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Renewable energy from wastewater - Practical aspects of integrating a wastewater treatment plant into local energy supply concepts

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ABSTRACT

The main purpose of wastewater treatment plants concerns water pollution control. However, recent research has shown, that wastewater treatment plants also seem to be interesting from an energetic point of view, as they have high potentials for heat generation beyond common digester gas combustion. Focusing on a case study we intend to feed the available surplus energy of the wastewater treatment plant into public energy distribution grids to supply external consumers. Different software tools are applied to support optimised integration: a central role plays the Geographical Information System based Energy Zone Mapping to analyse existing and future energy demands of different spatial units. Process Network Synthesis is applied to perform optimisation on an economical level. With the Sustainable Process Index the ecological footprint of the regarded technologies is assessed. Besides describing the theoretical background and the practical application of the tools, the paper presents the results obtained from the case study. The investigations give clear evidence, that significant amounts of heat could be supplied to the adjacent consumers at competitive costs and with considerable ecological benefit. Consequently, the wastewater treatment plant analysed provides local energy planners with an “unexpected” and locally available renewable source of energy.

1. Introduction

Today, the energy turn and the related replacement of fossil energy sources by renewable ones for climate protection purposes rank high on the international political agenda. On European level, several initiatives and strategies address this issue and provide the framework for the future development of the energy sector. The 2020 Goals (European Commission, 2007a) propose the urgency of limiting global warming to a temperature rise of 2 °C or less. These goals built the basis for the 2030 climate & energy framework (European Commission, 2014) that sets three more key targets for the year 2030:

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 27% share for renewable energy
- At least 27% improvement in energy efficiency

Even further, the EU has set itself a long-term goal of reducing greenhouse gas emissions by 80–95% below 1990 levels until 2050. The Energy Roadmap 2050 (European Commission, 2011) investigates the transition of the energy system in ways that would be compatible with these greenhouse gas reduction targets while simultaneously increasing competitiveness and security of supply. Moreover, the Strategic Energy Technology Plan (European Commission, 2007b) sets out long-term energy research, the development and deployment of low-carbon technologies and the promotion of their uptake by the market. On the global level, the United Nations (2015a) introduce Sustainable Development Goals focusing, among others, on access to affordable, reliable, sustainable and modern energy for all. Latest at the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal (United

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Nations, 2015b). The agreement sets out a global action plan to put the world on track to avoid climate change by limiting global warming to well below 2 °C. As a consequence, the extension of renewable energy supplies is an imperative societal goal. Therefore, the search for additional sources of renewable energy is an ongoing process. In this context, wastewater attracts professional interest as it can be considered a domestic and inexhaustible resource of permanent availability.

Nevertheless, the main purpose of wastewater treatment plants (WWTPs) is the removal of undissolved and dissolved substances from wastewater (cooking fats and oils, road grit, nutrients as carbon, nitrogen and phosphorous, etc.). Hence, WWTPs play a key role in sanitary engineering and water pollution control. Recently, the additional potential of WWTPs for energy generation beyond common on-site digester gas combustion or cogeneration and resource recovery is allocating attraction by wastewater professionals. Frijns et al. (2013) demand new concepts to view wastewater as a carrier of energy. Nowak et al. (2015) discuss ways to optimise the energy balance of WWTPs to the point of energy self-sufficiency or even further to be “energy-positive” taking thermal energy as well as chemically-bound energy into account. Kind and Levy (2012) identify a theoretical potential of 40% reduction of external electricity consumption of Swiss WWTPs and illustrate opportunities for heat transfer to the surroundings of WWTPs based on case examples. Chae and Kang (2013) present the potentials for small hydropower and photovoltaics to additionally contribute to the energetic independence of WWTPs. Stillwell et al. (2010) report about the energy recovery potential from biosolids (digested sewage sludge) incineration with electricity generation. Mo and Zhang (2013) highlight, that beside WWTP onsite energy generation, nutrients can be recycled from wastewater and treated wastewater may be reused, among others, for irrigation and industrial processes. Garrido-Baserba et al. (2015) discuss sewage sludge treatment alternatives by the integration of economic and environmental criteria into a single composite indicator. Nakakubo et al. (2012) address phosphorus recovery from wastewater/sewage sludge. In this context Stedman (2015) states, that in the Unites States of America WWTPs are already being seen as wastewater resource recovery facilities. To account for this development, the German Federal Ministry of Education and Research (BMBF) has launched a major funding program from 2013 till the end of 2017 dealing with future-orientated technologies and concepts for an energy-efficient and resource-saving water management. Thereby, wastewater related research focuses on issues of WWTPs as control components in energy distribution systems with renewable energy generation, WWTPs as energy storage systems and transformation of sewage sludge to energy, fertiliser and iron using metallurgical phosphorus recycling (BMBF, s. a.).

However, although recent WWTP related literature and research initiatives make an important contribution in the field of energy generation from wastewater, one might get the impression that currently the primary focus of research concerns electrical optimisation and electrical self-sufficiency. Aspects concerning thermal energy seem to play only a minor role at the moment. This seems a little surprising, as Kretschmer et al. (2015) describe that in Austria WWTPs with anaerobic digestion might achieve electric self-sufficiency under optimum performance of wastewater treatment and cogeneration, although in contrast, the degree of thermal self-sufficiency based on biogas combustion and heat recovery from wastewater is estimated from 600 to 800% and beyond. We assume that these findings might also be valid for other countries. In addition, Neugebauer et al. (2015) calculate the thermal energy potential of Austrian WWTPs (bigger than 2000 population equivalents (PE)) at around 3100 GWh/a. In Germany, the available wastewater heat potential is quantified in the order of the heat demand of 10% of the building stock (DWA, 2009). These figures show that, apart from onsite heat supply, WWTPs can play an important role in local heat supply by providing adjacent consumers situated outside the premises of the WWTP with excess heat from wastewater. Hereby, the spatial context is vital. On the one hand, distances of heat transport are limited due to heat loss in the supply networks. On the other hand, considering spatial analysis of energy efficiency, supply and resource potentials provide a powerful basis for a better decision base for energy planning (Stoeglehner et al., 2016).

