).

Figure 2: WWTP Freistadt, Upper Austria (RHV Freistadt und Umgebung)

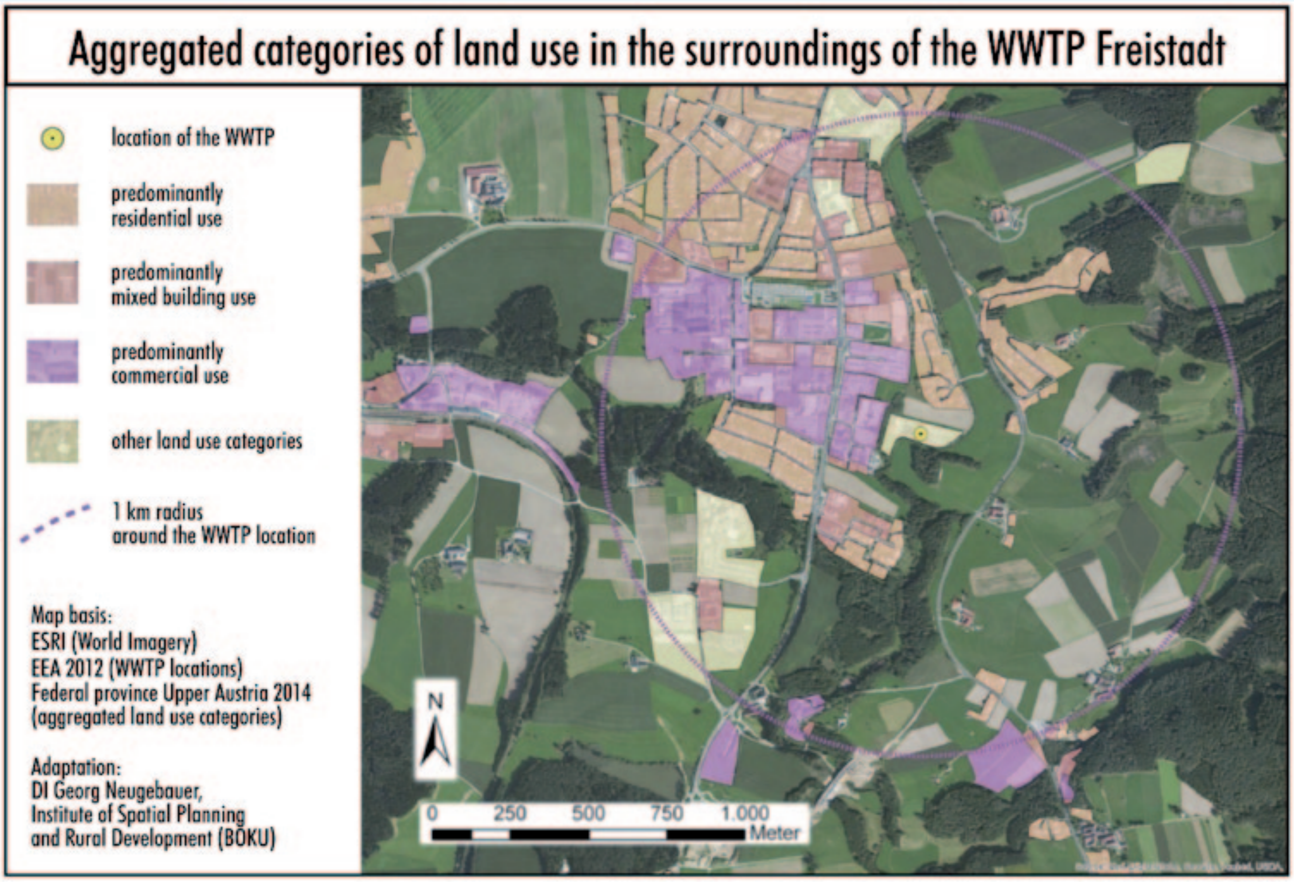

Figure 3: Aggregated categories of land use in the surroundings of the WWTP Freistadt

WWTP Freistadt as a regional energy cell

In the framework of the research project "Integration of Wastewater Infrastructure into Regional Energy Supply Concepts" the possibilities and potentials of different types of WWTPs as regional energy cells are being investigated in several case studies with reference to diverse spatial contexts.

One of these case studies is carried out at the WWTP in Freistadt, Upper Austria (Figure 2) that provides waste water discharge and treatment for the five municipalities Freistadt, Rainbach im Mühlkreis, Lasberg, Grünbach as well as Waldburg having a treatment capacity of 30.000 population equivalents. The site is located in the urban area of the district capital Freistadt (around 7500 inhabitants) with a compact settlement structure and, therefore, shows high potentials with regard to existing and future energy consumers. Figure 3 illustrates the current land use in the surroundings of the WWTP Freistadt on the basis of four aggregated categories of building use.

