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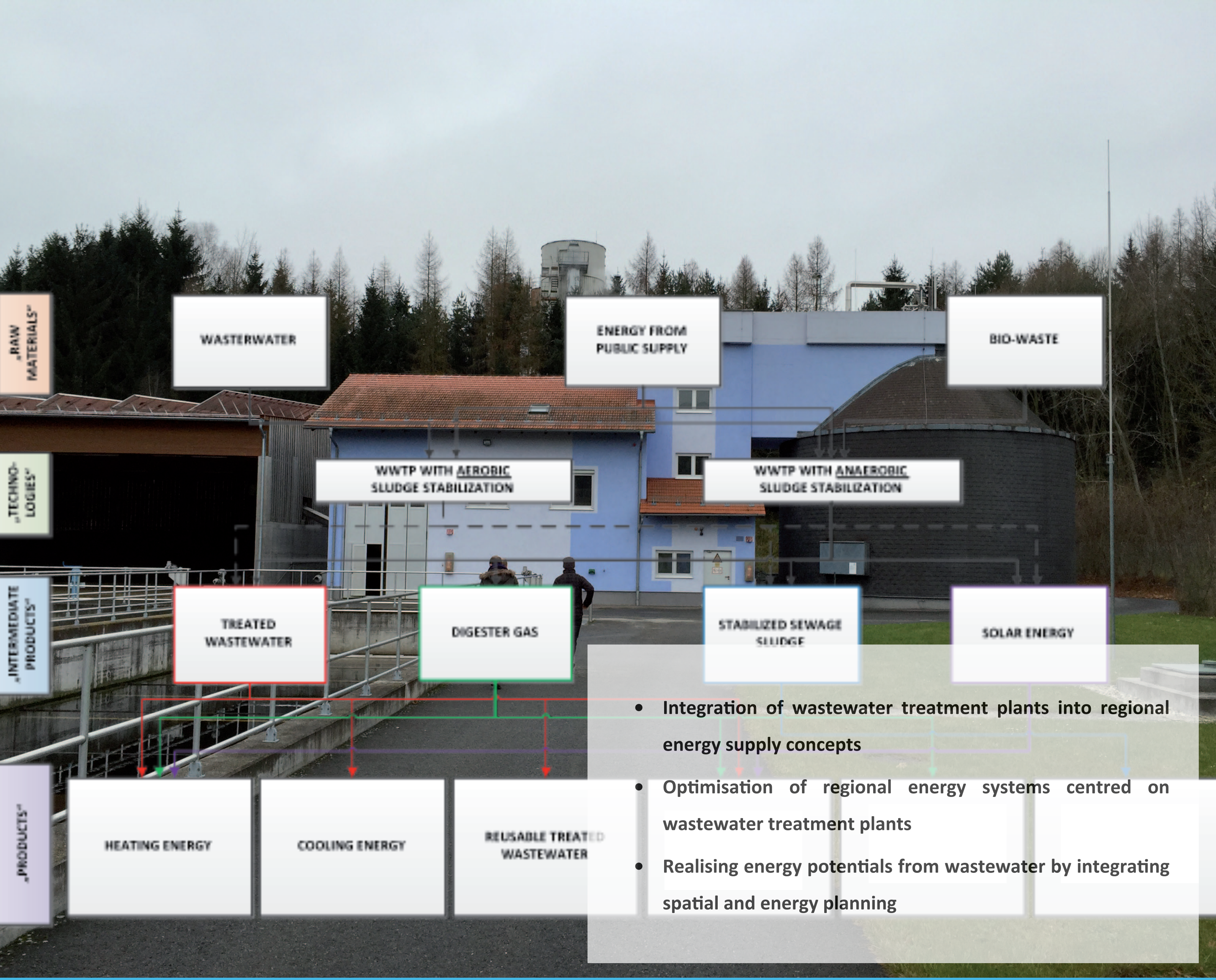

- **Integration of wastewater treatment plants into regional energy supply concepts**
- **Optimisation of regional energy systems centred on wastewater treatment plants**
- **Realising energy potentials from wastewater by integrating spatial and energy planning**

Energy/heat recovery

partner of:
sustainable sanitation alliance

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Sustainable Sanitation Practice (SSP) aims to make available high quality information on practical experiences with sustainable sanitation systems. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP targets people that are interested in sustainable sanitation systems and the practical approach to it. • Articles are published after blind review only. • Sustainable Sanitation Practice is published quarterly. It is available for free on www.ecosan.at/ssp.

Sustainable Sanitation Practice (SSP) hat zum Ziel praxisrelevante Information in hoher Qualität im Zusammenhang mit „sustainable sanitation" bereit zu stellen. „sustainable" also nachhaltig ist ein Sanitärsystem für SSP wenn es wirtschaftlich machbar, soziokulturell akzeptiert, technisch als auch institutionell angemessen ist und die Umwelt und deren Ressourcen schützt. Diese Ansicht harmoniert mit SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP richtet sich an Personen, die sich für die praktische Umsetzung von „sustainable sanitation" interessieren. • Artikel werden nur nach einer Begutachtung veröffentlicht. • Sustainable Sanitation Practice erscheint vierteljährlich, kostenlos unter: www.ecosan.at/ssp.

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Publisher: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • chairperson: Günter Langergraber • website: http://www.ecosan.at/ • scope: EcoSan Club was funded as a non profit association in 2002 by a group of people active in research and development as well as planning and consultancy in the field of sanitation. The underlying aim is the realisation of ecological concepts to close material cycles in settlements.

Medieninhaber: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • Obmann: Günter Langergraber • Gegenstand des Vereins: Der EcoSan Club wurde 2002 als gemeinnütziger Verein von einer Gruppe von Personen gegründet, die in Forschung, Entwicklung, Planung und Beratung in der Siedlungshygiene - Sammlung, Behandlung oder Beseitigung flüssiger und fester Abfälle aus Siedlungen - tätig waren und sind. Das Ziel des EcoSan Clubs ist die Umsetzung kreislauforientierter Siedlungshygienekonzepte (EcoSan Konzepte) zu fördern, um einen Beitrag zum Schutz der Umwelt zu leisten.

Cover Photo / ***Titelbild***

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Editorial

In many European countries, climate change and the dependency on fossil fuels lead to a search for alternative sources of energy. Wastewater is getting more and more into the focus of discussion. In several European cities installations for heat extraction from wastewater are already in use to heat buildings and to produce domestic hot water. However, it is not only the heat content which makes wastewater a potential future source of energy. “Products” like treated wastewater, digester gas, sewage sludge and the like shall also be seen as resources. They could be reused internally at a wastewater treatment plant as well as in the adjacent infrastructure. This makes the wastewater infrastructure part of the regional energy supply system.

In this issue of SSP three papers related to the Austrian research project “Integration of Wastewater Infrastructure into Regional Energy Supply Concepts” (duration 3 years, from April 2013 until March 2016) are presented. Within the project, different aspects concerning wastewater infrastructure as part of a regional energy supply systems are being investigated. The main contents of the project are as follows:

- Consideration of all types of energies contained in and related to wastewater (heat content in wastewater, digester gas, electric power generation, sewage sludge, etc.).
- Description of all internal and external usage possibilities of energy produced at wastewater treatment plants.
- Estimation of energy potentials available under consideration of energy and land use planning.
- Development of planning and decision support tools for the integration of wastewater treatment plants into regional energy supply systems (energy and land use planning, Process Network Synthesis and Sustainable Process Index)
- Carrying out of different feasibility (case) studies.