From a technological point of view, three main approaches for heat generation/recovery at WWTPs can be distinguished: (i) heat generation through digester gas combustion or cogeneration, (ii) heat generation/recovery through wastewater heat extraction by applying in-sewer heat exchangers and external heat pumps, and (iii) heat generation through solarthermics. Heat generation from sewage sludge incineration could also be mentioned. However, related installations usually are not found at the premises of a WWTP today. Consequently, the generated heat may not be referred to the WWTP but to the concerned incineration plant. While heat generation through combustion or cogeneration of digester gas has been common practice at many WWTPs (with anaerobic sludge treatment) around the world, heat recovery from wastewater, which can also take place in upstream sewer systems, is still not very wide spread today. Schmid (2008) report the application of about 500 facilities around the world with capacities from 10 kW to 20 MW. But one can expect today's figures to be already increased as more and more countries include thermal use of wastewater in their energy policies. Kretschmer et al. (2016) explain that in Austria, heat recovery from wastewater is stated explicitly in the new release of the Federal Law on the Increase of Energy Efficiency. The German Federal State of Baden-Württemberg subsidises feasibility studies, practical implementations of wastewater heat recovery facilities as well as related research activities (MECPES, s.a.). In Switzerland, the Association Infrawatt (s.a.) supports wastewater heat recovery related initiatives.

Heat generation through solarthermics, obviously, does not depend on the availability of wastewater. However, WWTPs usually have large free but unused space (roofs, etc.). Consequently, using this space for solarthermic installations can also contribute to heat generation (DWA, 2010). From a quantitative perspective solarthermics, anyway, play only a minor role today.

To counteract climate change and to contribute to the energy turn it seems imperative, not only to focus on different aspects concerning electrical energy but also to address issues related to thermal energy. The content of thermal (surplus) energy in wastewater is significant but currently still widely unused.

Consequently, this article aims at implementing heat provision beyond common WWTP onsite supply by introducing a novel method to assess the integration of WWTPs into local energy supply concepts. The method addresses spatial, economic and environmental perspectives and combines different tools which have already independently proofed their practicability in numerous projects. This integrated methodological approach involves site specific boundary conditions and thus provides decision makers with a sound and holistic information and decision base.

The theoretical concept is followed by a practical application in an Austrian small town. With this set of combined tools the following questions can be answered: (a) in which spatial context WWTPs can contribute to local heat supply, (b) how energy demand in the vicinity of a WWTP can be estimated, (c) how energy systems can be optimised from an economic point of view and (d) whether the proposed energy supply alternative is sufficiently contributing to the reduction of environmental pressures.

2. Methods

In order to assess the integration of a WWTP into local energy supply concepts, strategic planning tools considering spatial, economic and environmental issues can be applied in the context of the wastewater treatment infrastructure. Interlinking spatial analysis carried out with the (1) Energy Zone Mapping tool, economic optimisation applying the (2) Process Network Synthesis (PNS) and environmental appraisal with the (3) Sustainable Process Index (SPI) as depicted in Fig. 1 can reveal sustainable energy supply potentials of WWTPs.

The proposed method is a multi-stage procedure comprising three major steps: (a) definition of the aim of the analysis, (b) data collection and processing as well as (c) data assessment and decision making (optimised integration). Investigating the spatial context of a WWTP allows for an estimation of viable potentials for its integration into local energy supply concepts. Economic optimisation contributes to tracing the optimum solution from a broad spectrum of available technologies and environmental appraisal illustrates the impacts of the chosen energy supply system.

2.1. Spatial analysis and Energy Zone Mapping

Depending on the spatial context of a WWTP and the presence of existing or future potential energy consumers, thermal energy from wastewater can be applied (1) in agriculture and forestry for dewatering as well as heating and cooling purposes and (2) in settlement areas for purposes of climatisation. Therefore, land cover and land use data have to be analysed in a first step to estimate energy consumption in the vicinity of a WWTP. Neugebauer et al. (2015) differentiate three types of spatial contexts: (1) WWTPs within, (2) WWTPs near to and (3) WWTPs far from settlement areas. These types of WWTPs are associated with respective heat demand characteristics.

Energy Zone Mapping is a decision support tool that allows a zonal analysis of energy demand data for the purposes of integrated spatial and energy planning (Stoeglehner et al., 2016). Applying the tool permits an analysis whether the observed energy zones can be provided with grid-bound heat supply (e.g. bivalent district heating systems with wastewater heat pumps providing basic loads) from an economic point of view.

The Energy Zone Mapping tool can be applied to arbitrary predefined parts of a settlement (e.g. the vicinity of a WWTP) up to the whole municipality's territory. First, a zonal analysis of the current heat demand is carried out. Second, future demands according to energy saving and urban development scenarios are estimated. Core of the tool is the assessment of the feasibility of a grid-bound heating supply in the predefined energy zones. Therefore, criteria like energy density in terms of heat load and a defined maximum amount of heat losses are applied.

Fig. 2 depicts the results of a zonal analysis of the thermal energy demand for an Austrian urban settlement carried out for eight energy zones (Stöglehner et al., 2011). Based on energy indices derived from building periods, the Energy Zone Mapping tool estimates the current heat demand (Fig. 2, left). Input data for existing building structures can be derived from the Buildings and Dwellings Register (Statistics Austria, 2012) that contains structural data for buildings, dwellings and other usage units (e.g. building period, effective area). Further, a future heat demand based on spatially differentiated energy savings (Fig. 2, centre) is calculated. It can be assumed that future heat demand will change through the implementation of thermal insulation or new urban developments. Therefore, the tool offers two heat demand scenarios: With a reduction of 20 percent, the first scenario constitutes a moderate energy saving and efficiency potential. The second scenario is calculated again applying energy indices that represent a realistic and achievable target status for each building period after upgrading the building stock's energy performance. Heat demands of future energy consumers derived from urban development scenarios can be estimated based on assumptions of energy indices according to the buildings directive, a legally binding construction standard for buildings, and building types. Finally, the energy

