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Guidelines on integrated model for Water-Sludge-Energy cooperation

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Imprint

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Project note

The EU co-funded project **BSR WATER – Platform on Integrated Water Cooperation** (2018–2021; www.bsrwater.eu) aims to enhance cross-sectoral cooperation in smart water management by providing a possibility for transnational experience exchange, sharing of good practices and solutions, as well as delivering comprehensive overview of the current and future regional policy. The platform brings together experts representing diverse projects that have generated through transnational cooperation many replicable and unique solutions, covering broad variety of water-related issues.

The platform cooperation is based on practical achievements and results of seven projects addressing a wide range of water management challenges. The outcomes and practical findings of the contributing projects (IWAMA, BEST, iWater, Manure Standards, Village Waters, Reviving Baltic Resilience, CliPLivE) support the long-term development of regional environmental policy and recommendations, which will further strengthen the policy-practice link in implementation of advanced water protection measures, including smart nutrient management and sludge handling, storm water management and the energy efficiency cycle at the national and municipal levels.

1. Foreword

Efficient use of resources has become an important challenge in our society during the last decade, as we have become more climate conscious and can start to see the effects of our consumerism on the world. From almost islands made of plastic garbage on our seas and oceans to large regions severely polluted to due mining and other activities, the exploitation of primary resources cannot continue in the same manner. Circular economy exemplifies the approach we now need to take – maximise the reuse, recycling and refurbishing of materials and generate a market for these secondary resources. These recycling activities themselves also have to be done climate consciously, therefore investments into sustainable energy are the second side of this circular economy coin.

One of the key nodes in our society, where a lot of widely distributed resources intersect and exit our local systems, is the wastewater treatment plant (WWTP). Wastewater is a carrier of many resources, from the apparent ones such as nutrients and water itself to more complicated ones such as energy and valuable metals and compounds. Together with the recyclable resources is carried a lot of pollution, from pathogens and microorganisms to complicated and toxic organic molecules. In order to close the loop on many resources, efficient technologies, new circular approaches and business models are needed to take out the valuable parts from the waste and wastewater streams, while protecting the society from the pollution. The significant changes in WWTPs are not only required from the circular economy standpoint, but also to fight against climate change. Based on multiple studies [1]–[3] the wastewater treatment plants are one of the largest sources of greenhouse gases under the municipalities management and therefore are under the pressure for significant change to reach the climate goals set by the EU.

Historically the aim of the WWTPs have always been about cleaning the water to an acceptable quality and providing hygiene and sanitation to the society in the most financially feasible way. Very expensive technologies that have a good efficiency are often not used, as the price of wastewater treatment is paid by the public and their collective interest was towards the cheapest available options. At the same time, the list of substances WWTPs are required to observe has increased significantly due to better analytical capabilities and better understanding of the pollution pathways – from organic carbon, nitrogen and phosphorus compounds to heavy metals, specific organic substances, pharmaceutical residues etc. The standard of what we now call clean water is completely different and therefore new technologies and ideas need to be taken into use to achieve this.

With new approaches and technologies things often boil down to costs and financial feasibility. With most advanced technologies, the largest increase in demand is for electricity or chemicals. Therefore, one way of mitigating some of the advanced treatment costs is to achieve good energy production in the WWTPs themselves. Larger WWTPs already use anaerobic digestion and various utilisation ways for the biogas, to produce either exportable biomethane fuel or direct electricity and heat. Increasing these productions could be a potential way to counter the increased costs of advanced treatment and some technologies could even achieve two aims at once – increase energy production and degrade organic substances at the same time. Feasibility of distributed energy production is however very much tied to political decisions, legislation and local incentives, which can sometimes hinder the development.

Though national legislations are not always supportive, becoming energy neutral or positive is a goal many WWTPs have started to aim towards. This can be achieved with good maintenance of pumps and blowers, efficient biogas production and use or even further investments into sustainable energy production. Close cooperation with nearby industries may also give a large boost as in some cases more easily degradable organic can be accepted for enhanced biogas production.

From the climate standpoint, another potential goal for a WWTP is to become climate neutral/positive. Emphasis on climate means more thorough understanding of greenhouse gas (GHG) emissions from different processes within the WWTP and covering the amount of GHGs emitted with actions identified as climate positive. Such actions include investments into sustainable energy and fuel production, as renewable energy and fuels are considered with a negative GHG and therefore positive climate balance.

At the same time, as circular economy and nutrient recovery have more important topics, some forerunners in the sector are not only changing their energy or climate balance but going through a major change in the overall approach. This carries within a complete rebranding of the existing structure – instead of being a wastewater treatment plant, the aim is to become a Waste Resource Recovery Facility (WRRF). As the new name implies, these WWTPs are putting more emphasis in the resource recovery, with significant investments into nutrient recycling, energy generation and advanced treatment technologies.

Whichever of the three main new approaches a WWTP may consider, new technologies and increased cooperation between different sectors is the foundation of any change. Good industrial cooperation can result in lower hazardous substance inflow to the WWTP and increased biogas production, cooperation with public can change the WWTP influent quality, reduce the amount of litter, microplastics and hazardous organic substances in the wastewater. Cooperation with other municipalities and WWTPs can make sludge treatment more efficient and increase the biogas production in the larger central WWTPs, decrease the amount of diluted stormwater inflow or provide good additional financial measures. In some cases, other environmental issues and the resulting political or public pressure might also require financially unfeasible technologies to be used in the WWTP, while this could always be balanced with positive financial measures (incentives, tax benefits). Examples of this might include more advanced treatment to degrade more complex substrates, treatment of stormwater in highly industrialized areas or production of biomethane for the municipal public transportation network.

This document, called the Guidelines on integrated model for Water-Sludge-Energy cooperation, outlines possible points of cooperation for the WWTP. The points of cooperation are divided between incoming and outgoing points, with the first being about different streams of materials coming into the WWTP and the second about resources or energy that can be produced within the WWTP or even transported out. Each point of cooperation is outlined with a description of the recommendation, potential financial balance of the recommendation and in most case an example of the actions. Incoming points of cooperation also include an overview of different important parameters and potential overall effects to the WWTP, to help the stakeholders in making informed decisions.

As these guidelines are closely linked with the examples of practical implementation of the cooperation models, the updated list of different approaches to the circular water cycle can be found in the portal Baltic Smart Water Hub under the tag "**cooperation model**": **www.balticwaterhub.net/hub/tags/cooperation-model-134**.

This document should be used as a guide to identify possible cooperation options for a specific WWTP, consider important factors and parameters and find good examples and potential sources for extra information around the Baltic Sea region.

