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# The utilization of renewable energy potential in water utilities in Northern Finland

Lauri Mikkonen

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# TIIVISTELMÄ OPINNÄYTETYÖSTÄ

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Tiivistelmä

Veden ja jäteveden hankinta, jakelu ja käsitteleminen ovat energiaintensiivisiä prosesseja, minkä takia vesi – energia – yhteys on saavuttanut kasvavaa huomiota maailmanlaajuistesti. Toisaalta liikettä, lämpöä ja potentiaalienergiaa omaavasta vedestä ja jätevedestä voidaan saada energiaa, erityisesti jätevedestä. Näitä energiapotentiaaleja on harvoin kuitenkin otettu energiantuotannon käyttöön. Tässä työssä tarkoituksena on muodostaa kahdelle työhön valitulle vesilaitoksille alustava uusiutuvan energian analyysi, minkä perusteella on mahdollista tutkia uusiutuvan energian tuotantopotentiaalia ja energian käyttömahdollisuutta vesilaitoksen alueella.

Teoriaosiossa eriteltiin vesilaitosten tuottamat palvelut veden ja jäteveden hankintaan, jakeluun ja käsittelyyn kotitalouksille, palveluille sekä teollisuudelle käsittäen myös hulevesien keräämisen ja käsittelyn, perustusten kuivatusvesien poisjohtamisen ja lietteen käsittelyn. Suomessa vesilaitokset ovat joko kunnallisia, yhtiömuotoisia, osakeyhtiöitä tai vesiosuuskuntia, joiden toimintoja EU-direktiivit ja kansalliset säädökset laajasti ohjaavat. Vesilaitokset ulkoistavat yleisesti palveluita yksityiselle sektorille. Vesilaitosten taloudellinen toiminta perustuu vahvasti vesimaksuun, joka voidaan jakaa liittymis-, käyttö-, perus- ja palvelumaksuihin, riippuen kuitenkin vesilaitoksen hallinnollisesta rakenteesta. Lisäksi, vesilaitosten energiakulutuksen tutkiminen vesi- ja jätevesisektorilla osoitti pumppauksen ja kehittyneen jätevedenpuhdistamisen olevan energiaintensiivisimpiä prosesseja vesilaitoksien yhteydessä. Teoriaosiossa on myös esitelty uusiutuvan energian teknologioita ja kestävän kehityksen arviointia.

Työn kokeellisessa osiossa kartoitettiin vesilaitoksia uusiutuvan energian arviointia varten Pohjois-Suomen alueella. Arviointi käsitti myös taloudelliset ja sosiaaliset näkökohdat. Työn tuloksena Kemin Vesi Oy ja Tyrnävän Vesihuolto Oy lähtivät mukaan arviointiin. Kemin Vesi Oy:n kohdalla arvioinnin kohteeksi valittiin kuivatun lietteen mädättäminen ja prosessista saatava energiapotentiaali. Tavoitteena oli tutkia, olisiko nykyistä kompostointiprosessia mahdollista korvata ympäristöystävällisemmällä mädätysprosessilla. Arvioinnin tuloksena huomattiin, että korkean investointikustannusten ja matalan metaanituotannon vuoksi mädättämön kannattavuus asettaa rajan investoinnille. Toisaalta mädättämö voisi saavuttaa muita etuja, kuten $CO_2$ – päästöjen vähentämistä, lietteen kuljetuskustannusten välttämistä ja lietteen hajupäästöjen parempaa käsittelyä. Laitoksen kannattavuutta voisi olla mahdollista parantaa käsittelemällä myös muita biopohjaisia jätteitä laitoksella, kuten ruoka- ja maatalousjätteitä.

Tyrnävän Vesihuolto Oy:n kohdalla arvioitiin aurinkosähkön mahdollisuutta pohjavedenpumppauksessa. Tehtävänä oli tarkastella 4,4 kW moduulin vuotuista energiantuottoa, pumppauksen energiantarvetta sekä järjestelmän taloudellista kannattavuutta yksinkertaisin menetelmin. Tulosten perusteella voitiin todeta, että aurinkoenergialla toimiva vedenpumppaus voisi olla taloudellisesti erittäin kannattavaa. Energialaskentaan liittyy kuitenkin monia epävarmuustekijöitä, kuten ympäröivän metsän varjostava vaikutus. Lisäksi taloudellisissa laskelmissa on tehty paljon oletuksia, mitkä tuovat virhettä tuloksiin.

Tämä työn on tehty osana WARES (Water Asset Renewable Energy Solutions) – projektia, jonka on rahoittanut Euroopan Unioni.


Muita tietoja

# ABSTRACT FOR THESIS

University of Oulu Faculty of Technology

| Degree Programme (Master's Thesis)<br>Environmental Engineering | Major Subject<br>Sustainable Energy |
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Abstract

Water – energy nexus is gaining an increasing amount of attention worldwide as acquisition, distribution and treatment of water and wastewater requires intensive amounts of energy. On the other hand, water and wastewater possess a high potential of generating either electricity or thermal energy. Especially, wastewater has been perceived as a considerable source of energy. However, this energy potential is often unused. Thus, the aim and motivation of this work was to perform two preliminary renewable energy assessments for two selected water utilities in order to assess local hidden renewable energy potential on the utility's site and investigate how the utility could utilize produced energy.

In the theory part it was found out that Finnish water utilities are offering the supply and distribution of domestic drinking water, management of wastewater and sludge, storm water management, management of industrial and commercial water and wastewater and management of drainage water from building foundations. Water utilities are publically owned, co-operatives, shareholder companies or partnerships. The operation of utilities is greatly regulated by EU Directives and Finnish legislation, and many operations utilities offer are outsourced to the private sector. The operation of the utility is mainly funded by water charges consisting of usage, fixed, service and joining charge, depending on the structure and organizational level of the utility. Furthermore, the energy use of water utilities was studied in both water and wastewater sides, underlining that water pumping and advanced wastewater treatment processes can greatly contribute to the overall energy consumption of the utility. Renewable energy sources and sustainable impact assessment is also presented in the theory part.

In the experimental part, water utilities in Northern Finland were mapped in order to find suitable utilities for hidden renewable energy potential assessment including economic and social considerations. As a result, Kemin Vesi Oy and Tyrnävän Vesihuolto Oy were selected. Preliminary energy assessment for Kemin Vesi Oy included the potential of anaerobic digestion process for methane conversion from dried wastewater sludge including economic considerations. The motivation for this assessment was to study if current composting process could be replaced with more environmentally friendly process. Conclusions underlined that the viability of the plant processing dried wastewater sludge only may not sufficient for this purpose due to low methane production and high investment costs of the plant. On the other hand, besides energy production from methane, the plant could introduce other benefits, such as avoided costs of sludge transportation, reduced amount of odors, $CO_2$ reduction and reduction in the specific volume of sludge. The viability of the plant could be increased by introducing other biomass based raw-materials, such as food waste and agricultural waste.