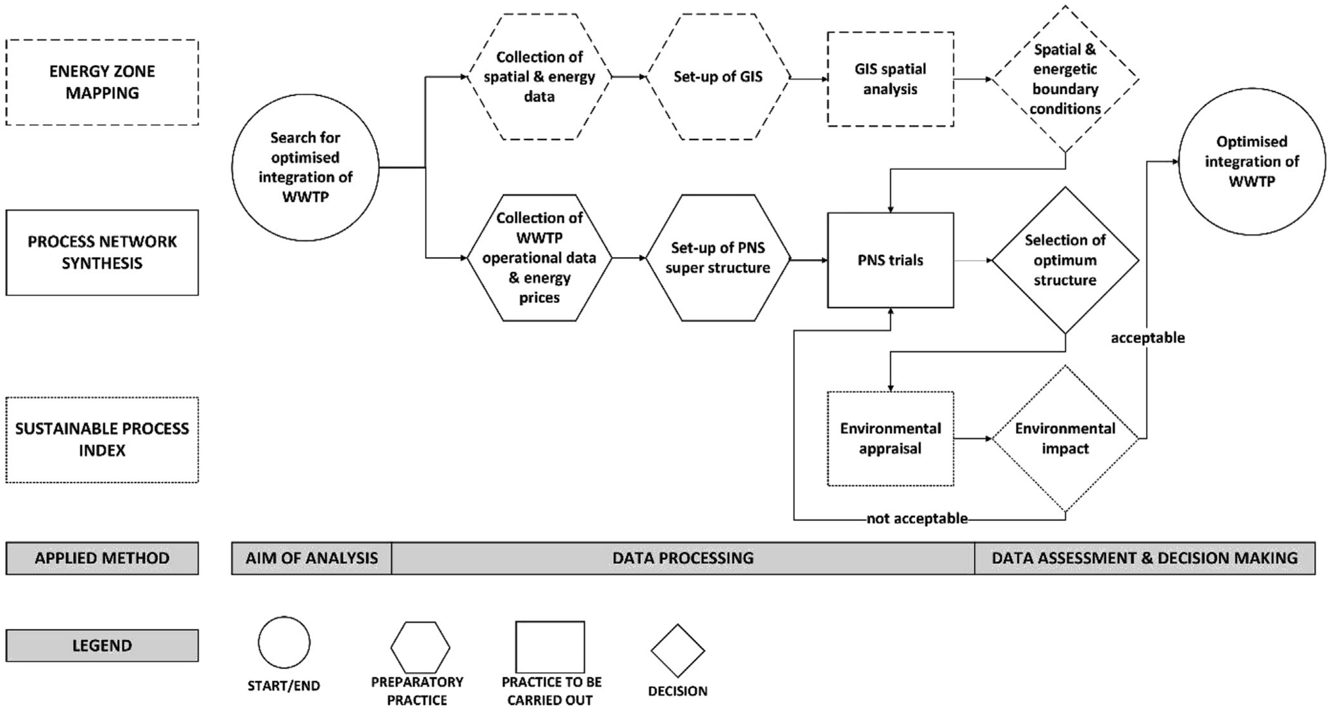


Fig. 1. Method to assess the integration of WWTPs into local energy supply concepts.

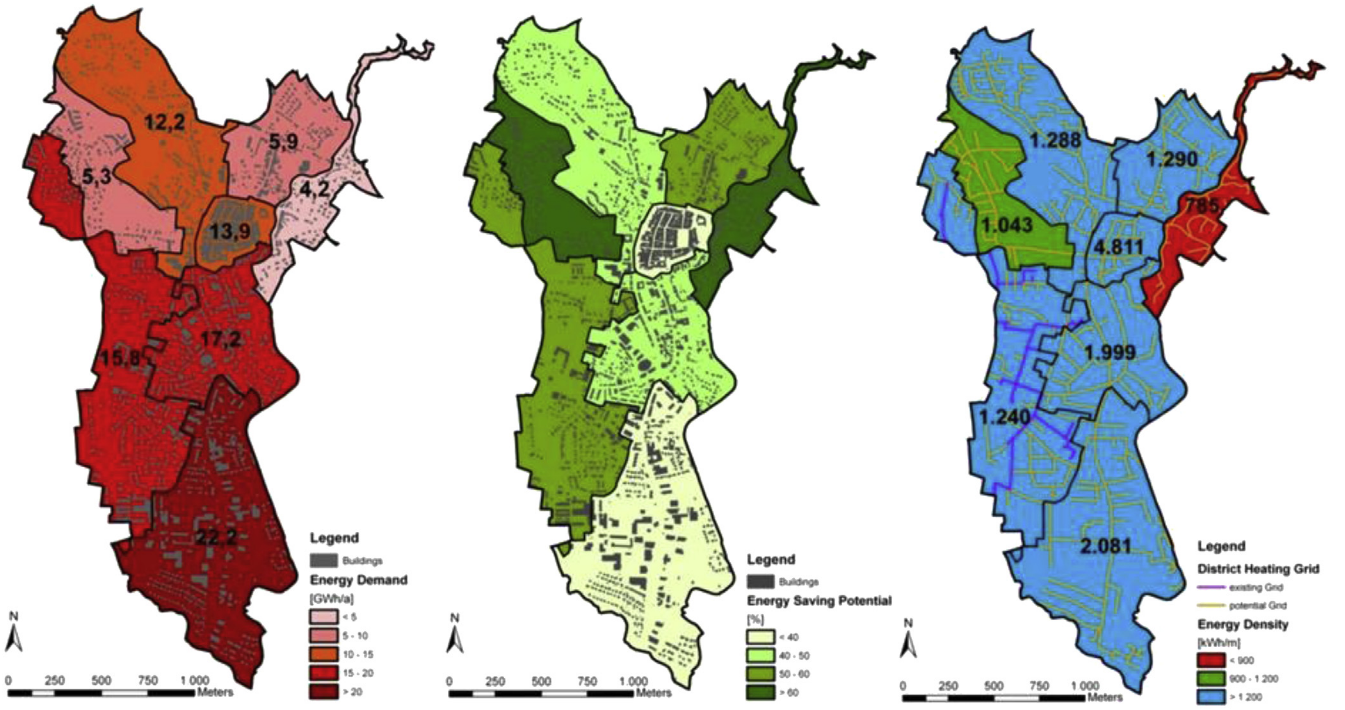


Fig. 2. Energy Zone Mapping as basis for a local development concept (Stöglehner et al., 2011).

densities (Fig. 2, right) as prerequisites for a cost-efficient operation of a district heating system are derived for both the current and the future heat demand scenarios. In the results window, the Energy Zone Mapping offers an overview of the grid parameters that allow for the appraisal, whether a grid-bound heat supply can be achieved from an economic point of view.

In order to estimate the heat demand of commercial and industrial facilities, the following statistical data can be interlinked: a useful energy analysis that breaks down the final energy consumption into items (e.g. space and water heating) differentiated according to the sectors of the manufacturing industries (Statistics Austria, 2015a) and census data on local units of employment (Statistics Austria, 2015b). This allows for the calculation of energy consumption data per employee differentiated according to the items of the useful energy analysis and branches.

For the application of the Energy Zone Mapping tool only few input data are required: (a) energy demand data on the level of buildings that can be estimated based on structural data from the Buildings and Dwellings Register, (b) georeferenced cartographic representation of the study area. This basic data have to be supplemented by two new data sets, a hypothetical district heating grid and the respective house connections.

2.2. Process Network Synthesis (PNS)

The methodical background of Process Network Synthesis (PNS) is the p-graph representation of flow networks, to establish feasible network structures using combinatorial rules (Friedler et al., 1995). PNS is a method to optimise material and energy flow systems (Lam et al., 2010). To identify the optimal design and implementation approaches, PNS Studio (Software Version 3.0.4, 2011, www.p-graph.com) has already been used for urban and regional planning (Narodoslawsky et al., 2008).

