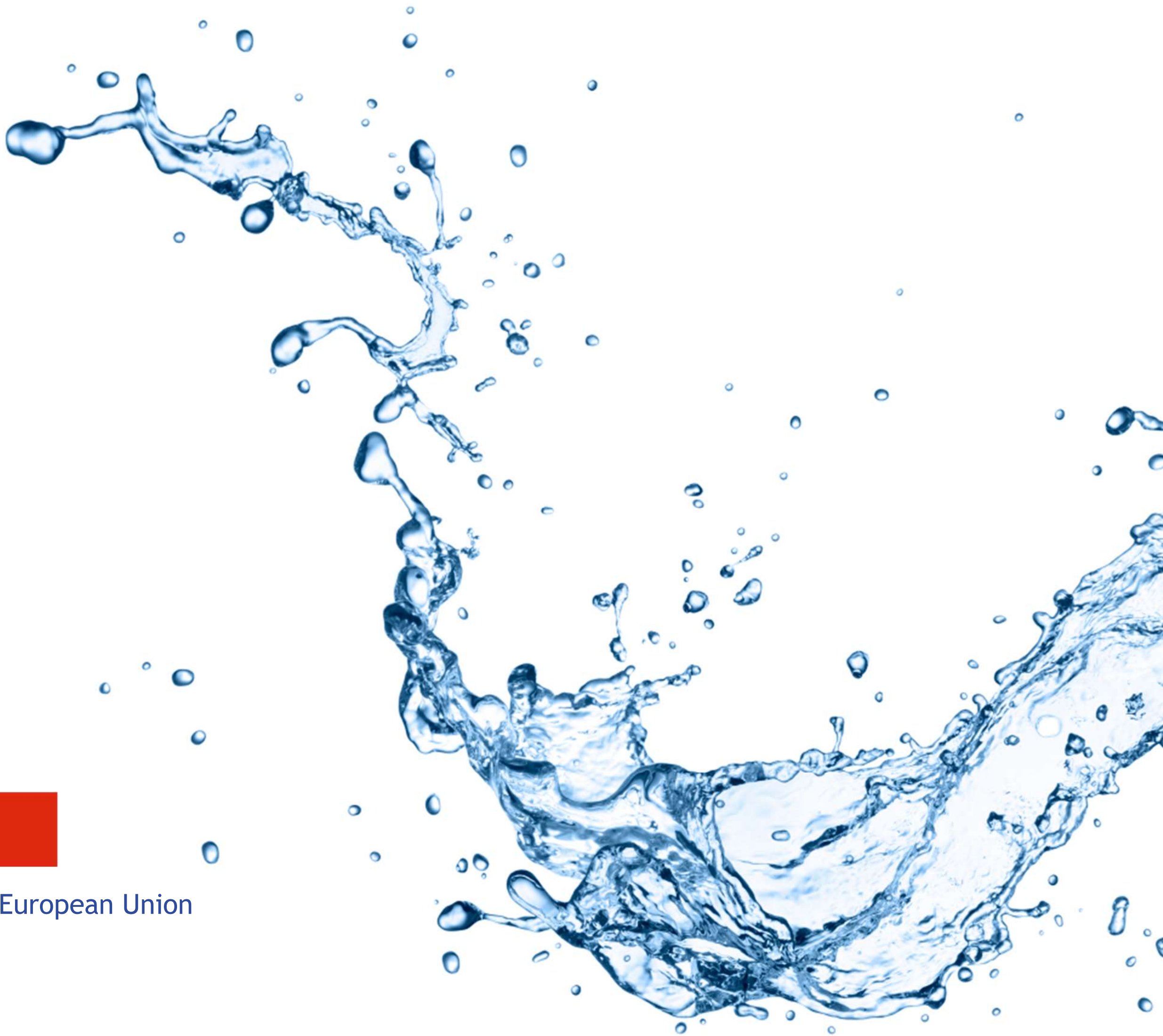
CHINA EUROPE Water Platform

Circular Economy of Water - Waste Water Treatment

White Paper: Circular Economy of Municipal Wastewater Treatment Plants in Europe



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annex 1 Compilation of Workshop for Circular Economy of Municipal Wastewater Treatment Plants

1. Introduction

This whitepaper discusses circular economy of municipal wastewater treatment plants (WWTPs) in Europe. It focuses on the implications of circular economy concepts on wastewater treatment, including energy capturing, nutrient recovery, material re-use and material efficiency, new partnerships and business models etc.

