TE-O-19 Energy production and resource recovery on sewage plants in Austria

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1. Objectives

Regarding renewable energy production from sources other than digester gas, municipal waste water treatment plants (WWTPs) were almost ignored in Austria till now. As investigations on real world case studies have shown, WWTPs can not only treat waste water, there is also a high potential for the efficient use of so far wasted heat and other resources.

2. Methodology

The main tool used in this study is the Process Network Synthesis (PNS), which is based on the p-graph method, employing combinatorial rules for generating technology networks [1]. The PNS is used for economic optimisations of complex process networks, which are represented in a super structure. The super structure contains all possible technologies, raw materials and resources, intermediate products which are produced within the structure and used as inputs in other technologies, and products sold on the market. All energy and material flows, as well as other parameters as capacities and costs of materials and technologies, available amounts of raw materials, and demands and prices for products need to be defined. The super structure builds the basis for the PNS calculation, performed by the software tool PNS Studio [2]. The result of this optimisation is the optimum structure, i.e. the optimal technology network, maximising total revenues [3], as shown in Figure 1.

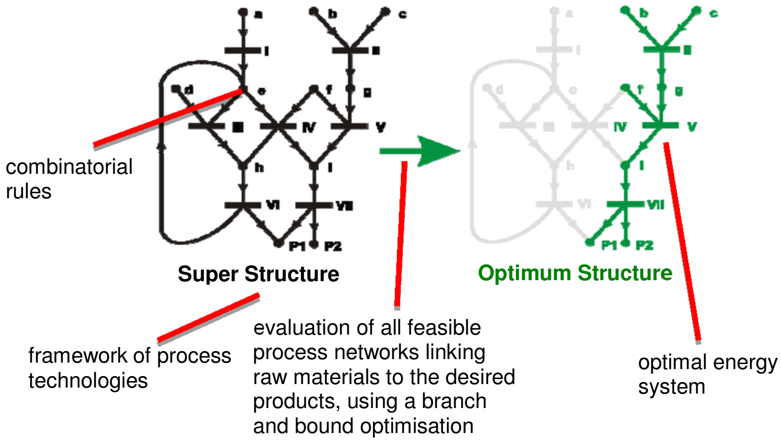

Figure 1: Super structure and optimum structure of a technology network [1], adapted

3. Case study and results

3.1 Energy consumption and production at WWTPs

For decades, the main purpose of municipal WWTPs has been to remove certain substances from waste water (road grit, nutrients, etc.) for protecting receiving waters from pollution.

For the proper treatment of waste water, different treatment steps are applied (mechanical treatment, biological treatment, advanced treatment). All treatment related technologies as well as the common infrastructure of the WWTP itself have demands on electrical and thermal energy. In general, these energies are provided by external suppliers. However, certain amounts of WWTPs' heat and electricity demand are already covered from combustion and cogeneration of digester gas, which is being produced during anaerobic sludge treatment. In addition to digester gas, other (waste water based) sources of energy can be found at a WWTP as well.

Today, a shift in professional opinion can be observed from considering waste water as waste towards considering it as a resource. According to Stedman (2015) [4], WWTPs in the United States now are seen and termed as waste water resource recovery facilities (WRRFs). Based on this approach, the authors of this article believe that WWTPs can also be integrated into local energy supply systems and thus serve as regional energy cells.

The following products can be produced at a WWTP:

Thermal energy:

- Low temperature heat (below 65 °C) by means of waste water heat pumps, solar heat, waste heat of pressure boosters
- High temperature heat (beyond 65 °C) by means of digester gas combustion, combined heat and power generation
- Cooling by means of waste water heat pumps

Electrical energy:

- Electricity by means of combined heat and power generation, gas turbines, turbines in the effluent of a WWTP, photovoltaic panels

Other resources:

- Treated waste water as service water
- Processed digester gas (biogas)
- Processed sewage sludge

Figure 2 gives an overview on the energy and resource consumption and production at a WWTP.