In the vicinity of the WWTP, mainly commercial areas and the regional hospital generate demand for heating and cooling energy. Additionally, further commercial areas are being developed along the new expressway S10 (Mühlviertler Schnellstraße) at a distance of about 1,5 km from the site. The current research work, therefore, will reveal the potentials for thermal surplus energy utilisation from wastewater that may cover a considerable part of the heating and cooling demand in the surroundings of the WWTP Freistadt.

The heat demand in the vicinity of the WWTP (including future commercial demands) will be shaped by applying the tool "Energiezonenplanung" (energy zone mapping). The tool was created in the framework of the research project "PlanVision" (Stöglehner et al. 2011) and allows the determination and visualisation of the heat demand, modelling energy saving potentials and, finally, analysing the feasibility of a district heating system.

Matching energy demand and supply via integrated spatial and energy planning

Spatial structures as well as spatial planning decisions have major impacts on the energy demand on the one hand and the availability of renewable energy resources on the other hand (Stöglehner et al. 2011). Due to structural energy efficiency (e.g. support of efficient use of energy via grid-bound energy sources) spatial planning can contribute to the reduction of energy consumption. The supply of renewable energy sources can be supported, as renewable resources are protected and adequate land areas for renewable energy generation are kept free from conflicting land uses.

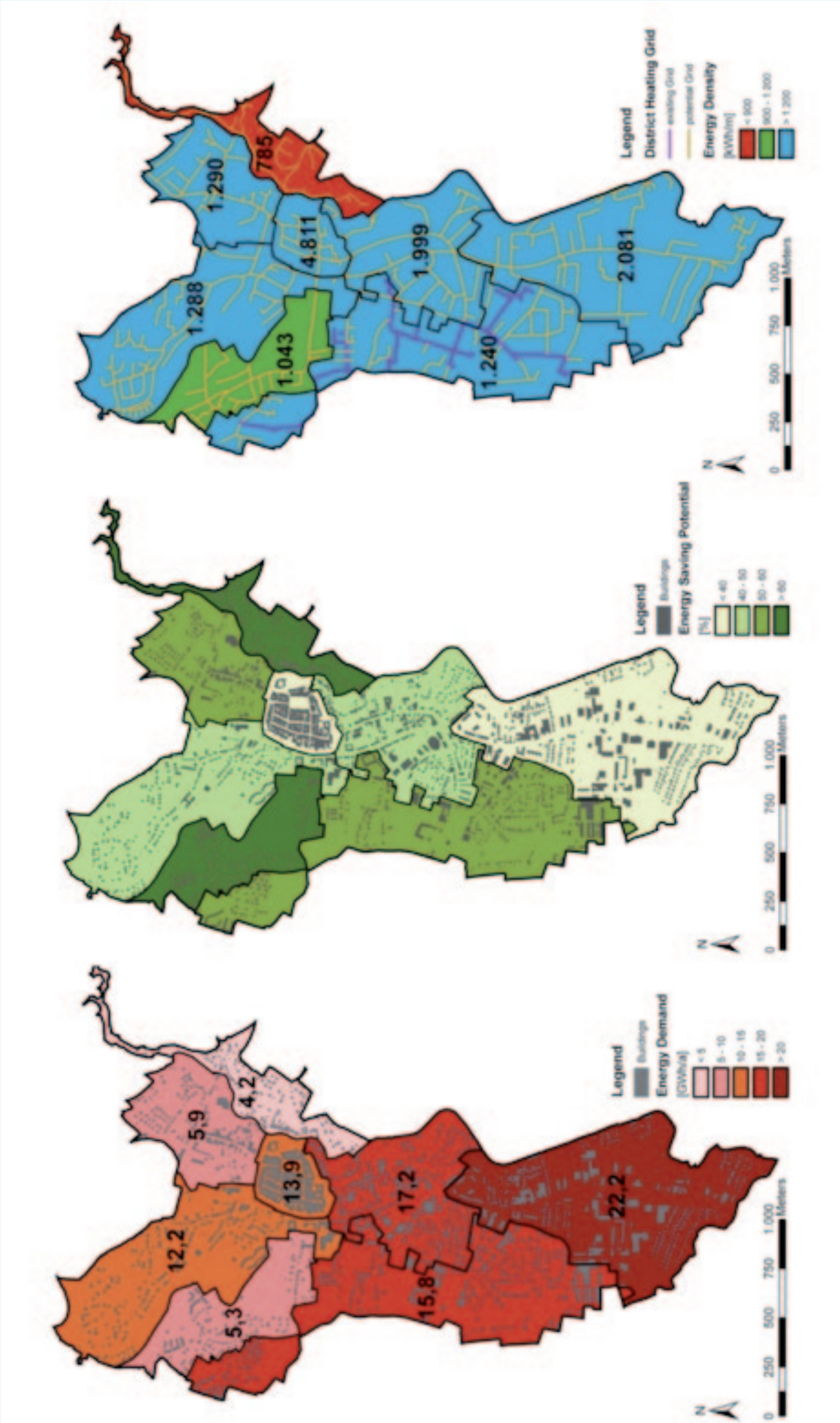

Figure 4: Energy zone mapping Freistadt as basis for the local development concept (Stöglehner et al. 2011)

