Integration of renewable energy provided by waste water treatment plants into regional energy concepts in Austria

René Kollmann*
Institute for Process and Particle Engineering,
Graz University of Technology, Inffeldgasse13/3, 8010 Graz, Austria
e–mail: rene.kollmann@tugraz.at

Georg Neugebauer
Institute of Spatial Planning and Rural Development,
University of Natural Resources and Life Sciences, Peter Jordan-Strasse 82, 1190 Vienna, Austria
e–mail: georg.neugebauer@boku.ac.at

Florian Kretschmer
Institute of Sanitary Engineering and Water Pollution Control,
University of Natural Resources and Life Sciences, Muthgasse 18, 1190 Vienna, Austria
e–mail: florian.kretschmer@boku.ac.at

Helene Kindermann
Institute for Process and Particle Engineering,
Graz University of Technology, Inffeldgasse13/3, 8010 Graz, Austria
e–mail: helene.kindermann@student.tugraz.at

Barbara Truger
Institute for Process and Particle Engineering,
Graz University of Technology, Inffeldgasse13/3, 8010 Graz, Austria
e–mail: barbara.truger@student.tugraz.at

ABSTRACT

The energy potential from waste water treatment and its integration into the local energy system will be analysed. Waste water treatment plants can not only clean waste water, there is also a high potential for the efficient use of waste heat and other sources on the site as recent investigations have shown.

These potential will be analysed in real life case studies in different Austrian regions. The recovered energy is primarily used to fulfil the in-house energy demand, the surplus is fed into public energy distribution grids. Local stakeholders are included from the beginning in the integration of energy from waste water treatment plants.

Several software tools were used to support interaction with different stakeholders. The main tool for optimising the waste water energy system used was the Process Network Synthesis (PNS) based on the p-graph method. PNS is used to perform optimisation on an economical level, it will calculate an optimum energy technology network taking all available technologies into consideration.

In addition to the discussion of the PNS calculations, the paper will include an investigation of possible energy consumers in the surrounding area of the sewage plant in Freistadt in Upper Austria, via a special planning tool based on Geographical Information Systems (GIS).

KEYWORDS

waste water treatment plants, energy sources, energy networks, regional, evaluation, Process Network Synthesis (PNS).

* Corresponding author

INTRODUCTION

Today's wastewater treatment plants (WWTPs) in urban areas are high-tech facilities. For decades their main purpose has been the removal of pollutants from wastewater. However, in recent times professional opinion also recognised additional benefits of WWTPs concerning energy and resource management. In the Unites States of America WWTPs are already being seen and termed as wastewater resource recovery facilities [1]. Furthermore the German Federal Ministry of Education and Research (BMBF) has launched a major funding program dealing with future-orientated technologies and concepts for an energy-efficient and resource-saving water management from 2013 till end of 2017. Wastewater related research focuses for instance on issues as WWTPs as control components in energy distribution systems with renewable energy generation, WWTPs as energy storage systems, transformation of sewage sludge to energy and the like [2].

Therefore one answer to the question of how to generate energy in a sustainable way can be the use of so far untapped energy sources at existing WWTP. The plants can not only treat waste water, there is also a high energy recovery potential out of the waste water itself, sewage sludge, sewage gas and other sources on the plant's area, as resent studies have already shown [1-6]. Several research efforts and realized wastewater heat recovery systems all over Europe in Switzerland [5, 7], Scandinavia [8, 9] and Germany [10, 11] have identified wastewater as a significant energy source. However in Austria this energy source is to date not as widespread as in the above-mentioned countries, even though some investigation has been already done [3, 12]. Therefor an Austrian research project "Abwasserenergie" (www.abwasserenergie.at) has been longed in 2013, examining the potential of energy produced on a WWTP and its integration into a regional energy supply concept. Specific attention is given to spatial contexts of the WWTPs due to the fact that spatial analysis of energy efficiency, supply and resource potentials provides a powerful basis for a better decision base for energy planning [13, 14]. The current results will be discussed on the basis of a real life case study in this paper.

Furthermore other renewable energy sources like biomass e.g. are requiring large land areas, land use conflict occurs among food and energy production, most of the time they have a seasonal dependents and usually biomass resources are more available in rural areas, while the cities are characterised by a lack of biomass and intensive waste generation [15].

Most of these issues can be neglected when producing energy on a WWTP site.

These renewable energy sources can be utilised year round. Waste water can be used for heat provision in winter, and cooling in summer [16, 17]. The energy can be used internally at the plant itself to increase the energetic self-sufficiency, or to supply external infrastructures. In the second case the waste water treatment plant can be seen as a renewable energy supplier [18].

These utilisations of energy from WWTPs can be economically reasonable [19] as the evaluation in this paper will show.

Today's waste water treatment plants are primarily used to remove undissolved and dissolved substances from waste water (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.

Different treatment technologies are applied for the removal of the undesired substances from waste water (mechanical treatment in screens, sieves and filters, biological treatment in activated sludge and/or biofilm systems, advanced treatment in membranes or the like). All treatment technologies consume certain amounts of electric and thermal energy. The majority of the energy demand is usually provided by external public suppliers, while a smaller part can be produced at the WWTP itself. Anaerobic sludge treatment at WWTPs equipped with digesters produces sewage gas. Today, the electrical and thermal energy gained from sewage gas combustion is generally used directly at the WWTP.