The project is coordinated by the Austrian Energy Agency, project partners are University of Natural Resources and Life Sciences, Vienna (BOKU), Graz University of Technology, Austrian Institute of Technology, InfraWatt and Ochsner Heat Pumps. Further information can be retrieved from www.abwasserenergie.at (currently only available in German language).

The three papers published in this issue address three main topics of the project work:

1. The paper “Integration of wastewater treatment plants into regional energy supply concepts” by Kretschmer et al, presents a brief overview on the different aspects of energy consumption and production at wastewater treatment plants and some basic ideas on the approach of integrating wastewater treatment plants into regional energy supply concepts.
2. The paper “Optimisation of regional energy systems centred on wastewater treatment plants” by Kindermann and Kollmann describes the methodologies being used to detect the best economic and ecological way to distribute the available energy. The economic optimisation of the energy system is performed by the Process Network Synthesis (PNS) and the ecological evaluation by the Sustainable Process Index (SPI). Furthermore, the article contains a description of a real life case study.
3. The paper “Realising energy potentials from wastewater by integrating spatial and energy planning” by Neugebauer and Stoeglehner, on the one hand, gives an overview on potential heating and cooling demands (consumers) in the vicinity of wastewater treatment plants. On the other hand it describes the application of integrated spatial and energy planning to match energy demand and supply.

Florian Kretschmer and Thomas Ertl (guest editors)
Institute of Sanitary Engineering, BOKU University

Content

Integration of Wastewater Treatment Plants into Regional Energy Supply Concepts

Wastewater treatment plants do not only treat wastewater but can also provide different types of energy and other resources.

Authors: Florian Kretschmer, Norbert Weissenbacher, Thomas Ertl

Abstract

The main purposes of sewer systems and wastewater treatment plants are to ensure public health and safety as well as environmental protection. To achieve this, different types of energy are consumed. But wastewater treatment plants do not only consume but also produce energy (and other resources). The produced energy can be reused internally to increase the energetic self-sufficiency of a treatment plant and/or externally to supply the adjacent areas and infrastructures. In the latter case the related wastewater treatment plant could be considered as a regional energy cell. This paper will give a brief overview on the different aspects of energy consumption and production at wastewater treatment plants and some basic ideas on the approach of integrating wastewater treatment plants into regional energy supply concepts.

Introduction

Climate change and energy sustainability is one major target of the current growth and jobs strategy of the European Union. By 2020 greenhouse gas emissions shall be 20 % lower than 1990, 20 % of energy consumed shall come from renewables and energy efficiency shall be increased by 20 % (European Commission, 2014).

Heat recovery from wastewater can make a contribution to reaching the targets. Heat exchangers extract thermal energy from wastewater. Heat pumps then bring the extracted energy even to a higher level of temperature. The heat gained can be used for the heating of buildings or even for the production of hot water. Depending on the technical equipment heat pumps are also able to produce cold for the cooling of buildings. Figure 1 gives an overview of the basic concept for heat recovery from wastewater.

Current Austrian research work shows that from a theoretical point of view up to 10 % of the households could be supplied with heat from wastewater. This number is consistent with experiences from Germany and Switzerland. However, it is assumed that only about one third of the potential heat recovery is economically feasible (Project Consortium “Energie aus Abwasser”, 2012).

The main purposes of sewer systems and wastewater treatment plants are public health and safety as well as environmental protection. Thermal use of wastewater may in no case impede these functionalities. In spite of inbuilt elements trouble-free sewer operation and maintenance must be possible at all times. And heat extraction from wastewater may not have any negative effects on the treatment efficiency of a wastewater treatment plant.

Negative impacts on the wastewater infrastructure can be avoided, if heat extraction is located in the effluent of a wastewater treatment plant. Other advantages of this extraction site are high and steady discharge quantities and increased water quality (treated instead of raw wastewater). One major disadvantage of this extraction site can be its remoteness and thus long supply distances to possible energy consumers.

Key messages:

- Wastewater treatment plants do not only treat wastewater but produce different types of energy and resources.
- The energy and resources produced may not only be reused internally but also externally.
- From an internal point of view the reuse of produced energy can help to increase energetic self-sufficiency of a wastewater treatment plant.
- From an external point of view wastewater treatment plants can be integrated into regional energy supply concepts serving as regional energy cells.
- Wastewater shall not be considered as waste but as a resource.

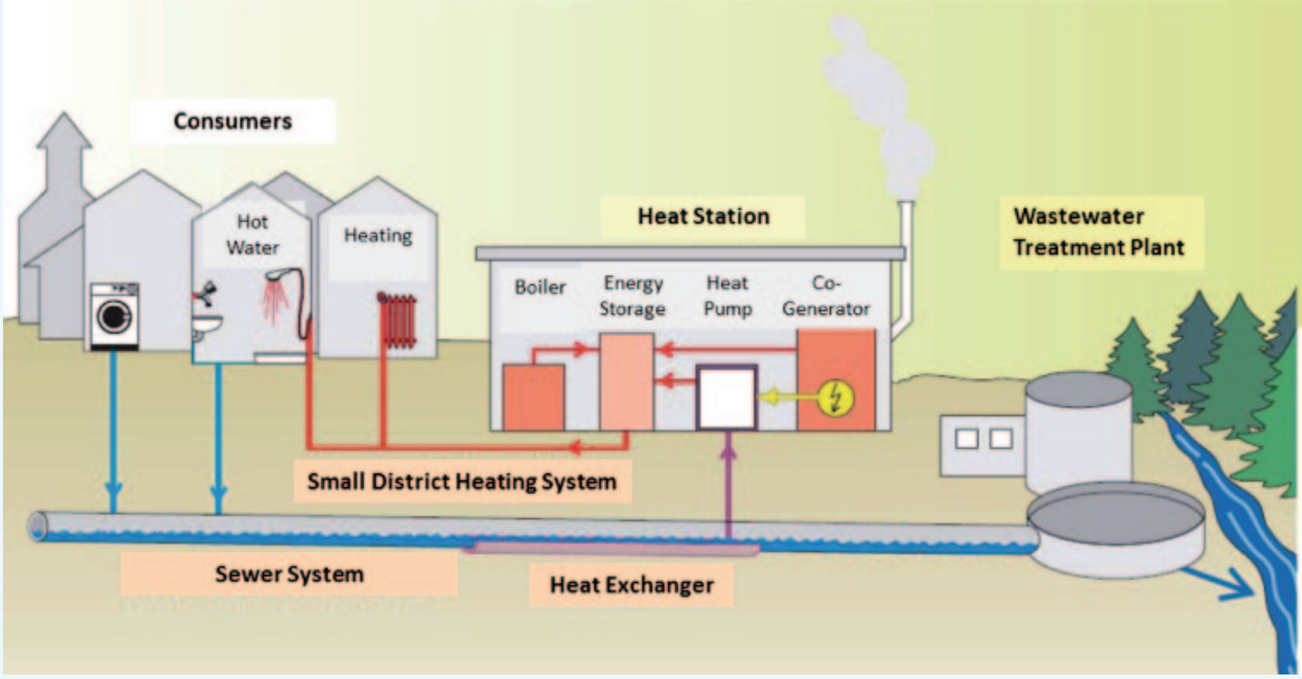

Figure 1: Basic concept for heat recovery from wastewater (Mueller et al., 2009, adapted)

In order to make the most efficient use of the heat from wastewater possible consumers should be brought into closer distance to wastewater treatment plants. This can be achieved be means of regional land use and energy planning (definition of energy zones, identification of priority development areas, etc.). The targeted location of companies and industries with high heat demand in close range to wastewater treatment plants can be seen as a first step towards the integration of wastewater infrastructure into regional energy supply systems.