To establish an optimal structure of the considered flow network, a “super structure” has to be set up. This super structure includes all flows and possible technologies. It distinguishes between resources, intermediate products, which can be used in other processes, and final products, which can be sold on the market. Technologies are characterised by their energy and material balances as well as costs. Transport is regarded as technology, transforming a flow at point A to one at point B. The user has to define the capacities and availability as well as the investment and operating costs of the technologies, time dependent load and consumption functions and cost of resources, the specific demand and price of the products and the transport costs and distances (Maier and Narodoslawsky, 2014). The program calculates an optimum energy technology network as a solution within the super structure as shown in Fig. 3. This optimal technology network contains only economically feasible structures. Optimisation is achieved with a branch and bound algorithm. The optimum structure represents the optimal way for a region to use its resources, taking all mentioned variables into account and regarding the technological network as an encompassing economic actor.

A super structure was created for a closer examination on an average WWTP site with anaerobic digestion. It includes all suitable resources such as net electricity, natural gas, bio wastes (e. g. cooking oil), accessible unused area and the wastewater itself, as well as all feasible technologies required to treat wastewater and to process digester gas, wastewater heat and solar energy into marketable heat and electricity. The structure includes reused intermediate flows, like internally used electricity or heat as well as final products to be sold on the marked (e. g. biomethane from digester gas) or to be disposed (e. g. ashes or sludge), treated wastewater, digester gas, electricity, heat and cold. In Fig. 4 this super structure is shown in a simplified manner to provide an impression of the complete system.

All material flows and costs are calculated for the period of one year. We do not use investment costs for already existing technologies, while we break down the investment costs of new technologies to one year by considering the estimated service life of the

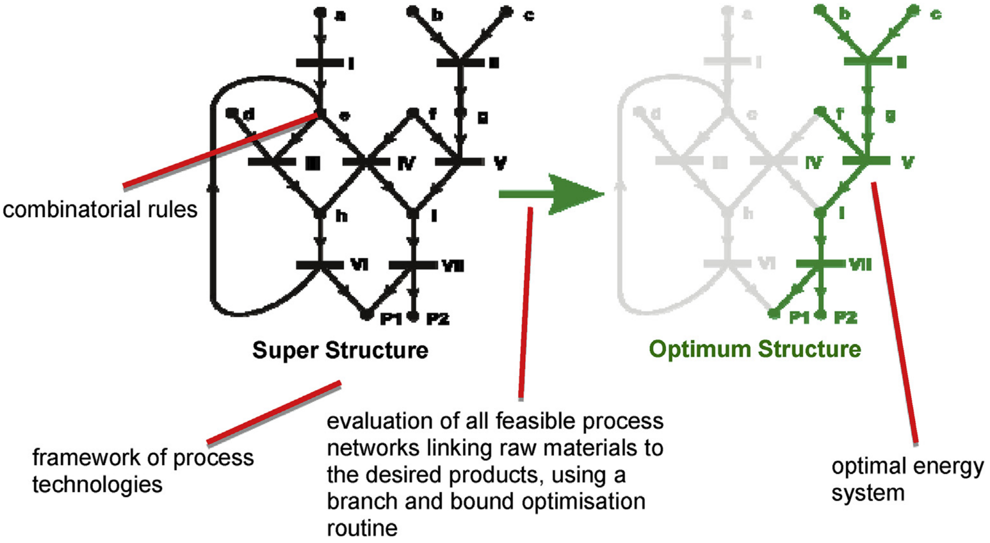


Fig. 3. Super structure and optimum structure of a technology network (Friedler et al., 1995), adapted.

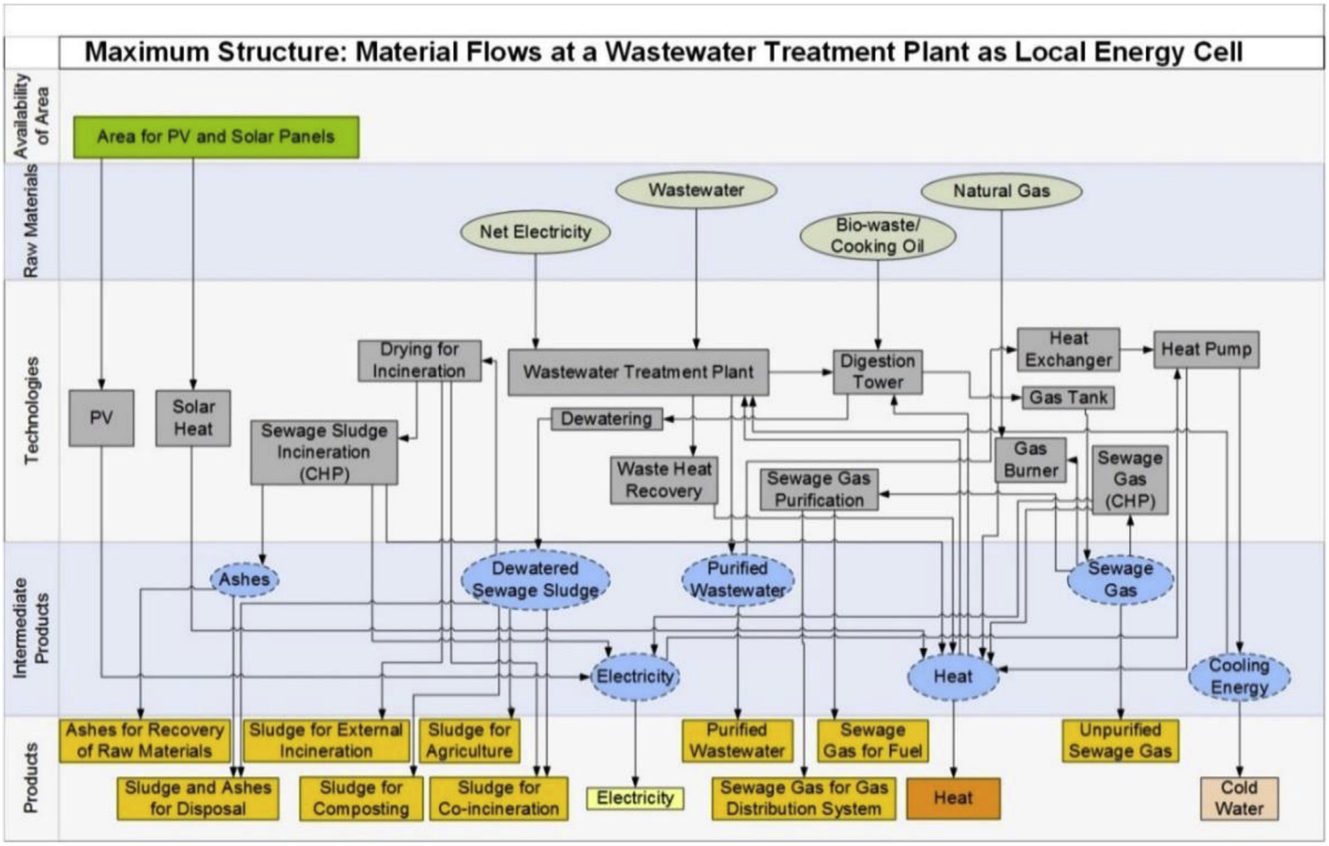


Fig. 4. Super structure of a wastewater treatment plant with digestion (Kindermann and Kollmann, 2015).

respective technologies. The average service life for machines and energy producing technologies is 10–20 years, while building facilities have an estimated lifetime of 30 years. Apart from investment and operating costs of technologies, the prices for raw materials and final products need to be considered. For electricity and natural gas, average Austrian prices are used if no specific price information from the WWTPs is available. The same holds for the prices of the produced goods and the costs of sewage sludge disposal. Regarding the price of the generated heat for external consumers, we conduct a sensitivity analysis.