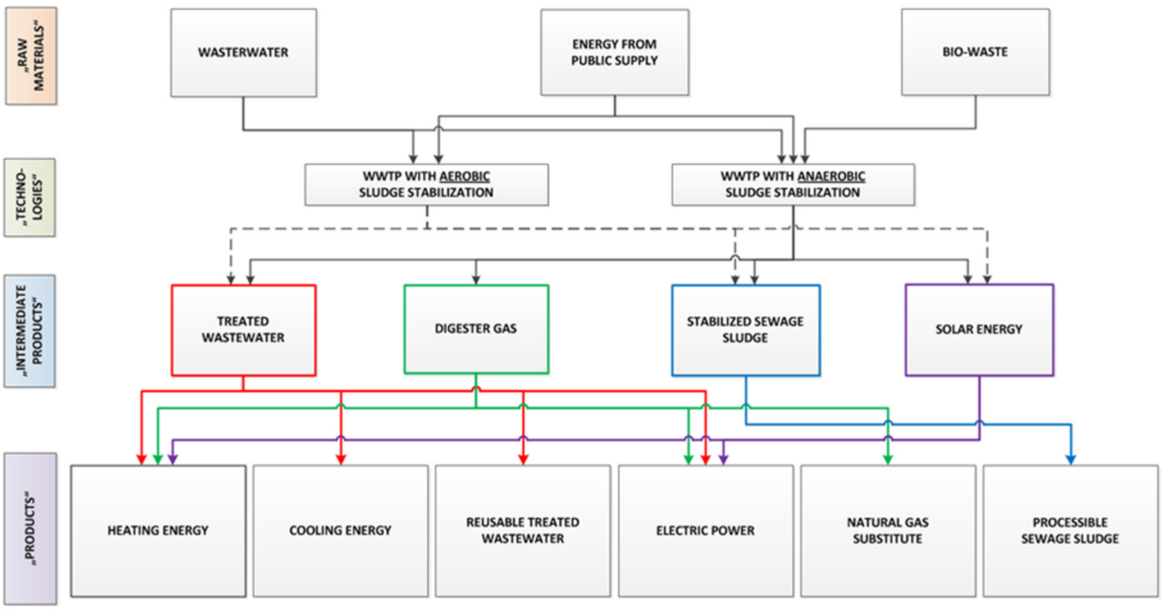

Figure 2: Energy and resource consumption and production at WWTPs [5]

3.2 Electricity and heat potentials at WWTPs in Austria

The annual amount of electricity generated from digester gas can be estimated based on the actual load entering the WWTP and an average energy supply of 15 kWh per population equivalent and year [6]. For the 158 Austrian municipal WWTPs equipped with digester towers [7], electricity in the amount of 115.5 GWh/a may be provided to cover energy consumption at the WWTPs themselves.

Moreover, thermal energy production from digester gas can be estimated in consideration of the actual load entering the WWTP and an average energy supply of 30 kWh per population equivalent and year [6]. Therefore, a thermal potential of 231 GWh/a arises from the above mentioned 158 WWTPs.

Concerning thermal energy from waste water, the available amount of treated waste water and the temperature level represent essential determining factors. Taking into account a 30 percent reduction of the wet weather flow, the annual runoff of about 1148 million cubic metres for 632 Austrian communal WWTPs with a capacity of more than 2000 population equivalents [8] results in an hourly dry weather discharge of about 91760 m^3.

The annual amount of thermal energy from waste water can be estimated based on the following assumptions:

- The specific thermal capacity of waste water is calculated with the appropriate value of water (1.16 kWh/m^3*K).
- The average waste water temperature in the heating period is estimated at 10 °C.
- The waste water in the effluent will be cooled down to 5 °C, so that 5 K can be extracted.
- Heat pumps with a performance factor of 4 are used for the energy generation in a dual mode system.