However, the heat content in domestic and industrial waste water is considerable, but its reuse is not yet very wide spread. The German guideline DWA-M114 (2009) [20], for instance, states that about 10% of the buildings in Germany could be supplied by heat from waste water.

HEAT RECOVERY FROM WASTE WATER

To recover heat from waste water, two technical components are needed: heat exchangers and heat pumps. Both technical components are connected by a pipe system in which a liquid heat transfer medium circulates. The heat exchanger is situated in the sewer systems and extracts thermal energy from the waste water. The heat pump is situated in a heat station outside the sewer systems. It is able to "pump" the extracted thermal energy to a higher level of temperature by using electricity. The heat gained can then be used for the heating of buildings or for hot water provision. Depending on the technical design, a heat pump could also be used for the cooling of buildings. Figure 1 gives an overview on the basic concept of heat recovery from waste water. The displayed co-generator can be used as a backup system for the heat pump during maintenance work as well as for covering peak demands.

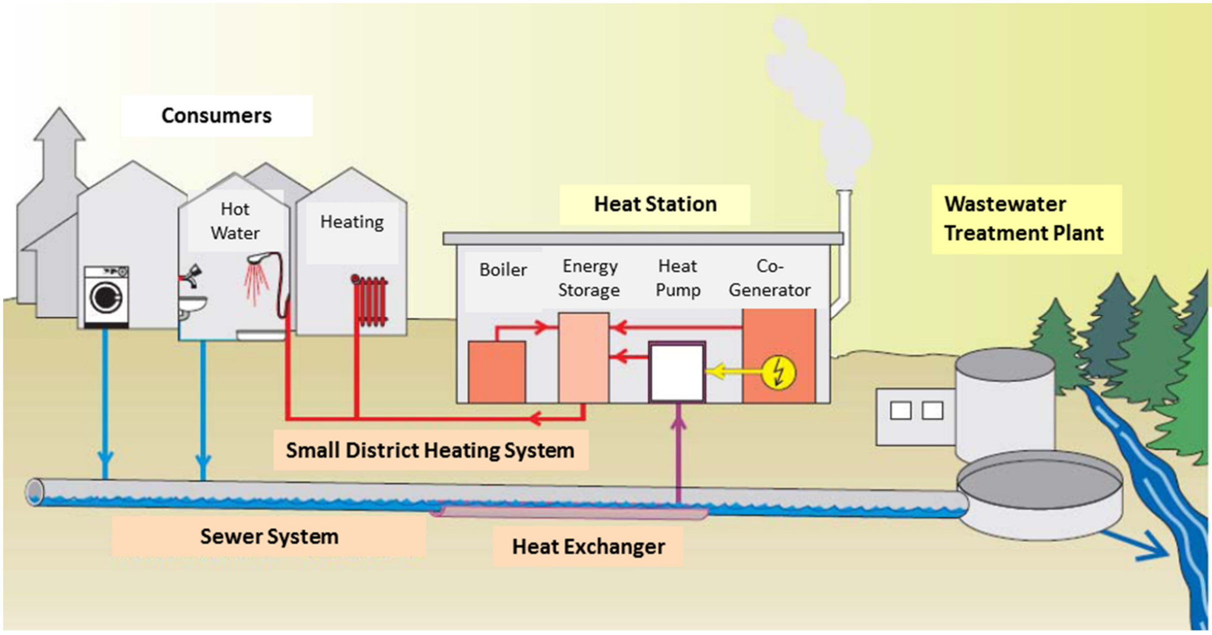

Figure 1. Basic concept of heat recovery from waste water [7], adapted

The heat exchanger cannot only be installed in the sewer systems (as shown in figure 1). Alternatively it can also be placed directly in a building or in the effluent of a WWTP. The different locations of waste water heat recovery are illustrated in figure 2.

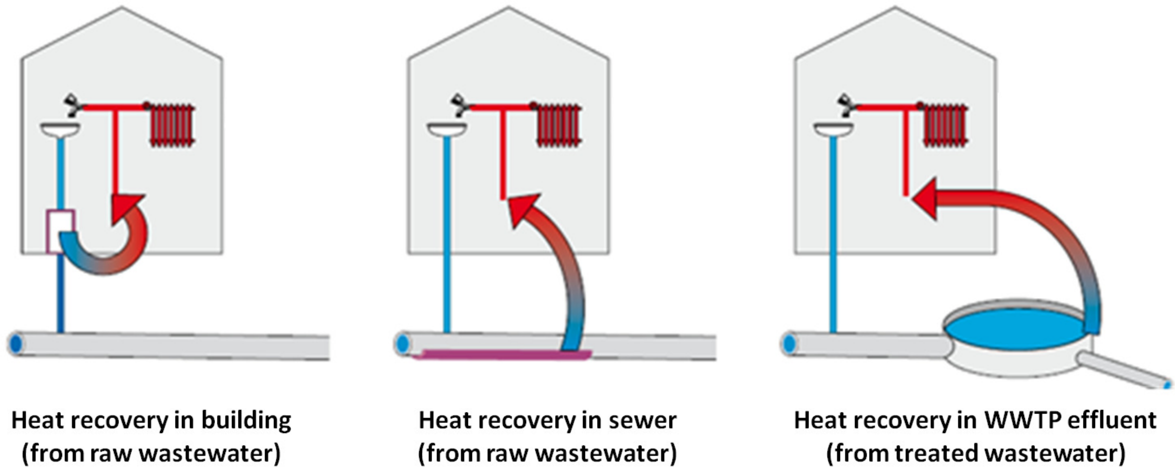

Figure 2. Locations of waste water heat recovery [7], adapted

Heat recovery from waste water in buildings is not very common yet. The advantage of very high waste water temperatures and short supply distances is offset by low and irregular discharges.