Table of contents

2. Visual model of the Points of Cooperation

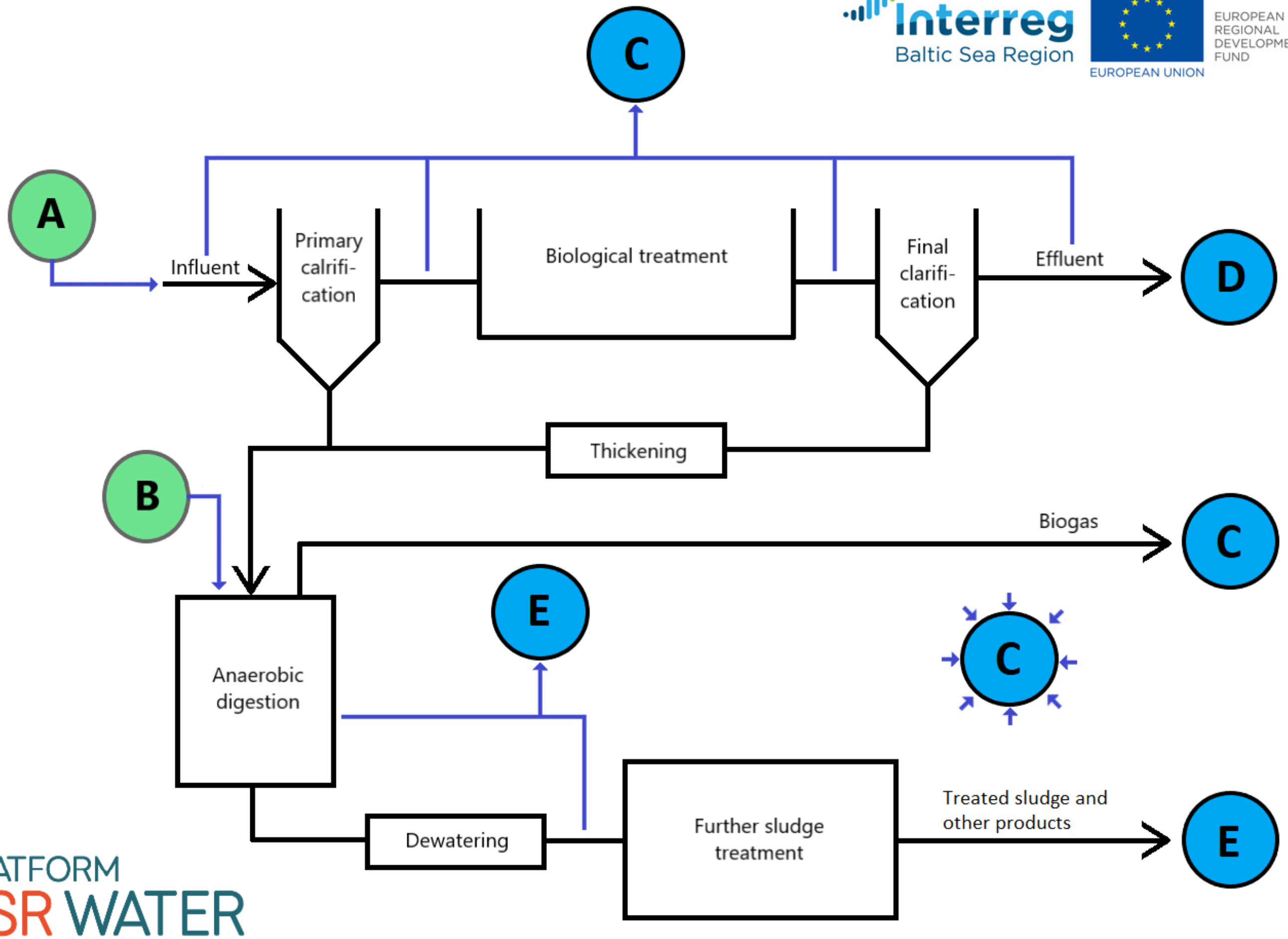

Figure 1 - Visual model of the Points of Cooperation. Incoming points are marked with green (Point A – Influent to the WWTP, Point B – Biodegradable material to anaerobic digestion), outgoing points marked with blue (Point C – Energy produced in the WWTP, Point D – Effluent of the WWTP, Point E – Treated sludge or material from treatment (ash, struvite)

3. Incoming points of cooperation

3.1. A – Influent to the WWTP

3.1.1. Recommendation A.1 – Separating stormwater and municipal wastewater sewer systems

Recommended for:

- WWTPs with combined sewers and problems with diluted influent, low influent temperatures, problematic peak loads exceeding maximal treatment or storage capacity.

Description:

Combined sewer system for stormwater and municipal wastewater brings quite many potential issues for wastewater treatment plants. Separated sewer systems are becoming a norm in order to keep the hydraulic retention time in the WWTP in optimal conditions, decrease the diluting effect of stormwater, increase influent temperature and decrease the flooding danger in the cities. Although this practice is widespread, separating the sewer systems needs significant investments, often takes years of time for infrastructure works and may come with considerably negative public opinion (increased roadworks and concern for environmental safety of stormwater). A good starting point is to separate networks whenever new areas are developed or renovation of existing structures is necessary.

Important parameters and potential effects:

- Wastewater temperature
    - When municipal wastewater temperature is often quite stable, stormwater temperature is dependant on the current weather. During winter, stormwater and meltwater runoff can significantly lower the temperature of influent to the WWTP, which can have a negative effect on biological nitrogen removal efficiency.
- Micropollutants (both plastics and chemicals)
    - While wastewater from urban environments has a variety of different micropollutants, stormwater can transport additional streams of pesticides, tire rubber (or tire wear), oils, gasoline and other pollutants to the wastewater treatment plant. Although these components should not enter the environment untreated, treating them separate from municipal wastewater and sludge might be cheaper/more efficient.

Financial feasibility:

Main financial benefit can come from the smaller daily hydraulic loads, which can significantly decrease aeration, mixing and pumping energies. Building out a separate sewer system is however a long-period investment; therefore the solution is not cost-beneficial in short-term.

3.1.2. Recommendation A.2 – Accepting controlled pumping of liquid streams from septic tanks, pit latrines and other onsite sanitation system streams without significant chemical addition

Recommended for:

- Larger WWTPs not greatly influenced by sudden higher loads of pumped septic material;
- Smaller WWTPs with a separate storage basin, capable of controlled addition of pumped septic material to the influent.

Description:

In many areas with low population density or limited sewer network, households are equipped with their own onsite sanitation systems, such as septic tanks and pit latrines. Although this material is recommended to be treated at a specialised WWTP, it is still often transported to municipal WWTPs. WWTPs accepting septage should have additional treatment capacity and an option to separate liquids and solids. Relatively small volumes can have large impacts on the organic, suspended solids and nitrogen loads and therefore solids separation, using sensors to determine the organic load, controlled mixing into the municipal stream and other good practices should be used to avoid overloading the biological treatment tanks [4]. Solid fraction separated from the septage can be used in anaerobic digestion (input to Point of Cooperation B).