In case of Tyrnävän Vesihuolto Oy, the potential of solar photovoltaic energy in groundwater pumping was assessed. The study included the annual energy production of 4,4 kW solar module, energy consumption of pumping and simple economic feasibility assessment. In conclusions it was found out that solar powered water pumping could be very profitable in Tyrnävä as providing additional high quality groundwater to the utility. However, many uncertainties in energy production of the solar cell, such as shading, can bring large error to calculations. In addition, many assumptions were made in economic calculations, causing some error to the assessment.

This research was done as in collaboration with WARES-project (Water Asset Renewable Energy Solutions) funded by European Union.

Additional Information

# PREFACE

This work has been conducted as a part of WARES (Water Asset Renewable Energy Solutions) project funded by European Union. The thesis has been carried out at NorTech, a research institute under Thule Institute at the University of Oulu in Finland.

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Finally, I would like to have an opportunity to dedicate this work to my loving family and my dear Elisa as a sign of my wonderful life.

Oulu, November 2013

Lauri Mikkonen

## Table of Contents

## List of abbreviations

| | |
|---|---|
| AC | Alternative Current |
| AD | Anaerobic Digestion |
| CHP | Combined Heat and Power |
| DC | Direct Current |
| EIA | Environmental Impact Assessment |
| GDP | Gross Domestic Product |
| GPI | Genuine Progress Indicator |
| IPPC | International Pollution Prevention and Control |
| kWh | Kilowatt hour |
| MWh | Megawatt hour |
| NPP | Northern periphery |
| PPP | Public Privater Partnerships |
| PV | Photovoltaic |
| RED | Renewable Energy Directive |
| SD | Sustainable development |
| SIA | Sustainable impact assessment |
| TOC | Total Organic Carbon |
| WFD | Water Framework Directive |
| WSA | Water Service Act |
| WWTD | Wastewater Treatment Directive |

## List of Symbols and Units

| | |
|---|---|
| $\Delta T$ | Temperature difference [°C] |
| °C | Celsius |
| $A_{cell}$ | Solar cell area [$m^2$] |
| $C_C$ | Capital cost [€] |
| $C_{O\&M}$ | Operation maintenance cost [€] |
| $c_p$ | Specific heat capacity [kJ/kg°C] |
| $E_{el}$ | Electricity production [MWh] |
| $E_{TH}$ | Heat production [MWh] |
| $E_{tot}$ | Total energy production [MWh] |
| f | Sizing factor [-] |
| $F_1$ | Cardinal point factor [-] |
| $F_2$ | Inclination factor [-] |
| $F_{pos}$ | Correction coefficient [-] |
| $F_{use}$ | Coefficient of usage [-] |
| g | Gravitational accerlation constant [$m/s^2$] |
| $G_{hor}$ | Irradiation received by horizontal plane [$kWh/m^2$] |
| $G_{sol}$ | Irradiation [$kWh/m^2$] |
| H | Effective pressure head [m] |
| $I_{ref}$ | Reference irradiation [$kW/m^2$] |
| $K_{max}$ | Peak power coefficient [-] |
| m | Mass [kg] |
| P | Mechanical power [W] |
| $P_{el}$ | Electricity price [€/MWh] |
| $P_{max}$ | Maximum power output [kW] |
| PP | Payback period [a] |
| $P_p$ | Pump power requirement [W] |
| $P_{TH}$ | Thermal energy price [€/MWh] |
| $P_{tot}$ | Total pump power requirement [W] |
| $P_{water}$ | Water price [€/$m^3$] |
| Q | Discharge [$m^3/s$] |
| $Q_{TH}$ | Thermal energy [MJ/a] |
| $q_{water}$ | Quantity of pumped water [$m^3/a$] |
| RT | Retention time [d] |
| W | Energy [kWh] |
| $W_{PV}$ | Solar cell energy production [kWh/a] |
| $V_R$ | Reactor volume [$m^3$] |
| $\eta$ | Efficiency [-] |
| $\eta_m$ | Motor efficiency [-] |
| $\eta_p$ | Pump efficiency [-] |
| $\rho$ | Density [$kg/m^3$] |

# 1 INTRODUCTION

The water – energy nexus is gaining an increasing amount of attention worldwide. Acquisition, treatment and distribution of water and wastewater require energy. Water can contain a certain amount of, say, potential, kinetic or thermal energy. (Siddiqi et al, 2011) Especially, wastewater has been recognized to be a valuable source of energy, but also one of the biggest energy guzzlers in water sector due to high treatment requirements and advanced wastewater processes. (Frijns et al, 2011) As energy can be converted from water and water treatment requires energy, a strong relationship has been discovered between water and energy usage, where energy consumption correlates strongly with water consumption. (Li et al, 2013)

The objective of the work is to assess hidden and unused energy potential on water utility's site by establishing Public Private Partnership, between the utility and its surrounding communities and industry. The ultimate goal in this work is a renewable energy investment having positive social and environmental impact on the utility's surroundings and by being able to return the initial costs of the system. Thus, the target is to find two water utilities as pilot cases in the area of Northern Finland. In each case, renewable energy potential is assessed at the site of the utility having focus on the energy production, environmental and social impact and the economic feasibility of the system.

This work was done as a part of the "Water Asset Renewable Energy Solutions" (WARES) Northern Periphery (NPP) project financed by European Union. The project was done in co-operation with International Resources and Recycling institute (IRRI) in Scotland (project leader), Mayo County Council in Ireland, Clar ICH in Ireland, University of Oulu in Finland, Action Renewables in Northern Ireland, Narvik Science park in Norway and Norut Research Institute in Norway. The aim of the work was to map out and select water utilities in Northern Finland. The renewable energy potential in the selected case was assessed with a certain renewable energy technology. In the theoretical part, development of water services, current financial model of water services and public-private partnerships were reviewed. Furthermore, different renewable energy technologies and sustainability assessment were studied. In the experimental part, two pilot cases were presented and renewable energy potential in each case with social, environmental and economic benefit was assessed

# THEORETICAL PART

# 2 ORGANIZATION OF WATER SERVICES IN FINLAND

The first piped water distribution system in Finland was built in the late 1800s. Before that, people acquired their drinking water mainly from wells and surface water resources. Due to the rapid increase in population, water quality in these resources declined, resulting to the use of water treatment and piping system. The progress of the water services provided by water utilities was initially rather slow: according to Hukka et al, 2007, 25 percent of the Finnish population was supplied with treated drinking water by the year 1950. However, the development accelerated rapidly and, by the year 1980, the amount of fresh water supply was 90 % of the total country's population. (Hukka et al, 2007)

Wastewater was not treated until the 1910s when the first wastewater treatment plant emerged in Helsinki. Again, the progress was quite slow and only a few areas had adequate treatment plants, until the new Water Act in 1961 obligated municipalities to take care of the produced wastewater as well. As a consequence, a rapid growth in the amount of wastewater treatment plants occurred after the act was enforced. According to Pietilä et al, in 2001, 96 % of the wastewater was treated with high-quality biological-chemical treatment method. In rural areas, however, households had discharged their wastewater without treatment until 2003, when the new decree of treating domestic wastewaters outside the sewerage network was involved to the Finnish legislation (Hukka et al, 2007) (Juuti et al, 2004)