This whitepaper is part of China Europe Water Platform (CEWP) plans create a base for discussion on the future of circular economy of water - wastewater treatment. The targeted events for discussions of technological development in China and how the Chinese experience reflects on the findings of the paper are at CEWP Business Events as well as different seminars for Water professionals in Europe and China.

Target of the whitepaper is to start a discussion between Chinese and European stakeholders on what the wastewater treatment sector will look like in the future and create opportunities for cooperation in business, policy and research.

In general, circular economy is a systemic approach in which the waste is minimized, life-cycle value of natural resources and products is maximized. The aim is to respond to global and local sustainability challenges. Most crucial topics are related to supply of water, energy and food for future population expected to grow to 10 billion by 2050. The concepts and technological solutions related to water and sanitation play an important role in adaptation to the population growth and climate change. On contrary to linear "take-make-waste" model, circular economy approach is based on principle of "Reduce-Reuse-Recycle-Restore-Recover, (5R)". Many resources like energy, water, materials, data, knowhow and value creation could be circular. For instance, applying X as a Service approach best value could be added to water (and wastewater). Production and consumption produce less waste and the waste is seen as a resource. In addition to data availability and transparency of systemic value chain in urban environment as well as maintenance and refurbishing are key factors in circular economy. The aim is to create sustainable economic value cost savings, new opportunities and innovation while ensuring availability of resources. [1] [2] [3]

Water has a global natural hydrological cycle. The circular economy of wastewater is in fact circular economy of water. In circular economy, water is used efficiently minimizing its loss. Substances dissolved in the water during its use and bound energy are recovered and returned to the circulation. This is achieved by using less fresh water and reusing the water upstream. From a more concentrated wastewater nutrients and materials can be recovered and the WWTPs needed are smaller. After collecting the valuables from the wastewater, it can be reused as industrial or even drinking water. Energy recovered from wastewater can be used in the WWTP and the surplus can be sold to the energy networks.

The paper includes a short overview of past developments and current situation, with a focus on innovations and technologies which are likely to be widely applied in the future. The paper concentrates on technologies in order to benefit both private and public actors interested in the topic. The paper covers only Europe and consider the general situation on the continent. It includes examples from European countries and examples of possible emerging technologies.

2. Past developments

The importance of sanitation was understood in the 19th century. For example, the first collectors were built in the streets in France then. There was a revolution of wastewater treatment in the 20th century when the term of biological oxygen demand (BOD) was created and tests for effluents were established. [4]

The usage of solids or sewage sludges as a fertilizer has been common from the beginning of time [4]. However, after stricter European Union regulations the circular usage of sewage sludge was declined. For example, in 1998, the European Union set limits on the amount of phosphorus applied to fields, which reduced the use of sewage sludge. From 2006 one should prove the hygiene of the sewage sludge prior its usage. Sewage sludges have thus been used for landscaping and energy production. However, recently a group of Nordic food industry players announced a market ban for agricultural use of sewage sludge based biofertilizers (digestate). [5]

A circular economy example from history is the wide usage of ferrous sulphate for removing phosphate from wastewater. The ferrous sulphate used is produced from a byproduct of a titanium dioxide process. [6]

Circular economy of wastewater treatment has trending recently, but sustainable development has been on the agenda for decades. New circular economy innovations have been plentiful, but the market for the new products and changes in people's mindsets are needed. Other challenges are the cost of investments, risks management approach to new technologies, cost competitiveness of recovered substances and maintenance deficit of existing infrastructure [7]

3. Current situation in Europe

3.1. Ecosystems and business models

Circular economy is built on business models and broad ecosystems where operators are interlinked to supply most sustainable and value creating solution for the cities, societies and industry. Here are some examples how the organizations' cooperation is organized in Europe. Administrative aspects, profits and exchange of resources are discussed.

