D.T2.5.1 REGIONAL STRATEGY_BERLIN

Project Title: REEF2W Increased renewable energy and energy efficiency by integrating, combining and empowering urban wastewater and organic waste management systems

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Abbreviations

BEK 2030	Berlin Energy and Climate Protection Programme 2030
BWB	Berlin Water Works (ger.: Berliner Wasserbetriebe)
CHP	Combined heat and power
dena	German Energy Agency (ger.: Deutsche Energie-Agentur)
DVGW	German Gas and Water Association (ger.: Deutscher Verein des Gas- und Wasserfaches)
EWG Bln	Berlin Energy Transition Law (ger.: Berliner Energiewendegesetz)
KWB	Competence Center Water Berlin (ger.: Kompetenzzentrum Wasser Berlin)
SenUVK	Department for Environment, Transport and Climate Protection of the Senate in Berlin
SenWEB	Department for Economics, Energy and Public Enterprises of the Senate in Berlin

1. INTRODUCTION

Climate change and exiting from fossil fuels are central challenges of our time, which must be met globally and locally with ambitious climate protection and energy transitions. As a response, the EU aims to achieve three key objectives by 2020: to generate 20 % of its total energy production from renewable sources, to increase energy efficiency by 20 %, and to reduce greenhouse gas emissions by 20 %.

These developments have also focused attention on the yet unexploited energy potential of the wastewater sector. Wastewater contains a high amount of unused energy, which can be easily converted into electricity, heat, or biogas. The amount of energy it contains can be ten times greater than the amount required for its treatment. This enables wastewater treatment plants (WWTPs) to become energy self-sufficient or even to serve as power plants. An increasing number of utilities are deploying energy-efficiency actions and novel technologies to better harness the energy of wastewater.

The project REEF 2W starts by recognising that wastewater plays a key role in transforming energy systems. The project's main objective is to increase energy efficiency and renewable energy production in WWTPs. It focuses on solutions that integrate wastewater streams and the development of new infrastructures. One of the project's key task is the development of a comprehensive assessment tool that provides proof that waste-to-energy technologies are technically feasible and economic viable. In a series of workshops, REEF 2W designed a tool in close cooperation with the utilities. Another key task of REEF 2W is to investigate the legal and policy framework conditions and to advocate for policy alternatives that spur the large-scale use of wastewater-to-energy solutions.

As part of the REEF 2W outcomes, the main goal of this Regional Strategy is to enable municipal governments to accelerate the implementation of wastewater-to-energy solutions in WWTPs. Wastewater utilities face various legal, political and economic barriers that impede the improvement of energy performance. Municipalities can actively support wastewater utilities to overcome some of these barriers in many ways and can thus contribute to the dissemination and implementation of innovative technologies. Actions include setting ambitious regulations, improving financing, or using their role model function by equipping own public buildings with these solutions. In the case of Berlin Pilot, the Regional Strategy has been developed in cooperation between: adelphi, the Competence Centre for Water in Berlin gGmbH (ger. Abb.: KWB) and the Department for the Environment, Transport and Climate protection (ger. Abb.: SenUVK). In the analysis of current and the development of new interventions, however, it does not replace existing energy-related strategies but complements them with a focus on selected wastewater-to-energy solutions.

2. APPROACH

The Regional Strategy focuses on several technologies that comprise the focus in the REEF 2W project at the WWTP in Schönerlinde. The analysis focuses on the period between 2010 and 2030. While several of the WWTPs that treat Berlin's wastewater are located in Brandenburg, subject to the analysis are only actions carried out by the Berlin government.

The development of this Regional Strategy is conceptually grounded in frameworks by Kaplan et al. (2008) and Adams and Harris (2005). These have been adopted to match the purpose of the REEF 2W project and specifically the current objectives and work of the Berlin Senate.

The Regional Strategy is structured into four major steps:

Step I: Background (section 3)

Background information will give the reader a brief introduction to the REEF 2W project as well as a basic understanding of the current situation of Berlin and the wastewater sector laying with regard to climate goals.

Step II: Defining a vision, strategic goal and objectives (section 4)

The vision, goal and objectives are closely aligned with the objectives in the Project REEF 2W.

Step III: Strategic analysis (section 5)

In this step, currently undertaken and planned actions by the Berlin Senate to implement the respective REEF 2W solution concepts are investigated. Additionally, possible strengths, weaknesses and gaps concerning these actions are discerned. Particular attention in this analysis is concentrated on actions that the Berlin Senate is already using to implement the Berlin Energy Transition Act (EWG Bln), which can be grouped into the following categories:

- Target group-specific information, communication, education and counselling
- Citizen participation, networking and cooperation
- Specific pilot and demonstration projects, promotion of innovation
- Supporting funding programmes and incentives for technologies, services and infrastructures
- Funding programmes and instruments for social resilience
- Improvement of planning tools and administrative regulations, lowering of barriers
- The exemplary effect of the public sector
- Recommendations for the federal level

First, the strategic analysis identifies and lists planned as well as completed and ongoing actions before it, second, evaluates the actions in terms of existing strengths, weaknesses and gaps.

Step IV: Strategy formulation (section 6)

On the basis of the strategic analysis, a set of new actions are developed to make progress in reaching the afore-defined goal/objectives and to overcome current barriers. The actions stem from the same action categories. Importantly, only actions that are relevant to the context of Berlin and which the Berlin Senate is able to implement realistically are considered. It is not the intention to develop an exclusive list of actions with detailed instructions for implementation, but rather to provide strategic directions to be taken.

The present strategy was developed in close cooperation between the Berlin Senate Department for the Environment, Transport and Climate protection (ger. Abb.: SenUVK), the Berlin Senate Department for Economics, Energy and Public Enterprises (ger. Abb.: SenWEB) and the REEF 2W project partners responsible for the Berlin case study, adelphi and the KWB in the course of several meetings. The groundwork of the Regional Strategy builds on several studies conducted within the REEF 2W project as well as official government documents and scientific studies relevant to this research.

3. BACKGROUND

3.1. Climate protection targets and the current state in Berlin

Energy and decarbonisation targets have been set at EU and national level that act as drivers for the implementation of waste-to-energy solutions. The Berlin government has translated these, in part, into its own targets. As the technological innovations of the REEF 2W approach are cross-sectoral, different targets concern the solution concepts in its implementation. This section provides a brief overview of the current situation and progress in implementing regional and international climate targets in Berlin.

The climate protection targets for Berlin and the instruments for achieving them are anchored in the Berlin Energy Transition Act (EWG Bln), which establishes a legal framework for sustainable climate protection. The action plan for the implementation of these climate targets is laid down in the BEK 2030.

CO_2 emissions

Berlin has set itself the goal in the EWG Bln of becoming climate neutral by 2050 and is thus responding to the challenges of climate change. This will be achieved if CO_2 emissions are reduced by at least 85 % by 2050 compared to 1990.

According to the BEK monitoring report in 2018, it is possible for Berlin to achieve the set target of a 40 % reduction in CO_2 emissions by 2020, assuming that the city's average emission development will continue from 2010 onwards, (SenUVK 2018a). Berlin could already achieve a reduction value of 33.3 % (SenUVK 2018a) and was thus above the EU-wide target of 20 % cut in greenhouse gas emissions (EU climate action).

Energy efficiency

In addition, Berlin was able to reach the set EU targets for energy efficiency (saving of 20 % of the primary energy consumption by 2020 compared to 1990 (Energy Efficiency Directive (2012/27/EC))) with a decline of 24.1 % (Amt für Statistik Berlin-Brandenburg 2019).

Renewable energy production

Berlin's implementation of the goals of renewable energy generation has so far not been as successful as the goals of energy efficiency. Where the EU targets (20 % share of renewable energy of gross final energy consumption by 2020 compared to 1990 (2009/28/EC)) and national targets (18 % share of gross final energy production, 35 % share of gross electricity consumption and 14 % share of heat consumption (BMWi 2019a)) are partially met across Germany with 16.6 % in 2018 (UBA 2019), 37.8 % in 2018 (UBA 2019) and 13.2 % in 2017 (BMWi 2019b), respectively (UBA 2019)), Berlin performed very poorly in comparison: 3.6 % (status 2015), 2.5 % (status 2016) and 3.4 %, respectively (AEE 2019).