From all available technologies in the super structure, the PNS searches for the technology structure minimising the total costs of the system, subject to certain boundary conditions. These might include resource availability, lower or upper bounds on capacities, or constraints regarding the demand of final products. Considering a WWTP, the constraints used are mainly the amount of wastewater, the capacities of existing technologies (data provided by the WWTP), the required degree of capacity utilisation of potential new technologies, as well as the estimated external demand for energy.

2.3. Sustainable Process Index (SPI)

The Sustainable Process Index (SPI) is a member of the ecological footprint family and it is compatible with life cycle analyses described in the EN ISO 14040 (ISO, 2006). SPI is a Life Cycle Impact Assessment (LCIA) tool for the evaluation of environmental impacts of processes, products or services which is an essential part of any Life Cycle Assessment (LCA) to evaluate the pressure on the environment (Čuček et al., 2012). SPI calculates the cumulative area [m^2] needed to embed the impact of all material and energy flows, as well as all produced emissions, sustainably into the biosphere (Krotscheck and Narodoslawsky, 1996). The method is based on the comparison of natural and anthropogenic material flows. The assessment of mass and energy fluxes is carried out according to two principles of sustainability (Sustain, 1994):

- Anthropogenic material flows must not alter global biogeochemical cycles, and
- Anthropogenic material flows must not alter the quality of the local environment.

In Fig. 5 the scheme for ecological evaluation by the SPI is shown.

For the calculation of the SPI the online tool SPIonWeb is currently used, which is freely available on http://spionweb.tugraz.at/. Within this tool, it is possible to compile entire life cycles in the form of process chains, which can be updated and improved with little effort (Shahzad et al., 2014). As results, the user gets the SPI-footprint, CO_2-life-cycle-emissions and the global warming potential (GWP) of the whole life cycle.

2.4. Case study

The methods described are applied at a case study in the Austrian small town Freistadt, which is located in Upper Austria close to the Austrian-Czech border. The town is a regional centre and district capital with about 7500 inhabitants and 5300 workplaces. The regarded WWTP is equipped with mechanical and biological treatment steps and has a built capacity of 30000 PE. In 2013 the average load was around 26000 PE resulting in an average daily inflow of about 4590 m^3. The average wastewater temperature is around 10 °C, with a winter minimum during snow melt around 6 °C and a summer maximum of about 17 °C. The wastewater comprises both domestic as well as industrial shares. Today, the WWTP is already equipped with one digestion tower in which sludge stabilisation takes place. Currently, digester gas is being combusted in a micro gas turbine resulting in an electrical energy output of around 496 kWh/d (about 30% self-sufficiency). In addition, 145 kWh/d are generated by means of photovoltaics (PV) installed at the premises of the WWTP. On-site heat demand is covered by excess heat from digester gas combustion and, if necessary, the additional use of two gas boilers. The drained sludge is reused in agriculture.

As already explained above, the super structure of the PNS comprises different resource and energy flows, technologies and products. The tool can be used to define the best system solution from an economic point of view. However, we consider the involvement of stakeholders in local planning activities concerning energetic use of wastewater as very important. Consequently, at the beginning of the case study, the local WWTP operator and representatives of the municipality were invited to define those products relevant to their specific local boundary conditions. As a result, the case study investigation only focused on the generation of electricity and heat. Generation of cold, resource recovery from sewage sludge, alternative sewage sludge disposal, digester gas for fuel, and biomethane production from digester gas were no options for the local stakeholders. Therefore, these aspects are not further addressed in this article. In addition, the existing technologies as e.g. the digestion tower, the micro gas turbine and gas boilers, are calculated with operating costs and material flows only, while new technologies require additional investment costs.

3. Results

Based on the case study, this section describes how the application of strategic planning tools can contribute to an optimal integration of a WWTP into the local energy supply system.

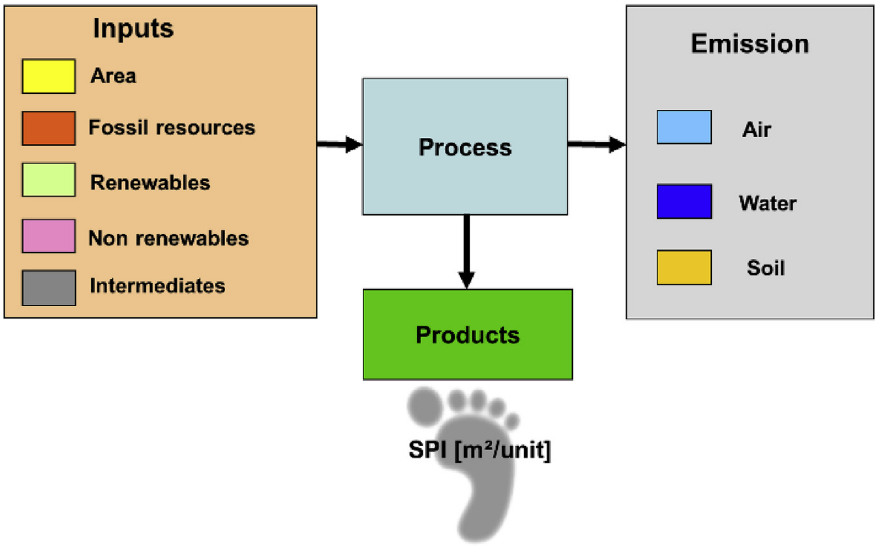


Fig. 5. Representation of calculation methodology (http://spionweb.tugraz.at/de/spi, 2016).

Subsection 3.1 explains the spatial context, subsection 3.2 the economic optimisation and subsection 3.3 the calculation of related environmental pressures.