Important parameters and potential effects:

- Concentrations of C, N, P (extra pollutant load)
    - Directly increases the expenses of the WWTP as increased load of nutrients will need to be dealt with. To larger WWTPs with anaerobic digestion, extra BOD and primary sludge can be rather beneficial.
- Toxic agents added to sanitation systems
    - Although it is not recommended to intake sanitation waste with high chemical use (portable chemical toilets), practice collected from WWTPs still show that sometimes purged liquid streams can still include these types of wastes unreported. Sensors, cameras and good bookkeeping can decrease the risks.
- Trash and foreign objects

Financial feasibility:

This type of cooperation can be financially feasible if the extra income from accepting the septage is higher than the cost of treatment and larger issues rendering municipal wastewater treatment ineffective can be avoided. Extra sensors and analyses decrease the potential profits, while can keep the operation safer and more controlled. In some cases, even pollutant load based payment fees might be worth to consider.

3.1.3. Recommendation A.3 – Accepting wastewater with high easily degradable organic content from industrial sources (food industry)

Recommended for:

- WWTP with anaerobic digestion or anaerobic treatment of wastewater;
- Smaller WWTPs struggling with biological nitrogen treatment due to low organic carbon content in the influent.

Description:

For a WWTP with biogas production, higher incoming easily degradable carbon can directly result in higher biogas production, in turn making energy neutral or even energy positive wastewater treatment plant operation a possibility. Food residues might however increase the maintenance needs of some of the equipment and therefore indirectly increase maintenance costs.

Accepting easily biodegradable carbon sources could also be feasible for smaller WWTPs with low BOD concentrations in their influent and additional methanol dosing for denitrification. In this case, small industries with lower flow rates are especially good, as too high incoming BOD can result in high secondary sludge production and create problems in sludge treatment.

Important parameters and potential effects:

- BOD and the BOD/COD ration describing biodegradability
    - Higher biogas production – with higher incoming BOD, both more primary and secondary sludge can be produced, increasing sludge mass transported to digestion and therefore biogas production as well.
    - For WWTP with too low organic carbon in the influent, accepting industrial high BOD influent can reduce or eliminate the need for external organic carbon addition via methanol dosing. This can also increase the efficiency of biological phosphorus and nitrogen removal and result in a cleaner effluent.
- Volume and redundancy of digesters
    - Accepting more organics means higher sludge production, therefore digesters need to have spare volume that can be used. In longer terms, building additional digesters could be feasible, while the stable industrial inflow and long-term agreements might be needed in case of new investments.
- Concentration of nutrients (nitrogen, phosphorus)
    - High additional N concentration can increase the aeration energy and potentially methanol dosing (depends on how much organics is taken out with primary sludge), resulting in higher expenses.
    - High additional P concentration can increase the need for chemical phosphorus precipitation, increasing expenses to precipitation chemicals such as $FeSO_4$ and $Al_2(SO_4)_3$.
- Hazardous components, such as heavy metals, different organic pollutants, pharmaceutical residues, microplastics etc
    - can deem the treated sludge unusable, create environmental harm, bring the need for tertiary treatment in order to get the effluent clean,

   - can cause inhibitions to biological treatment or digestion, lower the efficiency and increasing financial costs. In very bad cases, severe inhibition can destroy biological treatment and result in very high effluent nutrient concentrations, bringing forth high environmental fees and potential fines.

Financial feasibility:

Financial feasibility will mainly come from increased biogas and energy production and from lower electricity bills. Additional influent will of course increase the costs of treatment and influent from the food industry can also significantly increase maintenance costs of equipment. In most cases, the practice is very cost-beneficent and should result in fast financial feasibility, with no high return times on investment. Some additional information should be considered:

- Financial feasibility of higher biogas production depends greatly on the biogas utilisation. Using CHPs with high electricity production ratios can increase the feasibility greatly, as smaller amounts of electricity need to be bought from the network or could even be sold back if the circuit is developed to accept electricity from distributed generation.
- While upgrading biogas to biomethane still in most calculations loses money compared to electricity production; gas-powered public transportation can be supplied with the biomethane. This is often a political decision (EU green transportation goals), while with good financial compensation measures in place, can also bring positive financial effect to the WWTP.

Example: Grevesmühlen WWTP in Germany

3.1.4. Recommendation A.4 – Cooperation with nearby industries to accept industrial wastewater for a centralised pre-treatment or aid smaller companies with on-site pre-treatment

Recommended for:

- Municipal WWTPs with a high number of smaller industries nearby requiring separate wastewater cleaning or pre-treatment.

Description:

Industrial wastewater streams can be a large threat to many municipal wastewater treatment plants, mostly for the increased concentrations of nutrients, heavy metals or organic pollutants. Many industries are therefore required to have their own pre-treatment in order to remove the most problematic components from the wastewater then discharged to the municipal sewer systems. These pre-treatment technologies however can be quite expensive and difficult to operate, resulting in major problems for many smaller industries. It is sadly not an uncommon practice to dilute industrial wastewater or discharge it illegally to bypass public sewer system regulations.

In areas with many smaller industries or technological/industrial parks, joint or centralised pre-treatment is an option that has been quite overlooked. This of course might not always be useful due to potentially different production fields and thereby different needs for the pre-treatment systems, but in many areas similar industries group together. This can be especially useful for heavy industry mining areas, where most companies work with the same materials. This centralised pre-treatment station could be in the industrial park area or on the outskirts of the local WWTP, but it might be a good cooperation opportunity for it to be operated by the local WWTP. Wastewater personnel already have the knowledge and skills needed for good operation of treatment technologies, plus an understanding of the next processes and results pre-treatment would need to achieve in order to be safe for the general wastewater treatment. As smaller industries don't need to buy their own separate pre-treatment technologies and continuously operate them, financially this system should be beneficial to both the WWTP and the industries.

Another potential part of the recommendation is the pure technical cooperation between industries and the local WWTPs, where the WWTP either operates or advises the pre-treatment done at industries own site. This can also help to achieve better pre-treatment efficiency and establish more control for the WWTP for their incoming flows. As neither the WWTP nor the industry usually want to create problems or pay pollution fines, a good cooperation would be beneficial to all stakeholders.

Important parameters and potential effects:

- Concentrations of different toxic agents
    - With any industrial influents, the wastewater coming from pre-treatment needs to be safe for regular biological treatment, as some substances can cause significant biological inhibitions and decrease the nutrient removal efficiency of WWTP. Similarly, the pollutants are often adsorbed on particles, meaning the resulting sludge has higher concentrations of toxic agents as well.
    - When the pre-treatment is operated by someone else, the industry might not control their pollution or operate their systems in the most environmentally feasible way as

they don’t see the effect it has for pre-treatment capabilities themselves. Therefore, a good feedback mechanisms and smart contracts might be required.

Financial feasibility:

Investments to pre-treatment technologies can be very high for smaller industries, therefore by banding together with others, the share of investment becomes significantly lower. Any pre-treatment technology would require constant maintenance and operation; therefore, it should be feasible to outsource it to the local WWTP personnel who already work on similar issues. This can lower the overall costs of pre-treatment for industries, while also provide a side-revenue for the WWTP. As the WWTP can get better control on the pollution load coming to the public sewer system, this can also result in better overall operation of the WWTP and reduce the risk of inhibition events and potential pollution fines.