3.2. The REEF 2W approach

REEF 2W aims at tackling the challenge of developing and implementing solutions for increasing energy efficiency and renewable energy production by integrating, combining, and strengthening urban wastewater and organic waste treatment systems. In order to achieve this, REEF 2W pursues the approach of combining and integrating relevant public infrastructures of the municipal waste chain and wastewater treatment as well as improving the organic input mix and energy yields. Smart operated and equipped WWTPs have the potential to enable the coupling of supply and disposal sectors (water/wastewater - heat/electricity/gas) in a meaningful way (Schmitt et al. 2017).

The approach leads the way for more flexibility in the energy system enabling the integration of renewables. It extends the energy transition from power to heat and improves energy security meeting the Paris climate commitment.

Technological innovations

The REEF 2W approach encompasses a wide range of innovative technologies that enable an increase in energy efficiency and energy yields. Using smart storage methods and conversion methods, the REEF 2W approach creates new flexibility options in energy management. The following technological solutions are considered in REEF 2W and examined in five case study countries: thermal hydrolysis, biogas-upgrading, power-to-gas/methanisation, co-fermentation, heat pump, and grid injection concepts. Other actions to improve energy efficiency, such as on-site renewable energy generation by means of photovoltaics, hybrid plants and solar thermal energy or the increase of operational energy efficiency, are marginal to REEF 2W, but must be considered in order to take a holistic perspective. The selection of solutions considered in the German case study is explained in section 3.4.

Expected benefits and drivers

The implementation of REEF 2W technologies entails several advantages from an energetic, economic and environmental point of view (see Table 1).

Table 1: Expected benefits of the REEF 2W technology innovations

Energy optimization	Economic feasibility	Environmental sustainability
Additional process steps such as thermal hydrolysis or co-fermentation with organic substances increase biogas yields. Additional heat production is achieved by heat pumps in the sewer. A more efficient utilization of biogas is achieved by CHP or biogas-upgrading. More efficient energy consumption, increased energy yields, and the production of storable biomethane increase system security and flexibility.	Energy savings and self-supply of energy and heat lead to a reduction in operating costs. Sales of excess heat, electricity and biomethane allow for additional revenues. Reduced sewage sludge volumes reduce disposal costs, especially where cost-intensive waste incineration is the only option. Optimized economics of wastewater treatment plants lead to financial savings for municipalities.	Energy savings and reduced use of fossil fuels result in a lower CO_2-footprint of WWTPs. Biogas obtained from sewage is a more environmentally friendly biogas compared to crop-based feedstocks. Recycling of organic waste in sewage treatment plants replaces the CO_2-intensive disposal on landfills. The wastewater sector increases its contributions to a sustainable energy transition and climate protection.

3.3. The wastewater sector in Berlin

Berlin is the capital of Germany. With a population of 3.61 million (2017), it is also the largest city in the country and, with an area of 891.1 km^2 (2018), the second most densely populated one after Munich[1]. The city has a gross domestic product of 147.1 billion Euro (2018)[1].

In Berlin, a total of six WWTPs treat 624,000 m^3 wastewater daily (BWB 2019b). The location of the six WWTPs can be seen in

Figure 1. The capital can supply itself with drinking water from regional sources and reuses its wastewater after appropriate treatment feeding it in the water supply again. In Germany, wastewater disposal is the responsibility of the municipalities or other public

[1] https://www.statistik-berlin-brandenburg.de/Statistiken/inhalt-statistiken.asp

bodies (in the Berlin case: Berlin Water Utility (ger. Berliner Wasserbetriebe, BWB) (ATT et al. 2015)).

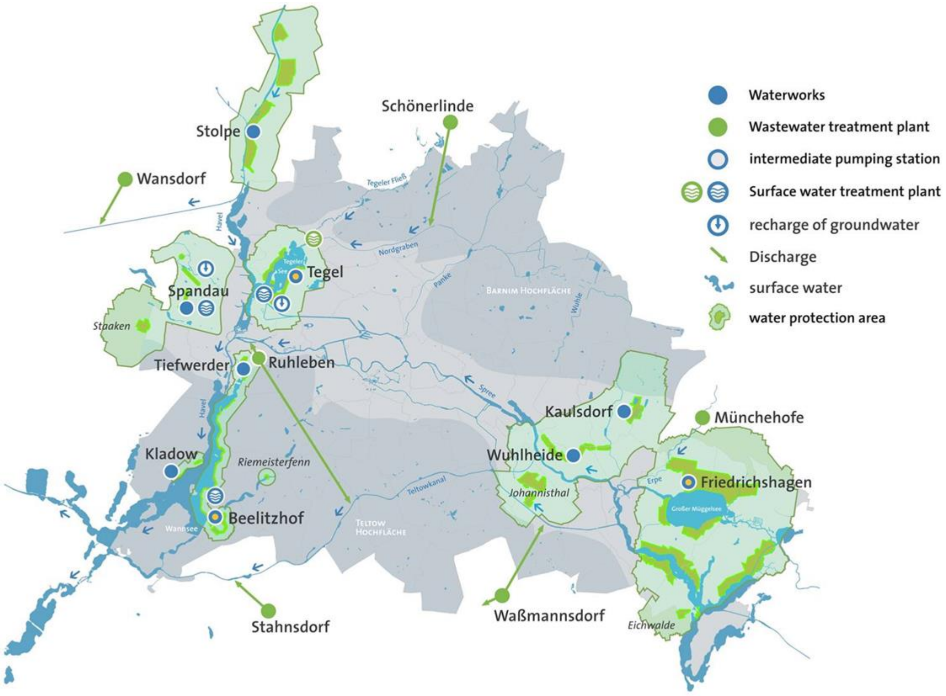

Figure 1: Locations of wastewater treatment plants in Berlin (BWB)

Up to 80 % of the greenhouse gases released by water supply and wastewater treatment in Germany originate from energy use. Increasing the efficiency of the energy use represents, therefore, a key action to a climate-friendly and sustainable water management (Veolia 2016). Through actions such as increasing energy efficiency, saving energy and reducing drinking water consumption, the BWB were already able to reduce CO_2 emissions by 50 % compared with 1990 levels (SenUVK and BWB 2016). Today, BWB already generates 70 % of the energy required by its WWTPs and 23 % of its total energy requirement itself, making it also one of Berlin's largest energy producers (SenUVK and BWB 2016). A leading example is the Schönerlinde WWTP, which is on its way to becoming Berlin's first energy self-sufficient WWTP. At Berlin's WWTPs, the majority of electricity and heat energy comes from the burning of biogas in CHP units. Currently, 46 % of the in Berlin generated sewage sludge is processed in biogas plants of the WWTP Schönerlinde, Münchehofe, Waßmannsdorf and Stahnsdorf (BWB 2019a). In addition, BWB owns the largest fleet of electric vehicles of any company in Berlin. Despite actions implemented to save and generate energy, the average annual electricity consumption of the six Berlin WWTPs is still over 90,000 MWh per year, which significantly contributes to Berlin's greenhouse gas emissions (40.000 t CO_2.eq/a) (CWB 2017). With regard to energy optimisation, there is potential for improvement, especially in the use of biogas. By using the biogas generated by all Berlin WWTPs, approx. 51 GWh of electricity can be generated each year, which corresponds to the annual requirement of 17,000 two-person households

(BWB 2019a). Addressing this, the REEF 2W approach aims to improve the production and utilization of biogas, thus contributing to Berlin's climate targets.

3.4. The REEF 2W case study site in Schönerlinde

In the REEF 2W project, one of the six Berlin WWTPs was selected to be one of five case studies within the project. The selected Schönerlinde WWTP (north of Berlin, see

Figure 1), treats currently about 1/6 of Berlin's wastewater (BWB 2019a), which makes it the third-largest WWTP in Berlin. In this case study, the REEF 2W approach was tested by means of a feasibility study (REEF_2W_D.T2.3.2), of which the results will be presented in the following.