Wastewater treatment plants may not only deliver thermal energy extracted from wastewater but different types of energies and resources are being produced. However, wastewater treatment plants also consume different types of energies and resources. From a sustainable sanitation and energy point of view wastewater treatment plants may therefore be viewed in a larger context: Wastewater treatment plants do not only treat wastewater but could also serve as regional energy cells.

Wastewater treatment plants and regional energy supply

On a macroeconomic level (national economy of a country) the energy demand of wastewater treatment plants is only of little significance. Anyway, on microeconomic level (business economy of a community) it is considered to be a major cost driver.

From an economic point of view two aspects are imperative regarding the wastewater and energy context: One the one hand the energy demand of a wastewater treatment plant shall be minimised. On the other hand the production of reusable and processible energies shall be maximised. Both aspects contribute to increase energetic self-sufficiency of wastewater treatment plants. Internal reuse of produced energy can be seen as a key factor.

However, surplus energy as well as certain resources cannot be used at a wastewater treatment plant (excess heat, stabilized sludge, etc.). In this case an external use of energy and resources in the surrounding area and infrastructure shall be striven. Hereby the technical and economic feasibility always depend on different local boundary conditions (wastewater treatment performance, infrastructural constraints, existing energy suppliers, energy prices, available energy demand, legal constraints, etc.).

Thus the integration of wastewater treatment plants into regional energy supply systems comprises three different aspects:

- Energetic optimisation of the wastewater treatment plant: Efficient use of electrical and thermal energy, increase of energy production output, internal reuse, etc.
- Targeted reuse of surplus energy and resources in the vicinity of the treatment plant: Identification of current and future energy demands, coordination with community and existing energy suppliers, etc.
- Optimisation of internal and external energy and resource flows: Identification of most appropriate points of energy and resource consumption from economic and ecologic points of view (inside and outside of a wastewater treatment plant)

Energy and resource consumption, production and reuse

Prior to an energetic optimisation of a wastewater treatment plant the major energy consumers have to be defined. At common wastewater treatment plants (activated sludge systems) these are the following (Lindtner, 2008):

- Regarding electrical energy
  - Inflow pumping station
  - Mechanical pre-treatment (automated screen and grit chamber cleaning, etc.)
  - Biological treatment (aeration, stirring, sludge recirculation, etc.)
  - Sludge treatment (mechanical sludge thickening, anaerobic digestion, dewatering, etc.)
  - Infrastructure (power supply of operational buildings and offices, electric lightning, heating and cooling of operational buildings and offices, etc.)
- Regarding thermal energy
  - Sludge treatment (sludge preheating, digester heating, heat loss compensation, etc.)
  - Infrastructure (heating of operational buildings and offices, hot water production, etc.)

Additionally, other resources as for instance nutrients (carbon, nitrogen, phosphorus, etc.) could also be considered as being “consumed” during the treatment process.

On the production side of a common wastewater treatment plant, the following intermediate products could be incurred:

- Treated wastewater
- Sludge containing nutrients (phosphorus, etc.)
- Digester gas (only at wastewater treatment plants with anaerobic sludge treatment)
- Solar energy (only with appropriate technical equipment)

Depending on the availability and the further “processing” of intermediate products different types of energies and resources could finally be provided by common wastewater treatment plants (activated sludge systems):

- Electrical energy
  - Electricity (production through digester gas powered co-generator or micro turbine, through hydroelectric turbine in the effluent, through photovoltaic)
- Thermal energy
  - Low temperature heat (production through wastewater heat exchange or solar heat)
  - High temperature heat (production through digester gas combustion or cogeneration)
  - Cooling (production through wastewater heat exchange)
- Resources
  - Treated wastewater
  - Subsequently processible stabilized sludge

Figure 2 gives an overview on the connections between energy and resources consumption and production at wastewater treatment plants. “Raw materials” consumed are wastewater (including nutrients, etc.), energy from public supply (electricity, natural gas, etc.) and occasionally bio-waste as a co-substrate for anaerobic sludge treatment. The goal of cogenerating bio-waste together with sewage sludge is to increase digester gas production.

Depending on the type of sludge stabilisation two different kinds of treatment “technologies” are distinguished (aerobic and anaerobic stabilisation).

The “intermediate products” can be further processed to final “products” mentioned above (heat, cold, reusable water, electricity, gas, sewage sludge).

The possible applications of heat, cold and electricity inside and outside of a wastewater treatment plant (internal and external use) are obvious. Energy from public supply systems could partly be substituted. The reuse of wastewater does not play an important role in Austria. The treated wastewater might be used internally for the cleaning of basins or the like. The digester gas can be used for heat and power production (co-generation, etc.) at the wastewater treatment plant itself or in remote “satellite” heat and power plants. In this case both plants would by connected by a digester gas pipeline. Alternatively pre-treated digester gas could also be used as a green-house-neutral fuel for cars and buses (e. g. public buses in the Swiss (capital-) city of Bern). Common application possibilities of sewage sludge are reuse in agriculture and incineration. In agriculture sewage sludge serves as a natural fertiliser and improvement for soil structure. Incineration of sludge delivers additional excess heat. The produced thermal energy can be used for heat supply or electric power generation. The ashes of mono-incinerated sludge can serve as a future source for the recovery of nutrients or other contents (phosphorus, etc.).

Energetic optimisation of wastewater treatment plants

Energetic optimisation of wastewater treatment plants on the one hand means reduction of electrical and thermal energy consumption. On the other hand the production of reusable and/or processible products has to be increased. As mentioned before, there are several measures which can make their contribution to the rise of energetic outputs.