The big advantage of heat recovery in the sewer system is the close vicinity to potential heat consumers. A potential problem of this location is the possible impact on the nutrient removal efficiency of the WWTP due to cooling down waste water at the heat extraction site.

If the heat is extracted in the effluent of WWTPs, negative impacts on the treatment performance can be excluded. Additional advantages are very high and continuous discharge rates and the fact that the waste water is already treated (a benefit concerning the applicability and performance of heat exchangers). A drawback of this location can be the lack of heat consumers in close vicinity to the heat extraction site.

However, from a waste water treatment point of view, the effluent of a WWTP is the preferred location for heat extraction. Kretschmer et al. (2014) [21] describe that the heat available at the effluent of a WWTP exceeds the heat demand of the plant itself by far (degree of thermal self-sufficiency 400% and beyond). To make this renewable energy available for other (external) consumers, WWTPs should be integrated into regional energy supply concepts.

METHODS

The Process Network Synthesis (PNS)

The methodical background of PNS is the p-graph representation of flow networks, to establish feasible network structure using combinatorial rules. PNS is a method to optimise material and energy flow systems [22-23]. 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 [16].

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 raw materials, intermediate products, which can be used in other processes, or 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 from point A to B. The user has to define the capacities and availability as well as the investment and operating costs of the technologies, time bound accessibilities and cost of resources, the specific demand and price of the products and the transport costs and distances [24]. Consecutively the program calculates an optimum energy technology network as a solution, within the super structure as shown in figure 3. This optimal technology network contains only feasible structures. Optimisation is achieved with a branch and bound algorithm. The optimum structure represents the optimal way for a region to use their resources, taking all before mentioned variables into account and regarding the technological network as an encompassing economic actor.

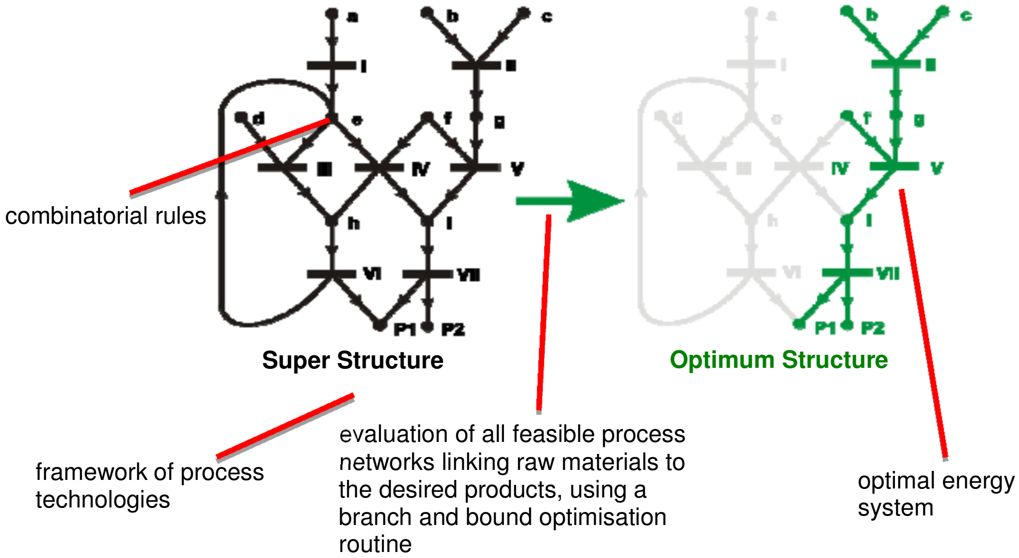

Figure 3. Super structure and optimum structure of a technology network [22], adapted

Energy zone mapping

The tool “Energiezonenplanung” (energy zone mapping) is a decision support tool for integrated spatial and energy planning that enables a zonal analysis of the current energy demand and an estimation of future demands derived from energy saving and urban development scenarios [25]. This tool is considerably easier to handle than other available planning tools [26-29].
For the analysis of thermal energy consumption in the vicinity of a waste water treatment plant, the energy zone mapping tool can be applied based on analysis of heat demand data [25]. The tool provides an economic assessment of the implementation of grid-bound heat supply systems (e.g. biomass district heating system) in predefined energy zones.
On the one hand, the tool enables a zonal analysis of the current energy demand, based on energy indices derived from building phases, on the other hand, future demands can be estimated according to energy saving and urban development scenarios. The core of the tool is the assessment of the feasibility of a grid-bound heating supply. Figure 4 illustrates the results of a zonal analysis of the municipality of Freistadt considering eight energy zones [25]. The tool estimates 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. In addition, figure 5 displays the energy zone mapping results window that gives an overview of the grid parameters and the energy density in terms of heat load.