Current technologies

Currently, mechanical and biological processes including biological phosphate elimination in combination with nitrification and denitrification treat the wastewater in Schönerlinde. The sewage sludge is digested in fermentation towers with mesophilic digestion at appr. 35°C and subsequently dewatered in centrifuges. The produced biogas is stored in gas containers, and used for drying the sewage sludge, or further converted into heat and electricity by burning it in a CHP unit.

The Schönerlinde WWTP is able to cover 83 % of the total energy demand of 22 GWh from energy generated locally (2016). 36.4 % of this demand was covered by biogas from sewage sludge by means of conversion via a CHP unit. Two wind turbines that have been installed at the site for self-supply in 2012 carried the remaining 46.6 %.

Planned technological upgrade

The technological upgrade considered for the Schönerlinde pilot study focuses primarily on the increased production of high-quality biogas, which can be sold for injection into the public gas grid where it is used as biofuel for instance. This is aimed to be achieved with the following technological solutions, which are shown integrated into the current process scheme in Figure 2:

- **Thermal hydrolysis:** As a renewable resource, biogas is increasingly requested in view of the growing need for renewable energies and sustainability. By burning biogas in a combined heat and power unit (CHP), WWTPs can generate some or all of their electricity and heat demand. A combination of high-pressure boiling of the sewage sludge and rapid decompression increases the biodegradability of the sludge and thus the biogas yields during anaerobic digestion and reduces the total digestate.
- **Biogas-upgrading:** Heat is usually produced in excess at WWTPs, of which most of it is lost to the environment due to the distance to potential external consumers.

Therefore, a complete burning of the biogas in a CHP unit might not be the best energetically solution. In addition, methane can be burned at a higher efficiency than raw biogas consisting of a mixture of methane and CO_2. The processing of the biogas into biomethane would make it possible to sell this gas to third parties and feed it into the natural gas grid. There, it can be used as biofuel for instance. This would also save the installation of larger storage tanks on the WWTP site. A biogas-upgrading unit will receive the biogas produced during anaerobic digestion and valorise the stream into biomethane.

- **Power-to-gas/methanisation:** When switching from fossil energy sources to non-dispatchable renewable energies, such as wind or solar energy, discrepancies often arise between supply and demand. By using **power-to-gas technologies**, electricity can be converted into storable energy sources, such as hydrogen (H_2). In this way, energy can be stored on the long term. Subsequently, the H_2 can be used directly, marketed to third parties or it can be converted into biomethane. As the injection of H_2 into the public gas grid is limited up to a maximum 9 % of hydrogen share (DVGW 260), a **methanisation** of the H_2 to biomethane can be advantageous. Unlike H_2, biomethane can be fed into the gas network unlimited, providing a significant, long term storage potential for energy. In addition, biomethane has a higher heating value hence representing a better fuel. Once fed into the gas grid, biomethane can be withdrawn at any point benefiting the mobile sector and the heat-sector for instance. Power-to-gas units can be easily integrated into the wastewater treatment process so that both processes benefit from each other. For instance, instead of pure water, the wastewater can be split in the electrolysis and thus treated simultaneously. In addition, the waste product CO_2 from fermentation can be used for the methanisation process of H_2. It can be concluded that WWTP are useful locations for power-to-gas plants from a resource and efficiency point of view (Schmitt et al. 2017). WWTP can thus make a contribution to the need-based relief and stabilisation of electricity grids (Schmitt et al. 2017).
- **Grid injection concepts:** As the project aims at exploring the potential for WWTP to become local providers of energy, temporary energy storage and feed-into the grid concepts are considered.

The integration of bio-waste streams into wastewater streams through co-fermentation was already tested by the BWB and had to be shut down due to economic unprofitability and foam formation in the digester. In Berlin, the common practice is to generate biomethane by digesting pure bio-waste without mixing it with sewage sludge. This is already happening on a large scale: 69,000 tonnes bio-waste are digested into biomethane refuelling half of the BSR vehicles (status 2017) (BSR 2018). Berlin intends to further expand this potential in the future (Hockenos 2016). For this reason, co-fermentation is not considered in the present Regional Strategy.

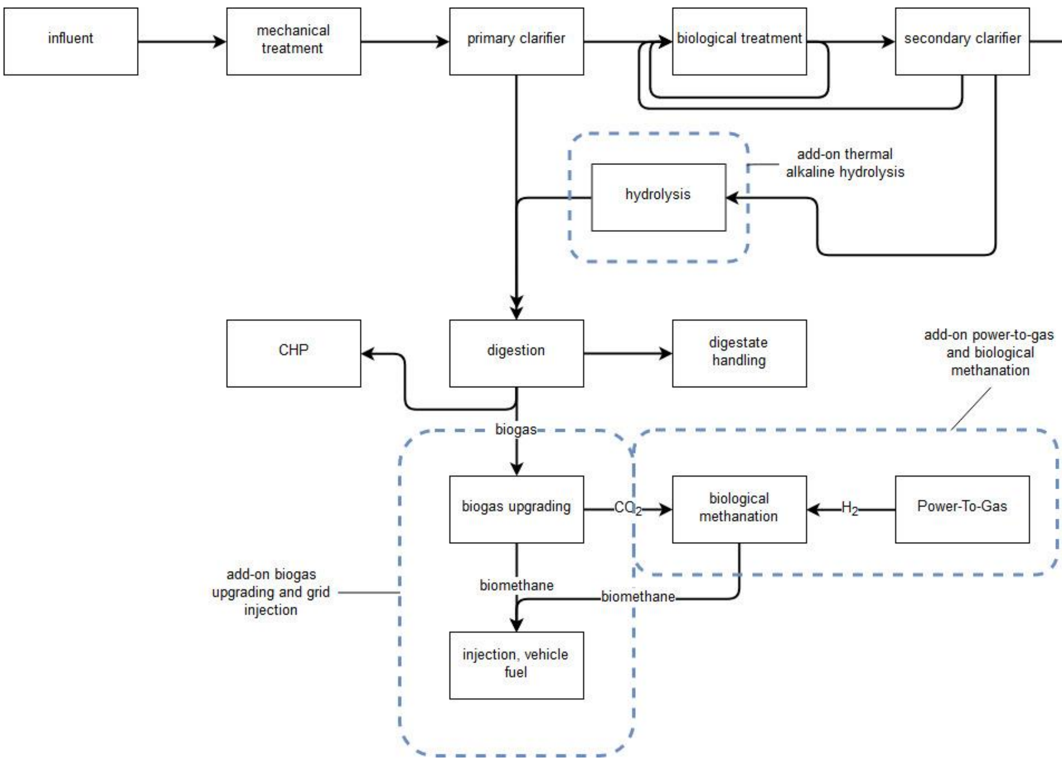

Figure 2: Technological Upgrade at WWTP Schönerlinde

Expected results at the case study Schönerlinde

The current energy performance of the Schönerlinde WWTP was analysed with the REEF 2W tool, which is freely available on the project's website. The results showed that the energy efficiency of the WWTP is comparable with the best WWTPs in Germany (DWA 2015). The total electric energy consumption with 23 kWh/(PE120a) was in the standard range from 20 to 50 kWh/(PE120a) determined by the DWA. It turned out, that the most energy-intensive treatment step is the biological purification with 69.1 %. The same accounts to the thermal energy consumption of the WWTP with 13.15 kWh/(PE120a) and an identified standard range of the DWA from 0 to 30 kWh/(PE120a). Most of the heat produced can be used on site. However, despite the very good energy performance, the tool revealed that the energy efficiency of the plant can be further improved by integrating new technologies. Some of the results are presented in the following.

Including a thermal hydrolysis unit, for instance, would be an appropriate action to generate more energy from wastewater and increase energy self-efficiency. A theoretical increase in biogas yields of 12 % and 15 % could be calculated with the tool by including thermochemical hydrolysis and thermo-pressure hydrolysis, respectively. In addition, the total generation of electrical energy could be increased by appr. 6 % through both thermal hydrolysis types.

The surplus thermal energy remains unused at the WWTP. The urban compatibility assessment of the tool showed that the connection density of the surrounding area of the WWTP is suitable for the construction of a district heating network between the WWTP and the nearby village. However, an economic evaluation is not yet included in the tool, which is important to make a final decision.