Water utilities have also taken care of the treatment and collection of stormwater in their given operating area. Stormwater has been discharged by a separate piping system, but it can be also combined with the sewage system. (Kuntaliitto, 2012)

Domestic water consumption has been steadily increased since the water supply piping system was installed. In 1973, domestic water consumption was at its highest, being around 400 liters per person per day. The amount of used water has since halved due to a more efficient water distribution system, new water saving technologies, improved leakage control and water end-user efficiency. Compared to the water consumption in 1973, the total water production produced by water utilities has stayed the same, around 400 million $m^3$/year. (Hukka et al, 2007) (Pietilä et al, 2004)

Water utilities can provide water for domestic use, but also for the industrial sector. In the industrial sector, pulp and paper factories are responsible for the majority of water use. These industries often organize their water supply and wastewater treatment through a separate system, which can be organized by the private sector. (Juuti et al, 2004)

Traditionally, water utilities were owned and run by municipalities, especially in population centers. Municipal water utilities were large, located in larger and wealthier municipalities. In rural areas, where there were insufficient resources to organize a municipally operated water supply system, people living in these areas had to come up with a solution by themselves. Initially, volunteers with special know-how about water utility systems were utilized in order to make the utility operate appropriately. These so called co-operatives have been running water utilities in rural areas and there has been estimated approximately 1000 co-operatives running rural water services. (Hukka et al, 2007) In addition to co-operatives, rural water supply has been managed by partnerships and shareholders. Partnerships cover more than 400 utilities and shareholder companies around 160 utilities (Pietilä et al, 2007). In most cases, wastewater treatment plants are owned by municipality, apart from a few exceptions where wastewater treatment plants are owned by co-operatives or shareholder companies. (Kajosaari, 1981)

Decision-making in Finnish water utilities is usually done by a higher organizational level, especially if the material investigation intended to be made is large. As municipality can freely decide how the management and ownership of the water utility are being organized, the decision making can differ from municipality to municipality. However, the municipalities have usually set up a limit for investment costs where the head of the water utility can make the decision. In shareholder companies and cooperatives, the utility presents ideas for investments to the government making the last decision. The highest decision-making is done during stockholders' meeting, in which for example the use of profit made by the utility can be decided. (Pietilä et al, 2007) (Ouka, 2013)

## 2.1 Current water services

Water utilities are providing the acquisition, treatment and supply of water for domestic use. Water can be acquired from surface or groundwater source. In addition to water for household consumption, water utilities can provide treated water for commercial and industrial use. The water utility is obligated to supply water in the operational area of the utility, which is defined by the Water Service Act (119/2001) in Finland. Furthermore, the domestic water network can provide water for hydrants and fire hydrants. (Pietilä et al, 2007)

Similarly, the other main service includes the collection and treatment of wastewater, which can be collected from domestic, industrial and commercial sources. Wastewater treatment forms biodegradable sludge as a side a product, which must be managed in a proper manner by the water utility. The residual waste from the sludge treatment process must also be taken care by the utility.

Water utilities are providing the discharge and treatment of rainwater in their operational areas. Rainwater includes rain and melting water from streets, yards and roofs. In addition, drainage water from building foundations can be discharged to rainwater sewage. The water utility can establish combined or separate piping system with rainwater and wastewater. In most cases, rainwater collection is organized by using a separate piping not requiring any further treatment. (Kuntaliitto, 2012) Figure (1) illustrates the services provided by water utilities.

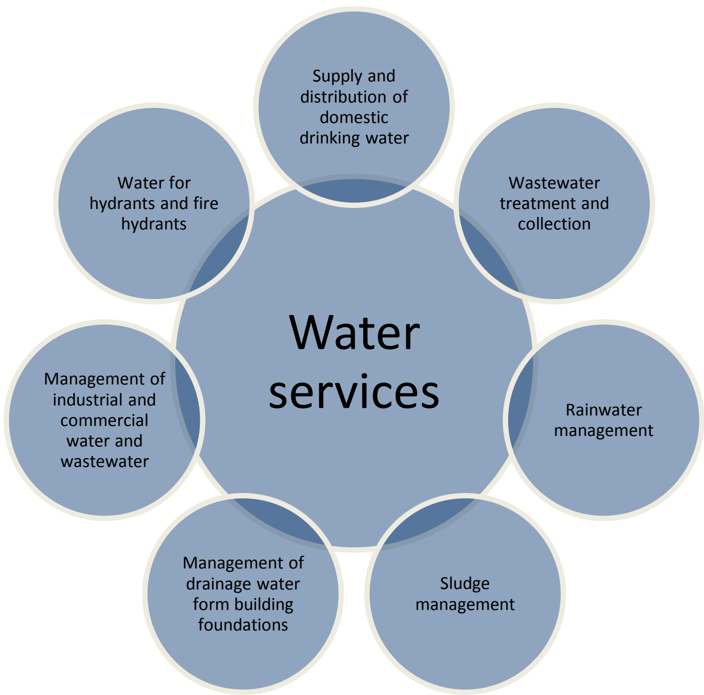


Figure 1 Services provided by water utilities (based on Kuntaliitto, 2012)

As we can see from Figure (1), water services in Finland are very extensively established. However, there can be a situation, in which more than one utility is organizing different water services in the same area. For instance, supply and distribution of domestic drinking water can be organized by another company, than the one organizing wastewater collection and management.

## 2.2 EU Directives

At the moment, the main directive put in force by the European Parliament and of the Council affecting water use and supply in Europe is Directive 2000/60/EC, called the EU Water Framework Directive (WFD). The object of WFD is to establish a framework towards sustainable water use and the protection of water resources from pollution. The WFD standardizes monitoring, planning classification of water systems, encompassing the whole hydrosphere. The directive promotes also cooperation towards water conservation between involved countries. (2000/60/EC)

The quality of water aimed at human consumption is standardized by Directive 98/83/EEC, the Drinking Water Directive. This directive involves the protection of human health from drinking water by ensuring that the supplied water is safe. (91/271/EEC) Furthermore, Directive 91/271/EEC, the Wastewater Treatment Directive (WWTD), protects the environment from adverse impacts of urban wastewater discharge. WWTD regulates also wastewater discharge of particular industrial sectors. The WWTD has been amendment to the Directive 98/15/EEC. (98/83/EC)

Water systems are targeted to be prevented from pollution by the Integrated Pollution Prevention and Control (IPPC) Directive, 2008/1/EC. The list of compounds can be found from the Annex 1 in the Directive. This Directive affects the treatment and use of sludge, aiming to prevent the environment from hazardous compounds contained in sludge. (2008/1/EC).