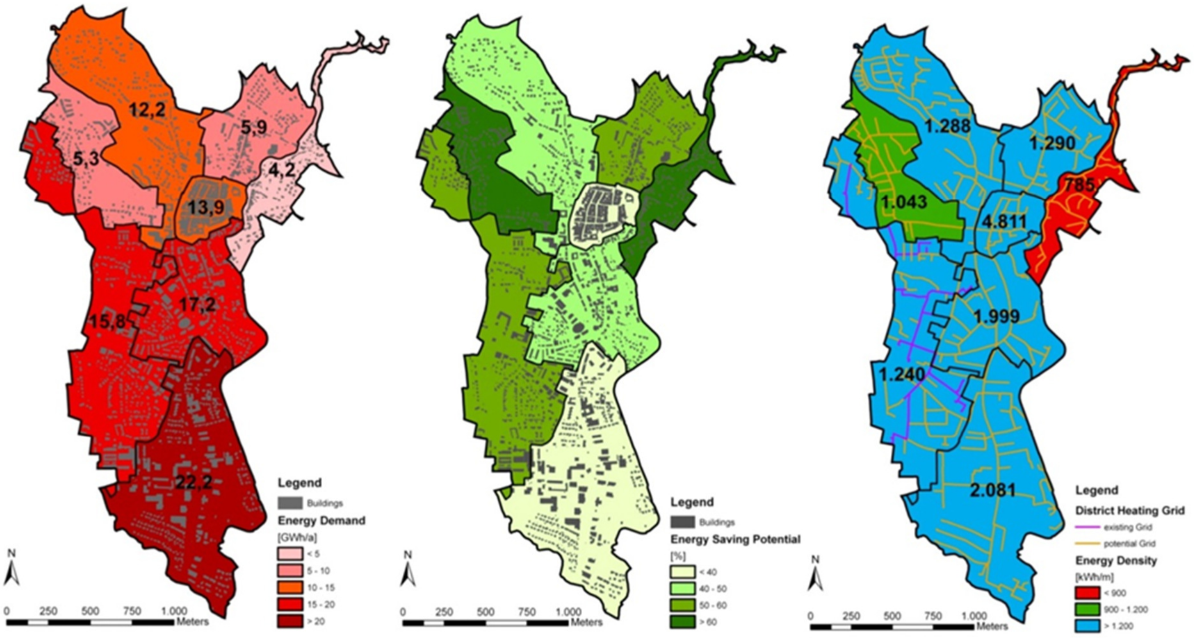

Figure 4. Energy zone mapping Freistadt as basis for the local development concept [25]

The optimal district heating supply system, based on the results of the energy zone mapping application, served as a starting point for the definition of district heating priority and supply areas. The municipality of Freistadt enacted these measures in its local development concept. Furthermore a second biomass district heating plant was established in November 2012.

These conclusions and developed results will be included within the PNS calculations and will guide the whole research project.

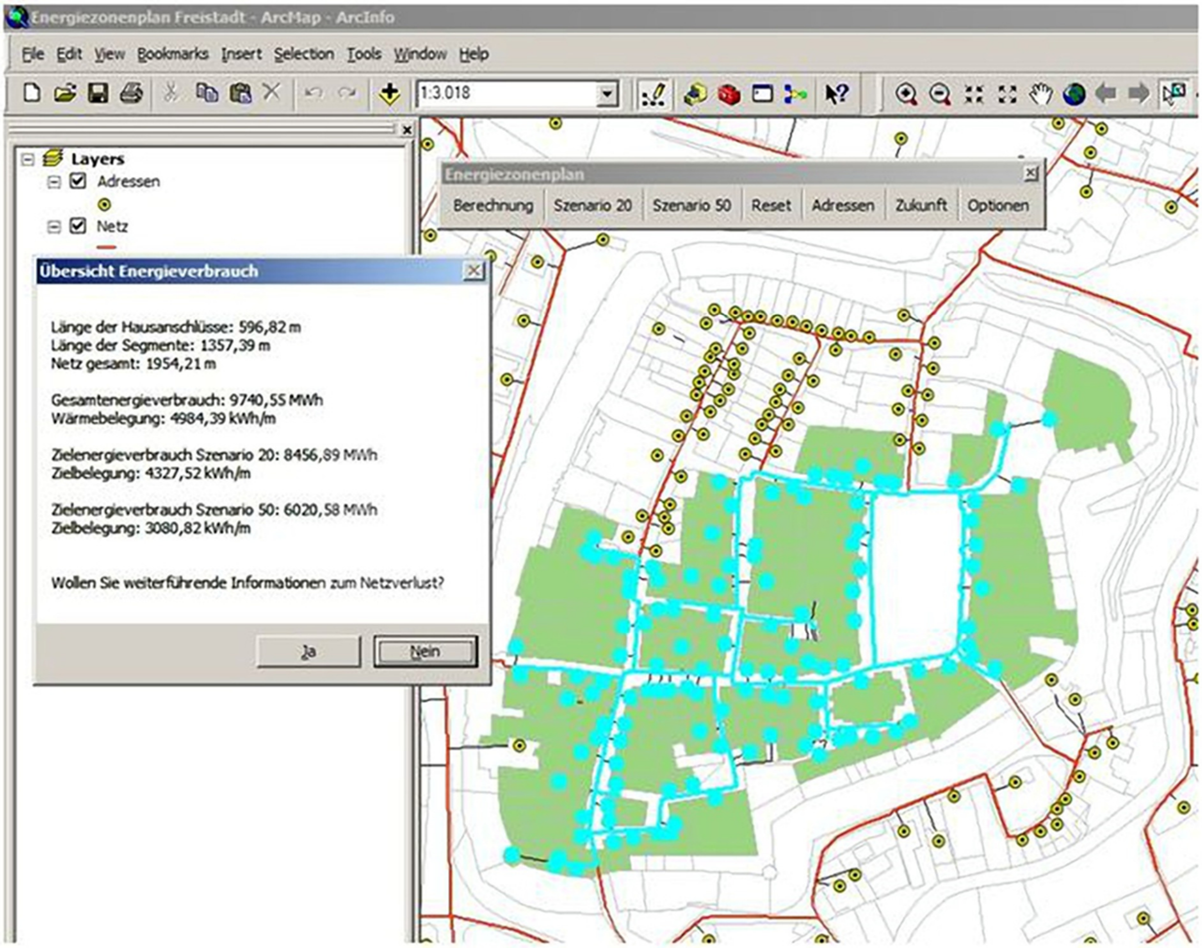

Figure 5. Energy zone mapping results window [25]