Most of the WWTPs are owned by municipalities or public actors in Europe. In Sweden, there is a low-hierarchy model in which an individual becomes a member, when the individual joins the water supply network. In the Netherlands WWTPs are seen as energy and resource factories. The society regards wastewater as a valuable source of renewable energy, raw materials, and clean water. In order to contribute to this transition, the water boards have set up a collaborative network organization called Energy and Resources Factory. The Dutch model joins the forces of the 21 water authorities with their umbrella organization and the Foundation for Applied Water Research (STOWA), several knowledge institutes and many other organizations. Eight sewage treatment plants have already been transformed into Energy Factories, with preparations underway for a further nine factories. They produce green electricity. Phosphate is recovered at seven sites applying Biological Phosphorus removal in the WWTP. There's also research on the recovery of valuable raw materials like alginate and cellulose from wastewater. [8]

A holistic view is a must when talking about an effective circular economy. It does not make sense to look at individual wastewater treatment plants, but according to the circular economy principle, operators who produce wastewater and operators who can utilize the resources recovered from wastewater should also be considered. For example, in Norrköping, Helsingborg and many other Swedish municipalities they have utilized the model of industrial and urban symbiosis. It has induced:

- reduced input and residue management costs
- reduced exposure to market volatilities
- increased share of renewable and biobased resources
- more value from local or regional resources
- reduced fossil and external resource dependence
- benefits to wider group of actors or sectors
- job creation and preservation
- removal of development bottlenecks
- increased local tax base
- improved environmental quality
- cheaper and better services
- improved collaborative innovation capabilities
- reduced overall resource demand
- reduced waste and emissions.

The model of industrial and urban symbiosis will be further utilized in Kisa and in Sotenäs in Sweden. [9]

In Finland the development of Pirkanmaa biogas ecosystem (see figure 1) is a reflection for ecosystem enabling diverse utilization of resources from municipal WWTP, too. It's a regional biogas cooperative -model in development. Local biogas production would be networked to local and regional actors. Owners of the cooperative would be the local farmers producing raw materials. Biogas plant owners could be other actors in the network, including the public actors. The actors in the network could be for example municipalities, industries, vegetable producers, farmers, services, energy distribution and biogas refinery facilities. Regional cooperation would help the establishment of local institutions and activity. There's also a circular economy park planned in the area. There will be Nokian Vesi Oy's new WWTP and Pirkanmaan Jätehuolto Oy's biogas plant. They have studied micro-sieving as a pre-treatment technology and how it will affect the sludge quality and usability. [10, 11, 12]