For larger industries, outsourcing or consulting a WWTP in their own pre-treatment can reduce the pollution load of industrial wastewater stream and optimise the pre-treatment system. Financial feasibility may not be as easy to reach, but considering different fines and new shifting regulations towards even lower environmental pollution, the overall result of cooperation should even financially be at least neutral or slightly positive.

3.2. B – Biodegradable material to anaerobic digestion

3.2.1. Recommendation B.1 – Accepting sewage sludge from smaller WWTPs and solid fraction of septage to thickening or anaerobic digestion processes

Recommended for:

- WWTP with anaerobic digestion or anaerobic treatment of wastewater.

Description:

As mentioned previously, municipal WWTP accepting septage from onsite sanitation systems should be equipped with solids separation. The solid fraction of the septage can be added to thickening or anaerobic digestion. Together with septage, larger WWTPs can also accept thickened secondary sludge from smaller WWTPs in the area (centralised treatment networks). These streams can be used to produce additional biogas and the additional sludge goes on to further sludge treatment. This cooperation between small and larger WWTPs can eliminate the need for small-scale sludge treatment technologies and bring significant cost-savings per kilogram of treated sludge.

Important parameters and potential effects:

- Volume and redundancy of digesters
    - Accepting more organics means higher sludge production, therefore digesters need to have spare volume that can be used. In longer terms, building additional digesters could be feasible, while the stable industrial inflow and long-term agreements might be needed in case of new investments.
- Concentration of nutrients (nitrogen, phosphorus)
    - Nitrogen and phosphorus are mostly left in the digestate and often transported back to biological treatment with reject water after dewatering. Proteins for example have a very high nitrogen content, which can significantly increase biological treatment costs. When a side-stream process such as anammox is used, the influence of extra nutrient loads is lower.
- Hazardous components, such as heavy metals, different organic pollutants, pharmaceutical residues etc
    - can deem the treated sludge unusable or even create environmental harm
    - Pollutants can get to biological treatment through reject water, cause inhibitions to biological treatment or digestion, lower the efficiency and increasing financial costs. In very bad cases, severe inhibition can destroy biological treatment and result in very high effluent nutrient concentrations, bringing forth high environmental fees and potential fines.

Financial feasibility:

Financial feasibility will mainly come from increased biogas and energy production and from lower electricity bills. Additional sludge will of course increase the costs of treatment, while transportation of sludge between WWTPs might be a significant cost as well. In most cases, the practice is very cost-beneficent and should result in fast financial feasibility, with no high return times on investment. Some additional information should be considered:

- Financial feasibility of higher biogas production depends greatly on the biogas utilisation. Using CHPs with high electricity production ratios can increase the feasibility greatly, as smaller amounts of electricity need to be bought from the network or could even be sold back if the circuit is developed to accept electricity from distributed generation.
- While upgrading biogas to biomethane still in most calculations loses money compared to electricity production; gas-powered public transportation can be supplied with the biomethane. This is often a political decision (EU green transportation goals), while with good financial compensation measures in place, can also bring positive financial effect to the WWTP.

Example: Grevesmühlen WWTP in Germany

3.2.2. Recommendation B.2 – Accepting external biodegradable material to anaerobic digestion in order to boost biogas production

Recommended for:

- WWTP with anaerobic digestion or anaerobic treatment of wastewater and unused digester capacity.

Description:

One of the easiest options to reach energy neutral/positive WWTP operation is to increase the biogas production in anaerobic digestors. Accepting biodegradable materials from different industries (food industry waste, oil trap waste from restaurants, sludge from smaller WWTPs) is the most common way of achieving this. Scientific research into co-digestion [5] has shown that the total sum on biogas produced is larger than the streams separately, therefore it enables higher biogas yield from previous stream as well. Biodegradable addition however can influence digestion properties and bring potential issues, therefore often requiring more precise operation.

Important parameters and potential effects:

- Volume and redundancy of digesters
    - Accepting more organics means higher sludge production, therefore digesters need to have spare volume that can be used. In longer terms, building additional digesters could be feasible, while the stable industrial inflow and long-term agreements might be needed in case of new investments.
- Concentration of nutrients (nitrogen, phosphorus)
    - Nitrogen and phosphorus are mostly left in the digestate and often transported back to biological treatment with reject water after dewatering. Proteins for example have a very high nitrogen content, which can significantly increase biological treatment costs. When a side-stream process such as anammox is used, the influence of extra nutrient loads is lower.
- Hazardous components, such as heavy metals, different organic pollutants, pharmaceutical residues, microplastics etc
    - can deem the treated sludge unusable or even create environmental harm
    - Pollutants can get to biological treatment through reject water, cause inhibitions to biological treatment or digestion, lower the efficiency and increasing financial costs. In very bad cases, severe inhibition can destroy biological treatment and result in very high effluent nutrient concentrations, bringing forth high environmental fees and potential fines.

Financial feasibility:

Financial feasibility will mainly come from increased biogas and energy production and from lower electricity bills. Additional waste streams will of course increase the costs of treatment, more complex streams such as fats from food industry or biowaste can also create significant problems with different pieces of equipment and increase maintenance costs. In most cases, the practice is very cost-beneficent and should result in fast financial feasibility, with no high return times on investment. Some additional information should be considered:

- Financial feasibility of higher biogas production depends greatly on the biogas utilisation. Using CHPs with high electricity production ratios can increase the feasibility greatly, as smaller amounts of electricity need to be bought from the network or could even be sold back if the circuit is developed to accept electricity from distributed generation.
- While upgrading biogas to biomethane still in most calculations loses money compared to electricity production; gas-powered public transportation can be supplied with the biomethane. This is often a political decision (EU green transportation goals), while with good financial compensation measures in place, can also bring positive financial effect to the WWTP.

4. Outgoing points of cooperation:

4.1. C – Energy produced in the WWTP

4.1.1. Recommendation C.1 – Increasing electricity production with new co-generation engines

Recommended for:

- WWTP using older biogas CHPs with low electrical efficiency;
- WWTP building new anaerobic digestion and/or biogas utilisation infrastructure.

Description:

Biogas produced at a WWTP can be used in combined heat-power stations (CHPs) to produce heat and electricity. As many WWTPs often have a surplus of heat energy and no real way of distributing it to the network, electricity production should be the main emphasis of CHPs. While older technologies had a maximal electrical efficiency of 10-20%, new technologies are able to turn up to 24-45% (even up to 54% [6]) of total higher heating value to electricity. This increase in electricity production reduces the amount of heat generated, while the value of electrical energy is much higher. New technologies with very high electrical efficiency include combined cycle gas turbines, reciprocating engines, microturbines and fuel cells. Some of these technologies are quite new and the investment cost might be very high up-front, but as their use gets more and more common, the prices also become more feasible.

