Resource Recovery from Wastewater in Austria – Wastewater Treatment Plants as Regional Energy Cells

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Abstract: Although the main function of a wastewater treatment plant (WWTP) is to remove certain constituents from wastewater it can also serve as a source of energy and other materials. The produced resources can either be used internally at the WWTP or externally at the adjacent infrastructure. In the course of a current national research project the possibilities and potentials regarding the integration of WWTPs into local energy supply concepts are being investigated in Austria. First results show that especially the amount of thermal energy available exceeds by far the internal demands of WWTPs. Even internal electrical energy demands could be self-covering under certain conditions. This paper will give an overview about the energy consumption and production at Austrian WWTPs. Concerning the internal and external use of energy, the first approach to optimise energy flows at WWTPs as well as relevant planning aspects concerning the integration of WWTPs into regional energy supply systems will be presented.

Keywords: Anaerobic sludge treatment; digester gas; heat exchanger; heat pump; mass/energy flow; spatial planning

INTRODUCTION

To strengthen the competitiveness of the European Union and its Member States in a fast changing world the European Commission (s. a.) defines five strategic targets to be reached by 2020. Regarding the issues of climate change and energy sustainability the sub-targets are as follows: Greenhouse gas emissions must be 20 % lower than 1990, 20 % of the consumed energy has to come from renewable sources and energy efficiency has to be increased by 20 %.

Obviously the main function of a wastewater treatment plant (WWTP) is to remove certain constituents from wastewater and thus to ensure public health as well as pollution control. However, apart from this task a WWTP can also serve as a source of energy and other resources. Today, several activities in the field of sanitary engineering as well as related international literature concern energy efficiency and energy generation at WWTPs (e. g. Frijns et al, 2013, Kind and Levy, 2012, McCarty et al., 2011, Rulkens, 2008).

In April 2013 a national three years research project was launched in Austria. One main goal of the project is the evaluation of the possibilities and potentials regarding the integration of wastewater infrastructures into local energy supply concepts.

The major energy demands of WWTPs concern electricity and heat. Electricity is needed for the wastewater treatment process (inflow pumping station, mechanical pre-treatment, biological treatment), for sludge treatment (thickening, possibly digestion, dewatering) and for infrastructure (heating, light, etc.). Thermal energy is needed for infrastructure (heating of buildings, hot water production) and sludge treatment (pre-heating of sludge, digester heating, compensation of transmission losses). However, WWTPs do not only consume but also produce certain kinds of energy and other resources. The most evident outputs are treated wastewater and nutrient containing sewage sludge. In the case of the presence of a digester additional output as digester gas (biogas) as well as electricity and waste heat can be provided. Furthermore the thermal energy content in the (treated) wastewater has to be considered.

The energy produced at a WWTP can be used internally at the WWTP itself or externally at the adjacent infrastructure. From a technical point of view the internal use can be realized in a rather quick and simple way. However, the optimisation of related mass/energy flows can be rather challenging. Applications on external level are a rather complex task as well. The reason for this complexity is the need for consideration of different local and regional boundary conditions as for instance the availability of potential energy consumers, the existing energy supply infrastructure, land use, possibilities to construct connection lines between WWTP and energy users (e. g. integration in a thermal grid) and the like. It is obvious that for a successful integration of WWTPs into regional energy supply infrastructures not only technical and operational data concerning the WWTPs have to be considered but also information on spatial planning in the adjacent area.

This paper will give a brief estimation on the amount of energy consumed and produced at Austrian WWTPs. Therewith the (theoretical) potentials for integration of WWTPs into regional energy supply systems can be described. Concerning the internal and external use of energy, on the one hand the applied method for the optimisation of mass respectively energy flows at a WWTP will be presented. On the other hand the most relevant boundary conditions and limitations regarding the integration of WWTPs into regional energy supply infrastructure will be described.

MATERIAL AND METHODS

Energy Consumption and Production of WWTPs

In the year 2010 in Austria 1841 WWTPs larger than 50 population equivalents (PE) existed. Those WWTPs have a total treatment capacity of about 21.5 million PE. The treated wastewater volume was about 1061 million m³ per year. Out of the total amount of WWTPs, 635 have a capacity of 2000 PE or more (BMLFUW 2011, 2012). Industrial WWTPs and the related wastewater volumes are not considered.