CASE STUDY and RESULTS

Three different WWTPs have been chosen as case studies for the current Austrian research project “Abwasserenergie” to characterise the different conditions. The focus of the case studies is an economic optimisation of the energy system centred on WWTPs calculated with PNS Studio [17].

This paper concentrates on the case study of Freistadt, a medieval city with 7500 inhabitants in Upper Austria. The waste water treatment plant in Freistadt is planned for a population equivalent of 30000. In the beginning, local stakeholders like economic, social, political and administrative actors, were informed in a workshop about the project. Possible energy consumers and future energy demands have been defined. The heat supply of a manufacturing and business area, which is planned to be built up in the surrounding area of the WWTP, was spotted as an option by the stakeholders [19].

Integration of WWTPs into Regional Energy Supply Infrastructure

Assessments of integrating WWTPs into regional energy supply systems have certain boundary conditions and limitations. In a first step, land cover and land use data have to be analysed to investigate the external use of heat from WWTPs. Next, the theoretical potentials can be contrasted with technical and economic reasonable potentials by considering the availability of potential energy consumers. Additional factors are the settlement structure, its density and the possible energy demand in the neighbourhood of the WWTP. Due to limited data availability, a more detailed consideration on the level of settlements will be necessary [21].

WWTP Freistadt as regional energy cell

Taking into account spatial contexts, WWTPs can be classified into three different types: (1) WWTPs within, (2) WWTPs near to and (3) WWTPs far from settlement areas. Correspondingly, these types of WWTPs show different potentials for the utilisation of surplus thermal energy.

According to the presence of existing or future potential energy consumers, thermal energy from waste water 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.

The WWTP Freistadt can be considered as a facility within settlement areas. Figure 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 the expressway development (S10 Mühlviertler Schnellstraße).

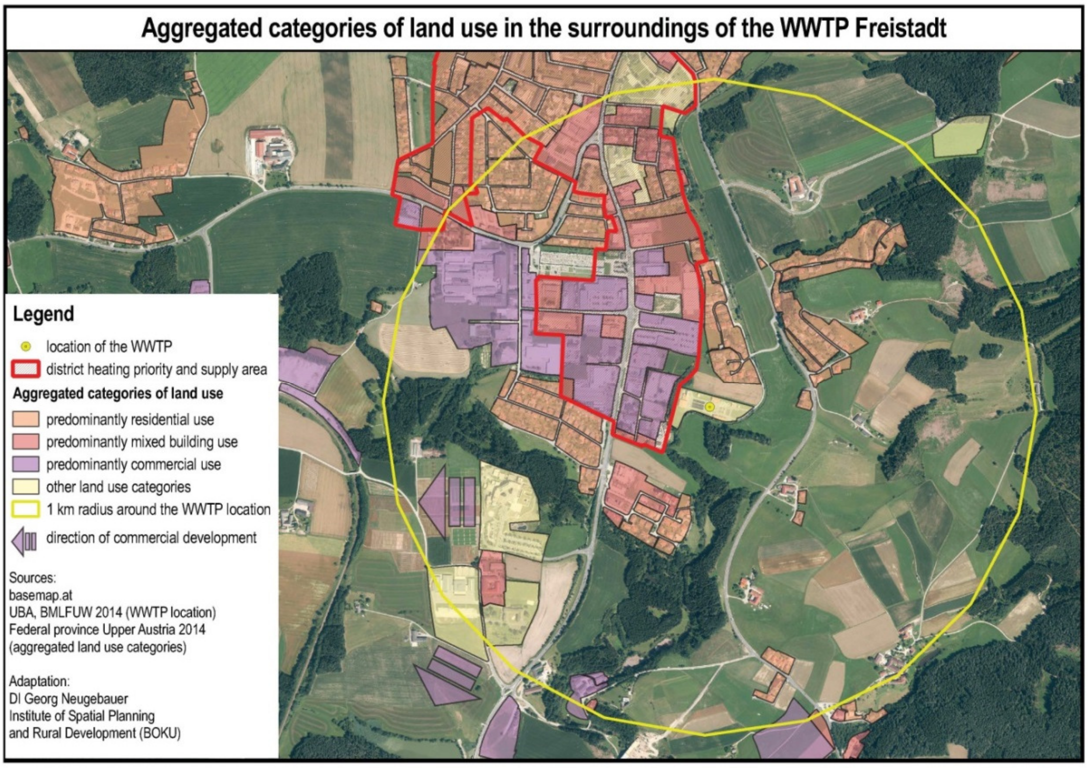

Figure 6. Aggregated categories of land use in the surrounding of the WWTP Freistadt

Therefore, the WWTP Freistadt shows high potentials for thermal surplus energy utilisation from waste water with regard to existing and future energy consumers. These consumers are subject of the investigation in the current research project by applying the above presented energy zone mapping tool. For instance, a spatial analysis with the Geographical Information System (GIS) tool energy zone mapping illustrates that about 100 buildings, located in the district heating priority and supply area within the 1 km radius around the WWTP, and representing an energy consumption of 11 GWh, can be supplied by a district heating system with a total pipeline length of 5.5 km and an energy density of about 2100 kWh/m.