In addition, the results showed that a 2 MW electrolyser, which converts the electricity from a 6 MW wind turbine in the Schönerlinde sewage treatment plant, could generate around 2,300,000 m^3 of H_2 per year. A further methanisation of H2 to biomethane would mean an increase in biogas production by a further 66 %.

A detailed analysis of the energy optimisation potentials of the case study site Schönerlinde can be taken from the feasibility study of the REEF 2W project D.T.2.3.2.

3.5. General scope of action for the Berlin Senate

Public authorities such as the Berlin Senate can overcome not all barriers that impede the implication of solutions. In the following, frequently used instrument categories are listed, which give an idea of the possible framework of action of the Berlin Senate:

- Target group-specific information, communication, education and consultation
- Citizen participation, networking and cooperation
- Execution or support of feasibility studies with potential analysis and location identification
- Specific pilot and demonstration projects
- Supporting funding programmes and incentives for technologies, services and infrastructures
- Promotion programmes and instruments for social cushioning
- Improvement of planning tools and administrative regulations, such as the waste water disposal plan, obstacle dismantling
- The exemplary effect of the public sector
- Recommendations on the federal level.

4. VISION, GOAL, AND OBJECTIVES

The REEF 2W approach is in line with the EU energy principles. Nevertheless, many of the targets that the city of Berlin has set itself have not yet been achieved, although cities in particular are given a special position and advantage in becoming climate-neutral. Furthermore, according to estimates, cities emit around 60-80 % of global emissions, which increasingly emphasises the responsibility of cities in the energy transition process (SenUDE 2014). In order to reach the set climate protection targets, the city system as a whole—meaning across sectors—must contribute. The water sector, with its high-energy consumption, but also its manifold possibilities to increase the flexibility of WWTPs, has an important leverage effect. Thus, in order to make Berlin climate neutral by 2050, making the water sector climate-neutral would be one important and crucial step. To actively advance the energy transition of Berlin, this strategy provides recommendations for action to extent and refine the Senate's current action plan in the sense of the following set vision, goal and objectives:

Vision

The WWTPs in Berlin become energy self-sufficient and use surplus energy to supply the market. The BWB become an important agent in flexibilising the regional energy markets, thereby contributing to key energy-related targets in the BEK 2030.

To achieve this vision, the following goal will be important to be achieved:

Goal

The Berlin Senate introduces effective measures to support the BWB in successfully implementing REEF 2W solutions.

In order to achieve the set goal, actions developed for the Senate are based on the following three objectives:

Objectives

I: Increased biogas yields and improved utilisation

II: Improved energy storage for secured generation capacity

III: Improved conditions for energy injection into the regional grid

5. STRATEGIC ANALYSIS

The Strategic Analysis creates the foundation for formulating the Regional Strategy in the next section. It does so by **first**, describing to what extent the respective technology is already implemented. **Second**, it identifies key technological, institutional, and policy barriers that impede the uptake of the wastewater-to-energy solutions in the WWTP in Berlin. **Third**, it summarises ongoing and planned actions undertaken by the Berlin Senate to promote the wastewater-to-energy solutions.

The Berlin Senate has planned or already undertakes a variety of actions to achieve the targets listed in section 3.1, many of which are intended to address the three objectives of the present strategy. All of these actions are determined in the below documents which comprise the strategic planning framework for energy and climate policy:

- **Feasibility Study *Climate-Neutral Berlin until 2050* (SenUDE 2014).** It provides a status quo analysis, future scenarios, and contains action and high-priority projects relevant for waste-to-energy solutions
- **Climate Protection Agreement between Berlin Water Works (BWB) and Department for Environment, Transport and Climate Protection of the Senate in Berlin (Sen UVK) (2016).** The agreement has the goal to significantly reduce CO_2 emissions caused through activities by BWB. For that purpose, it provides spectrum of actions.
- **The Berlin Energy and Climate Protection Programme 2030 (hereafter referred to as BEK 2030) (SenUVK 2018b)** is the central instrument of climate protection and energy policy in Berlin for the period 2017 to 2021. It builds on the EWG Bln (2016) and the objectives set in the feasibility study *Climate-Neutral Berlin 2050* (SenUDE 2014).
- **The Berlin Energy and Climate Protection Programme 2030 – Implementation concept for the period until 2021 (SenUVK 2018c).** This document complements the BEK 2030 by developing 107 actions in five sectorial areas with specific objectives, expected effect in more detail, and assigns responsibilities to the respective Senate Administration
- **Report about the Implementation of the Berlin Energy and Climate Protection Programme (BEK 2030): Reporting Year 2018 (SenUVK 2018a).** Monitoring Report about progress on implementing the BEK 2030.

Within the government of Berlin, different administrations are responsible for navigating the implementation of wastewater-to-energy solutions. With respect to the actions formulated in the implementation plan that completes the BEK 2030, the following are most important and are therefore the main target group of the recommendations for action of this Regional Strategy:

- Berlin Senate Department for Environment, Transport and Climate Protection (SenUVK)
- Berlin Senate Department for Economics, Energy and Public Enterprises (SenWEB)

5.1. Increased biogas yields and improved utilization

Two of the REEF 2W solutions are regarded as particularly suitable for increasing biogas yields and improving biogas utilization at WWTP: Thermal hydrolysis to increase the biogas yields and biogas-upgrading to improve biogas utilization. Both solutions will be discussed in more detail below.

Current state at Berlin's WWTPs

In Berlin, five out of six WWTPs (Münchehofe, Stahnsdorf, Schönerlinde, Waßmannsdorf and Wansdorf) contain digesters in which biogas is produced out of sewage sludge.

Thermal hydrolysis

Thermal hydrolysis to increase biogas yields at the five aforementioned WWTPs is apart from research facilities not a current practice. According to BWB, they carried out several studies to integrate this technology efficiently and economically into wastewater treatment processes, but without success.

Biogas-upgrading

Taking a look at the objective to efficiently use the produced biogas, the biogas is processed exclusively in CHP units at the WWTPs in Berlin, primarily for power generation (BWB 2019a). Biogas-upgrading is a technology that is very well known, but currently not considered by the BWB.

Barriers

Thermal hydrolysis

Thermal hydrolysis has been successfully deployed in WWTPs. With regard to a review of *sewage sludge-to-energy recovery methods*, thermal hydrolysis enables an increase of 29 – 59 % biogas yields (Oladejo et al. 2019). Nevertheless, according to BWB, the biogas yields are still too low to make the technology economically viable implemented at the WWTPs in Berlin. Reasons are additional costs due to back loading caused by the return of process water from thermal hydrolysis to the inlet of the WWTP. Strict regulations in Germany prohibit deterioration in the effluent values of a WWTP. According to this, the existing treatment steps of the WWTP in Berlin would need to be adapted to the new pollution.

Biogas-upgrading

Barriers that impede the application of biogas-upgrading also related mostly to low economic viability. Currently, electricity costs on the market are relatively high. It is therefore more lucrative for the BWB to use the biogas generated and to produce electrical energy for self-supply through CHP units. In this way the purchase of more expensive electrical energy can be avoided. In comparison, the sale or incineration of biomethane generates too little profit.

Planned and ongoing actions by the Berlin Senate

The promotion of biogas production and utilisation is anchored in the BEK 2030 action plan as well as in the climate agreement between the BWB and the Berlin Senate.

Thermal hydrolysis

It remains widely unknown to what extent technologies to increase biogas yields have been applied beyond the few examples mentioned here. The first monitoring report for BEK 2030 (SenUVK 2018a) mentions recent research projects. A project example referred to here is E-VENT funded by the Berlin Programme for Sustainable Development (BENE). In E-VENT the application of thermal hydrolysis is tested on a pilot scale at WWTPs. First results are expected in mid-2020. The climate agreement between BWB and the Berlin Senate foresees to increase biogas production by constructing new digestion towers at the WWTP in Stahnsdorf (M2.10). A technological upgrade by thermal hydrolysis units is, however, not mentioned in this agreement.