The Landfill of Waste 1999/31/EC prescribes the threshold content of biodegradable compounds in waste going to a landfill. By the Directive, the amount of biodegradable waste must be reduced to 35 % of the total amount of weight. This indicates that majority of sludge should be treated appropriately for energy production, for instance. However, the Finnish Council of the State has put in force a new decree of restricting the discharge of biodegradable organic waste to a landfill. According to the decree, biodegradable waste having total organic carbon content (TOC) more than 10 per cent should not be discharged to a landfill after 2016. The result is that for example discharging sludge from wastewater treatment plants to a landfill is forbidden. (1999/31/EC) (Ympäristöministeriö b, 2013)

The operation of water utilities in EU is also standardized by two directives of Public Procurement (2004/18/EC and 2004/17 EC). These Directives govern public work contracts, service contracts, supply contracts and procurement procedures between the services. (Pietilä et al, 2007)

## 2.3 Finnish legislation

The Directives mentioned in 2.2 are enforced in Finnish legislation. By following the Directives, the Ministries of Environment, Agriculture & Forestry and Employment and the Economy are setting up acts and decrees concerning water supply and sewerage. These operations given by the ministries are so called performance guidance, whilst expert services can be acquired from the Finnish Environment Institute (Ministry of Agriculture and Forestry 2013). However, main law and regulation categories related water supply and sewerage are put in force: Water services legislation, water and environmental protection legislation, health protection legislation and other relevant legislation. Each law of applied field affecting water utilities consists of a number of laws and acts presented in Table (1). Standards in the Finnish legislation can be even stricter than those in EU Directives.

Table 1 Key Acts and laws affecting to water utilities in Finland (based on Pietilä, et al).

| Application field | Law/Act | Number of act |
|---|---|---|
| **Water services** | Water Services Act | Act 119/2001 |
| | Act and Decree on Assistance for the Community Water Supply Measures | Act 56/1980, Amendment to Act 123/2001; Decree 97/1995 |
| **Health Protection** | Health Protection Act | Act 763/1993, Amendment to Act 120/2001 |
| **Water and Environmental Protection and Land use** | Water Act | Act 264/1961, Amendment to Act 121/2001 and Act 587/2011 |
| | Government Decree on Treating Domestic Wastewater in Areas outside Sewer Networks | Decree 542/2003 |
| | Environmental Protection Act | Act 86/2000 |
| | Environmental Protection Decree | Decree 169/2000 |
| | Act on Environmental Permit Authorities | Act 87/2000 |
| | Land Use and Building Act | Act 132/1999, Amendment to Act 22/2001 |
| | Act on Environmental Impact Assessment | Act 468/1994 |
| | Decree of Environmental Impact Assessment | Decree 268/1999 |
| **Others** | Local Government Act | Act 365/1995 |
| | Consumer Protection Act | Act 38/1978 |
| | Competition Restriction Act | Act 480/1992 |
| | Public Procurement Act | Act 1505/1992 |
| | Cooperatives Act | Act 1488/2001 |

The main act concerning Finnish water utilities is the Water Service Act (WSA) 119/2001. The aim of WSA is to ensure that water utilities are able to provide high quality drinking water and organize wastewater collection and treatment for a reasonable charge in the operational area of the utility. The WSA standardizes the organizing the water supply, the operational area of the utility and the connection of property to a water supply network. Furthermore, the WSA includes agreements between a property and water and wastewater network as well as the regulation of fees which water utility can charge from the users. (FINLEXa, 2013)

The Water Service Act also concerns the procedures that a property, aiming to connect to the network organized by the water utility, have to consider if the property is located in the operational area of the utility. The WSA defines that the water network must be in the immediate vicinity of the property. These distances are not prescribed in WSA. In practice, the maximum distance between a property and the water network is 20 meters at zoned areas and 100 meters at scattered settlements. (FINLEXa, 2013) (Vesilaitosyhdistys a, 2013)

The Water Act 587/2011 aims to protect any water system from human activities. According to the act, a permit is needed if the activity would alter a water system. Water utilities in Finland have to consider this Act when acquiring water from a water body. Initially, this act was implemented in 1961 and revised several times until 2011, when the Act was redone. The new Water Act includes, among others, a preference order in which water undertakings should provide water supply. For example, the first priority is given to water supply for domestic use. The act has several connections to other acts, such as Environmental Protection Act and Land Use and Building Act. (FINLEXb, 2013) (Ympäristöministeriö a, 2012)

According to the Health Act 763/1994 (amendment to Act 120/2001) activities with impact on the environment must be minimized and the health of an individual should be maintained and improved. The act defines that the water intended for domestic use has to be provided to consumers without any significant health effect and the operation of the whole utility should not release any hazardous compounds for human health. Moreover, the act takes care of proper handling, storing and distribution of wastewater. (FINLEXc, 2013)

The Land Use and Building Act (132/1999) prescribe the land use and construction of buildings in a way that these activities should promote sustainable development, including public preparation and planning process of a desired activity. The act promotes also open information about raising issues, such as environmental impacts of the construction work, to all parties involved. Due to the act, buildings and other constructions related to a water utility must have a building permission. Public building operations are also regulated in the act. (FINLEXd, 2013)

The Environmental Protection Act 86/2000 intends to prevent the environment being affected by human activities by promoting sustainable use of natural resources. Furthermore, the aim is to enhance the involvement of citizens with decision making processes concerning the environment. The act has been amendment several times. According to the amendment 4.3.2011/196, properties outside the water utility network are responsible in taking care of their own wastewater with a separate treatment unit in a way that the activity does not damage the environment when discharging the waste to the water system. However, small amount of sanitary wastewater can be discharged in the case it will not damage the environment. (FINLEXe, 2013)

## 2.4 Financial model

End-users of water services organized by water utilities, i.e. the water consumers, have water meters measuring the water consumption in volume consumed. The price is separately set up also for wastewater and in some cases for rainwater, as mentioned earlier. However, water utilities can set a price for the water in order to cover the process and other operating costs of the utility. The price of water and wastewater can vary regionally, depending on the processes and structure of the water utility. The quality of water can also affect on the price. In addition, if the water utility has been subsidized by the municipality, nation or EU, the support must be considered in the amount of water charge. (Vesilaitosyhdistys b, 2013) (Ranta, 2007)

In Finland, the water fee can be separated into four different categories

- Usage charge
- Fixed charge
- Joining fee
- Service charge

Usage charge covers the amount of consumed water supplied by the utility, whilst fixed charge is independent from the water consumption. As mentioned before, the usage charge is set up for wastewater separately and it is possible to include fees for rainwater as well. The joining fee is paid when the property joins to the water network provided by the utility. There can be additional fees later, if the conditions of the property are changing substantially compared to initial conditions when the joining fee has been paid. Moreover, water utilities can collect service charges from other installations, such as construction of plot pipes. (Vesilaitosyhdistys b, 2013) (Vaasan Vesi, 2013)