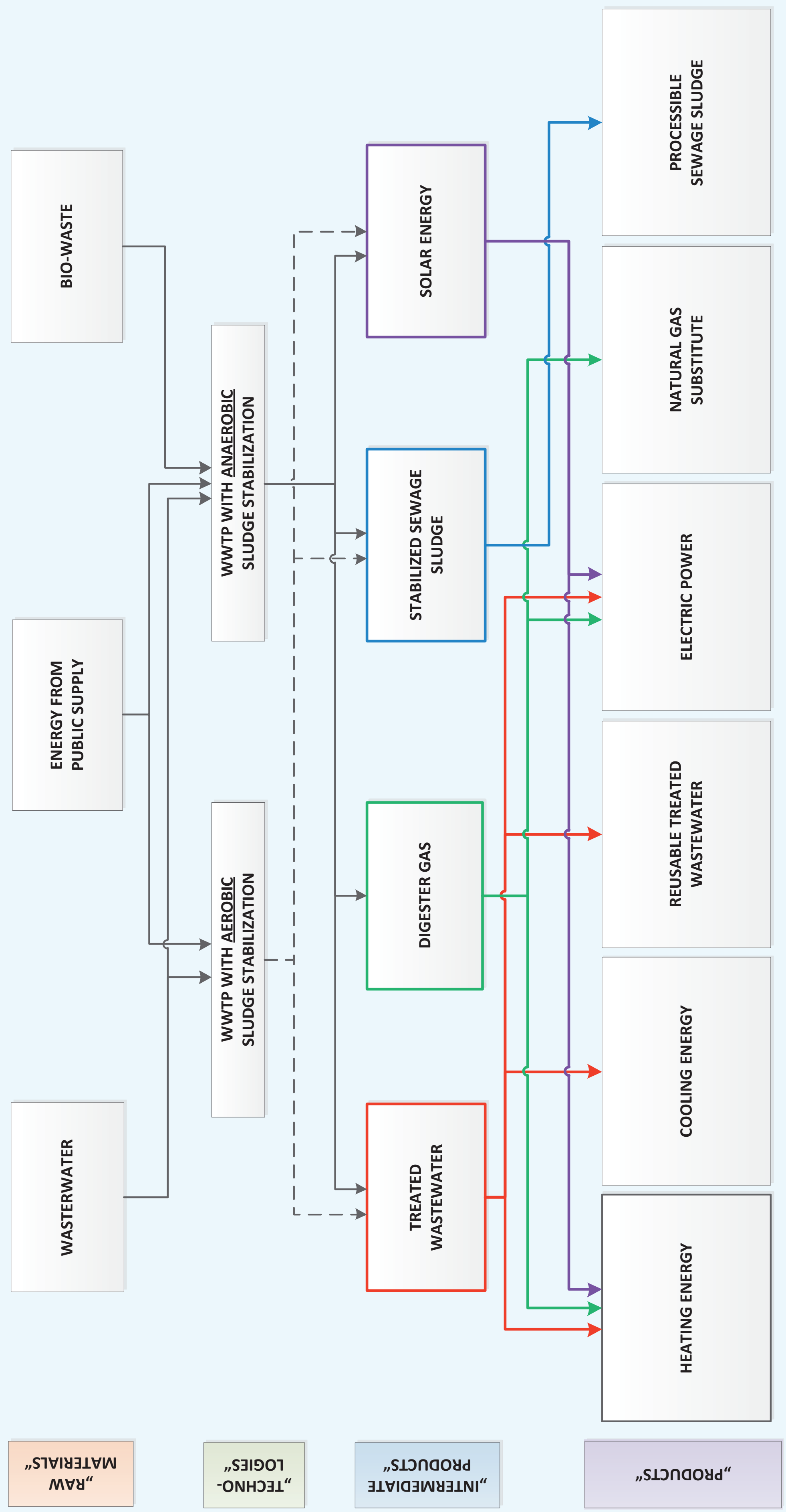

Figure 2: Energy and resource consumption and production at WWTPs

According to Hofmann (2012) some of the main consumers of electric energy are:

- Aeration (by far the biggest consumer)
- Stirring
- Inflow pumping
- sludge recirculation

The consumption of electrical energy can be reduced by the exchange of out-dated (aeration) technologies, the reduction of infiltration water, the shift from aerobic to anaerobic sludge stabilisation and the like.

Thermal energy is mainly used for the pre-heating of the sludge as well as for the heating of the digester tower and the compensation of heat loss (only at treatment plants with anaerobic sludge stabilisation). Thermal energy for heating other operational buildings or the like is of minor importance. Heat loss can generally be reduced by appropriate thermal insulation of related buildings and pipe networks.

Table 1 gives an overview on standard range of energy consumption and production at common wastewater treatment plants per population equivalent (PE) and year in Austria and shows that production of electric energy from digester gas usually will not be enough to cover electrical energy demands (consumption). For electrical self-sufficiency additional power producing measures seem to be necessary. Regarding self-sufficiency of thermal energy it seems that due to combustion or co-generation of digester gas heat demands can be cover in many cases. From an energetic point of view wastewater treatment plants with anaerobic sludge stabilisation (digestion) have advantages compared to those with simultaneous aerobic stabilisation.

Table 1: Standard ranges of energy consumption and production at wastewater treatment plants (Lindtner, 2008)

	Consumption [kWh/PE*a]	Production* [kWh/PE*a]
Electric energy	20 - 50	10 - 20
Thermal energy	0 - 30	20 - 40

*produced from digester gas

Production of energy at a wastewater treatment plants is traditionally equated with the production of digester gas. The amount of digester gas and thus the amount of electrical and/or thermal energy available can be increased due to co-fermentation (bio-solids, sewage sludge from neighbouring treatment plants, etc.). Additional use of solar energy and hydroelectric turbines in the effluent could also contribute to the increase of energetic output of a wastewater treatment plant and thus to its energetic self-sufficiency.

It is obvious that energetic optimisation must never be made at the expense of the performance of wastewater treatment.

Integration into regional energy supply systems

If an internally optimised wastewater treatment plant could produce a surplus of electrical or thermal energy, it might also serve as a regional energy cell. As mentioned above, this depends on different boundary conditions. On the one hand regional energy and land use planning have to be addressed. On the other hand all relevant energy and resource paths inside the wastewater treatment plant as well as their external interactions with the surrounding infrastructure have to be taken into consideration.

Conclusion

The main function of a wastewater treatment plant is the treatment of wastewater for water pollution control. Therefore different types of energy and resources are needed (heat, electrical power, etc.). However, wastewater treatment plants also produce certain kinds of energy and resources.

The energetic performance of a wastewater treatment plant can be optimised if consumption is minimised and production is maximised. The major energy consumers as well as possibilities to increase the energy output at wastewater treatment plants has been described in this paper.

The aim of an energetic sustainable operation of wastewater treatment plants should be a high grade of self-sufficiency regarding electrical and thermal energy. However, if a wastewater treatment plant could produce surplus energy, it should be integrated into regional energy supply concepts and serve as a regional energy cell.

Wastewater and sewage sludge should not be considered as waste anymore. It seems far more appropriate to be considered as resources.

Acknowledgement

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Optimisation of Regional Energy Systems Centred on Wastewater Treatment Plants

This article discusses local energy systems centred on wastewater treatment plants, optimised by Process Network Synthesis and evaluated ecologically by the Sustainable Process Index.

Authors: Helene Kindermann and René Kollmann

Abstract

In addition to the treatment of wastewater, sewage treatment plants are able to generate energy. On the one hand the energy can be used to cover the in-house demand of the plant and on the other hand surplus energy can be integrated in the local energy system. This article describes the basic ideas of the methodologies being used to detect the best economic and ecological way to distribute the available energy. The economic optimisation of the energy system is performed by the Process Network Synthesis (PNS) and the ecological evaluation by the Sustainable Process Index (SPI). Furthermore the article contains a description of a real life case study.

Key messages:

- Optimising the internal and external energy flows at wastewater treatment plants requires economic and ecologic considerations.
- Process Network Synthesis (PNS) can be used for economic optimisation, whereas the Sustainable Process Index (SPI) can be used for ecological evaluation.
- The concepts are demonstrated using the case study of a wastewater treatment plant treating wastewater of 30‘000 persons

Introduction

An answer to global warming can be to focus on the regional use of renewable resources. Using the infrastructure of an existing wastewater treatment plant for generating energy out of wasted local resources, e.g. the wastewater itself or sewage sludge and gas, can help provide energy in a sustainable way. This is not only helping the climate, it also can also be economically reasonable. This sustainable approach is discussed in this article.