Biogas-upgrading

The focus of the BEK 2030 action plan with regard to improved biogas utilization is rather on actions expanding and improving the performance of CHP units than on biogas-upgrading. The CHP technology is seen as a key technology for achieving the energy transition in Berlin (E-2, E-24, BEK 2030) (SenUVK 2018a). Following the same purpose, the Climate Protection Agreement between BWB and SenUVK endeavours to retrofit the CHP units in two WWTPs (Waßmannsdorf and Münchehofe, M2.6). Other methods to improve biogas yields are not explicitly mentioned in the two documents.

5.2. Improved energy storage for secured generation capacity

Two of the REEF 2W solutions are regarded as particularly suitable to serve this objective: power-to-gas and subsequent methanisation. Both solutions will be discussed in more detail below.

Current state at Berlin's WWTPs

Power-to-Gas

Power-to-gas implementations in Berlin's wastewater sector remain at the stage of research and development. In 2018, the start-up company Garforce and BWB started a demonstration plant in Adlershof, Berlin, where wastewater or process water from digesters are split into O_2, N_2 and H_2 in a so-called plasmalyzer. The H_2 is planned to be methanised afterwards to use the outcome as fuel (Graforce hydro 2019). In addition, the POWERSTEP project investigated the application of power-to-gas technologies, in which BWB contributed to as an associate partner (BWB and SenUVK 2016).

Outside the business of the BWB, and the wastewater sector, there are two successfully running demonstration plants within Berlin: the multi-energy filling station at BER Airport and the E.ON pilot plant in Falkenhagen. In 2011, the German Energy Agency (dena) launched the Power-to-gas strategy platform in order to develop power-to-gas system solutions, to present them to the general public, and to discuss future deployments with stakeholders from business, industry, science, and politics. The various activities carried out so far show that the technology is receiving increasing attention. The German energy agency considers the area Berlin-Brandenburg-Central Germany as one of four clusters where the conditions for a successful integration of power-to-gas applications in current infrastructure are particularly suitable (dena 2016). Factors that had been looked at include high capacities of fluctuating renewable energy, appropriate infrastructures and possibilities for gas storage.

Methanisation

Like the power-to-gas technology, methanisation has currently no application at the WWTPs in Berlin.

Barriers

Power-to-gas

The feasibility of power-to-gas application has been proven. However, a large-scale application is not economically viable for the BWB. The reasons for this are too high investment costs and insufficient access to cost-effective surplus energy in the neighbourhood of WWTP. Attempts to gain access to surplus energy produced by nearby wind power plants generally fails. These barriers mentioned by the BWB also apply in other contexts, as stated in the final report of the arrivee project by Schmitt et al. (2017) and in the roadmap for power-to-gas technologies by the German Energy Agency (dena) (2017). Moreover, the legal framework for power-to-gas installations is fragmented and inconsistent, which, despite political prioritisation, leads to an increase of operating expenses and thus to an inhibition of power-to-gas applications (Schmitt et al. 2017). For example, the non-recognition of gases produced in P2G in the Renewable Energies Heat Act (EEWärmeG) as renewable energies (§ 2) and the exclusion of sewage treatment plants from the CHP bonus within the framework of the KWKG for the use of synthetic gases have an inhibiting effect (dena 2017). Furthermore, electricity is currently burdened to a greater extent than other energy sources with various levies and charges such as EEG levy and grid fees, resulting in disadvantages for power to gas.

Methanisation

Technical barriers to the application of methanisation are not known. However, the economic viability of an application depends on the utilisation and marketing potential of both products: H_2 and biomethane. According to the BWB a subsequent methanisation of the H_2 will be economically more viable due to the higher heating value of biomethane compared to H_2. The marketing potential will be discussed in the next section 5.3.

Planned and ongoing actions by the Berlin Senate

Generally, it is a key objective of the BEK 2030 to drive technological innovations as for flexibilisation of energy use and production in WWTPs. The Feasibility Study “Berlin

Climate Neutral until 2050" (SenUDE 2014) declared "Flexikläranlagen" as a top-priority project seeking to optimise the energy use at WWTP. Climate Protection Agreement between BWB and SenUVK 2016 also envisions several actions that aim to improve the flexibilisation of energy use and production in Berlin's WWTPs.

Power-to-gas

Dealing with the construction of Flexi-WWTP, action E-24 of the BEK 2030 action plan mentions that WWTPs should be equipped with technologies that had better exploit generated surplus electricity. While not explicitly mentioned, it can be assumed that power-to-gas applications are part of these suggested technologies (SenUVK 2018b). The Feasibility Study "Berlin Climate Neutral until 2050" (SenUDE 2014) explicitly mentions the advantages of combining power-to-gas technology and WWTP.

Furthermore, action E-17 of the BEK 2030 has the goal to identify locations for power-to-gas facilities within Berlin and enables that they are considered in planning processes early on. This will be achieved through

- Feasibility study that identifies suitable locations for future power-to-gas facilities and assesses which planning instruments would be of use to secure these locations.
- Communication of its results and prepare its integration into planning instruments

However, it is not clear whether action E-17 applies to WWTPs.

Action E-28 seeks to promote initiatives and research on the power-to-gas technology to usher in the envisioned energy transition. This will be achieved by

- Assessing whether existing EFRE-funding programmes can be strengthened pilot and demonstration projects
- Check existing funding opportunities to identify existing gaps and to develop solutions permitted under the funding regulations
- In further developing the research landscape of Berlin, asses if there are possibilities for further establishing research focal points at Berlin universities

Action M3.16 of the Climate Protection Agreement by BWB and SenUVK aims at assessing options for flexibilising waterworks and WWTPs to produce base load energy to balance out peak demands. However, only battery storage systems are mentioned as energy storage methods (M3.19), power-to-gas applications remain unmentioned except for the research on power-to-gas applications in the POWERSTEP research project (M3.22).

Methanisation

The methanisation of H_2 from power-to-gas plants as a standalone technology is not mentioned in the planning documents of the Berlin Senate. However, the Berlin Senate is planning to promote the expansion of the infrastructure, especially for the transport sector, H_2 and biomethane. The marketing potential of H_2 and biomethane is discussed in the next section 5.3.

5.3. Improved conditions for energy injection into the regional grid

Current state at Berlin's WWTPs

Most of the energy generated in WWTP is used for self-supply. This applies for almost the total amount of electrical energy, thermal energy and the biogas produced on site. 4.8 GWh electrical energy could fed into the grid in 2017 (BWB 2018). Thermal energy is often generated in excess, which occur especially during the summer months. This energy, however, is not sold but lost unused into the environment. Biogas produced at the plants is also not upgraded and sold to third parties, but used locally for self-supply via incineration in CHP units, although according to the BWB, all WWTP of Berlin are well connected to the gas grid, enabling good conditions for grid injection. With regard to the current described status, this section will focus on the selling of gas, in particular H_2 and biomethane, and thermal energy.

Barriers

In general

According to the dena (2017), national targets are too low to effectively promote the development of an infrastructure of biomethane, liquefied petroleum gas and H_2 filling stations in Germany by 2030 (dena 2017). Without more ambitious targets, action by the Berlin Senate or at the national level, the demand for alternative fuels in general is likely to remain low.

H_2

According to FZ Jülich, the H_2 infrastructure including terminals, pipelines, and storage facilities is insufficient in order to use power-to-gas effectively and to achieve the climate goals (Stolten and Robinius 2019). Therefore, it is important to rapidly compensate here for deficits, as an expansion will require a long time. Currently, there are only five H_2 filling stations in Berlin (Bath 2019). At the same time, there is a shortage of vehicles that can take off H_2 (Stroedter 2015). Moreover, the marketing potential of H_2 as a fuel in the transport sector is limited. The reasons for this are high procurement costs and the fact that alternative fuels have not yet been available throughout the region (SenUVK 2018a).

H_2 can also be feed into the public natural gas grid. However, the feed-in is limited to 10 % and in some regions even lower due to additional application restrictions (DVGW regulations). This limit value is to be increased in the future. GASAG, the operator of the gas grid in Berlin, is already paving the way for an increase of the share of H_2 to 20-25 % by 2030 (Seelos 2019). This year, as part of a joint project between the energy group Avacon and DVWG, initial tests were carried out in a village in Saxony-Anhalt investigating the feed-in of 20 % H_2 into the natural gas grid (DVGW 2019b). The results are to be included into the DVGW regulations. However, an increase of the limit value cannot be done without investments, as devices, grid connections etc. must be adjusted (DVGW 2019a).