In municipally owned utilities, it is recommended by the law that the profit that has been made by the utility is deposited and used for future investments, which may be for example renovating the piping system or improving the water purification process. The profit from water charges can partly go outside the utility; municipally owned utilities can be required to enter a certain amount of their profit as income to the municipality (usually around 5 – 25 % annually). On the other hand, the municipality can then subsidize the utility. The board of directors can obligate the utility to investigations and the committee finally defines how much profit the utility can obtain. As municipally owned utilities are often obligated to enter a part of the profit to the municipality, shareholder companies and cooperatives must pay 26 % of income tax to nation and municipality. The part of profit made by these companies must be shared as dividend to the owners. (Ranta, 2007)(FCG)

Finnish utilities can receive financial support in using renewable energy sources. The support can be either investment support or so called feed-in tariff support. In feed-in tariff, wind mills and biogas plants can have benefit, which is paid as a difference between target price and the average market price of electricity. The target price is 83,5 €/MWh for anaerobic digesters. Wind mills have higher feed-in tariff until the end of 2015, 105,3 €/MWh. Furthermore, biogas plants producing and utilizing thermal energy can receive an additional support of 50 €/MWh. The Finnish Energy Market Authority decides on the amount of support and feed-in tariff and the Ministry of Employment and Economy decides on the investment support. Table (2) summarizes the differences in investment support and feed-in tariffs. (Energiamarkkinavirasto, 2013)

Table 2 The amount of investment support and feed-in tariffs (based on Energiamarkkinavirasto, 2013)

| Technology | Investment support [%] | Information | Feed-in tariff (target price) | Other support |
|---|---|---|---|---|
| Solar photovoltaic | 30 | - | - | - |
| Solar thermal | 20 | - | - | - |
| Small-scale hydropower | 15 - 20 | - | - | - |
| Anaerobic digestion | 20 - 30 | Investment support valid if not accepted for feed-in tariff | 83,5 €/MWh | 50 €/MWh |
| Wind power | 20 - 25 | Investment support valid if not accepted for feed-in tariff | 105,3 €/MWh | - |
| Heat recovery from wastewater | 20 | If done with heat pump system | - | - |

The investment support values presented in Table (2) are maximum values that a certain energy plant can have. It must also be noticed that feed-in tariff can be paid maximally for 12 years. After this period, the tariff is no longer valid. There are also scale-related issues, which are taken into account when deciding on admitting feed-in tariff. (Energiamarkkinavirasto, 2013)

## 2.5 PPP

Even though water utilities in Finland are often owned and operated by municipalities and co-operatives, private sector can be involved in order to achieve economic and operational benefits and adding the know-how of a particular sector of the water utility. The agreement between public and private sector is generally called as Public-Private-Partnership (PPP). PPP has been often used by domestic water utilities. In industrial sector, there are a few private operators organizing water management. Nevertheless, private operators offering domestic water services in Finland have been very, very few. (Hukka et al, 2007)

In order to involve the private sector for producing a specific service, water utilities can be required to arrange a competition. The competition is organized if the threshold value and procurements outside the organization exceed a certain limit

(30 000 € for material investment and services and 150 000 € for construction contract) (HILMA, 2013). All private enterprises can participate in the competition, offering a tender. The private sector defines on which price and under which conditions they can offer required services to the water utility. Furthermore, water utilities can outsource services to the private sector. Outsourcing means that the public sector subcontracts the private sector in order to produce specific services. This kind of co-operation is widely used in Finland by water utilities. Services such as sludge treatment, construction work, laboratory services and equipment supply are often outsourced. (Pietilä et al, 2007) (Hukka et al, 2007)

The cash flow from water utilities to private sector varies between 21 – 65 per cent, which indicates that PPP is intensively used by Finnish water utilities. As discussed before, the Finnish legislation allows also that the public sector can give the right to the private sector in arranging water services. However, there are only a few cases in which this kind of procedure have been executed, especially in domestic water supply and treatment. Still, as mentioned before, private enterprises often take care of providing water services at industrial level. (Pietilä et al, 2007)

## 2.6 Case Oulun Vesi

Oulu Waterworks (Oulun Vesi liikelaitos) acting in the municipality of Oulu was chosen to be a case due to the fact that it is a rather large utility supplying water and collecting wastewater from a large area, being thus interesting from organizational and economical points of view. Oulu waterworks is a municipally owned water utility providing water services to the inhabitants of Oulu. The highest organizational level of the utility is the board of public utilities (liikelaitosten johtokunta), being responsible for the utility lines and decision making of the utility. The second highest organizational level includes the managing director and the third level administrative, operations, network and development managers. The head of Oulu waterworks can decide about material investments under 100 000 € and construction contract under 500 000 €. The board of directors decides on investments exceeding these amounts. The board of directors manage the higher economy of municipally owned water utility in the frame work that the city council has given, being the highest decision making level. (Oulun Vesi, 2012)

Oulu waterworks has two main water treatment plants acquiring water from Oulu river. In addition, small amount of ground water is extracted, especially for water hydrants. The average specific water consumption in 2012 was 191 liters per person/day. According to Oulun Vesi, the level of specific water consumption has been stable compared to two previous years. Yet, due to the population growth, the total water consumption has been increasing slightly. Wastewater from the operational area of Oulu waterworks is discharged to Taskila wastewater treatment plant, where all wastewater is treated. The total length of the network in 2012 was 990 658 m for water pipes, 684 709 m for sewers and 549 335 m for rainwater sewers. (Oulun Vesi, 2012)

During 2012, the revenue of the utility was 25,9 million euros. The price of water and sewage fee has been increasing slightly since 2010, reaching the price of 1,34 €/$m^3$ for drinking water and 1,83 €/$m^3$ for wastewater. The sludge from the wastewater is being dried by Oulu Waterworks. The utilization of sludge has been outsourced to a chemical company Kemira, which provides the so called *Kemicond* treatment. The post-treatment for the sludge is done either by composting or discharging the sludge for agricultural use. ViherRengas Järvenpää Oy is organizing the composting and distribution of sludge. However, the municipality of Oulu is planning to install an anaerobic digestion process for wastewater sludge management and heat recovery from wastewater by 2014. (Oulun Vesi, 2012)

## 2.7 Case Limingan Vesihuolto Oy

Water services by Limingan Vesihuolto Oy are organized fully in the municipality of Liminka. In addition, Limingan Vesihuolto Oy organizes partly water services in the municipalities of Tyrnävä and Rantsila. Limingan Vesihuolto Oy is so called shareholder company. The largest shareholder is the municipality of Liminka, owning 69,81 %. The municipality of Kempele owns 22,5 %, enterprises 4,75 %, private sector 2,9 % and the municipality of Tyrnävä 0,04 %. Wastewater is treated at Lakeuden Keskuspuhdistamo Oy owned by the municipalities of Kemple, Liminka, Oulunsalo, Tyrnävä, Temmes, Lumijoki and Hailuoto. Decisions are made during stockholders' meetings by a separate board of trustees, which is chosen by the shareholders. (Limingan Vesihuolto Oy a, 2013) (Limingan Vesihuolto Oy b, 2012)