Methods

Process-network synthesis (PNS)

The Process Network Synthesis is an optimisation tool (Friedler et al.; 1992) which may include different technical, environmental, economic and social constraints. It is realised in the software package PNS Studio. Originally the PNS was developed to design chemical processes but it is also suitable to construct and analyse structural alternatives for supply chains (Kalauz et al., 2012), therefore it is applied for the energy supply of wastewater treatment plants in this case study.

The base of a network synthesis is a set of specifications. These specifications consist of the definition of materials, operating units and products. The maximum structure which includes all feasible structures of technologies for the process system is then generated using combinatorial rules. Out of these possibilities the PNS finds optimal structures for a given problem (Friedler et al.; 1992).

To generate the maximum structure for a case study with PNS Studio certain types of information need to be obtained, evaluated and specified. The procedure is as follows:

Step 1: Specification of materials.

The specification of materials involves the differentiation of raw materials and intermediate materials. Raw materials are defined by their type and price. There may also be defined a required as well as a maximum flow. The price for materials follows the convention: If the system has to pay for materials they are assigned positive prices. Intermediate materials are only defined by their type. The amount of intermediates is determined by the calculation.

Step 2: Specification of operating units.

Operating units (technologies) need to be specified by their in- and output flows (materials and energy) as well as investment and operating costs. If technologies already exist, investment costs are not considered. Upper and lower boundaries can be set to limit the capacity of technologies.

Step 3: Specification of products.

Products need to be classified in the same level of detail as materials: type, price and optional a required as well as a maximum flow. There is also a sign convention for products as it is for materials. If it is waste with fee-based disposal their price is negative.

In the case of dealing with wastewater treatment plants additional aspects have to be taken in account:

- Time dependent load and provision: A multi-period model to depict dependences like resource availability (e.g. sun for photovoltaic installations) or product demand (e.g. heat). In this study the year is divided into the following three periods:

  Winter: 1 December – 31 March
  Midterm: 1 April – 31 May plus 1 Oct – 30 Nov
  Summer: 1 June – 30 September

- A static economic depreciation is used with pre-defined operating time spans for different technologies/installations.
- A maximal operating time of 8000 h/y is considered, actual operating times may be subjected to multi-periods optimisation.
- Technologies with different capacities are implemented to take economy of scale into account. This means the PNS can choose e.g. between heat pumps with 660 kW, 460 kW or 210kW heat output.

The maximum structure of a wastewater treatment plant is displayed in Figure 1.

PNS Studio applies an accelerated branch-and-bound (ABB) mathematical optimisation algorithm to find the optimal structure. This algorithm progresses from the product level through the maximum structure up to the raw material level. At each branch the algorithm decides which operating unit should produce a predefined material (Varga et al., 2010). If the optimisation target function is economic, the aim is to identify the least expensive solution structure or to develop the profit to a maximum (Figure 2) (Süle et al.; 2011). The ABB algorithm has, compared to general solvers, one major advantage: in addition to the generations of a global optimum it also generates the n-best suboptimal structures. The variable n is given by the user (Bertok et al., 2013). This allows comparison between feasible structures.