Biomethane

The injection of biomethan into the public grid remains low. The main reasons for this are according to the German Biomass research Centre (DBFZ) high grid connection costs and the regular delays in grid connection procedures (Adler et al. 2014).

Furthermore, the demand for total natural gas is assumed by the feasibility study *Climate-Neutral Berlin 2050* to decrease by 2030 (SenUDE 2014). This will be caused in particular by the building sector, as the share of households supplied with natural gas is expected to fall by 70-73 %. However, biomethane could become more important in the future as a substitute for coal due to the expected phase-out of coal by 2038. In addition, taking into account that gas-fired power plants are more effective than any other power plants at cushioning over- and underproduction in wind energy and photovoltaics, the Enquete Commission recommends a rapid transition to gas (Stroedter 2015). It will be important to ensure that the decline in demand for natural gas does not lead to a situation where the natural gas infrastructure is no longer maintained and renewed and thus no longer available for supplying biomethane. Instead, it should be expanded and barriers removed in a targeted manner.

Thermal energy

As for investigation by the BWB, all six WWTPs in Berlin are too far distant from heat consuming districts, making marketing unprofitable due to excessive heat energy losses along the grid.

Planned and ongoing actions by the Berlin Senate

In general

The BEK emphasises that the coupling of the different sectors including heat and water supply will be important in order to achieve Berlin's climate protection targets and to optimally exploit the city's potential. Mentioned actions to foster sector coupling are the development of different formats of collaboration, networking activities, and information exchange. Furthermore, economic research can and should provide specific and creative impulses. Appropriate human resources at the administrative level will be earmarked by the Berlin Senate to achieve these objectives (SenUVK 2018a).

H_2 and Biomethane

The Berlin Senate aims to promote the use of H_2 as well as biomethane in the transport sector in the BEK 2030. Action V-9 (SenUVK 2018a), which deals with the support of CO_2-neutral transport, seeks to create new natural gas and biogas stations for private motor traffic. The development of a H_2 infrastructure is beeing sought in action V-13 (BEK 2030). This is to be implemented Berlin-wide through the installation of filling stations. Furthermore, the Berlin Senate wants to establish a good example and plans to power all state-owned vehicles electrically or with H_2 in the long term (V-19, BEK 2030). Not yet specified in concrete actions, but already mentioned in the BEK 2030 as an objective and necessity, is the creation of incentives at EU, national and regional level for vehicles powered by alternative fuels, as well as a stricter restriction of fossil-fuelled vehicles.

5.4. Cross-objective actions

Information and monitoring

The Berlin Energy Atlas was published in 2018. It is an online platform which provides information about energy production and consumption in Berlin. Offering valuable insights for planning and decision-making processes, it plays an important role in the implementation of the energy and climate protection policy of Berlin.

The BWB provides a set of various information for the public through their company website. News on up-to-date topics relevant for the water sector are published and the detailed insights into current and completed research projects are provided. This includes links to the respective project websites offering more project information and results.

As well in 2018, the Digital Information and Monitoring System (diBEK) for BEK 2030 was launched. The goal of the system is to track and document the implementation process of the BEK for the public transparently. Of concern are climate mitigation and climate adaptation. Climate impacts are also monitored to develop new and adopt existing actions in the BEK 2030. On an annual basis, the responsible Senate Department provides a monitoring report to the Berlin House of Representatives, demonstrating the progress as for the implementation of BEK actions. Every two years, a more comprehensive monitoring report has to be compiled, also including advances made in implementing the Berlin Climate Mitigation targets and the Berlin Energy Transition Law (EWG Bln).

BWB monitors the progress on the implementation of actions and associated reductions in CO_2-emissions defined in the Climate Protection Agreement. An interim report will be published in 2021 for the period 2016-2020 and the final report will be published in 2026 for the second period.

Finance and funding opportunities

For the period between 2017 and 2021, 88 million euros are earmarked for the implementation of actions defined in the BEK 2030.

To manage these resources, the Berlin Senate has developed a financing concept that is based on three pillars:

- **Development of specific funding lines that support the implementation of strategies and actions of the BEK 2030.** A few of them have been developed, yet none seems particularly relevant for wastewater-to-energy solutions. Additional funding guidelines are expected to be published in 2019.

- **The complementation and strengthening of existing funding programmes relevant for the BEK 2030** to avoid overlaps and additional administrative work for applicants. This concerns for instance the "Berlin Programme for Sustainable Development (BENE)".
- **Financing of individual projects for the implementation of BEK 2030.** Especially pilot projects and those that promise substantial positive effects are supported.

The programme BENE provides funding for innovative actions, projects and initiatives that contribute to a climate-neutral and environmentally friendly Berlin between 2015 and 2020. This also includes projects promoting wastewater-to-energy solutions (see focus area two: energy efficiency and renewable energy in public infrastructures) such as the BENE funded project E-VENT. BENE is co-financed by the European Regional Development Fund (EFRE).

Furthermore, the Berlin Senate guarantees in the climate protection agreement with the BWB support in the application for national and European funding as well as in reporting on the use of these funds (SenUVK and BWB 2016). For instance, the seventh Energy research programme of the federal government could be an appropriate funding programme to investigate the application of the REEF 2W approach. This programme was launched in September 2018. Proposals for funds can be submitted at any time. By 2022, around 6 billion euros will have been awarded in total to projects. The programme enables the scaling of technology solutions relevant for the energy system transition—in particular H_2, sector coupling, and energy storage—to an industrial scale under special regulatory conditions. In the climate protection programme of the federal government (Bundesregierung 2019), the concept of "Reallabore" and thus the seventh energy research programme, which forms the basis for this, is to be further established and financially strengthened. An extension until 2030 is planned as well as the development of a new funding guideline in 2020.

5.5. Evaluation of current actions by the Berlin Senate

In this section, the potential to foster the REEF 2W approach by the Berlin Senate will be analysed. For this, gaps for necessary action within existing planning documents of the Berlin Senate are identified based on the perceived barriers in sections 5.1, 5.2 and 5.3.

REEF 2W solutions being promoted by existing planning documents

The objectives pursued and technological solutions investigated in REEF 2W play an important role in the current strategic planning documents by the Berlin Senate. The actions of the BEK 2030 show the potential to support the REEF 2W approach, such as the promotion of power-to-gas applications and the associated efforts to improve and expand the city's infrastructure. Especially the identified barriers for feeding energy into the Berlin grid are well addressed. From the BEK 2030 it can be concluded that the district gas grid will retain its importance in the future and decentralised feed-in will be facilitated. In addition, the utilization of H_2 and biomethane as advanced fuels in the transport sector are planned to be further established. Moreover, the Berlin Senate provides extensive and up-to-date information on the use and generation of energy in Berlin through the web-based platform Energy Atlas. This platform aims to improve the planning of energy management processes.

Drivers in place ensuring successful implementation of the action plans set

The set actions within the BEK 2030 are to be conducted with clear deadlines and comprehensive digital information and monitoring system has been launched (diBEK). This indicates that implementation is taken seriously and non-compliance can be tracked by the public. Another positive sign is that the Berlin Senate engages with BWB (Climate Protection Agreement between BWB and Sen UVK) and other stakeholders relevant to pursue the REEF 2W approach. For instance, the Berlin Senate is involved in research projects such as POWERSTEP, working closely together with the KWB. Without close collaboration, it is unlikely that any high-level policy objective would be implemented.

Limitations during analysis

However, given the limited scope of the BEK 2030 and the large variety of actions, it presents, for each single action only a rough overview, objectives, and possible impacts are outlined. It therefore often remains unclear whether the wastewater sector belongs to the target group of an action. Moreover, limited information exists on progress in implementing the BEK 2030. While progress for some of the actions has been evaluated in the first monitoring report a few months after the publication of the BEK 2030, only the evaluation report due in 2021 will enable a more precise picture of the overall implementation. Arguably, this makes it difficult to elaborate a sound evaluation of whether single measures or the sum of them is sufficient to support the future uptake of wastewater-to-energy solutions. While the wastewater sector plays an important role in the energy transition, there are other sectors whose potential to save energy or contribute renewable energy production is considerably greater (SenUDE 2014). This can explain why wastewater is not mentioned as a prime target sector in the description of the BEK 2030 measures.