For the project work two different types of WWTPs are considered: WWTPs with aerobic and anaerobic sludge stabilisation respectively. As mentioned before, WWTPs consume and produce different kinds of energy and resources. Figure 1 gives an overview of the input and output resources at a WWTP (resource consumption and production). The corresponding possibilities to further use the produced resources are also displayed.

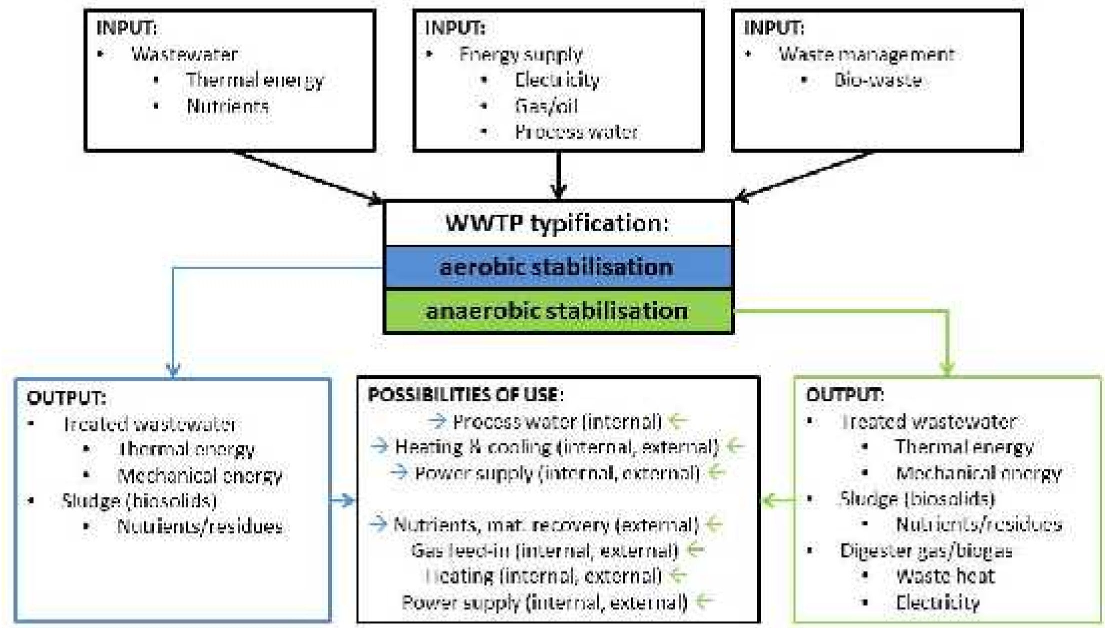

Figure 1 Resources consumption (input) and production (output) at WWTP and possibilities to further use the produced resources

From the input side the current project work considers the thermal energy and nutrient (phosphorus) content of wastewater, electricity and gas supply as well as bio-waste including cooking oils.

From the output side the focus is laid on the thermal energy content of the treated wastewater as well as on sewage sludge processing (dewatering, drying, nutrient recovery). In the case of WWTPs with anaerobic sludge treatment digester gas (biogas) and related electricity and waste heat production is considered as well.

The possibilities of use for heating and cooling as well as electric power supply will be considered on internal and external level. The use of untreated and treated biogas can also be investigated on both levels. Whereas outputs from nutrient recovery from sewage sludge processing can only be evaluated at the external level.

To get a first impression on the energetic potential regarding the integration of WWTPs into regional energy supply concepts the energy consumption (electricity, heat) and production (electricity, heat) of certain Austrian WWTPs will be estimated. One basis for this estimation will be the standard ranges of energy consumption and production at Austrian WWTPs from Lindner (2008) given in Table 1.

Table 1 Standard ranges of energy consumption and production at Austrian WWTPs (Lindner, 2008)

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

*produced from digester gas

Regarding the thermal energy the data in Table 1 just consider the heat produced from digester gas. It does not contain the thermal energy from (treated) wastewater. However, as the total wastewater flow for Austria as well as the specific thermal capacity of (waste-) water is known, estimations can be carried out. The results of these estimations will be presented later.