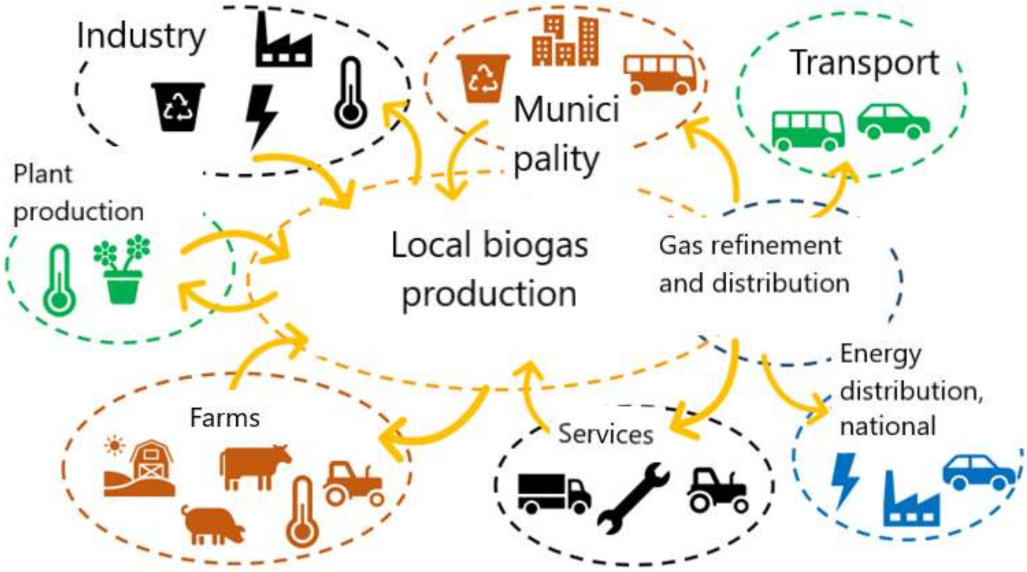

Figure 1 *Pirkanmaa's biogas model with English translations* [12]

Also, a model where multiple municipal WWTPs' sludges are collected and processed by a private company is an option. For example, Lakeuden Etappi Oy in Ilmajoki, Finland, collects municipal WWTP sludges and biowaste and processes them with anaerobic digestion. The digestate is thermally dried and pressed into soil improvement pellets. Biogas is used in drying process. [13]

A sponge city aspect developed and widely applied in China has become popular in Europe. The rainwater is absorbed into the designed systems and then naturally filtered by the soil to aquifers. The water can be used for increasing the city's water supply. Instead of impermeable materials, the city needs open green spaces, interconnected waterways, channels and ponds. Green roofs and porous roads and pavements can be used, too. The model supplies more clean water for the municipality, reduces flood risks, lowers burdens on drainage systems, makes urban environment more enjoyable and enriches urban biodiversity. [14, 15]

3.2. Energy capturing

WWTPs should be viewed as energy (and resource) factories as in the Netherlands as they have a great potential. Energy capturing methods in this scope include i.e.

- biogas plants that produce biogas from WWTP sludges with or without thermal hydrolysis or co-fermentation
- heat recovery from compressed air (aeration), wastewater or effluent
- coupling of district heating or cooling from the water and wastewater networks.

Only 10 % of techno-economic potential of the Finnish biogas is utilized [16]. The common understanding of Finnish biogas industry stakeholders for the biogas production in year 2030 in Finland is 4-7 TWh [17]. However, there's a boom in building biogas plants. For example, there are 5 biogas plants in municipal WWTPs in only western Finland, but the amount will rise to 7 in the beginning of the 2020’s [18]. There are more plants there in general but 5 of them are in municipal WWTPs. The use of biogas as vehicle fuel is more popular e.g. in Sweden [7]. Anaerobic digestion as an energy source at WWTP is getting more common every day. For example, when Linköping’s WWTP needed to be renovated, an anaerobic digestion plant was built. The new WWTP will generate over 700 MWh of renewable energy each year through anaerobic digestion and sell this power to the grid. Also advanced wastewater treatment processes are in place because the water source of the municipality is polluted by the WWTP and neighboring industries. The municipality of Linköping developed the Circular Wastewater System that will decrease pollutants and pathogens in local effluents and remove pharmaceuticals, hormones and micro-plastics. [19]

Heat recovery from wastewater is applied in Central Europe [7]. In many countries heat recovery from municipal wastewater is an economically viable solution. Technologies for heat recovery in the WWTP and for district heating and cooling are available. However, technically feasible energy recovery from residential wastewater has not been carried out in multiple places in Finland because it has been assessed as economically unviable. Helsinki area is an exception where heat is recovered from treated wastewater and it warms the houses around the city (see figure 2). Heat recovery is hampered by the production tax that must be paid in Finland, even if the energy is produced only for the operator's own needs. However, it is seen that the future lays in heat recovery: such as biogas production from sewage sludge and heat recovery of the effluent. [20]