Limingan Vesihuolto Oy organizes the water supply by extracting water from six different places. The specific water consumption is around 140 l/per/day/person. The annual amount of supplied water has been slightly increasing due to population growth. The charge for the drinking water in 2012 was 1,12 €/$m^3$ and 1,39 €/$m^3$ for wastewater. The revenue of Limingan Vesihuolto Oy in 2012 was 1,457,900 €. Table (3) in the next page shows the difference of drinking and wastewater charges between Oulun Vesi and Limingan Vesihuolto Oy. (Limingan Vesihuolto Oy b, 2012)

Table 3 Comparison between water charges of two water utilities in Finland (based on (Oulun Vesi, 2012 and Limingan Vesihuolto Oy b, 2012)

| | Drinking water charge €/m$^3$ | Wastewater charge €/m$^3$ |
|---|---|---|
| **Oulun Vesi** | 1,34 | 1,83 |
| **Limingan Vesihuolto Oy** | 1,12 | 1,39 |

As one can see from Table (3), Oulu waterworks has higher prices for both drinking water charge and wastewater charge. For drinking water this can be due to the fact that more expensive chemicals are needed to purify water in Oulu waterworks as water is acquired from Oulu river, containing a very high humic concentration. For wastewater, it may be that the long network requires lot of maintenance and pumping, increasing thus the price of wastewater treatment charges. (Oulun Vesi, 2012)

# 3 ENERGY USE OF WATER UTILITIES

Energy is vital for water utility in order to operate and organize services for consumers. Energy is needed in water and wastewater treatment, for pumping and in the utility buildings. Due to this, water utilities consume a substantial amount of energy, especially electricity. According to Plappally et al, 2011, waste water treatment consumes approximately 7 per cent of electricity consumption in the world. Generally, electricity consumption can constitute around 5 – 30 per cent of the total operation costs of the utility. (Liu et al, 2012)

## 3.1 Energy breakdown of drinking water side

The largest energy consumer at drinking water side is usually pumping, which can cover up to 70 – 80 per cent of the overall electricity usage. (Liu et al, 2012) Pumping of surface water into the purification plant and distribution purified water to the consumers requires significant amount of energy. However, the energy consumption of pumping and distribution of surface water can be very area specific. Among others, distances, elevation height, climate and the pipe characteristics define significantly to the energy consumption of pumps. The geometry, size and friction factor of the pipe greatly affect to energy consumption of the pumping system. (Plappally et al, 2011)

Pumping consist usually larger fraction of electricity consumption in groundwater plants due to the fact that water must be elevated from lower groundwater sources to the treatment plant. (Plappally et al, 2011) The energy required for groundwater pumping increases as the elevation height increases. On the other hand, groundwater often require less purification, resulting to decreased energy consumption at the treatment process compared to surface water plants. (Liu et al, 2012)

As mentioned before, water treatment processes can also share a considerable part, around 1 – 10 %, of the electricity use of the utility. Electricity is used for both mixing and pumping at the treatment plant, besides to possible processing and disposal of organic waste produced by purification processes. Buildings at treatment plants consume both electricity and heat (can require also cooling) for lighting and heating up spaces. Nevertheless, the energy need of buildings can be rather low, being only less than 1 per cent of the overall energy consumption. (Liu et al, 2012) However, this amount could be larger in Finland due to the cold climate.

Advanced water purification processes, such as ultra filtration, membrane filtration and reverse osmosis may provide cleaner water for water distribution with low installation and operation costs. However, these technologies may require high pressure in order to operate. Thus, these kinds of technologies can increase the energy consumption at the treatment phase, depending on the system used before. (Pearce, 2007)

## 3.2 Energy breakdown of wastewater treatment side

Electricity shares usually the largest part of energy consumption at a wastewater treatment plant. The plant energy consumption depends greatly on the size and the process architecture at the plant. The energy consumption reaches its peak around midday and continues until the evening due to the fact that more wastewater is being produced and more energy is thus needed for pumping and purifying the water. (Tchobanoglous et al, 2004)

The largest proportion of energy at wastewater treatment plant is consumed in biological water treatment and drying solids and biosolids. According to Zhang et al, 2012, pumping can also share a substantial part of electricity consumption at the wastewater plant. More advanced wastewater purification processes require more energy, for instance ultraviolet disinfection processes and activated sludge treatment. Figure (2) illustrates the energy breakdown of typical wastewater treatment plant having activated-sludge process. (Tchobanoglous et al, 2004)

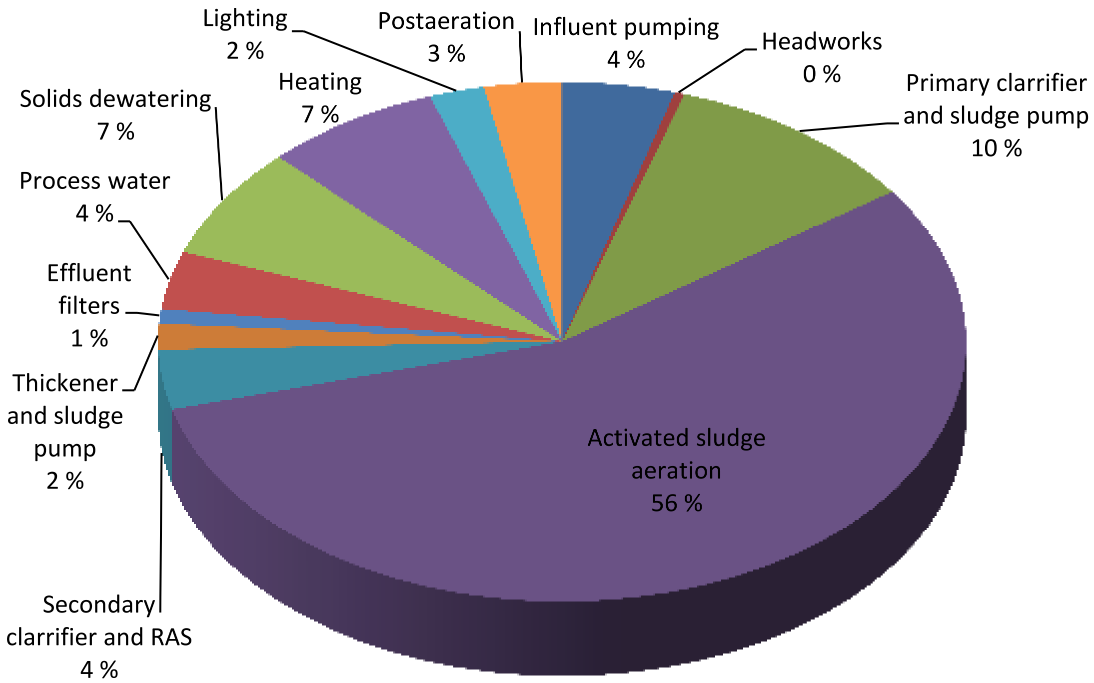


Figure 2 Energy breakdown of wastewater treatment plant with activated-sludge treatment (Based on Tchobanoglous et al, 2004)