Optimisation of Energy Flows in WWTPs

As already mentioned before, there are different sources of input and output energy at a WWTP. In the sense of an efficient (energetic) operation of the WWTP it is important to optimise the different mass respectively energy flows. In this regard both, internal as well as external sources and consumers have to be considered.

In the project the system will be optimised using Process Network Synthesis (PNS), based on the p-graph method (Friedler et al., 1995). PNS is a method to optimise material and energy flows. Its aim is to determine a system containing process technologies to transform raw materials into products (including energy). This method requires the optimisation of process structures as well as the optimisation of continuous flows such as material and cost flows. Nowadays when resources are limited and energy prices are increasing, this task has great importance. The approaches of process synthesis have already been engaged to generate process structures in industries, based on input-output relations for process steps and the belongings of material and energy flows. These methods can also be applied to regional material flow networks like WWTPs.

PNS-Studio (Friedler et al., 2011) is employed to perform this optimisation. First a maximum structure of all flows and costs for possible technological options will be created. Containing materials, energy and transport distances the program calculates an optimum energy network as a solution. This optimal technology network covers the most feasible structure that can be created executed with a branch and bound algorithm.

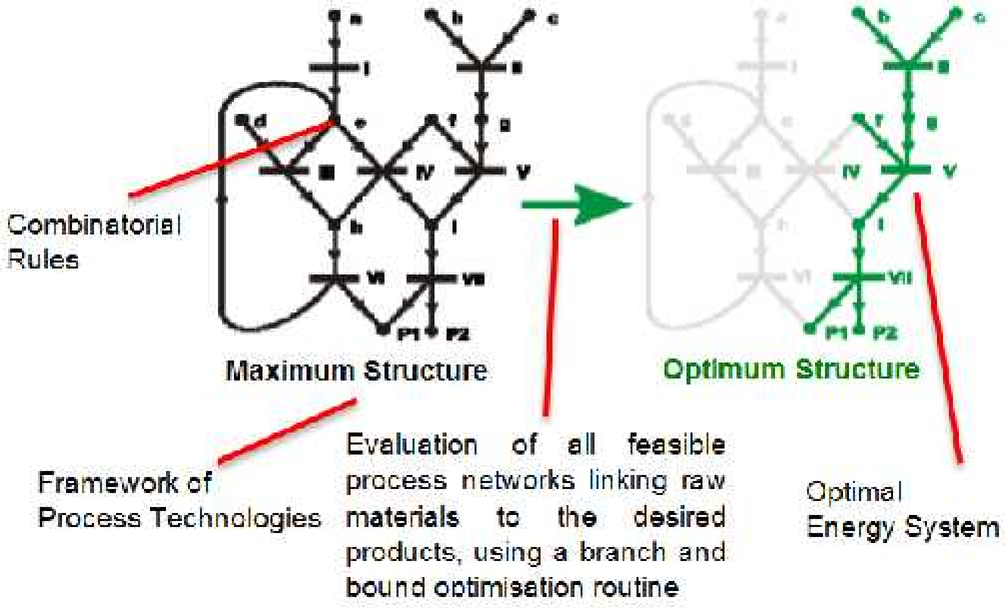

Figure 2 Maximum and optimum structure of a technology network (Friedler et al., 1995, adapted)

The optimum structure symbolises the ideal use of regional resources in term of the highest economic benefit for the region. The current draft of the maximum structure developed in the project will be presented later.

Integration of WWTPs into Regional Energy Supply Infrastructure

Excess energy from a WWTP could be consumed at external level in the adjacent infrastructure. However, there can be certain boundary conditions and limitations regarding the integration of WWTPs into regional energy supply infrastructure. The external use of thermal energy from wastewater treatment depends on spatial preconditions around WWTPs, which can be investigated in a first step by analysing land cover and land use data. Subsequently, theoretical potentials for the external use of thermal energy from wastewater treatment can be contrasted with technical and economic potentials by considering the availability of potential energy consumers. Further essential factors are the settlement structure and density as well as (potential) energy demand in the surroundings of the WWTP, that require more detailed considerations on the level of settlements or even buildings. In the framework of the research project such analysis will be exemplarily carried out for certain Austrian WWTPs.