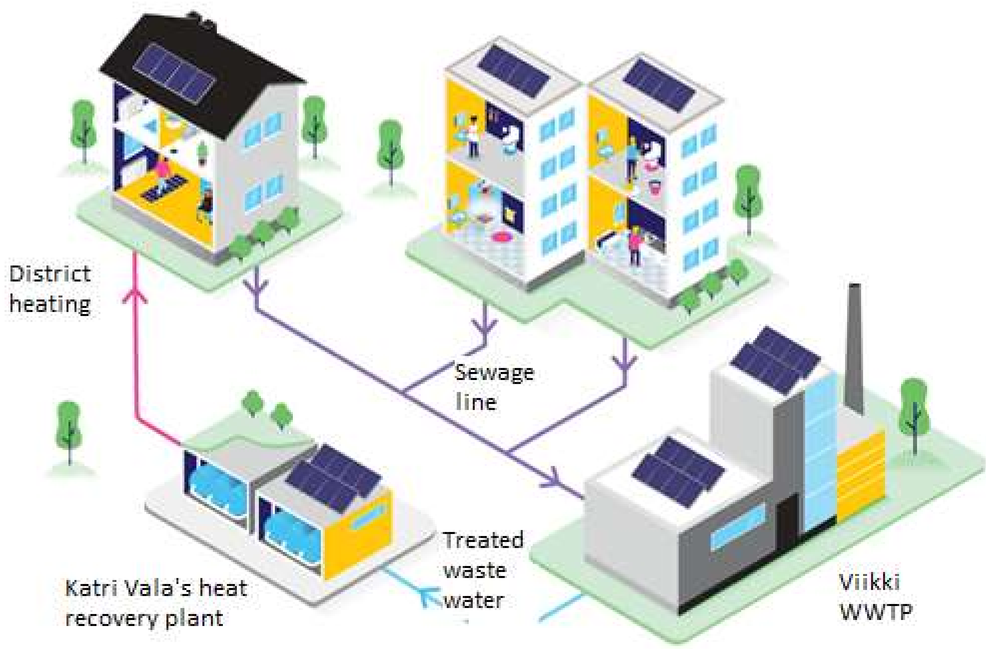

Figure 2 An image of heat recovery for municipality in Helsinki area with English translation [21]

In the Southern Europe there's advantages due to the climate and heat recovery energy is more viable option there. In the Nordic countries the biological processes are operated in lower temperature already. In Germany solar drying, low thermal drying and hybrid systems are used for sludge drying, too [22]. [7]

Netherlands specialty is decentralized heat recovery, riothermy (gasless energy). Riothermy is a technique for recovering energy from wastewater from the sewage system via heat exchangers. It has been in use at least from 2016. Then the first swimming pool was heated with only gasless energy. In addition to savings on heating costs (up to more than 50%), this technique also reduces CO_2 emissions. [23] An example for heat recovery from sewage systems is the use of heat exchangers as seen in the figure 3 below.

Figure 3 *Heat exchangers in a sewage line by Kasag Swiss AB* [24]

3.3. Resource recovery and efficiency

Resources recovered from European wastewaters are for example nutrients such as phosphorus and nitrogen for agricultural use, metals, CO_2, alginate, proteins and cellulose. Also, water can be reused. Many substances are easier and more profitable to recover from wastewater when they have not yet been mixed with the wastewater of municipal wastewater treatment plants. As is usually the case in a circular economy, the utilization of streams does not take place in one direction only. A WWTP can also utilize industrial by-products in its process.