Financial feasibility:

With any purchase of equipment, there is a significant investment payback time, but that should be well calculable beforehand based on the extra electricity generated. A new and effective CHP might help the WWTP reach energy neutral or even positive status, lowering the overall cost of operations and increasing the overall financial stability. In most cases, when pre-purchase feasibility calculations have been done the long-term financial feasibility can almost be guaranteed.

4.1.2. Recommendation C.2 – Selling surplus energy to the network

Recommended for:

- WWTP with positive/neutral energy balance;
- WWTP with periodically higher energy production (solar panels, wind turbines, periodical use of CHP).

Description:

The move towards sustainable energy means centralised electricity production is becoming less dominant. Distributed generation is rising in popularity and networks are being rebuilt to accommodate two-way power flows. The option to sell the electricity produced at WWTPs is not only necessary for energy positive plants but can also be used by WWTPs with periodical surplus electricity production. The financial gain from selling electricity can be significant and help invest more money into the system.

An important note to consider though, is that the legislation system is in most countries not ready for distributed generation or WWTP as electricity producers. Therefore, different fees, taxes and other inhibitory levers can still be in place making the change towards energy producers more difficult. It is however likely to change in the near future as current climate policies necessitate the change.

Financial feasibility:

Selling surplus electricity already produced at the WWTP back to the network should automatically be an extra income, while due to different contracts and taxes, it might not actually be so black and white. That also means without further investigation into national legislation, any investments done solely to start selling back electricity to the network might not be feasible. With the quickly changing legislation distributed energy generation should become more feasible in the coming years, but the final feasibility will still be based on the overall market prices. As Europe is moving toward sustainable energy, the electricity generation and price is estimated to decrease in stability (solar panels only generate electricity during the day, wind turbines only during windy days). As the biogas energy utilisation does not depend on weather patterns, the WWTP might be able to provide some stability in the market or profit from the fluctuating energy prices.

4.1.3. Recommendation C.3 – Equipping the WWTP with heat exchangers to extract heat from sewage, sidestream or effluent

Recommended for:

- WWTP with anaerobic digestion;
- WWTP with high temperature wastewater coming from the sewage;
- WWTP with indoors/covered treatment with low heat loss.

Description:

Wastewater has often been described as one of the biggest unused streams of heating potential. After entering the sewage system, the typical wastewater temperatures range between 10 °C and 25 °C [7]. This can not only be used for heating during winter but also for cooling during summer, giving the heat recovery system a year-around use. The produced heat or cold can be used for both the operational and administrative buildings or be sold to other nearby facilities. The total energy consumption of heating and cooling can be reduced by more than 50% with the use of heat recovery, while the wastewater itself is not significantly influenced by the recovery operations (changes in average wastewater temperature are usually lower than 0.1 °C [8]).

Although the investment cost can be quite high, depending on the local market, newer research has shown that even in colder climates the payback period of the total investment could pay back in around 11-12 years [9]. Different technologies and set-ups are available depending on the climate and source of heat (influent, sidestream, effluent). Heat exchange could even be more economically feasible for WWTPs accepting warmer wastewater from some industrial processes and companies.

Financial feasibility:

As discussed earlier, heat recovery operations usually have a fairly long payback period of more than 10 years. This is greatly influenced by both the local market and many situational parameters; therefore performance assessments should be carried out before investing in the solution. As the system can also significantly reduce the carbon footprint of the WWTP, additional benefit in some countries can be achieved through lower taxes or other financial measures.

4.1.4. Recommendation C.4 – Equipping the WWTP with solar panels

Recommended for:

- WWTP with large unused land areas or flat roof areas;
- WWTP trying to achieve energy/climate neutral or positive operation.

Description:

Distributed energy production is getting more and more common as we try to reduce our dependence from fossil fuels and non-renewable electricity production. As WWTPs often have a quite large and open area, solar panels for some extra electricity production are a viable option to get closer to the energy and climate neutral operation. Solar energy could also be used for technological purposes (solar drying, advanced treatment via electrolysis, algae production for biofuels [10]), but this recommendation focuses on the use of solar panels for electricity generation.

So far solar panels have been used in the BSR WWTPs for mainly heat production, electricity production has been shown more in the southern regions. Electricity generated with solar panels could be used in the WWTP itself or sold to the network, whichever works best with the specific WWTP opportunities, finances and goals.

Beside regular silicone-based stationary solar panels, new approaches and innovations are also very common concerning the solar energy market, one of such is foldable solar panels that could be installed on top of the biological treatment tanks [11]. While the financial feasibility of new innovations is usually lower (costs are significantly higher than normal), these options might also prove viable in the near future.

Financial feasibility:

Solar energy has become more and more affordable and should be a feasible solution for many WWTPs. As the investment costs for a solar park has steadily declined during the last decade (from 0.378 USD/kWh to 0.039 USD/kWh [12]), in many situations the solar energy is now cheaper than electricity generation from coal or other fossil sources. The financial feasibility for a WWTP can be dependent on the local market and the landscape at the WWTP, but in many cases feasibility should be reached within 6-9 years even in the Baltic Sea region [13]. As the political climate is also moving more and more toward renewable energy, the payback time could be further reduced with upcoming changes in legislations and taxes.

4.1.5. Recommendation C.5 – Equip the WWTP with wind generators

Recommended for:

- WWTP with large unused land areas, especially in rural areas;
- WWTP trying to achieve energy/climate neutral or positive operation.

Description:

Wind energy is another important option for renewable energy production and in some situations could be produced at the WWTP as well. Although there are not very large specific benefits on building wind turbines together with WWTPs, being next to a large consistent (24/7) energy consumer has its own benefits. On good wind conditions, the renewable energy could be directly used in WWTP, making batteries or accumulators unnecessary. As one of the main problems with wind energy is the inconsistency, using it as a secondary option to cover WWTP electricity needs on some days could be a solution. Energy losses using the wind energy directly without long-distance transportation or intermittent accumulation and storage are also lower.

As WWTPs are often in the outskirts of urban areas and have some free land area, investing into wind turbines might be a possibility for some, especially if the WWTP is trying to reach energy and climate neutral/positive operation. With only a few turbines, more than 50% of the total electricity consumption of most WWTPs could be substituted (most wind turbines have a capacity of 1.5-3 MW) [14]. Once again however, this option is very situational and while solar panels could be usable in most WWTPs, wind power is suitable for only a small fraction of treatment plants built in specific locations. Like always with wind turbines, other factors, such the views of the nearby community and other cultural or political oppositions can be an important barrier in front of the investment.

Similar to solar power, there are also some interesting innovations tied to wind energy use in WWTP, such as wind-powered aeration (mainly used for constructed wetland aeration [15]), but this recommendation will not look into those in-depth.

Financial feasibility:

The up-front investment cost for wind turbines is very high and the payback time greatly depends on the local wind situation and grid electricity cost [14]. Although like for solar energy, the investment cost for wind turbines has dropped significantly (around 50% during the last decade), the average wind turbine still costs around 800 000 to a million USD per installed MW. Advances in technology have made the turbines about 30% more effective than a decade earlier, but the payback time for an investment in wind energy is still considered to be more than 10 years in good cases, up to 20 in medium wind scenarios [12]. That means investments into wind energy are with quite high risk and need to be evaluated very carefully, at the same time fast payback of the investment should not be expected.