Existing potential for improvement

Nevertheless, despite the advantages the REEF 2W solutions offer, most of them have not yet been applied on a large-scale in the WWTP in Berlin, due to barriers of which some could be identified in the strategic analysis. This indicates an existing potential for action on the part of the Berlin Senate, which is only partially covered by the BEK 2030.

In the following, the potential to foster the REEF 2W approach by the Berlin Senate will be analysed. For this, gaps within the planning documents of the Berlin Senate are identified based on the perceived barriers in sections 5.1, 5.2 and 5.3 and potential actions are discussed to fill them. The aim is not to change existing actions, but to complement them.

Gap analysis

➢ **Lack of certain information fostering the implementation of REEF 2W solutions**

While BWB is generally aware of the potential in optimising energy outcomes and very well positioned with development and research department, there are certain information lacking the Berlin Senate can provide support to generate. This applies for example to the cases given in the following:

According to the BWB, access to surplus energy is not sufficient for an economic operation of power-to-gas units. One reason for that are insufficient photovoltaic and wind power plants close to Berlin WWTP and/or limited access to surplus renewable energy generated in Brandenburg. Potential for the installation of large wind power plants exists on the outskirts of Berlin (in particular commercial and industrial areas) and on Berlin-owned areas in Brandenburg (SenUVK 2018). In a feasibility study, it could be examined whether available plots of land exist in the vicinity of WWTPs and, accordingly, if new locations are chosen for photovoltaic plants (E-4, BEK 2030) and wind power plants (E-5, BEK 2030), to consider the proximity to WWTP as a decision criterion in the BEK 2030.

Another gap is the lack of proximity of WWTPs to heat consumers. According to BWB, the sale of heat to external customers is not economically viable.

➢ **Difficulty in keeping track of all innovations and progress in the various sectors**

The energy sector and its possibilities for optimising energy management for the water sector are characterised by rapid changes, which will be particularly evident in the coming years. In order to prevent a sector from lagging behind, it is necessary to make up-to-date knowledge available and understandable for everyone. Both Berlin and Brandenburg, unlike many other German regions, do not offer water utilities guidelines for the energy optimisation of WWTP. The energy atlas offered by the Berlin Senate (since 2018) is limited to the actual state of Berlin's energy supply structures (diagrams and location maps of renewable energies in Berlin with little background information). There are other federal states that offer platforms with better aggregated and public information on renewable energies, such as the Bavarian atlas: background information on current research, economic efficiency, best practice examples, planning, funding options, etc. According to BWB, they are well networked with various relevant actors, very well positioned and internal experts are well aware of opportunities for energy optimisation. However, effort could be reduced by aggregating information from different sectors and actor. These include besides the Berlin Senate and the BWB Public utilities, research institutions, etc.

- **Shortcomings in H_2 infrastructure**

The expansion of the H_2 infrastructure is integrated into the BEK 2030 action plan, although detailed descriptions of the planned measures are missing. Unlike other German regions, such as northern Germany, Berlin does not have a H_2 strategy. However, with conceptual planning and exemplary business models for financing and operating the infrastructure, this strategy could set important accents to ensure the necessary expansion to achieve the climate targets. A national H_2 strategy is to be published before the end of 2019 (Bundesregierung 2019).

- **Low level of detail in planning documents of the BEK 2030**

Action E-24 on fostering the flexibilisation of WWTPs of the BEK 2030 addresses as the only action the optimisation of energy management at WWTPs. It is formulated in general terms and some of the solutions interesting in REEF 2W remain unmentioned or are only hinted at, such as biogas upgrading and thermal hydrolysis. This also applies to the climate agreement between BWB and SenUVK, where, for instance, flexibility options are to be promoted (action M3.16), but power-to-gas remains unmentioned under examples. In order to more effectively support waste-to-energy solutions in the wastewater sector, the BEK 2030 could more explicitly name targeted technology concepts including the REEF 2W solutions, if appropriate, and provide more detailed implementation plans for them.

- **Insufficient cooperation across sectors**

BWB expressed the need to have the possibility of a regular exchange with relevant departments of the Berlin Senate. Berlin energy targets as well as wastewater policy targets demand the inter-sectoral action of the WWTP operators with other actors such as operators of the gas and electricity grid, local energy suppliers, and politicians.

For example, improving cross-sectoral cooperation could pave the way for better access for BWB to surplus renewable energy in Brandenburg. Currently, according to the BWB, access to surplus energy is not sufficient for the economic operation of power-to-gas plants. However, Brandenburg ranks third in the list of federal states with the largest installed capacity of wind turbines. Accordingly, a lot of surplus energy is generated. In order to make these energy resources available, an improvement of the cooperation and communication structures between sectors of Brandenburg and Berlin (Stroedter 2015), in particular between WWTP operators in Berlin and the operators of wind power and photovoltaic plants in Brandenburg, could be a solution.

Another example is the need for improvement of cooperation and communication between the heat and the water sector. So far, most of the surplus heat energy on WWTPs is lost to the environment.

➢ **Limited funding programmes for REEF 2W solutions**

There is little incentive for BWB to introduce new technologies, as running them would be economically not viable. This applies for example to the application of thermal hydrolysis technologies. One solution would be to further develop the technology solutions through research projects. However, the number of funding opportunities is small (see section 5.4). In the example of thermal hydrolysis, the technology is currently being investigated in the ongoing research project E-VENT financed by the Berlin funding programme BENE. Based on the project results, further actions are recommended to develop to promote an improved waste-to-energy management at WWTPs.

In the climate agreement, the Berlin Senate agrees to support the BWB in applying for funding. However, a well-developed advisory infrastructure is lacking for this purpose.

➢ **The application of some innovative waste-to-energy solutions is impeded by policy and legislation at national and EU level.**

The analysis revealed that the ability of Berlin's players to promote wastewater energy solutions often depends on policy and legalisation, such as with respect to subsidies, at national and EU level. Legal barriers, for example, make power-to-gas and thermal hydrolysis applications uneconomical for the Berlin water sector. According to the BWB, the cooperation between the Berlin Senate is currently not sufficient to promote an appropriate legal framework and to strike a better balance on regulations as for energy-efficiency and water quality targets for instance. The Berlin Senate is not in a position to directly change national or international legal frameworks, but can pass on recommendations in order to promote the interests of the regional water sector.

6. STRATEGY FORMULATION

The following recommendations are preliminary, based on a literature review and first meetings with both BWB and the Berlin Senate. In order to develop recommendations that are more precise, further meetings with relevant actors are planned. Therefore, the following recommendations are a first draft serving as a basis for further discussion through further interviews and meetings.

I. Creation of information that BWB or other involved actors lack

Current gap: Lack of certain information fostering the implementation of REEF 2W solutions

I.I Insufficient access to surplus renewable energy for power-to-gas applications. According to the BWB, access to surplus energy is limited.

I.II Lack of heat costumers near Berlin’s WWTPs

Objective: The aim of this action is to explore the feasibility and potential of innovative wastewater-to-energy solutions for energy generation from waste, the application of which is impeded.

Potential actions:

I.I

- Potential analyses for improving access to surplus energy (wind or/and solar) from Brandenburg
- Feasibility studies for the identification of sites for new photovoltaic and wind power plants near Berlin's WWTPs

I.II

- Potential analysis for the installation of heat-using buildings and industries near WWTPs

II. Providing guidance for systematically optimising the energy efficiency in WWTPs

Current gap: Difficulty in keeping track of all innovations and progress in the various sectors

Objective: This action aims to develop capacity on innovative solutions for energy optimisation in the wastewater sector. Furthermore, it offers communicate relevant education and experience exchange to facilitate knowledge and awareness about best practices and the newest technological developments.