Sewage sludges processed in a biogas plant and/or a compost are further utilized in the agriculture, especially in the Nordic countries [7]. Separated solids are further processed into a fertilizer or used in the fields as such. The liquid fraction is further processed into nutrient-rich concentrate which can be used as an industrial raw material in addition to its usage as a fertilizer. However, organic fertilizer products produced in the biogas plant process are not exempted from REACH registration by the European Chemicals Agency unlike fertilizer preparations produced by composting which make utilization harder. [20]

There are already well-established processes for phosphorus recovery, as phosphorus recovery is required by law at least in Switzerland and Germany. Some phosphorus recovery technologies widely used in the Central Europe are EuPhoRe, crystallization process, Nuresys, Pearl, Wastrip and Airprex. In the Netherlands and southern Europe biological phosphorus removal is widely applied. In the Northern countries parallel precipitation is favored because the circular economy use of ferric sulphate from industry is the most economical option. Even though nutrient recovery might face challenges, there are multiple ongoing studies about the subject. For example, in the capital area of Finland WWTP sludge is treated with biowaste in a biogas plant and a tunnel compost. There’s development of certification of circular fertilizers and a pilot plant for the pyrolysis of sewage sludge. Also studies about the utilization of carbonized sewage sludge and the separation of fatty acids from digestate as a raw material for chemical industry are ongoing. [25]

There’re studies about recovering scarce metals such as heavy metals, noble metals and other industrial materials from the wastewater. Some WWTPs consider recovery of rare metals such as gold, silver and platinum from London sewers. [11] However, the most feasible option for metal recovery seems to be recovering them from the factories’ effluents upstream. For this, there’re multiple different technologies and concepts [26]

CO_2 can be re-used from combined heat and power engines in the WWTPs. With sufficient scrubbing (e.g. with iron chloride and active carbon filtration) CO_2 can be re-used in greenhouse schemes. [11]

Dutch regional water authorities are building new plants producing alginate-like materials from sludge as a part of the LIFE Waste2NeoAlginate project. Among other things, the project will develop a process in which alginate-like material called Kaumera Nereda® Gum can be extracted from sludge granules at WWTPs. Alginate is widely used, including in plaster molds for medicine, paper production, textiles and food stabilizers. Alginate granules are presented in the picture below. [27]

Figure 4 *Alginate granules (Creative commons)*

There's also a project called power to protein in the Netherlands. There it is aimed to revive proteins from the wastewater via biosynthesis, using lithotrophic hydrogen-oxidizing bacteria in a reactor system. Raw materials needed are hydrogen, CO_2, ammonium and oxygen. The figure below details the process for a WWTP's sludge treatment plant's reject water. Coupling the Power-to-Protein to the wastewater cycle, in which ammonium is extracted from the reject water from the sludge treatment. [28]

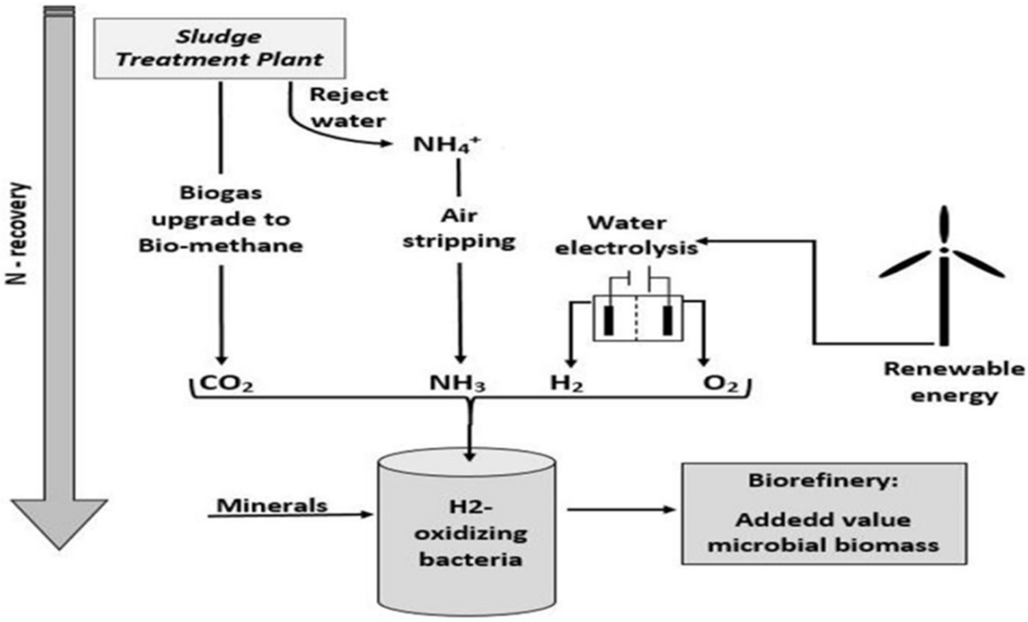

Figure 5 *Power-to-Protein cycle from powertoprotein.eu/about* [29]