As we can see from Figure (2), more than a half of energy is consumed by an aeration process. Aeration is essentially required in biological treatment phase for mixing wastewater and oxygen supply for microorganisms. (Plappally et al, 2011) Energy consumption of an aeration process depends greatly on the compressor efficiency and raised pressure by the compressor. Efficient air supply is also required for microorganisms. Thus, energy-intensive turbulent flow is often involved, in which the design type of the mixing device can have a significant effect on energy consumption of mixing. (Crites et al, 1998)

Second largest section in energy consumption is primary clarifiers and pumping. Dewatering of solids shares almost one tenth of the energy consumption. (Tchobanoglous et al, 2004) However, energy required for wastewater treatment can substantially depend on the quality of wastewater. For instance, the nitrogen content of wastewater can increase the energy consumption of the aeration process. As discussed before, water pumping often shares the biggest part of energy consumption in the water cycle. However, according to Venkatesh et al, 2010, wastewater treatment can, in some cases, consume more energy than water pumping. (Venkatesh et al, 2010)

## 3.2 Case Oulun Vesi

Drinking water treatment plants operated by Oulu waterworks consumed together 5 790 MWh of electricity during 2012. The amount of electricity used for treated cubic meter of water was 0,6 kWh/$m^3$. The amount of electricity consumed at wastewater treatment plant in 2012 was 5 732 MWh and the amount of heat was 1623 MWh, respectively. The cost of electricity was 1,101,592 €/year and 164,954 €/year for heating energy, respectively. (Oulun Vesi, 2012)

The amount of energy, especially electricity, is expected to grow since the amount of citizens is growing due to the joining of seven municipalities in total. Especially at the wastewater plant, the purification of increased amount of wastewater will require more energy to be cleaned. More energy will be also required for drinking water distribution and treatment. However, more energy efficient technologies can lower the consumption of energy, especially at the pumping and distribution. (Oulun Vesi, 2012)

# 4 RENEWABLE ENERGY TECHNOLOGIES

European Commission has forced in a Renewable Energy Directive (RED) (2009/28/EC) in 2009 in order to establish a framework for promoting the use of renewable energy in each Member States. The Directive obligates all Member States to produce at least 20 % of the gross final consumption of energy and 10 % of the final consumption of energy in the field of transportation by using renewable energy sources by 2020. The gross final consumption of energy means all energy consumed in households, industry, public sector, agriculture, fishery and forestry including losses in distribution and transmission. According to RED, each Member State should adopt a plan for using renewable energy sources, ensuring proper information, training and administrative procedures. The progress must be reported every second year. RED sets out also rules for joint projects between the member states. Furthermore, electricity grid, transmission system and energy storage should be developed to suitable for the production and utilization of renewable energy. (2009/28/EC)

Through the RED, the European Commission compels Finland to increase the amount of renewable energy from the gross final consumption of energy to be 38 % by 2020. Renewable energy sources are defined by the RED are solar, wind, aero-thermal, geothermal, hydrothermal, hydropower, ocean energy, biomass, landfill gas, sewage treatment plant gas and biogas. In the case of energy extracted by heat pump from aerothermal, geothermal or hydrothermal source, the energy produced can be considered as renewable if the amount of produced heating or cooling energy significantly exceeds the amount of primary energy input. In addition, a sustainability evaluation for biomass based energy sources must be undertaken to conclude whether a certain biomass energy production method is renewable or not. (2009/28/EC)

## 4.1 Renewable energy in water services

Renewable energy technologies can produce either electricity or thermal energy, depending on the technology. Produced energy can be used for pumping and treatment processes, or heating up spaces. Installed renewable energy technologies can be grid connected or stand alone (off-grid) systems, and these technologies can produce either direct current (DC) or alternative current (AC). (Mohanraj et al, 2013)

The utilization of small-scale wind power (1 – 10 kW) in groundwater pumping has been researched in Saudi Arabia by Rehman et al, 2012. The study concluded that it is possible to pump 30 000 $m^3$ of ground water annually from the depth of 50 meters by using 2,5 kW wind turbine with low costs. Similar study has been conducted in Central Nigeria, where wind power was assessed in water pumping from a borehole. The analysis concluded that daily required amount of 10, 20 and 30 $m^3$ of water could be satisfied with by utilizing wind energy by using wind mill rotor diameters of 4,9, 6,1, and 7,4 meters, respectively. (Rowley et al, 2011)

Rowley et al, 2011, besides wind power, assessed also the use of solar photovoltaic cells in water pumping. In their study, 70 $W_p$ cells were assessed. In order to compare the daily requirements of 10, 20 and 30 $m^3$ of borehole water, cells were constructed into 12, 24 and 36 modules, respectively. Modules targeting to pump 20 and 30 $m^3$ of water included a battery and charge controller in order to secure water pumping during insufficient irradiation hours. The study concluded that daily water requirement could be satisfied by using solar photovoltaic technology. In addition, it was found out that even though the initial costs of solar and wind energy systems are relatively high, the cost of water, compared to conventional petrol based system, is significantly lower when using solar and wind energy based system. (Rowley et al, 2011) In United States, several solar photovoltaic arrays have been installed in remote areas in order to provide energy for water pumping. It has been assessed that these systems can provide, if designed properly, enough energy for water pumping without any serious environmental impact. (Meah et al, 2006)

Energy produced by renewable resources can be utilized also in water treatment processes. In Jyväskylä, Finland, electricity is produced from biogas by using a 157 $kW_e$ motor. Produced electricity is used for compressors supplying air for an aeration process. Similarly, in Tampere, Finland, produced biogas is converted into electricity and thermal energy, and produced electricity is used as additional energy at the wastewater treatment plant. (Latvala, 2009)

Water utilities could utilize thermal energy produced by renewable energy technologies. For instance, heat recovery from wastewater has been utilized in order to heat up building spaces at wastewater treatment plants. In Lapua, Finland, a 120 kW heat pump recovers energy from wastewater for heating utilization. Similarly, a heat pump system is used for space heating at a wastewater treatment plant in Vaasa, Finland. (Tekes, 2013) It has been also suggested, that solar thermal collectors could be used in order to heat up anaerobic digestion reactors. (Latvala, 2009)

## 4.2 Anaerobic digestion

Anaerobic digestion (AD) is based on microbiological processes occurring in the absence of oxygen. The main target of AD is to decompose organic matter in order to produce the end-product, biogas, consisting namely 50 – 75 % of methane and 30 – 40 % of $CO_2$ and other gases depending on the feedstock and processing procedures. Most of energy is bounded to chemical bonds of methane. Thus, $CO_2$ and other gases are often separated from methane. Impurities can also damage the energy conversion unit. (Rutz, 2012)