3.1. Spatial context and heat demand

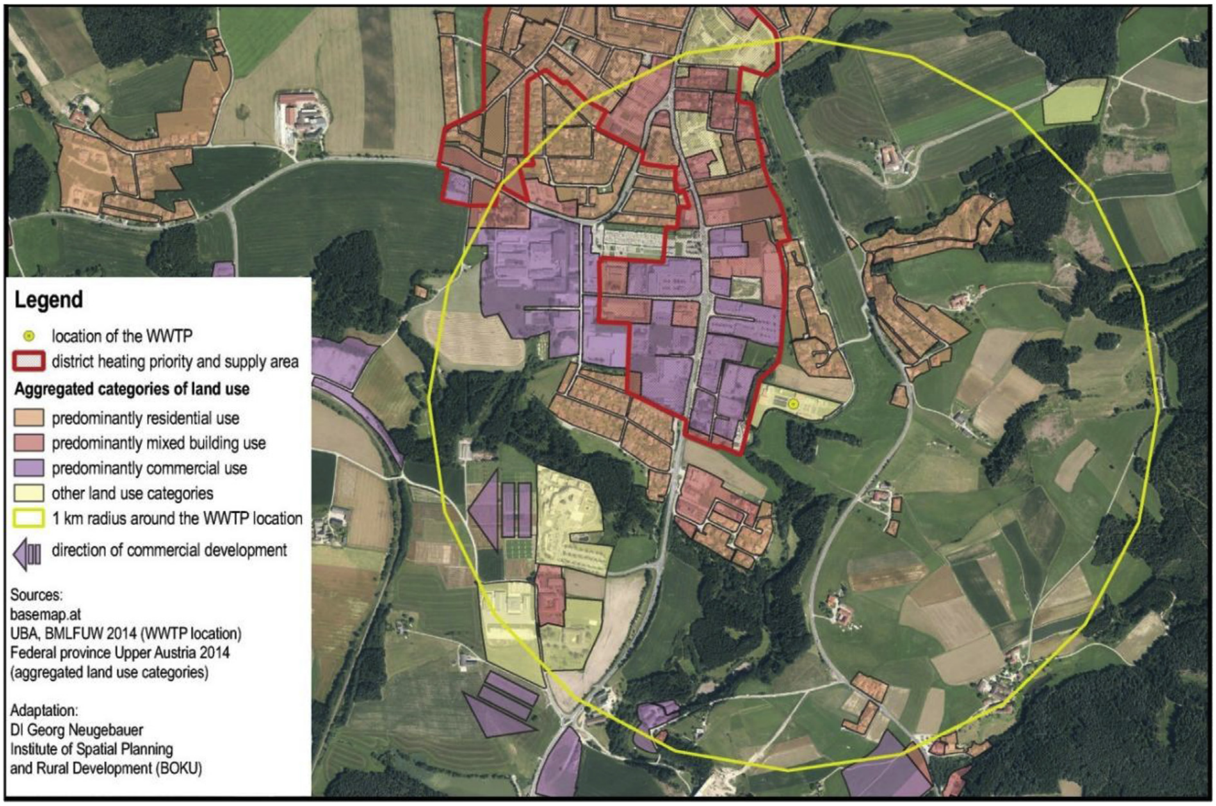
Taking the spatial context into account, the regarded WWTP can be considered as a facility within settlement areas. Fig. 6 depicts the current land use in the vicinity of the plant, encompassing mainly commercial areas. In addition, the regional hospital is located in the surroundings of the site, and further commercial areas are being developed at a distance of about 1.5 km from the site in the course of an expressway development. Therefore, according to the spatial context the WWTP shows high potentials for thermal surplus energy utilisation from wastewater with regard to existing and future energy consumers.

In the framework of a stakeholder workshop, the provision of heat from wastewater energy for future business locations according to the spatial development strategy was defined as research subject. These business developments are part of an intercommunal planning strategy for commercial and industrial areas. In order to estimate the energy demand of the future business location, a targeted mix of branches was jointly determined including food production, wood processing and machinery. The commercial areas considered in the calculation amount to 11.42 ha, which results in 286 employees estimated with a density of employees of 25 per hectare taking into account both empirical data about Austrian business parks gained in own surveys as well as specifications in planning tools (Bosserhoff, 2014). Based on sector-specific energy indices derived from useful energy analysis and census data on local units of employment, the heating demand for the regarded business locations can be estimated amounting to 4300 MWh$_{th}$/a for space heating and 4757 MWh$_{th}$/a for process energy including drying, process water and heat up to a temperature level of 100 °C.

3.2. Economic optimisation

A sensitivity analysis with PNS Studio (Kindermann and Kollmann, 2015) based on the estimated demand at new industrial and commercial areas nearby was used to assess the possible range of thermal energy supplied by the WWTP. The sensitivity analysis also took different heat prices into account. The demand was calculated for space heating only, which would occur mostly during winter, and for heating including process energy, e.g. heat for drying processes in the respective sectors of the manufacturing industries. Process energy is assumed to be demanded over the whole year. The heat is considered to be low temperature heat (approx. 65 °C) and is generated with heat pumps directly at the WWTP or externally close to the heat consumers. The results are given in Table 1. In both cases, the internal heating demand of the WWTP is covered, even if no heat is sold. The external heat demand (Table 1) refers to the industrial and commercial development described above as potential consumers.

The results show that the minimum heat price to supply external consumers with heating energy depends on the amount of the demand. For space heating the demand is lower over the year which requires a higher heat price to supply the consumers with heat. The minimum price for supplying heat is however 5% lower than the current district heating price in the area of about 57 €/MWh. This heat price of 54 €/MWh results from the investment and operating cost of a new installed Combined Heat and Power (CHP) plant as well as several new heat pumps plus the required heat grid, Additionally, around 80% of the used electricity have to be



Sources:
basemap.at
UBA, BMLFUW 2014 (WWTP location)
Federal province Upper Austria 2014
(aggregated land use categories)

Adaptation:
DI Georg Neugebauer
Institute of Spatial Planning
and Rural Development (BOKU)

Fig. 6. Aggregated categories of land use in the surrounding of the case study WWTP.

Table 1
External heat demand and supply from the case study WWTP.

	External demand [MWh$_{th}$/a]	Minimum price [€/MWh]	Minimum price relative to current price per MWh$_{th}$ [%]
Heating	4300	54	−5
Heating incl. process energy	9057	45	−21

imported from the electricity net causing overall cost of approx. 230000 €/yr. These costs are facing an estimated revenue of round the same value per year, caused by the fact that at 54 €/MWh the PNS calculations are generating the first minimal economic benefit for the system.

Considering process heat as well, the demand is doubled. The higher amount and the more constant demand over the year decrease the unit costs in production, and hence a lower price that would be 21% lower as the current heat price in this region and would allow sufficient supply of external consumers. At this price, however, only 89% of the 9057 MWh$_{th}$/a can be covered with the applied heating technologies (the demand is highest in winter and cannot be met completely at this price). To cover the whole demand, larger facilities are necessary, resulting in a higher price for consumers due to the fact that higher investments have to be done as well as more electricity has to be imported from the net.