Cellulose is recovered from the wastewater in the Central Europe. Mechanical sieves for primary treatment recovers cellulose which is further treated into pellets. The recovered cellulose can be used in insulation applications, as an inhibitor for dripping of asphalt in pavements and roads and for production of fatty acids which then can be used as carbon source for denitrification. In the Netherlands there has been a research for using the recovered cellulose in dewatering of digested sludge in order to enhance the dewatering result and decrease the need for chemicals. The project is called CADOS, Cellulose Assisted Dewatering of Organic Sludge. [7] [11]

The near future of municipal WWTPs lays in the recovery of substances (especially phosphorus) from the wastewater. Developing small-scale solutions and the possibility of transporting the recovered fractions for centralized processing are highlighted. To promote market creation, an obligation to use recycled phosphorus as part of products (blending obligation) should be placed. State's support for farmers using recycled nutrients could also be considered. The use of recycled fertilizer products could be favored for tax purposes, for example by imposing a tax on mineral-based fertilizers or with carbon compensation fee paid to farmers. [20]

It is common that treated wastewater is used in the WWTP process for rinsing purposes instead of drinking water. Even though reuse of purified wastewater outside the WWTPs is not widely applied, there are some examples in Europe. For example, in Spain drinking water sources aren't abundant. Holmen paper mill reuses its whitewater from the paper machine after ultrafiltration to paper machine showers, the cleaner the process water the better the reuse potential and feasibility. In addition, reclaimed water from Arroya Culebro WWTP is recycled to paper mill. The effluent from the municipal WWTP is pre-treated, then ultrafiltrated, treated with reversed osmosis and UV-treated. Rejects from ultrafiltration and reversed osmosis are returned to the WWTP [30]. European actors see that the future lays in recycling of water for industrial operators, into gardening or into infiltration to boost groundwater formation [20, 7].

An example of a wastewater treatment that uses industrial by-products is SHARON plant. SHARON is a treatment system for the total removal of nitrogen components through nitrification/denitrification. Compared to conventional techniques there is a significant saving of energy and consumables. The process is optimized for using by-products of biofuel production industry as COD source for denitrification. [31]

4. Future scenarios

A workshop was arranged for discussion for the paper that included Sweco's European specialists. During discussion about future technologies in municipal wastewater treatment several subgroups were identified. They were reuse of water, new power solutions, nutrient and wastewater, new treatment goals, integrated/new approaches and climate change, advanced wastewater treatment, resource recovery, decentralization, modeling, source separation, new ecosystems, process optimization and scalable technology. The technologies ideated are presented in annex 1. There's a figure of a possible future outlook of a municipality in figure 6.

Figure 6 *Future in a municipality. More green is present. Renewable energy sources are used. Digital data is collected and used from multiple sources to control the holistic system.*

According to the workshop results, the future of circular economy in WWTPs in Europe in ten years looks more holistic. Less waste will be produced: industry and municipalities will be connected. They will offer each other with nutrients, water, heat and electricity. Similar waterboard approach as the Dutch water authority model will be widely spread. There will be more decentralized solutions as a part of a holistic plan. There will be a framework in place that promotes reuse from WWTPs. The valuables coming to the WWTP will be reused. Water reuse, substance recycling and energy recovery will be more a rule than an exception. Drinking water quality will be used only where it is really needed so the usage decreases. There'll be less pollution and more efficient handling of resources. [7]