Project perspective

To estimate the possible thermal energy supplied by the WWTP, a sensitivity analysis with different heat prices was carried out with PNS Studio [19], based on the estimated short and medium term (up to five years) demand at new industrial and commercial areas nearby. These intermediate results show, that at a price of 44 €/MWh_{th} the energy demand of the closest consumers, 1874 MWh_{th}/a, can be covered by the WWTP with a micro gas turbine, a gas burner, a heat pump and solar thermal energy. If a price of 48 €/MWh_{th}, which is still lower as the current district heating price, the whole estimated energy demand of 3490 MWh_{th}/a can be covered, with the same technologies as mentioned before, and an additional heat pump at the WWTP.

The potential for the total energy supply at the WWTP is considerably higher, at over 12200 MWh_{th}/a. This would include a micro gas turbine, a gas burner, solar thermal energy, as well as heat pumps recovering waste water energy, and a heat pump to recover waste heat, shown in figure 8 as an optimised superstructure (figure 7).
Furthermore, if the whole potential is utilised by additional consumers (e.g. a future industrial part or settlement development) the energy from WWTP can be provided at a considerable lower price.

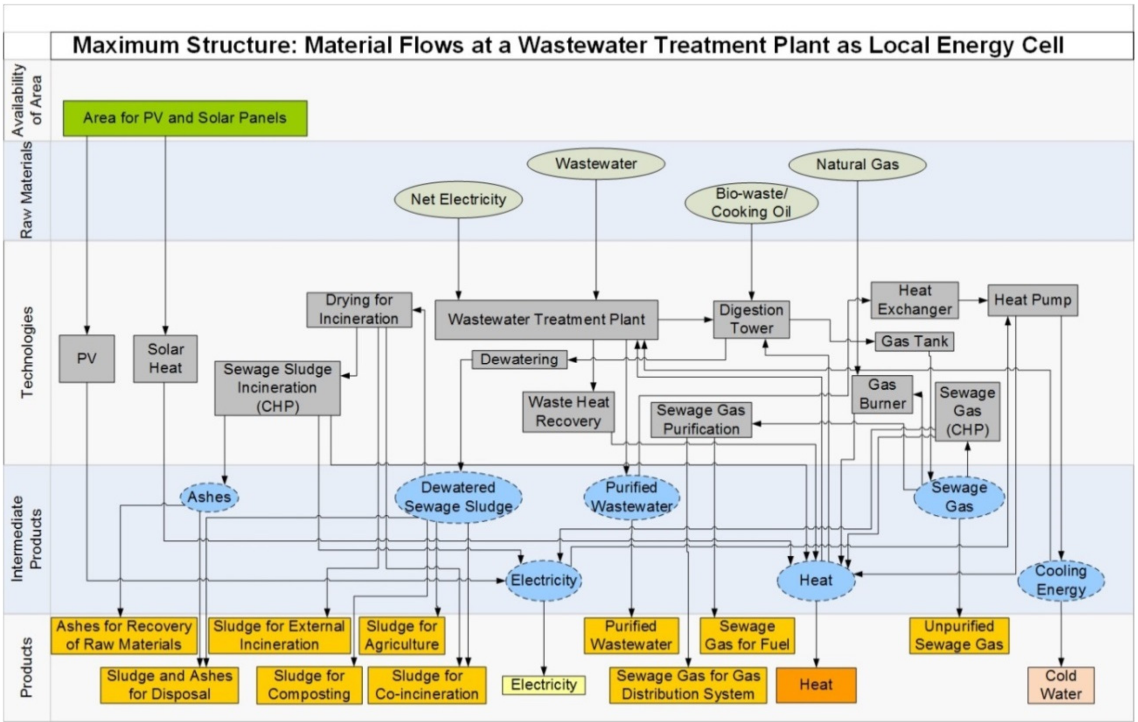

Figure 7. Super structure of a waste water treatment plant with digestion

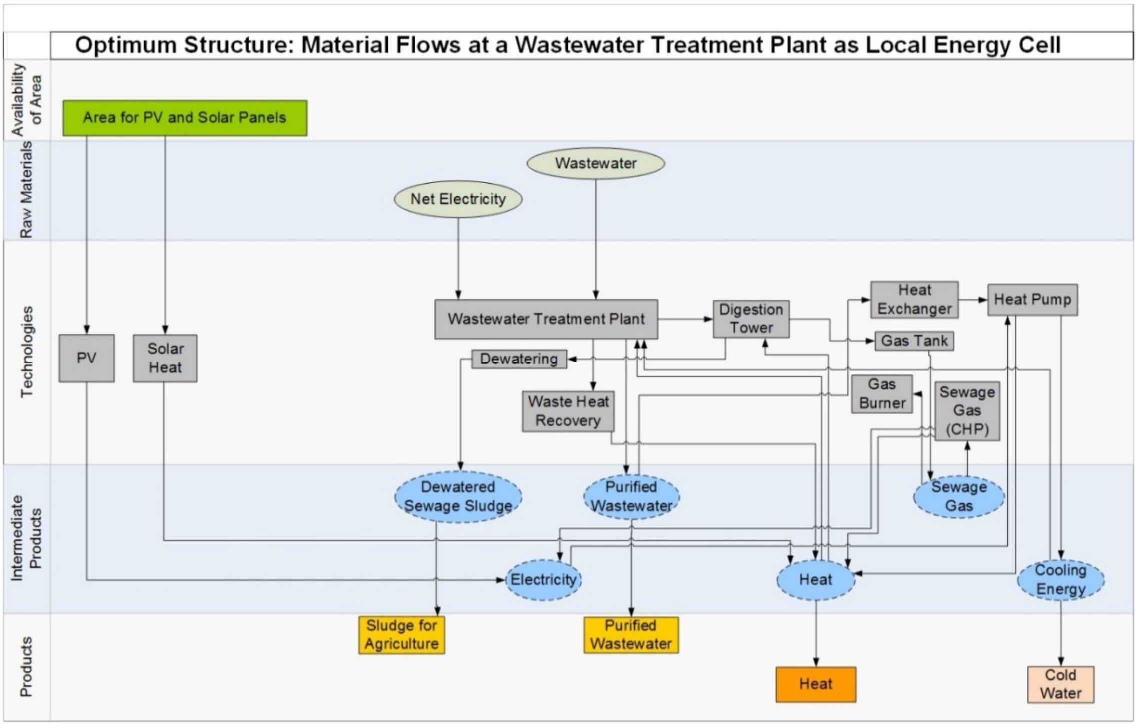

Figure 8. Optimum structure of a waste water treatment plant focused on the heat supply

CONCLUSION

The results illustrate in various scenarios how the heat generation at the sewage plant in Freistadt could look like, considering different feed-in tariffs. The possible heat supply and the producing technologies can change just within a small price range. If the plant gets a price above 48 €/MWh_{th} there is a broad range of used technologies for heat production. In most cases it is easy to supply the in-house heat demand of the plant. Moreover, industrial and residential areas nearby will benefit from the intelligently used energy from waste water. The analysis of the energy systems centred on the WWTP will help stakeholders in the region to make solid decisions for using energy at the plant and supplying its surrounding areas with excess heat in the future.

NOMENCLATURE

PNS: Process Network Synthesis; GIS: Geographical Information Systems; WWTP: waste water treatment plants; DWA: Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall; GWh: gigawatt hour; km: kilometre; kWh/m: kilowatt hour per meter; €/MWh_{th}: euro per megawatt hour thermal; MWh_{th}/a: megawatt hour thermal per year

REFERENCES

1. Stedman, L., The wastewater resource recovery facility of the future. Water 21, *Magazine of the International Water Association,* Feb. 2015, pp 41-42.
2. Federal Ministry of Education and Research (BMBF) , Future-oriented Technologies and Concepts for an Energy-efficient and Resource-saving Water Management (ERWAS), URL: http://www.bmbf.nawam-erwas.de/en [accessed June 26, 2015]

3. Zach, F., Kretschmer, F.; Ertl, T., Müller, E., Adelberger, G., Kolla, L., „Energie aus Abwasser“, Energie aus Abwasser – Abwasserwaerme- und -kaeltenutzung mittels hocheffizienter Grosswaermepumpen (Energy from Wastewater - Heat and Cold Extraction from Wastewater Using High Efficiency Heat Pumps), pp 1-12, Vienna, Austria, 2012.