The maximum energy provision potential by the WWTP is even higher than the estimated demand, at over 12200 MWh$_{th}$/a. This includes high temperature and low temperature heat produced by a sewage gas CHP, a gas burner, solar thermal energy, as well as heat pumps recovering wastewater energy, and a heat pump to recover waste heat from air, shown in Fig. 7 as an optimised superstructure. If the whole potential is utilised by additional consumers, the energy from the WWTP could be provided at an even lower price.

3.3. Environmental pressure

Life Cycle Assessment is becoming more and more integrated in Research and Development projects. Even if it does not always receive appropriate attention it is helpful finding environmental friendly solutions (Sandin et al., 2014). SPIonWeb is used in the current research project for the ecological comparison of different heat producing technologies. In the presented case study, according to the PNS results, a maximum external heat demand of 9057 MWh$_{th}$/a was taken in consideration for the ecological evaluation. Different scenarios were created for heat producing technologies using the PNS optimisation, such as heat exchanger and heat pump operating with three different electricity mixes, heat from solar collectors or heat from natural gas to provide the heat demand of 9057 MWh$_{th}$/a. The three evaluated electricity mixes are the EU electricity mix, the average Austrian mix and a mix based on renewable energy sources (hydro power 73.62%, wind power 19.45%, biomass fired power 3.30%, PV power 2.64% and other renewable resources 0.99%). This renewable electricity mix is based on the share of an Austrian electricity provider available for industrial as well as private customers (Oekostrom, 2016).

In Fig. 8 the influence of the used electricity mix to run the heat pumps on the ecological pressure, and the comparison to a solar thermal and a business as usual scenario (a system supplied by

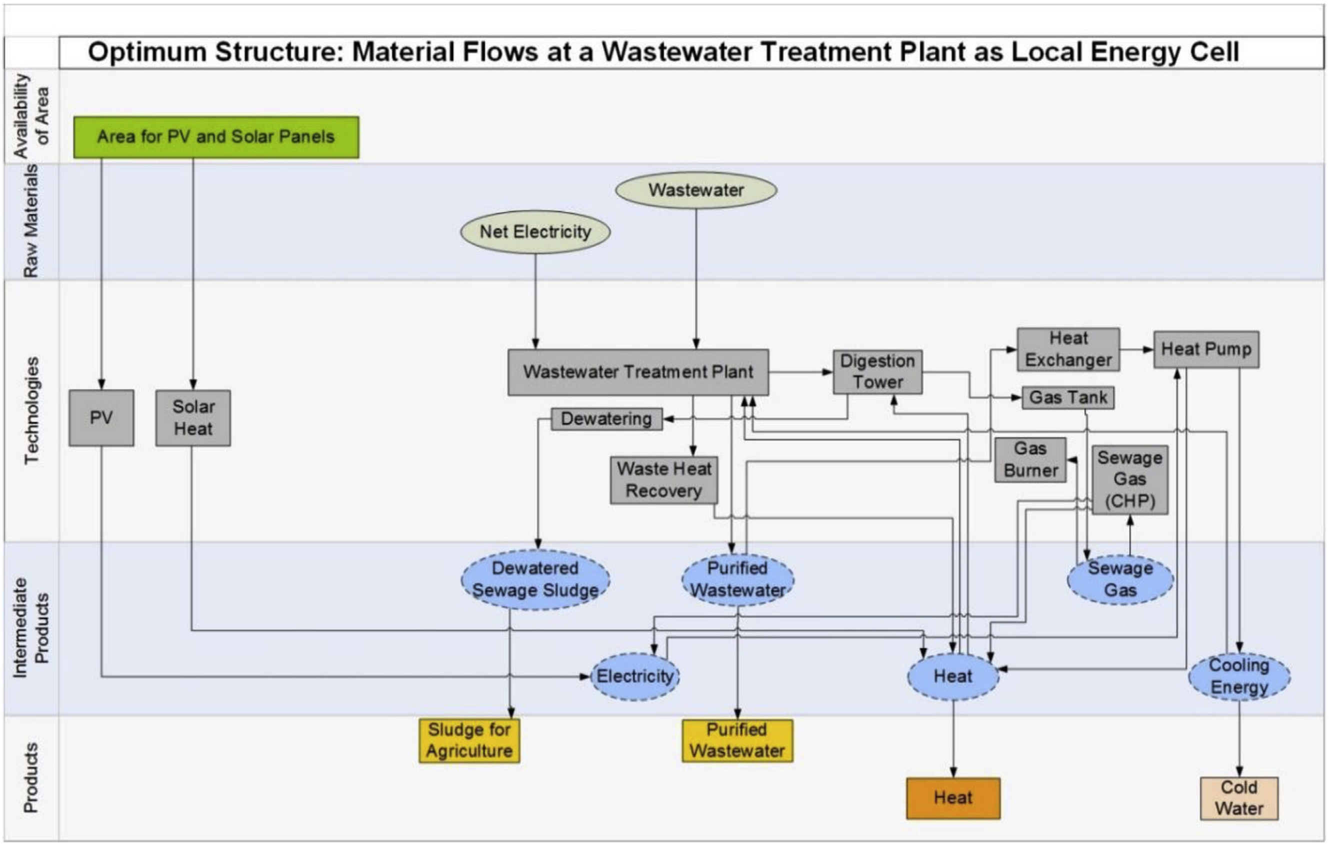


Fig. 7. Optimum structure of a wastewater treatment plant focused on the heat supply (Kindermann and Kollmann, 2015).