4.1.6. Recommendation C.6 – Producing hydropower from wastewater

Recommended for:

- WWTP with different elevations from the catchment area or receiving water body;
- WWTP trying to achieve energy/climate neutral or positive operation.

Description:

Although hydropower generation in WWTPs is not very common at the moment, research around Europe has shown that there is potential in the technology. This rise is interest is mainly due to new micro-turbines, which can be used in various location, both in the WWTP or in the sewage network. As hydropower generation from natural sources has seen many setbacks lately do to their negative effects to the aquatic ecosystems, power generation from the sewage networks has no such concerns. There might even be benefits to wastewater treatment such as increased dissolved oxygen concentrations with a smart use of the technology [16]. As more hydropower is produced at higher load times, the technology also matches peak demands very well [17].

The actual feasibility and profitability of the technology still greatly depends on the natural elevation of the region. Both upstream (before the WWTP, in the sewer network) and downstream (between WWTP and the receiving water body) small-scale hydropower generation is possible if the elevation difference between two points is enough. Although this elevation difference (also called "head") should be as high as possible, small-scale systems with heads as low as 4 meters can already be feasible [17]. Country-wide assessments and profitability calculation methods relying on satellite data have been developed for Spain [18] and Switzerland [17], which could also be adapted to the northern regions.

The installed power of the turbines in WWTPs is usually around a few hundred and few thousand kW, while small systems with as low as 13 kW have been built [17]. As the turbine size and number is very well scalable, this recommendation should not be too much size-dependant and could be profitable for both very small and very large WWTPs. They might be especially useful for small rural areas with a centralised WWTP in more mountainous regions (Sweden).

Financial feasibility:

Similar to solar and wind power, the hydropower investment cost has decreased within the last few decades, greatly decreasing the baseline of profitability. Still the main factors when calculating financial feasibility are the elevation difference and the total load (installed power). With lower loads and elevations, the installation cost of a small-scale hydropower station might be between 1500-6000 €/kW, while with higher loads and elevations the cost might be significantly smaller, being in the range of 200-800 €/kW [19]. As with all energy production feasibilities, the payback rate of the investment also depends on the local energy market and overall prices.

Although a payback period for hydropower installation in the WWTP is very difficult to calculate and varies the most compared to wind and solar, payback times such as 6 – 10 years should be considered for high-potential cases [20].

4.2. D – Effluent of the WWTP

4.2.1. Recommendation D.1 – Reuse treated and clean effluent water in nearby industries for cleaning, cooling and other processes

Recommended for:

- WWTPs with good effluent quality near industrialised areas;
- WWTPs with advanced treatment technologies (tertiary treatment) producing very clean effluent.

Description:

As the current European policy has been aimed heavily towards circular economy, waste and wastewater reuse are key factors in the new paradigm. One of the main opportunities is the reuse of treated effluent in different industries where drinking water quality is not required – such as cooling, cleaning or variety of other processes. Within the water circular use models, water once already pumped from natural sources should be used as many times as possible before being returned – each industry should not take their water directly from natural sources when other options are present [21].

Wastewater reuse for industrial cooling systems is not a new concept, in many areas with higher water scarcity, it has been a important topic since late eighties [22]. Strongly linked to global climate change, drought periods have become more and more common even in the Baltic Sea region, requiring us to develop new measures and adapt solutions already used in arid areas around the world.

At the same time, due to the rising concern about micropollutants, effluent reuse is not seeing us much progress as expected. With new studies showing the danger from pharmaceuticals, per- and polyfluorinated alkyl substances, microplastics and other pollutants not sufficiently removed with current wastewater treatment practices, the effluent reuse practices have not gained a foothold in the region.

This situation might however be changing soon, as more and more emphasis is given to advanced effluent treatment technologies, such as ozonation, granular or powdered activated carbon treatment (GAC/PAC), microfiltration, foam fractionation and others. While most of these technologies come with significant investment and operational costs, combined use of oxidation and absorption methods has shown very high, up to 99% degradation of many different micropollutants [23]. The treated effluent is therefore with a very high purity and in most cases should be with better quality then surface water used in many industries. This is a very important point for collaboration, as some of the cost of these technologies could be covered with the revenue gained from selling the treated effluent.

Financial feasibility:

The effluent reuse business models are still underdeveloped and their feasibility is not proven. The main positive revenue stream for WWTP should come from lower effluent discharge fees as a part of effluent is sold to a nearby industry not discharged. With smart pricing, the clean effluent from the WWTP should also be cheaper for the industry rather than the water pumped from natural sources, therefore providing a financial benefit for them as well. In some industries, where freshwater from lakes or rivers is used, the cleaned effluent can also be with better quality and result in lower maintenance fees than previously.

4.3. E – Treated sludge or material from treatment (ash, struvite)

4.3.1. Recommendation E.1 – Direct use of treated sludge for agriculture and recultivation

Recommended for:

- Smaller WWTPs with good sludge treatment technologies in rural areas;
- Medium-sized WWTPs with very high-quality treated sludge.

Description:

Although the direct use of wastewater and treated sludge has become less popular in the recent decades due to emerging micropollutants, rapidly growing knowledgebase and public opinion, it is still a viable option for smaller WWTPs. Recovery of phosphorus is one of the main new aims of wastewater treatment, while most of the new solutions and techniques are usable for medium or large WWTPs. With sufficient analysis and smart application, smaller WWTPs can still direct the sludge to be used in agriculture, recultivation or landscaping. In many countries, specific certification processes are developed for WWTPs to make an official product out of the treated sludge, such as the REVAQ system in Sweden [24].

The legislation for direct use of treated sludge is very different around the Baltic Sea and due to rising concern about micropollutants, direct use might become more complicated in the future. The practice can also be risky for the WWTPs, as some amounts of treated sludge might not pass the quality requirements set for direct use and need direct disposal. Still the practice should be seen as a viable option for small WWTPs, especially in rural areas where transportation of sludge to a larger facility is not feasible.

Financial feasibility:

If the new goal in sewage sludge treatment is to recycle/recover the nutrients in it (nitrogen and phosphorus), direct use of treated sludge is by far the cheapest way to do it. There is a wide variety of tested and cheap technologies that can be used to stabilise and hygienise the sludge to a quality standpoint that a few decades ago was deemed completely safe. Although these standards are still in effect in some countries, they are in the process of becoming significantly stricter.

As treated sludge has no official End-of-Waste legislation for the whole European Union, these national standards are therefore the most important thing to consider when discussing feasibility. In some countries (Estonia), treated sludge can also be used in some areas as waste, without even being certified as a product. The financial feasibility of the direct use of sludge therefore greatly depends on the national systems in place. Direct use of treated sludge can help the WWTPs save from the disposal and landfilling costs, as it is a mean for getting rid of the sludge. At the same time, direct use of treated sludge is not a future-proof solution in the Baltic Sea region at the moment, therefore long payback time investments might be quite risky.