Assuming an application of the thermal energy in a mixture of functions (e.g. for residential, commercial and agricultural purposes), the annual duration of thermal extraction can be calculated in the order of 4500 hours, which is considerably higher than potential full load hours for the exclusive heat supply of residential buildings in the range of 1500 to 2200. Subsequently, the thermal energy potential from waste water can be estimated with an amount of 6386 GWh/a. This potential shall be contrasted for clarification of the magnitude with the heat generation in Austrian heating plants (without cogeneration of heat and power) of 8602 GWh in the year 2012 [9]. Table 1 presents the potential energy supply of Austria's WWTPs.

Table 1: Potential electric and thermal energy production at Austrian WWTPs

Electricity / GWh_{el}	**Heat / GWh_{th}**	
Production from digester gas	Production from digester gas	Production from waste water
115.5	231	6386

3.3 The case study Freistadt

To make the results more visible on a smaller scale, three different municipal WWTPs (30000 - 150000 population equivalents) in Austria were chosen as case studies in a current national research project. The research is focused on an economic optimisation of the available energy producing technologies, by calculating an optimal energy supply system for the plant, using PNS Studio [10].

One of those case studies is the WWTP Freistadt with a population equivalent of 30000, located in a city of 7500 inhabitants in the province of Upper Austria. The average waste water load of nearly 1.7 million m^3/a is treated mechanically and biologically. The result of the PNS Studio calculation shows that it is economically worthwhile to produce electricity on the plant location and cover parts of the in-house demand to reduce the need for net electricity. The remaining energy potential is converted into heat. In Table 2, the potential of electrical and thermal consumption and production in the plant in Freistadt is illustrated. It is to be noted, that high heat production levels come at the cost of lower electricity production, since the high heat price in those scenarios favours heat production. These intermediate results are sensitive to changes in energy prices, external demands and distances to energy consumers.

To evaluate the possible thermal energy production on the plant, a sensitivity analysis was carried out using PNS Studio, considering different heat prices [11]. Up to a price of 35 €/MWh_{th}, which is considerably lower than the current district heating price, the WWTP Freistadt only covers its in-house heat demand of roughly 497 MWh_{th}/a. In this scenario the heat producing technologies would be a micro gas turbine and a gas burner. Taking higher heat prices as well as heat consumers in the surrounding area into consideration, more heat producing technologies were included in the optimum energy system solution within the PNS results, which are producing a much higher heat amount on the WWTP, as shown in Table 2.

Table 2: Potential annual energy production and consumption of the case study Freistadt

Heat price / €/MWh		Electricity / MWh Production	Electricity / MWh Consumption	Electricity / MWh Balance	Heat / MWh Production	Heat / MWh Consumption	Heat / MWh Balance
35	WWTP[a]	292	671	-379	546	496	50
	Waste water heat pumps						
50	WWTP[b]	292	849	-3962	1812	497	12491
	Waste water heat pumps		3405		11176		
80	WWTP[c]	53	849	-4201	2085	497	12764
	Waste water heat pumps		3405		11176		

WWTP-waste water treatment plant
[a] including a micro gas turbine, a gas burner, and photovoltaic panels; [b] including a micro gas turbine, a gas burner, a heat pump recovering waste heat from boosters, solar thermal energy, and photovoltaic panels; [c] including a gas burner, a heat pump recovering waste heat from boosters, solar thermal energy, and photovoltaic panels

The results show that not only the in-house energy demand would be covered, it could moreover be economically reasonable to supply surrounding areas of the plant with additionally produced heat. At a heat price of 50 €/MWh, for instance, only 7% of the electric demand (including heat pumps) can be covered, but the heat produced is 26 times the internal demand.

4. Conclusion and outlook

The results of the PNS calculations for economically optimal energy producing technologies on an Austrian WWTP show that the internal thermal energy requirements could be covered by the plant itself and, under certain conditions, excess energy can be used to meet external demands of neighbouring consumers. First results show that especially the in-house heat demand on a plant could be covered by various technologies. For instance, heat exchangers and heat pumps using the warm waste water as source seem to have a high potential. Even parts of the internal electrical energy demands could be covered by the WWTPs themselves. Moreover, including local stakeholders helped to evaluate the market potentials of the produced resources like heat, electricity and biogas and integrate them into the energy network of the plant and the surroundings.

Acknowledgements

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