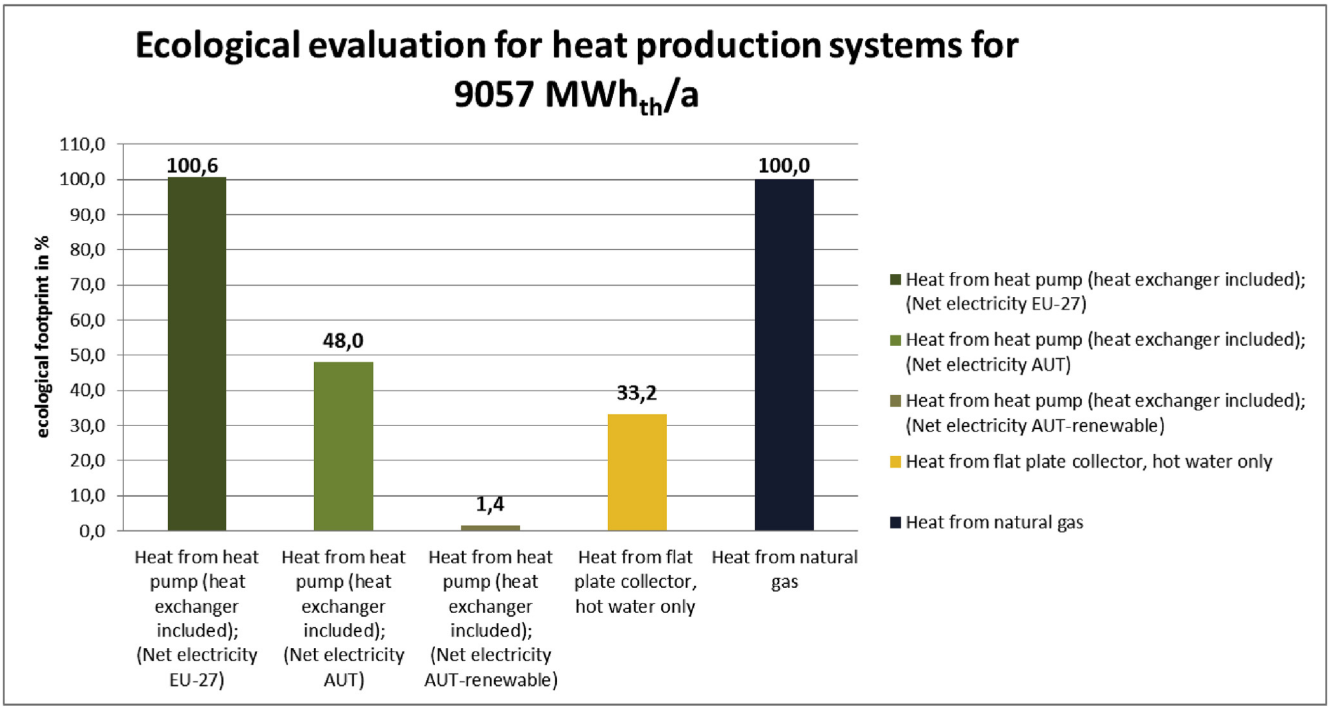


Fig. 8. SPI-Footprint for heat production systems generating 9057 MWh$_{th}$/a in % (based on SPIonWeb).

natural gas) is presented. The heat pump driven by the EU mix generates roughly the same ecological footprint as thermal heat produced using natural gas. An ecologically friendlier option is to use heat pumps with an average Austrian electricity mix (52% footprint reduction compared to the natural gas system) or even better heat generated from solar heat collectors (66.8% reduction). By far the most sustainable option for producing the heat demand of 9057 MWh$_{th}$/a for the considered case study is the scenario using a wastewater heat pump supplied by electricity from renewable resources only, resulting in an ecological footprint reduction of almost 99% compared to the business as usual scenario run by natural gas.

4. Discussion

In this section strengths and benefits of the proposed set of methods are highlighted and potential weaknesses are pointed out. Finally, the discussion focuses on the question which role the integration of WWTPs can resume in the light of the energy transition.

4.1. Strengths and benefits of the proposed set of methods

Although addressing spatial, economic and environmental aspects, the proposed set of methods is based on rather easily accessible data (operational data of WWTPs, spatial structure, and energy consumption). Consequently, data collection efforts are considered to be manageable. The consideration of a multitude of options for energetic integration of the available thermal energy on-site at the WWTP and on the level of external demand and their integrated assessment based on different parameters supports the identification of best solution in terms of strategic energy planning. Finally, the combination of different assessment methods results in a multidimensional planning approach fostering the involvement of different stakeholders and disciplines. This approach complies with the requirements of early stakeholder involvement claimed, e.g. in the EU Water Framework Directive (WFD, 2000).

4.2. Weaknesses of the proposed set of methods

As described above, the SPI tool has already been made available online and the results were presented several times e.g. Narodoslawsky and Krotscheck (2004) as well as for the use of LCA (Niederl-Schmidinger and Narodoslawsky, 2006). Concerning Energy Zone Mapping and PNS applications the development of freely available and user friendly tools is still in progress. Although the related methods and their documentation have already been published in the case of spatial analysis and Energy Zone Mapping by Stöglehner et al. (2011), as well as for using the PNS (Vance et al., 2015), their practical application still requires comprehensive expert knowledge. This implies the need for special training of the parties concerned. As mentioned above, the proposed set of methods involves a multidisciplinary approach. Consequently, the increased stakeholder involvement leads to more complex and resource requiring planning processes. Finally, the existing PNS maximum structure currently considers the most common technologies and energy flows inside and outside a WWTP. The application in the described case study already gave suggestions for improvements towards a more flexible and expandable design of the maximum structure.

4.3. Wastewater energy in the context of the energy transition

Climate-protection efforts and a consistent transition of the current energy system essentially based on fossil and nuclear energy sources into a renewable based one constitute imperative societal and political targets. Therefore, strategies formulated on the global (United Nations, 2015a), European (European Commission, 2011, 2015) or national level (e.g. BMLFUW and BMWFW, 2010) mainly comprise two approaches: (a) the reduction of energy consumption and (b) the substitution of fossil and nuclear by renewable energy carriers. Thermal heat recovery from wastewater can play an essential role for the realisation of the energy turn if heat demands of existing built structures or future urban developments in the vicinity of a WWTP are satisfied. Applying wastewater energy can result in a significant reduction of environmental pressures (Neugebauer et al., 2015). As demonstrated by the application of the proposed set of methods, the SPI-footprint of the wastewater energy application based on a renewable electricity mix for the required heat pumps accounts for only 1.4 percent of the footprint related to a business as usual scenario including heat generation from natural gas. Even though additional electricity is required, the wastewater energy application results in a significant reduction of environmental impacts.

5. Conclusion

Depending on their spatial context, WWTPs can serve as local energy sources. Applying the proposed set of methods reveals the potentials to integrate a WWTP into local energy concepts considering spatial, economic and environmental issues. Including biogas combustion or wastewater heat recovery, WWTPs dispose over heat generation potentials beyond their own thermal requirements. The excess heat can be used to satisfy heat demands in the vicinity of the plant. Spatial analysis including estimations of heat demand and its spatial localisation supports realistic outcomes of feasibility studies as technical potentials are transferred into viable potentials. Economic optimisation can provide evidence that heat generation from wastewater represents an alternative at competitive costs. The application of wastewater energy reduces environmental pressures considerably as demonstrated by a comparison of several heat generation systems with the SPI-footprint. Based on these results we conclude that depending on the spatial context renewable energy from wastewater can play a substantial role in sustainable energy systems. Therefore, this source of energy should be broadly taken into account in local energy supply concepts. The set of methods proposed in this paper hopefully inspires both researchers and practitioners to thoroughly consider this source of energy in their efforts towards more sustainable energy strategies.

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