Example: REVAQ system in Sweden

4.3.2. Recommendation E.2 – Transporting treated sludge to a centralised treatment plant

Recommended for:

- Small WWTPs in semi-urbanised areas;
- Medium-sized WWTP in the near vicinity of a larger WWTP with advanced technology.

Description:

As the direct use discussed earlier is becoming more and more strict, more advanced technology is often needed to meet the requirements. As nutrient recovery from wastewater and sludge is slowly rising to a priority at least in the Baltic Sea region, many larger WWTPs are doing large investments to keep of with the new paradigm. For smaller and medium sized WWTPs, this however is not always the option, as many technologies can only be feasible in large scale applications. While the debate between centralised and decentralised wastewater treatment is quite active [25], for sludge treatment and nutrient recovery centralised systems are both financially and effectively more feasible.

Although transporting sludge is expensive and causes direct GHG emissions, it can still be a feasible option for smaller WWTP as the centralised treatment of the sludge from smaller WWTPs can overall be more climate friendly and financially beneficial practice. The transportation costs are the most dependant on sludge dry mass – the total volume and mass of transportable sludge depends on the water content. With the application of different thickening, dewatering or even drying processes, the transportation costs can be significantly lowered [26].

Financial feasibility:

The business models and specifics for centralised sludge treatment can vary greatly depending on the processes and technologies used. In some cases, unstabilised dewatered sludge can be transported from smaller WWTPs to a larger one for digestion and subsequent treatment. Within this business model, the receiving WWTP can get a financial benefit from extra energy production and the smaller WWTP does not need to invest into a sludge treatment technology or pay the sludge disposal costs beside transportation. In these cases, the financial feasibility usually comes down to the DM content of the sludge, it's calorific value and the distance between two WWTPs.

Another option is to transport stabilised or dried sludge from a small/medium WWTP to a larger one for incineration and/or nutrient recovery. Although this business model, especially for the nutrient recovery side, is not as common yet, it has high potential for many densely populated areas. The financial benefit can come from the heat energy produced from incineration or potential recycled nutrient product produced at the facility. Although in the current market situation neither of these might be significant enough to cover the investment or operation costs of the facilities, there is hope for new legislation and incentives in the EU level that would help turn these revenue streams to the positive side.

4.3.3. Recommendation E.3 – Extraction of phosphorus from sludge incineration ashes

Recommended for:

- Large WWTPs with the sludge incineration technology.

Description:

Phosphorus recovery from sewage sludge ash (SSA) is a very promising new approach, with potentially highest P-recovery efficiencies compared to other nutrient recycling approaches [27]. These various technologies however, such as wet chemical, thermo-chemical or electro-chemical extraction, are all only applicable in very large WWTPs. There is also a possibility for a centralised nutrient recovery facility, which could be fed with the ash from multiple large WWTPs – compared to sludge, ash is much more compact and can be transported with lower costs [28]. Sewage sludge ash has high overall phosphorus concentrations, usually between 5 to 11%, while in some cases up to 20% [27]. With rising concerns for micropollutants, nutrient recovery from SSA can reduce those risks as almost all organic pollutants are completely degraded during incineration. Although SSA have potential to be used directly, further extraction processes are usually recommended due to high heavy metal concentrations and low bioavailability of phosphorus in the ash.

Compared to struvite precipitation and other nutrient recovery methods from sludge and wastewater, the phosphorus recovery technologies from SSA are not as mature yet as full-scale applications require huge investments and carry significant risks [28]. Still, there is a number of promising applications currently being developed such as TetraPhos®, Ash2Phos®, EcoPhos® and PHOS4Green for wet-chemical extraction; AshDec® for thermo-chemical extraction; RecoPhos® for thermo-electrical extraction [29]. More specific information about nutrient recovery from sewage sludge ashes can also be found in another publication produced by the BSR WATER project, called the Palette of Solutions for Nutrient Recycling in the Baltic Sea Region [30].

Financial feasibility:

Although the phosphorus recovery from ashes can possibly take place in-situ at the WWTP, centralised phosphorus extraction facilities are slowly being developed, to which WWTP incineration ashes can be given away or sold to. This lowers the amount of material needed to be landfilled and decreases overall costs – potentially even gaining new revenue from the sale of the ashes (could be problematic based on local legislations). At the moment the recycled phosphorus products are in market competition with rock-based phosphate products and in most cases financial feasibility can’t be reached due to low primary phosphorus prices. This also resulted in the first larger company using SSA to recover phosphorus declaring bankruptcy in 2012 [31]. In order to support P-recycling, changes in legislation, public opinion and/or market behaviour are needed to alleviate the risks currently tied to full-scale P-recycling investments.

4.3.4. Recommendation E.4 – Struvite or hydroxyapatite precipitation from wastewater or sludge

Recommended for:

- WWTP with enhanced biological phosphorus removal (EBPR) and anaerobic digestion;
- WWTP with acute struvite scaling problems and large maintenance costs.

Description:

Precipitation of different high phosphorus concentration minerals is currently one of the most developed nutrient recycling technologies from wastewater and sludge. The two most common minerals precipitated are struvite and hydroxyapatite, both of which have their own benefits and specific technologies [32]. Different technological applications can also be used to precipitate those minerals from wastewater, sludge matrix or anaerobic digestion supernatant/leachate. These precipitation processes take place in alkaline conditions and often require a seed material such as quartz, silica sands, calcite, recycled struvite etc to facilitate the crystallisation [33].

Struvite aka MgNH4PO4·6H2O aka MAP is a potential phosphorus recovery resource, while also being one of the main causes for pipe blockages in most WWTPs. Intentional struvite precipitation, especially from the warmer sidestream (digester effluent) has currently the most potential for phosphorus recovery from wastewater. In most WWTP, the sidestream water is circulated back to biological treatment, with anammox-processes sometimes in between to reduce the nitrogen back-load. Struvite precipitation however can reduce both the N and P back-loads, produce a potential mineral fertiliser from the process and decrease both maintenance and operational costs of the WWTPs. Struvite precipitation is dependant on pH, temperature and concentrations of magnesium, ammonium and phosphate in the solution [33].

Hydroxyapatite aka Ca5(PO4)3OH aka HAP is another potential phosphorus recovery resource, which instead of magnesium and ammonium includes calcium. As no ammonium ions are needed, the process is also suitable for P-recovery from wastewater, where low concentration of NH4+ is one of the main barriers for struvite precipitation [34]. Formation of the HAP crystals is dependant on phosphate, calcium and bicarbonate concentrations and pH [35].

More specific information about MAP and HAP precipitation can be found in another publication produced by the BSR WATER project, called the Palette of Solutions for Nutrient Recycling in the Baltic Sea Region, including the in-depth explanations about the crystallisation process and overview of different technologies and providers currently on the market (AirPrex®, Pearl®) [30].