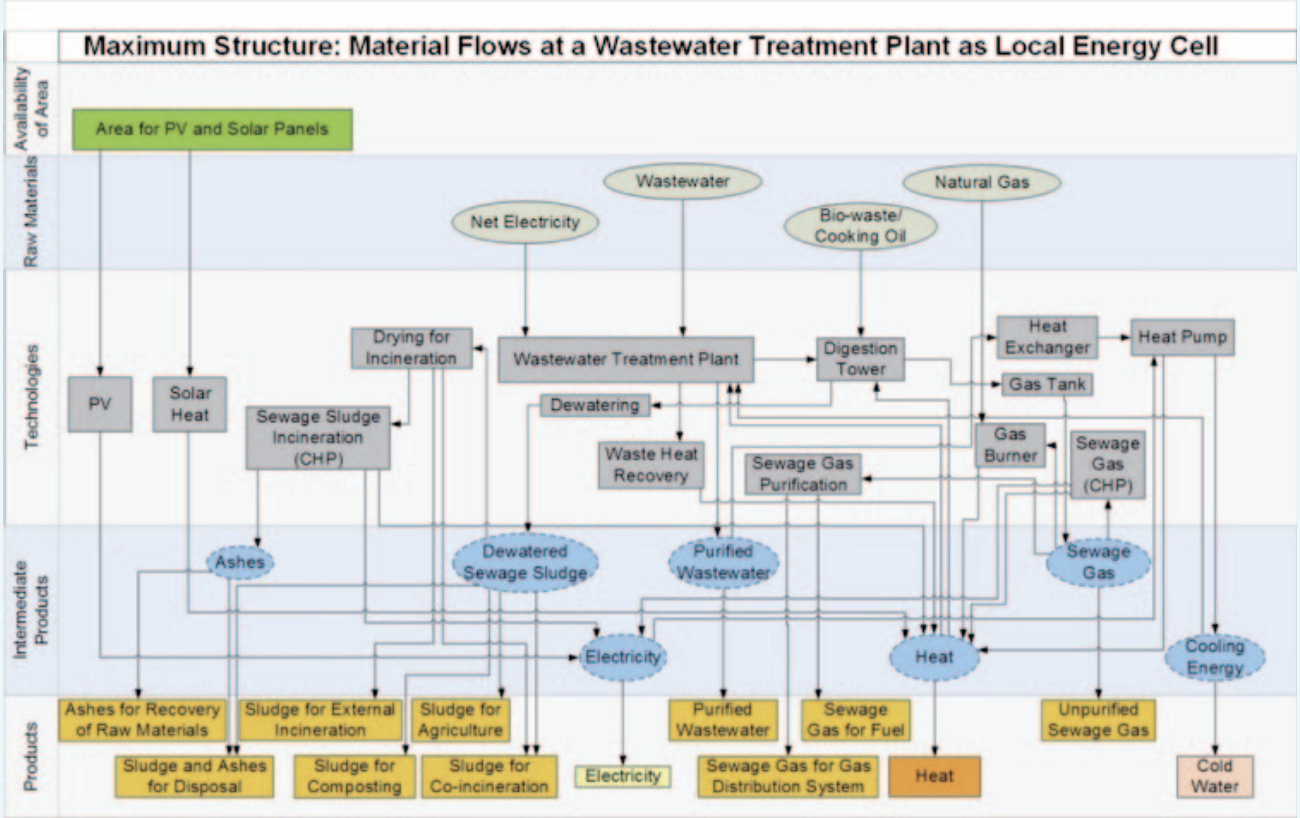

Figure 1: Maximum structure of a wastewater treatment plant with digestion

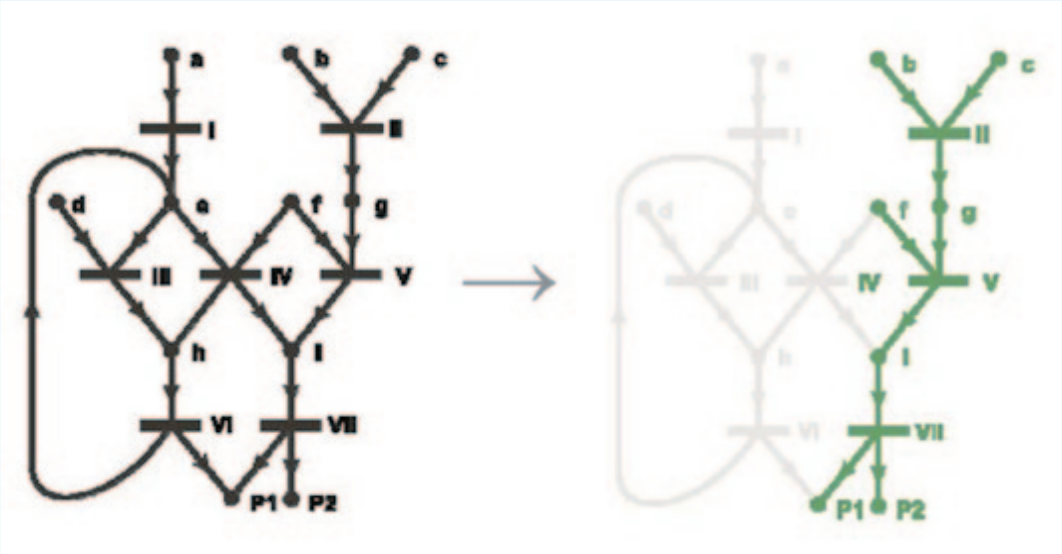

Figure 2: From a maximum structure to an optimum structure (Friedler et al. 1995 adapted)

Sustainable Process Index (SPI)

The Sustainable Process Index (SPI) is a member of the ecological footprint family. It is compatible with the procedure of the life cycle analyses (LCA) described in the EN ISO 14040 (ISO, 2006). Ecological footprints are indicators based on the principle of strong sustainability. They measure human demand for natural income for different production processes and services like food production, mobility, waste disposal, etc. and compare it with Earths capacity to convert natural income (in the form of solar radiation). The Sustainable Process Index follows this approach for the evaluation of environmental impacts of processes, products and services.

The SPI is calculated using material and energy flows extracted from and dissipated to the ecosphere and compares them to natural flows (Krotscheck and Narodoslawsky, 1996). Two main principles govern the calculation to integrate human activities into the ecosphere in a sustainable way:

- Human activities are neither allowed to change the quality nor the quantity of natural material cycles in the long run, e.g. the carbon or nitrogen cycle
- Anthropogenic changes of material flows in and out of the compartment air, soil and water must not exceed the natural variations in quality or quantity

For the comparison between human induced and natural flows, SPI uses the following data for natural systems: sedimentation rate of carbon in oceans, natural concentrations of substances in soil and water, the exchange rates per area unit of volatile substances between forests and atmosphere as well as the local renewal rates for soil and water (Kettl, 2013).

The SPI calculates the ecological footprint from the following partial areas as shown in Figure 3:

- Direct area consumption for infrastructure
- Area consumption for provision of non-renewable resources
- Area consumption for provision of renewable resources
- Area consumption for dissipation/sedimentation fossil carbon
- Area consumption for dissipation of emissions in water
- Area consumption for dissipation of emissions in the soil
- Area consumption for dissipation of emissions in the air

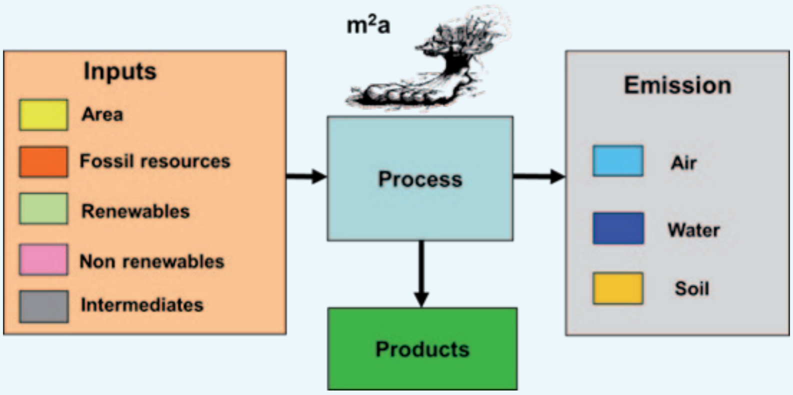

Figure 3: SPI calculation, input and emission flows of a process (SPIonWeb, 2014)

The main advantage of the SPI is the possibility to compare different environmental pressures caused by processes by converting them to one unit, namely area [m²]. In particular it can compare fossil based processes with those on a renewable resource base.

SPIonWeb

For a fast calculation of the Sustainable Process Index a web based software tool SPIonWeb, has been developed at the University of Technology in Graz. This tool is available on http://spionweb.tugraz.at/ as free ware. SPIonWeb can assemble whole life cycles through process chains and process cycles, based on the mass and energy balances of the process. A main database, including processes e.g. for energy production, mobility, chemicals and base substances is implemented in the tool. This helps the user to build life cycles from raw materials to end products (or services) by using existing building blocks. The idea is that users are be able to evaluate the whole life cycle and calculate as results their SPI Footprint, CO$_2$-life-cycle-emissions and Global Worming Potential (GWP) based on the ecological inventory of just the process he focusses on, using database processes for the pre-chain. These results can help the user to find the most environmentally friendly solution when it comes to production or offering services (Kettl , 2013).

Further information on SPI and different ecological footprint calculators is available on http://www.fussabdrucksrechner.at.

Case Study

For the current research project three Austrian wastewater treatment plants were selected to represent the different roles of a plant as a local energy cell. These roles depend on the size of the plant as well as the geographical context e.g. possible energy consumers. The case studies are focusing on an economic optimisation of the energy system centred on wastewater treatment plants with PNS Studio. In addition to that, an ecological evaluation, using the SPI methods will be performed. The aim is to cover the in-house heat demand of the plant and to supply local energy systems with energy in an economic and ecological way.

In this article the first steps regarding the case study of a city with 7500 inhabitants in the Austrian province of Upper Austria is briefly explained. The wastewater treatment plant corresponds to a population equivalent of 30000. First of all local stakeholders like economic, social, political and administrative actors were informed in a workshop about the project. In an ensuing discussion conceivable energy customers and future energy demands have been defined. The heat supply of a local hospital and an industrial area, which is planned to be built in the vicinity of the wastewater