RESULTS AND DISCUSSION

Energy Consumption and Production of WWTPs

According to Spatzierer (2012) 159 of the Austrian municipal WWTPs are equipped with digester towers. These WWTPs represent a treatment capacity of about 11.6 million PE (around 55 % of the total capacity of municipal WWTPs), representing a current load of about 7.9 million PE (EEA, 2012). On the one hand electrical and thermal energy from digester gas processing is available at these WWTPs. On the other hand thermal energy can be retrieved from the wastewater (effluent) by the use of heat exchangers and heat pumps. The latter is also available at WWTPs without digester towers. However, regarding the estimation of energy consumption and production the focus in this paper is laid on digester gas producing WWTPs.

Table 2 shows estimated energy consumption and production of WWTPs including digestion towers. The calculated values are based on a current load of about 7.9 million PE and the energy standard ranges mentioned in table 1. Average and optimised performance in the first column refer to the performance of the WWTPs. Based on the ranges given in table 1, average performance represents mean values in energy consumption and production (for electric and thermal energy from digester gas processing). Optimised performance represents minimum values for energy consumption (as the minimum value regarding thermal energy consumption is zero the mean value was here used as well) and maximum values for energy production. The estimation of thermal energy from wastewater is based on a municipal wastewater flow of about 1061 million m³ per year (BMLFUW, 2011). The estimated pro rata dry weather flow of the WWTPs with digester towers is about 390 million m³ per year (about 40000 m³/h). The specific thermal capacity of water is 1.16 kWh/m³*K, this value was adopted for wastewater. Further it was assumed, that the wastewater in the effluent will be cooled down by 5 °C and the annual duration of thermal extraction (operation of a heating system) is 2200 hours (this value can be higher, if the system is operated during the whole year). The average value only considers the thermal energy content of wastewater. The optimised value comprises the electric energy use of a heat pump with a seasonal performance factor of 4.

Table 2 Estimated energy consumption and production of WWTPs including digestion towers

	Consumption [GWh/a]		Production from digester gas [GWh/a]		Production from wastewater [GWh/a]
	electric	thermal	electric	thermal	thermal
average performance	277	119	119	237	510
optimised performance	158	119	158	316	681

The ratio between energy consumption and production gives the degree of self-sufficiency of the considered WWTPs. In table 3 the different values are given. It seems that self-sufficiency regarding electric energy can be achieved or even exceeded in the case of boundary conditions and WWTP performing near the optimum. However, the thermal energy produced during digester gas processing usually exceeds the WWTP demands even under average conditions. If heat extraction from wastewater (effluent) is also considered, WWTP can certainly be regarded as a significant regional source of (thermal) energy. This statement also applies to WWTPs without digestion towers.

Table 3 Degree of self-sufficiency regarding electrical and thermal energy

	Degree of self-sufficiency [%]		
	electric energy	thermal energy	
		excluding wastewater	including wastewater
average performance	43	200	631
optimised performance	100	267	841

Optimisation of Energy Flows in WWTPs

Prior to the supply of adjacent infrastructure with excess energy from a WWTP the internal mass/energy flows within the WWTP should be optimised to reach the highest degree of self-sufficiency possible. Figure 3 shows the current draft of the PNS maximum structure developed in the project to optimise mass/energy flows in a WWTP. The structure comprises all relevant “raw materials” (input data as wastewater, gas, bio-waste and electricity), “technologies” (the WWTP itself, digestion tower, heat exchanger and heat pump, etc.) “intermediate products” (treated sewage sludge, digester gas, etc.) and “products” (electricity, heat, etc.). Additionally all possible mass/energy flows are defined. Based on pre-defined costs (raw materials, technologies, products) the software can calculate the best structure (most cost efficient) of a certain system. For practical application the maximum structure will be adapted and applied at three different WWTP in Austria at a later stage of the project.