Financial feasibility:

Struvite precipitation is currently the most widespread P-recovery technology. Although the total P recovery rate is lower than from ashes (15-40% from wastewater, 40-60% from sludge or supernatant [36]), the up-front investment costs are usually lower and other beneficial effects of the technologies, such as increased dewaterability, lower polymer and pipe maintenance costs, help increase the feasibility of the processes. For example, data from the AirPrex® process has shown around 2-4% increased dry solids concentrations of dewatered sludge and 35% lower polymer consumption [37].

Quite a lot of financial information and working business models are shown by some of the specific struvite precipitation technology providers, to get new customers and advance the nutrient recycling in EU. For example, AirPrex® (Centrisys CNP) already has 13 full-scale implementations, showing around 3 million euros as the up-front investment costs with annual savings of around 400 000€ without even the sale of the final struvite product [37]. Similar data is reported with Pearl® (Ostara), promising a payback on capital investment in 3-7 years, decreasing with larger sizes of the WWTPs. The Pearl® business model also includes selling the produced struvite back to Ostara, where a registered commercial fertiliser called CrystalGreen® is produced [38].

4.3.5. Recommendation E.5 – Vivanite magnetic separation

Recommended for:

- WWTP with chemical phosphorus removal ($FeSO_4$) and anaerobic digestion.

Description:

While most technologies for HAP or MAP production are significantly more feasible in WWTPs with enhanced biological phosphorus removal, vivianite magnetic separation is a technology developed for WWTPs using chemical phosphorus removal. Vivianite aka $Fe_3(PO_4)_2 \cdot 8H_2O$ is a mineral with magnetic properties, which can form during the digestion of iron-rich sludge [39]. Vivianite forms in organic matter and iron rich and non-sulphidic conditions [40]. While this presents an opportunity for a very feasible P-recycling technology, vivianite magnetic separation technology by KEMIRA has not been thoroughly tested in full-scale conditions as of 2021.

From pilot-scale tests the technology has shown great promise overall. While the amount if iron dosed during chemical precipitation of phosphorus would need to be increased, this might also reduce the amount of H_2S produced during digestion. No negative effects on biogas production or sludge dewaterability have been shown [41], while the mineral itself has limited bioavailability and would need re-processing before possible use as a fertiliser [42].

More specific information about vivianite magnetic separation and other new innovative pilot-scale technologies for P-recycling (such as the RAVITA process) can be found in another publication produced by the BSR WATER project, called the Palette of Solutions for Nutrient Recycling in the Baltic Sea Region [30].

Financial feasibility:

As vivianite magnetic separation is a new innovation in the region without full-scale implementation, feasibility data is not available yet. The Vivimag process by KEMIRA shows potential for chemical dosing agent recovery together with vivianite re-processing, which can result in reduction of chemical dosing and maintenance costs together with the production of a fertiliser product [43].

Example: No full scale implementation yet

5. Afterword

From the circular economy perspective, the wastewater treatment plants are one of the easiest points along the resource distribution chains to approach with significant changes. This can mean both the recovery of important resources from the waste stream, but also the production of energy and biofuel (biomethane). **A comprehensive understanding and a holistic approach to waste and wastewater treatment can decrease the WWTP operational costs and the carbon footprint as well as increase the benefits produced for the society.** Many of the recommendations outlined in this document can be feasible and beneficial when applied separately in the WWTP, but when applied together can significantly change a wastewater treatment plant into a true waste resource recovery facility.

Although many of the outlined recommendations should have almost guaranteed financial benefits and should be easy to adapt, the real situation is much more complicated. WWTPs are often owned by municipalities and tied with very strict and specific legislations, as they provide a necessary primal benefit to the society. That means the water fees are very tightly controlled by other parties and in many countries are tied directly to the water production and treatment costs. At the same time, the costs of additional technologies or treatment steps not outlined by the local legislation cannot be calculated into the fee, as it might unfairly increase the water prices in a specific region. Although these strict rules are in place to provide everyone with a clean and low-price water; today it also means that no environmentally beneficial investments or innovations can be done in the WWTP if it's not directly required by law.

The current strictly fee-based system is also effectively hampering the energy production in the WWTP – in many countries if the treatment plant produces extra revenue with additional effort, it may also lower the water tariff. This means more effort and additional work is often punished, as no financial benefits can be gained. Although these problems are sometimes bypassed by leaving energy production to an external company and drawing a strict line between water treatment and any other activities, **the current political and legislation system strongly hinders the development of waste resource recovery facilities or energy/climate positive wastewater treatment plants**.

Societal or public pressure can also come from another side – requiring potentially unfeasible technologies and approaches for the WWTP. One of the best examples of this is biomethane upgrading from biogas, which in most cases is still financially a negative action, as electricity from the direct utilisation of biogas is still usually more beneficial. The pressure to produce biomethane or CNG however comes from the EU sustainable transportation goals and therefore many municipalities need a local source of biofuel.

To support the overall development of waste recovery, circular economy and distributed energy production, some key messages should be considered:

- The current systems used to calculate water prices should be significantly altered to include or exclude different costs and revenue streams connected to circular economy and environmental protection goals. Sustainable energy and materials production have to be decoupled from water tariff calculations;

- Advanced treatment option for the degradation of micropollutants should be included in EU or local legislative systems, enabling them to be included in water tariff calculations if the water price is not significantly higher than the national/EU average;
- The new waste resource recovery facility approach needs to be legalised and supported, sustainable business models need to be developed and included in the legislations;
- Positive cooperation between industries and wastewater treatment facilities should be encouraged;
- Distributed sustainable energy production needs to be made more feasible and back and forth buying and selling electricity based on the current production and need should be supported;
- Secondary raw material production (recovery of materials) should be prioritised as much as possible, positive financial support systems to compete with the abundance of unsustainable primary raw material inflow from outside EU need to be formed;
- EU and national investment funds should be allocated to large regional waste resource recovery projects, which significantly contribute to our move towards circular economy.

Based on the 6th Assessment Report from the Intergovernmental Panel on Climate Change [44]: "It is unequivocal that human influence has warmed the atmosphere, ocean and land." The report was also called a "code red for humanity" by the current UN Secretary-General António Guterres [45]. More than ever before, quick acting and legislational support is needed to move towards more sustainable society. The technology and knowledge to make significant changes in the wastewater sector are already existing and examples of the operational models are also highlighted in the current document. These guidelines show, how a wastewater treatment plant can be a model for the water-sludge-energy cooperation and move towards becoming a sustainable Waste Resource Recovery Facility. There are still some barriers on the way (outdated legal systems, low price of primary materials) that need to be demolished in order to make such an approach possible, but it seems our region is currently working on many of them. Nevertheless, good cooperation between industries and WWTPs is the basis for the new model and is recommended to all WWTPs, regardless of location, size or technological level.

Disclaimer

We issue no guarantee on the correctness and completeness of the information and results in this guide. Liability claims referring to material or immaterial damages, which are caused by use or non-use of the presented information or the application of incorrect or incomplete information, are categorically excluded.

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