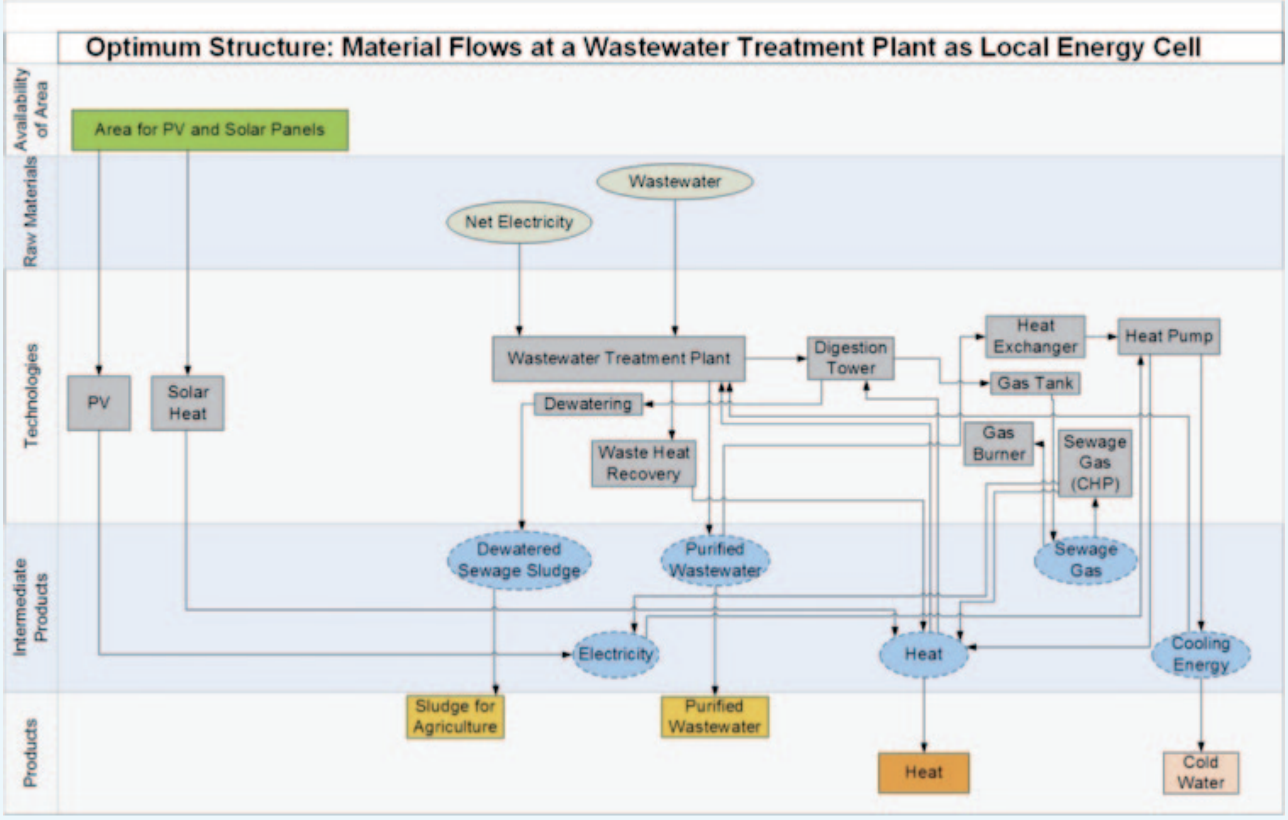

Figure 4: Example for an optimum structure of a wastewater treatment plant focused on the heat supply in a scenario under current economic conditions

treatment plant, were identified as options by the stakeholders.

The case study is still an on-going project. For the economic optimisation it is not clear yet which heat energy price can be achieved. For this reason a sensitivity analysis on the heat price with PNS Studio was realised. The largest possible amount of heat with the available technologies is produced according to Figure 4.

Having the sensitivity analysis in mind less heat producing technologies were chosen by the PNS and the amount of heat output decreases as well if the prices for the produced heat are decreasing.

Currently discussions with all relevant stakeholders about useful technologies and the achievable heat energy price in the particular region are ongoing. Once a price is specified the optimum economic system will be calculated and the selected technologies will be evaluated in an ecological way.

Conclusion

It seems likely for this case study to supply the in-house heat demand of the plant itself in a more economical and ecological way. Industrial and residential areas nearby may benefit from an integrated and optimised energy system centred on the sewage plant as local heat provider. The investigation of the centred energy systems will help the operator, political decision makers in the region and other stakeholders to utilise the potential of energy supply for the sewage plant and its surrounding areas in the future.

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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

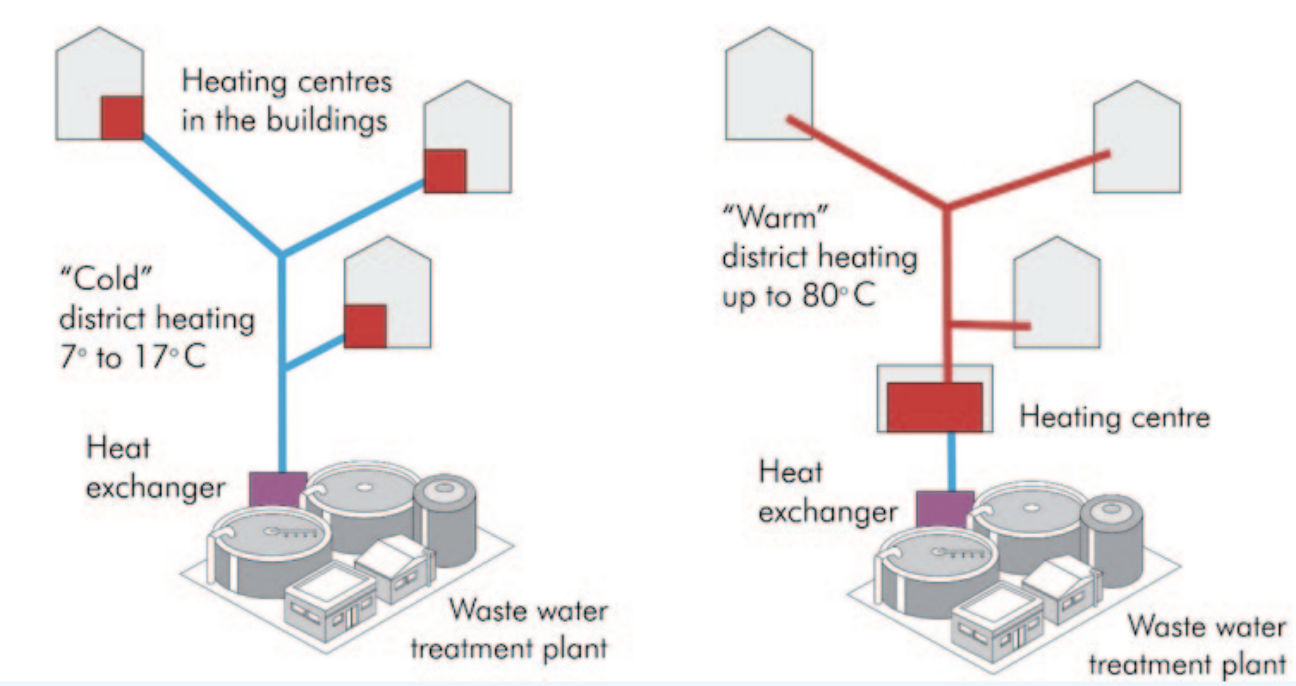

Figure 1: Principle of „cold“ (left) and „warm“ (right) district heating
(DBU, BWP, IEIA 2009; Tracey Saxby, IAN Image Library (http://ian.umces.edu/imagelibrary/),own adaptation)

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)