4. Frijns, J., Hofman, J., Nederlof, M., The potential of (waste)water as energy carrier. *Energy Conversion and Management*, Vol. 65, pp 357-363, 2013.
5. Kind, E., Levy, G.A., Energieeffizienz und Energieproduktion auf ARA (Energy Efficiency and Energy Production at WWTP). Swiss Federal Office of the Environment: Bern, Switzerland, 2012.
6. Meggers, F., Leibundgut, H., The potential of wastewater heat and exergy: Decentralized high-temperature recovery with a heat pump. *Energy and Buildings*, 43, pp 879–886, 2011.
7. Müller, E. A., Schmid, F., Stodtmeister, W., Kobel, B., Heizen und Kuehlen mit Abwasser – Ratgeber fuer Bauherren und Kommunen (Heating and Cooling with Wastewater - Guideline for Building Owners and Communities), Deutsche Bundesstiftung Umwelt, Bundesverband Wärmepumpen e.V., Institut für Energie in Infrastrukturanlagen: Osnabrück, Germany, 2009.
8. Venkatesh, C., Brattebø, H., Energy consumption, costs and environmental impacts for urban water cycle services: case study of Oslo (Norway). *Energy 2011*, 36, pp 792-800, 2011.
9. Pandis Iveroth, S., Vernay, A.L., Mulder, K.F., Brandt, N., Implications of systems integration at the urban level: the case of Hammarby Sjöstad, Stockholm. *Journal of Cleaner Production*, 48, pp 220-231, 2013.
10. Müller, E., Kobel, B., Graf, E., Roth, Y., Müller, K., Billmaier, K., Lambauer, J., Makowezki, V., Blesl, M., Fahl, U., Untersuchungen der Voraussetzungen für Projekte zur Wärmerückgewinnung aus dem Abwasser (Investigations on the conditions for projects using heat recovery from waste water). Institut Energie Infrastrukturanlagen: Winterthur, Schweiz, 2010.
11. Müller, E.A., Butz, J., Abwasserwärmenutzung in Deutschland: aktueller Stand und Ausblick (Wastewater heat recovery in Germany: current status and future prospects). *KA Korrespondenz Abwasser, Abfall*, 57:5, pp 437-442, 2010.
12. Nowak, O., Enderle, P., Varbanov, P., Ways to optimize the energy balance of municipal wastewater systems: lessons learned from Austrian applications. *Journal of Cleaner Production*, 88, pp 125-131, 2015.
13. Stoeglehner, G., Niemtz, N., Kettl, K.-H., Spatial dimensions of sustainable energy systems: new visions for integrated spatial and energy planning. *Energy, Sustainability and Society*, SpringerOpen, Vol. 1:2, pp 1-9, 2011.
14. Stoeglehner, G., Baaske, W., Mitter, H., Niemetz, N., Kettl, K.-H., Weiss, M., Lancaster, B., Neugebauer, G., Sustainability appraisal of residential energy demand and supply – a life cycle approach including heating, electricity, embodied energy and mobility. *Energy, Sustainability and Society,* SpringerOpen, Vol. 4:24, pp 1-13, 2014.
15. Lam, H.L., Varbanov, P.S., Klemeš, J.J., Regional renewable energy and resource planning. *Applied Energy,* Elsevier, Vol. 88, Issue 2, pp 545-550, 2011.
16. Narodoslawsky, M., Niederl-Schmidinger, A., Halasz, L., Utilising renewable resources economically: new challenges and chances for process development, *Journal of Cleaner Production,* No. 16/2, pp 164-170, 2008.
17. Kollmann, R., Maier, S., Shahzad, K., Kretschmer, F., Neugebauer, G., Stoeglehner, G., Ertl, T., Narodoslawsky, M., Waste Water Treatment Plants as Regional Energy Cells - Evaluation of Economic and Ecologic Potentials in Austria. Chemical Engineering Transactions, Vol. 39, pp 607-612, ISSN 1974-9791, *17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction,* Prague, Czech Republic, August 23 - 27, 2014.