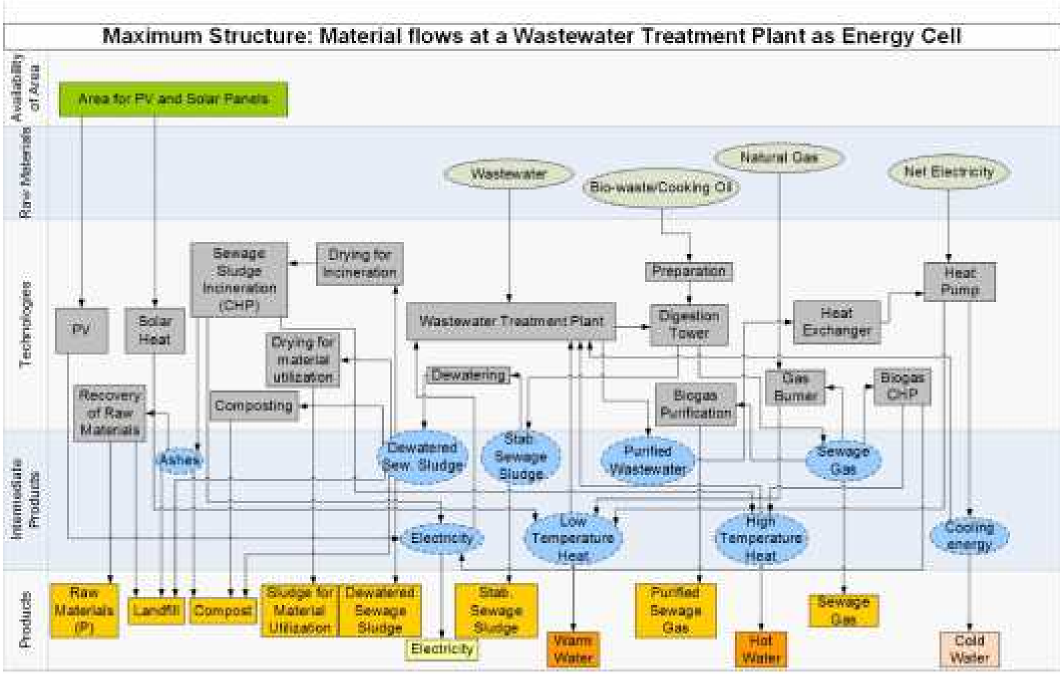

Figure 3 Current draft of the maximum structure regarding material (mass/energy) flows at a WWTP

Integration of WWTPs into Regional Energy Supply Infrastructure

After the optimisation of the internal mass/energy flows at a WWTP and the definition of the available quantities of excess energy the local situation and the demands regarding the adjacent infrastructure have to be evaluated (e. g. spatial planning). In some cases, rather the availability of potential energy consumers in certain distances around WWTPs represents the limiting factor than the thermal energy capacity (Project Consortium "Energie aus Abwasser", 2012). Therefore, spatial management and planning are of great importance by interlinking potential present and prospective energy consumers and available excess energy. Furthermore, bridgeable distances between WWTPs and potential energy consumers depending on the energy demand are underestimated. Existing energy supply infrastructures may compete with thermal energy provision gained from wastewater, but also offer possible synergies. Eventually, energy recovery projects are not realised even at locations with adequate preconditions for lack of information about the potentials of wastewater as energy source.

CONCLUSIONS

The main function of a WWTP is to remove certain constituents from wastewater. For the treatment processes and the maintenance of the infrastructure different sorts of energy are needed (electricity, heat, etc.). However, WWTPs also produce different kinds of energy and other resources (electricity, heat, treated sewage sludge, etc.). The available energy can either be used internally at the WWTP or externally at the adjacent infrastructure. WWTP thus can be also considered as regional energy cell.

In the course of a current research project the possibilities and potentials regarding the integration of WWTPs into local energy supply concepts are being investigated in Austria. First results show that especially the amount of thermal energy available (from digester gas processing and recovery from wastewater) exceeds by far the internal demands of WWTPs. Also internal electrical energy demands could be self-sufficient under certain conditions.

The optimisation of mass/energy flows in a WWTP is a first step towards energy self-sufficiency. In the project process network synthesis is being applied to identify optimum flows within a defined system. For this purpose a pre-defined maximum structure will be adapted and applied at three different WWTP in Austria at a later stage of the project.

Excess energy available should be used to supply the adjacent infrastructure. However, for a successful integration of WWTPs into regional energy supply systems it is crucial to be aware of and to consider relevant local boundary conditions and limitations (spatial planning, etc.) already at an early planning stage.

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