Potential actions:

- Provide roadmaps: Develop a roadmap to explain background knowledge on the topics and opportunities how BWB can contribute to the energy transition.
- Web based platform (for instance elaboration of Berlin's energy atlas): provide gut well-prepared information on current research (recent publications), economic efficiency, best practice examples, planning, funding options, news, references to other consulting websites, etc.
- Offering contact to experts (i.e. REEF 2W internal trainers)

III. Enhancement of the H_2 infrastructure

Current gap: Shortcomings in H_2 infrastructure

Objective: This action aims to enlarge and facilitate access to the H_2 market, which further is able to replace fossil fuels and to accelerate energy transition.

Potential actions:

- Strategy: H_2 strategy for Berlin with conceptual planning of the expansion of the existing infrastructure that includes terminals, pipelines, and storage facilities
- Business models for the financing and operation of a H_2 infrastructure

IV. Elaboration of a more detailed implementation plan for wastewater-to-energy solutions

Current gap: Low level of detail in planning documents of the BEK 2030

Objective: This action aims to provide more detailed insights into planned actions as well as to set more binding concrete targets and actions to improve energy management in the wastewater sector and to better achieve its climate protection objectives. Furthermore, this action will update the existing action plan on wastewater-to-energy solutions in the BEK 2030 and in the climate protection agreement between the BWB and the Berlin Senate from 2016.

Potential actions:

- Developing a format for regular exchange between representatives of the BWB and Berlin Senate at which the set objectives and implementation of the action plans will be discussed, monitored, regularly adjusted to current research, and further developed
- Developing a more detailed implementation plan for the wastewater sector that includes the actions developed in this Regional Strategy, if appropriate. This plan will serve as a supplement to the BEK 2030 and climate protection agreement between the BWB and Berlin Senate and will be regularly updated.

V. Elaboration of improved cooperation and communication structures between relevant sectors

Current gap: Insufficient cooperation across sectors

Objective: This action aim at fostering exchange and collaboration of relevant actors, sector coupling, and multi-stakeholder participation. Furthermore, multi-sectoral information transfer, education, and targeted knowledge building are to be increased.

Potential actions:

- Potential analysis to identify which actors need to be brought together (including BWB, energy providers, departments of the Berlin Senate, the private sector, and investors) and formats that would be useful
- Establish working groups on the topic of wastewater-to-energy solutions or even more specific niches (this could be inspired by the Cluster-Working Group Wastewater Heat Utilization in Bavaria, which is a network of scientists, municipalities and municipal enterprises, entrepreneurs, politicians who advise independently on the topic)
- Development of a joint energy concept between Berlin and Brandenburg that paves the way for improved inter-regional sector coupling and coordinates the planning of renewable energy production in both federal states (Stroedter 2015)

- Establish a suitable platform where BWB and the Berlin Senate (and possibly other actors) have the opportunity to discuss and exchange information. Dialogue topics may include:
    - How can conflicts of objectives between water protection and climate protection be resolved?
    - How to improve/update Berlin-related strategies including the BEK 2030, climate protection agreement between the BWB and the Berlin Senate?
    - How can surplus energy resources in Brandenburg more effectively used in Berlin?

VI. Enable improved access to funding programmes

Current gap: Limited funding programmes for REEF 2W solutions.

Objective: This action enables the Berlin Senate to better support the BWB in the identification and development of unknown financing sources. Funding can be provided for example for pre-feasibility studies, new demonstration sites, or research and development initiatives to promote optimised energy management in WWTP. Innovative waste-to-energy solutions that are not yet economically viable, but promise to have a major impact on the transformation process of the energy system, become economically lucrative, for instance.

Potential actions:

- Develop funding programmes such as in BEK-related funding (see section 5.4) that WWTP can access for energy-related measures
- Support BWB with information and capacity on how to access federal and EU funding programmes
- Provide improved advisory infrastructure, offer contact to experts

VII. Advocacy to adapt national and EU policy and legislation taking into account the needs of the Berlin water sector

Current gap: The application of some innovative waste-to-energy solutions is impeded by policy and legislation (e.g. in relation to subsidies) at national and EU level.

Objective: Representation and promotion of the interests of the Berlin Water Sector on national and international level in order to facilitate the implementation of innovative waste-to-energy solutions.

Potential actions:

- Improve cooperation between Berlin Senate departments and the BWB to strike a better balance on regulations

- Conduct a potential analysis to identify inappropriate regulations and give recommendations on how to change these favouring the interests of the Berlin water sector

Examples for appropriate legal framework:

for Power-to-gas applications

- Harmonise levies and allocations across sectors (dena 2017): Electricity is currently burdened to a greater extent than other energy sources with various levies and charges such as EEG levy and grid fees, resulting in disadvantages for power to gas.
- Power-to-gas applications should be understood as "storage technologies" of the energy system, which would exempt them from charges and taxes related to the generation, transport or consumption of energy (Stroedter 2015),(Ravn et al. 2017): In particular, the "levy on final consumers" is commonly considered to be unjustified for power-to-gas applications.
- Temporary reduction or exemption from individual ancillary electricity costs for technology concepts that are network or system serving (Schmitt et al. 2017): Results of the project arrivee on Flexi-WWTP (BMBF, 2014-2017) recommend a temporary (dynamic) reduction or exemption of individual ancillary electricity costs (EEG levy, grid usage charge, grid-related charges, concession fee, electricity tax) for sewage treatment plants and in particular long-term energy storage facilities (in this case power-to-gas) that are networking or system serving
- Classification of fuels from Power-to-gas plants as biofuels and thus as an emission reduction measurement in the German federal imission protection law (BImSchG): this is already agreed at EU level (Directive (EU) 2015/1513), but still needs to be translated into national law.
- Reduction of the obligatory minimum distance between wind turbines and buildings (Bundesregierung 2019): According to FZ Jülich (Stolten and Robinius 2019) the energy revolution is only possible with an increase in the power supply through wind power and photovoltaics. The measures set out in the German government's climate protection programme (Bundesregierung 2019) to expand wind power are unlikely to be sufficient (Stolten and Robinius 2019).

for thermal hydrolysis applications

- Possible actions are feasibility studies for the adaptation of effluent value requirements and for the introduction of more flexible framework conditions for WWTP effluents with regard to their ecological effects.

Addendum: Some of the listed recommendations for action were also taken up in the recently published climate protection programme of the Federal Government (Bundesregierung 2019). These include the exemption of power-to-gas applications from charges and taxes related to the generation, transport or consumption of energy, and an adjustment of electricity prices. This is to be made possible by using the revenues from CO_2 pricing (action 3.3.1).

7. CONCLUDING WORDS

The analysis revealed that the wastewater sector plays an important role in Berlin's energy transition. This applies not only to the reduction of energy consumption and CO_2 emissions, but particularly to the provision of green biogas.

The WWTP in Berlin already show a high degree of self-sufficiency of 70% of energy requirement and, according to the DWA benchmark, are among the 20% most energy-efficient WWTP in Germany. However, the Berlin climate targets and the targets set by BWB demand a further optimisation of the energy management.

Although the BWB considers most of the REEF-2W solutions in current research projects, there is no large-scale implementation to date. The current political-legal and economic framework conditions make it unattractive for the BWB to increase sewage gas production significantly and to feed this sewage gas into the public grid. To overcome these economically and regulatory barriers, however, the Berlin Senate can only act and provide support to a limited extent.

The recommended actions in this strategy include the elaboration of feasibility and potential studies, recommendations at national and/or EU level for the formulation of appropriate legal frameworks, as well as the consideration of WWTP in RE-infrastructure planning documents. Furthermore, it has been identified that cooperation between sectors and regions (Berlin and Brandenburg) is important for achieving the objectives set. As some of the REEF 2W solutions require further research activities such as thermal hydrolysis and power-to-gas technologies additional support by means of developing sound funding programmes or supporting the BWB to apply for national/international funding programmes is recommended by this strategy.

The Berlin Energy and Climate Protection Programme (BEK) 2030 of the Berlin Senate offers a concrete first possibility for a political implementation of the recommendations for action. The BEK 2030 is to be continued and revised after the first implementation period in 2021. The Berlin Senate is willing to consider the points of the regional strategy in this respect.

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