Taking this context into account, an expert group for the implementation of the Austrian Spatial Development Concept in the field of „Integrated spatial and energy planning“ created the following definition: “Integrated spatial and energy planning represents an integral part of spatial planning that comprehensively addresses the spatial dimensions of energy consumption and energy supply”. Accordingly, two key objectives were elaborated addressing the spatial dimensions of energy consumption and energy supply (Stöglehner et al. 2014):

1. Preserve and activate spatial potentials for energy generation from renewable energy resources in sufficient and affordable extents
2. Maintain and improve spatial structures, that enable energy-saving and energy-efficient lifestyles and economic habits

These objectives were concretised in several fields of action, where integrated spatial and energy planning can develop its effectiveness. In the context of WWTPs, interlinking unused energy potentials (e.g. thermal energy from wastewater) and energy consumers via grid-bound solutions can lead to increasing energy efficiency by using a maximum of waste heat in energy cascades.
An initial step in this direction can be data acquisition on unused energy sources (e.g. waste heat from energy generation, industry or wastewater treatment infrastructure) and energy consumers as well as their spatial distribution. In this regard, Swiss cantons and municipalities can draw on cantonal and municipal energy structure plans that are intended to analyse the energy supply and identify strategies to optimise the use of localised waste heat and renewable energy sources (Knüsel 2011). For instance, the guidance on municipal energy structure plans in the canton Graubünden sets out priorities for the use of energy in the sense of a ranking list (ARE / AEV 2009). The top priority is given to localised high-grade waste heat (e.g. waste incineration, long-term available heat from industrial and commercial sites) followed by localised low-grade waste and ambient heat (e.g. wastewater treatment plants, heat recovery from water bodies, deep geothermics) and in the third place renewable energy sources (e.g. biomass, wood, near-surface geothermics). Fossil energy sources are situated at the bottom of the ranking, whereby fossil grid-bound energy sources (gas) are prioritised over free applicable fossil energy (fuel oil).

Experiences in Switzerland over many years have shown that municipal energy structure plans are powerful instruments in interlinking spatial and energy planning. On this base, several projects for the use of thermal energy recovered from wastewater have been initiated.

The tool “Energiezonenplanung” (energy zone mapping) (Stoeglehner et al. 2011) provides decision support for integrated spatial and energy planning on the municipal level. The tool enables a zonal analysis of the current energy demand and an estimation of future demands according to energy saving and urban development scenarios. Subsequently, the tool provides an analysis of the feasibility of a grid-bound heating supply. In the framework of the research Project “PlanVision” (Stoeglehner et al. 2011), the tool was applied for the municipality of Freistadt considering eight energy zones. Figure 4 illustrates the results for the current energy demand (left), a future demand based on spatially differentiated energy savings (centre) and the derived energy densities (right) as prerequisites for a cost-efficient operation of a district heating system.

Based on these results, an optimal district heating supply system for the territory of the municipality Freistadt was designed. This network served as a basis for the district heating priority and supply areas that the municipality zoned and enacted in the framework of its local development concept in order to enhance spatial development in these areas. Subsequently, a second biomass district heating plant was established in November 2012.

Combining Swiss experiences in the implementation of energy structure plans in combination with the energy zone mapping tool, Austrian municipalities have the possibility to enact “communal energy concepts” as an integral part of the local development concept (Stöglehner et al. 2014). To date such energy concepts as part of the local development concept are intended only in the federal province of Styria, with little content requirements. In other federal provinces specifications in this regard can be made within infrastructure concepts.

Conclusions

A well-founded examination with potentials of localised waste heat and renewable energy sources by interlinking spatial and energy planning leads to increased quality of conventional energy concepts and can support the recovery of by now unused energy potentials.

As wastewater effluent is discharged continuously from a WWTP, thermal energy recovered from the wastewater is steadily available. Therefore, meeting steady energy demands and/or combining time-limited energy demands, as well as satisfying both heating and cooling demands can ensure the optimum utilisation of this energy source.

The application of energy from wastewater treatment can be considered as a valuable contribution to a sustainable regional energy supply. Energy from wastewater treatment results in energy savings as conventional fossil energy sources are substituted with the consequence of reduced CO2 emissions. Introducing spatial analysis in strategy formation can help decision-makers to establish WWTPs as local and regional energy cells.

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