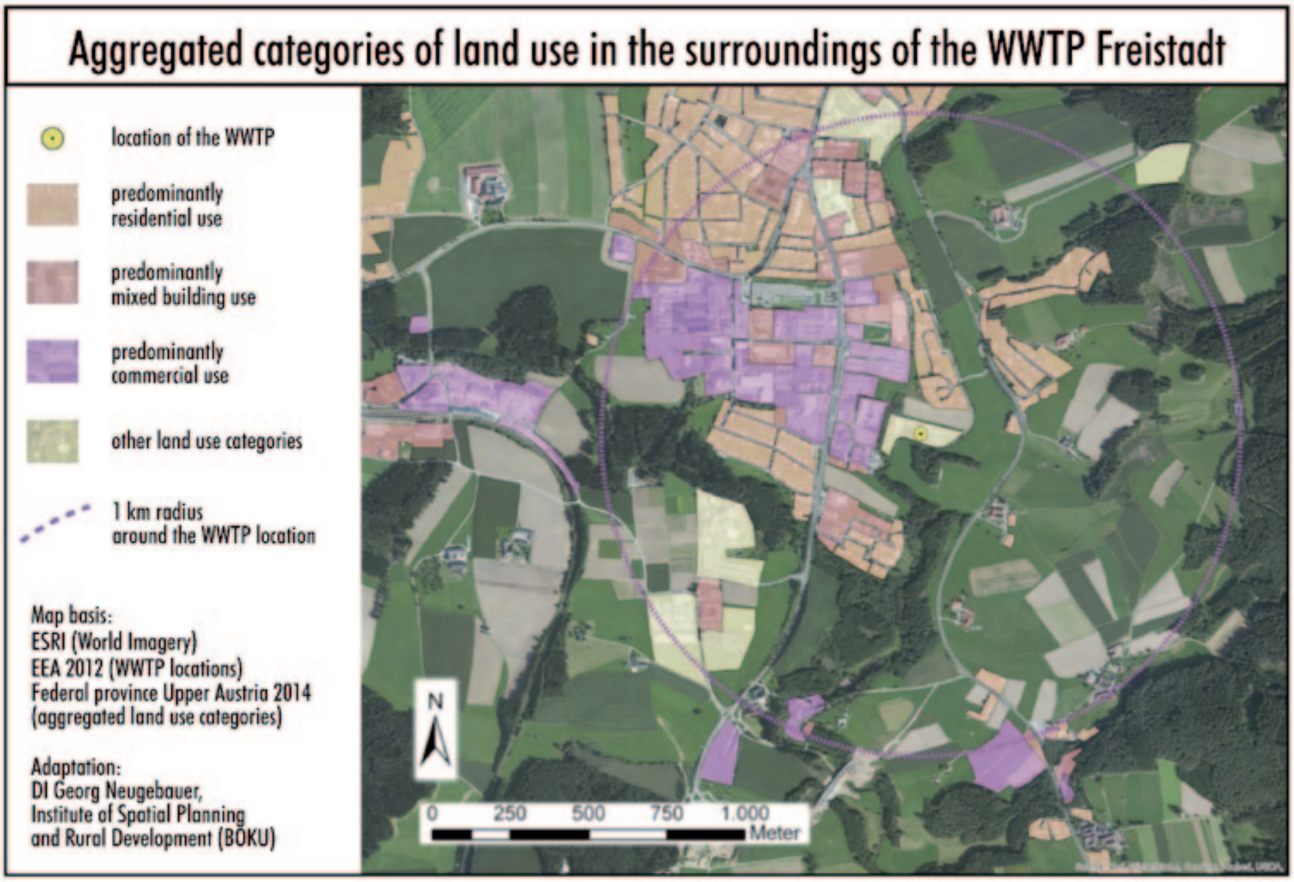

Figure 3: Aggregated categories of land use in the surroundings of the WWTP Freistadt

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.

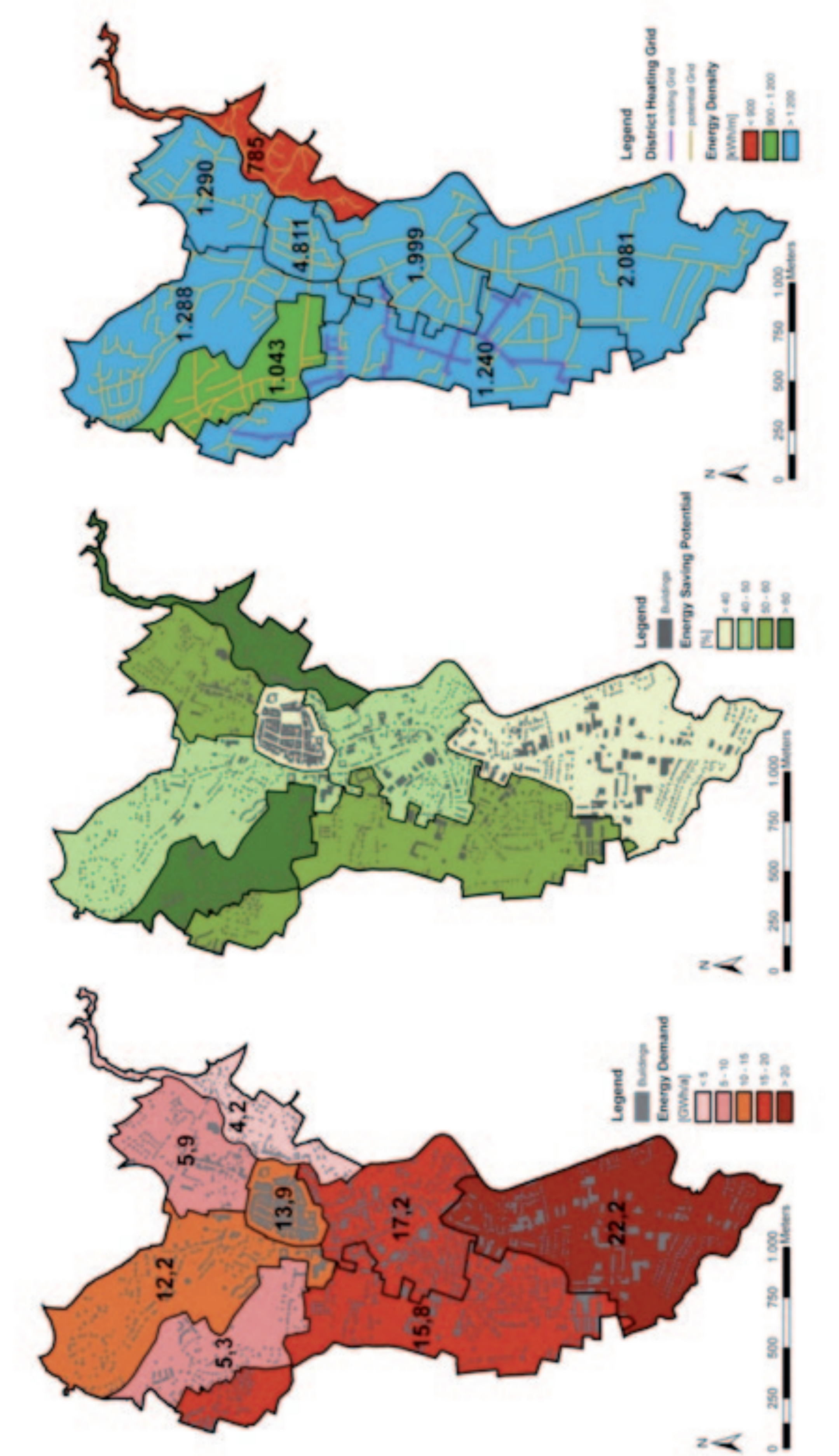

Figure 4: Energy zone mapping Freistadt as basis for the local development concept (Stöglehner et al. 2011)

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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Notes

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