The change and development will need best practice scenarios to be accomplished. A holistic assessment of the urban water system should be put in practice first, then decentralized applications. Change of mentality and creating awareness play key roles in this. Social innovation and the ideology of minimizing the waste and maximizing reuse, recycle and recovery are needed. Economical use of the European freshwater resources and the usage of new water sources like wastewater and rainwater are important. Also, there is potential in utilizing wastewater networks for district heating and cooling. [7]

Modern technology is needed for a city scale approach. Multiple meters spread around district systems should be installed. The data is needed for example from sewage systems, weather stations and forecasts, process parameters and so on. Evolved mathematical processes and AI technology could learn and forecast system changes. The changes could be due to changes in industry effluents, weather or human activity. [32]

According to the workshop results, the future of circular economy in WWTPs in China in ten years will take major steps forward. The specialty in the culture is that when a way to go is chosen, needed resources will be there and things will proceed quickly. The specialists' vision is that large scale closed systems will be applied including municipalities and industry. The applications will be large in scale and the industrial production will be cleaner. All the industries and municipalities will be connected to WWTPs and the most valuable resources will be reused. [7]

Also in China, the change of mentality is highlighted for a successful increase in circular economy in WWTPs. The mind set change to facilitate the ideology of minimizing the waste and maximizing reuse, recycle and recovery is needed there too. Distributed treatment with focus on holistic mind set will help achieving the future scenario in China. In general, industrial WWTPs should be constructed for reuse of valuables at source. Focus is needed on the sustainability and cost calculation for life cycle. There's also lots of savings potential in minimizing the water footprint. As urban development may proceed quite a pace, a holistic view could be in many greenfield projects. For example, different sewage lines for different types of water could be constructed. [7]

5. Conclusions

The circular economy of wastewater treatment has historically been mainly the utilization of nutrients either from sludge or directly from wastewater in agriculture. There are currently several projects in Europe that seek to develop the circular economy through holistic ecosystem thinking and cooperation, which is also the starting point for the circular economy in the big picture. Energy recovery is increasingly taking place through biogas or heat recovery, which is important for climate change. In addition, as primary sources become scarcer, resource utilization from wastewater has become an increasingly profitable option. Currently, nutrients, metals, carbon dioxide, alginate, proteins and cellulose can be recovered from wastewater for industry. Water reuse and recycling is also very important, especially in countries where fresh water sources are scarce. Wastewater treatment plants can also utilize industrial by-products in their process.

In Europe, developments will continue in the future. New holistic communities will be formed to recycle energy and resources – instead of wastewater treatment the WWTP's are seen as Energy and resource factories. The holistic view includes water reuse, food and resource utilization from wastewater, new energy solutions, integrated or new approaches to combating climate change, new treatment targets, decentralized systems and source separation. Technologies for implementing these exist in Europe already, and now mind change and holistic concepts for their management and best use will be required.

The future of the circular economy in Europe is not possible without digitalization and AI. The above prospects will be made possible by automatic management. New energy solutions and treatment goals, integrated approaches, advanced wastewater treatment, modeling and process optimization, and scalable technology all need a large amount of data and its mathematical management, different metrics, and extensive use of existing data. In the future, artificial intelligence will use the process and environmental parameters to predict how the processes of a WWTP should be run in order to control the predicted event in the coming days.

In the future, Europe can offer China concept and package solutions focused on holistic management, where the result is better than the sum of its parts. The new big cities offer huge opportunities for the introduction of a holistic and controlled circular economy system.

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The municipal water companies interviewed are:

- Mikkelin Vesiliikelaitos Oy
- Nokian Vesi Oy
- Tampereen Seudun Keskuspuhdistamo Oy
- Turun Seudun Puhdistamo Oy
- Turun Seudun Vesi Oy

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- Demet Antakyali, Team leader (environmental business consulting), Germany
- Mats Ejderby, Senior consultant (wastewater), Sweden
- Mika Kierikka, Senior advisor (circular economy), Finland

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