18. Kretschmer, F., Weissenbacher, N., Ertl, T., Integration of Wastewater Treatment Plants into Regional Energy Supply Concepts. *Sustainable Sanitation Practice,* No. 22/2015, ISSN 2308-5797, pp 4-9, 2015.
19. Kindermann, H., Kollmann, R., Optimisation of Regional Energy Systems Centred on Wastewater Treatment Plants. *Sustainable Sanitation Practice,* No. 22/2015, ISSN 2308-5797, pp 10-14, 2015.
20. DWA-M 114, Energie aus Abwasser - Waerme- und Lageenergie (Energy from Wastewater - Heat and Potential Energy), *German Association for Water, Wastewater and Waste DWA,* Hennef, 2009.
21. Kretschmer, F., Neugebauer, G., Kollmann, R., Eder, M., Zach, F., Zottl, A., Narodoslawsky, M., Stöglehner, G., Ertl, T., Resource Recovery from Wastewater in Austria – Wastewater Treatment Plants as Regional Energy Cells, *IWA World Water Congress and Exhibition,* Lisbon, September 21-26, 2014.
22. Friedler, F., Varga, J.B., Fan L.T., Decision-mapping: a tool for consistent and complete decisions in process synthesis. *Chemical Engineering Scienc,* Vol. 50, pp 1755-1768, 1995.
23. Lam, H.L., Varbanov, P.S., Klemeš, J.J., Optimisation of regional energy supply chains utilising renewables: P-graph approach. *Computer Aided Chemical Engineering,* Elsevier, Vol. 34, Issue 5, pp 782-792, 2010.
24. Maier, S., Narodoslawsky, M., Optimal Renewable Energy Systems for Smart Cities, Editors: Jiří Jaromír Klemeš, Petar Sabev Varbanov and Peng Yen Liew, *Computer Aided Chemical Engineering,* Elsevier, 24th European Symposium on Computer Aided Process Engineering Vol. 33, SN - 1570-7946, pp 1849-1854, 2014.
25. Stöglehner, G., Narodoslawsky, M., Steinmüller, H., Steininger, K., Weiss, M., Mitter, H., Neugebauer G.C., Weber, G., Niemetz, N., Kettl, K.-H., Eder, M., Sandor, N., Pflüglmayer, B., Markl, B., Kollmann, A., Friedl, C., Lindorfer, J., Luger, M., Kulmer, V., PlanVision – Visionen für eine energieoptimierte Raumplanung (PlanVision – Visions for an energy optimised spatial planning system), *Projektendbericht (project endreport),* Gefördert aus Mitteln des Klima- und Energiefonds. Wien, 2011.
26. Connolly, D., Lund, H., Mathiesen, B.V., Leahy, M., A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, Elsevier, Vol. 87, pp 1059-1082, 2010.
27. Girardin, L., Marechal, F., Dubuis, M., Calame-Darbellay, N., Favrat, D., EnerGis: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas. *Energy*, Elsevier, Vol. 35, pp 830-840, 2010.
28. Lund, H., Möller, B., Mathiesen, B.V., Dyrelund, A., The role of district heating in future renewable energy systems. *Energy*, Elsevier, Vol. 35, pp 1381-1390, 2010.
29. Lund, H., Münster, E., Modelling of energy systems with a high percentage of CHP and wind power. *Renewable Energy*, Vol. 28, pp 2179-2193, 2003.