The processing of feedstock into the end-product in AD can be distinguished into four main sub-processes: Hydrolysis, acidogenesis, acetogenesis and methanogenesis. In hydrolysis, larger organic matter, mainly fats, proteins and carbo-hydrates are being degraded into smaller units by hydrolytic micro-organisms. In the next step, acidogenesis, acidogenic bacteria degrade fatty acids, sugars and amino acids from the previous step into carbon acids, alcohols, ammonia, hydrogen and $CO_2$. These products are further processed to acetic acid, hydrogen and $CO_2$ through acetogenesis. Finally, methanogenic bacteria produce methane and $CO_2$ through methanogenesis. Between these processes, methanogenesis is the most critical and slowest process, so effort for organizing adequate operation conditions for methanogenic bacteria is essential. Figure (3) illustrates microbiological steps in AD from feedstock to the end-product. (Seadi et al, 2008)

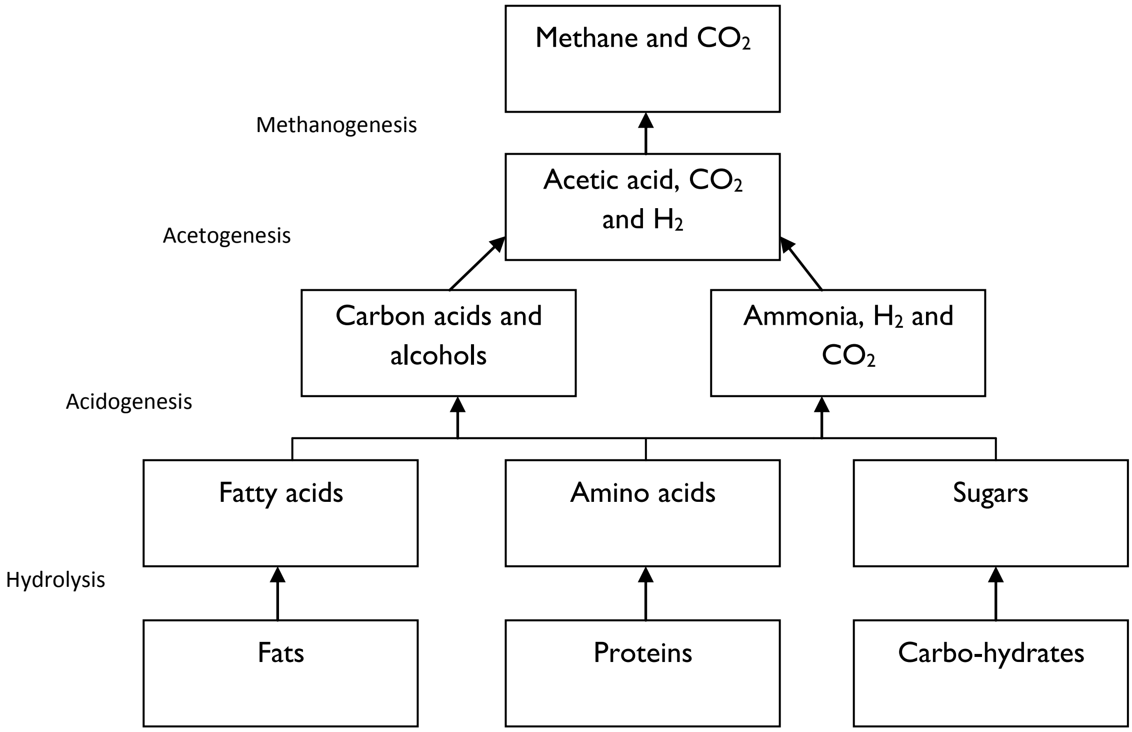


Figure 3. Microbiological processes in AD (based on Rutz, 2012)

AD processes (reactors) can be distinguished according to the temperature into psychrophilic (T < 25 °C), mesophilic (25 °C < T < 45 °C) and thermophilic (45 °C < T < 70 °C). Reactors can be also categorized into wet and dry reactors and batch, semi-batch and continuous reactors. Main rector parameters affecting to the biogas yield are the retention time of the feedstock in the reactor and the temperature in the reactor. In most of the cases, thermophilic reactor has the highest biogas yield and lowest retention time. Co-digestion of wastewater sludge and bio waste by using a thermophilic reactor can increase the biogas yield around 45 -50 % compared to mesophilic reactor. (Cavinato et al, 2012) Thermophilic reactors often have other advantage being able to destroy pathogenic bacteria. Other central factors affecting to the biogas yield in the reactor are pH-number and properties of feedstock, such as solid matter content, organic matter content and homogeneity of feedstock. (Seadi et al, 2008)

Sludge from wastewater treatment plants contains substantial amount of water. (Lo et al, 2012) The most significant part of the sludge is organic matter and is thus well suited for AD, especially for a wet reactor if the sludge is not being dried. At wastewater treatment plants, the AD processes are not only used for generating biogas, but also for stabilizing the sludge and reducing the amount of the final waste.

For these purposes, the thermophilic process is most commonly used because its advantages described above. (Latvala, 2009) (Frijns et al, 2011)

Biogas can be utilized in order to generate electricity or heat or both simultaneously. In most cases, biogas is used in combined heat and power (CHP) units, being able to generate both heat and electricity. Most of the applications generate more heat than electricity. For this purpose, CHP plants use engines such as Gas-Otto, Gas-Diesel, Gas-Pilot or other devices e.g. fuel cells and stirling motors. Furthermore, micro gas turbines can be used. However, an option for utilizing biogas is to purify the end product from $CO_2$ and compounds containing sulphur and use $CH_4$ as fuel for vehicles. (Rutz, 2012) (Holm-Nielsen et al, 2008)

The residual waste from anaerobic digester can be dried and incinerated. However, the residual waste can be also utilized as fertilizer. This kind of procedure may require composting or so called thermal drying, depending strongly on the feedstock of the AD. In the case of sludge used as feedstock, the residual waste can composted or thermally dried in order to fulfill hygienic criteria and stabilize the waste, resulting to an opportunity to use residual waste as a material for land construction. (Latvala, 2009)

AD includes various unit processes in order to operate appropriately. The investment costs of AD plant with full equipment can be rather high. In addition, maintenance is needed frequently. According to Seadi et al, 2008, the payback period for anaerobic digestion can be more than 20 years. From environmental point of view, anaerobic digestion can substantially decrease $CO_2$ emissions originating from the wastewater treatment plant. (Shahabadi et al, 2009) In future, anaerobic digestion research will focus strongly on reducing investment costs of the system. In this way, payback period can be also reduced. (Holm-Nielsen et al, 2008)

## 4.3 Solar photovoltaic

Solar cells, also called as solar photovoltaic devices, are gaining more attention in the field of renewable energy technology. Cell prices are predicted to get lower and the efficiency higher in future. Being able to generate emission free energy from irradiation coming from an abundant energy source, from the Sun, solar cells can be considerable technology for electricity generation. Solar cells are also available at various scales from watt scale to hundreds of kilowatts. The amount of power produced by a cell is rated by watt peak ($W_p$) under standard testing conditions with incident power density of 1000 W/m$^2$, air mass of 1,5 and temperature of 25 °C. (Nelson, 2004)

The amount and properties of incoming solar radiation are affecting significantly to the power production of a cell. Indeed, solar radiation flux varies greatly seasonally and daily due to the movement of the Earth. For example, during summer time the amount of irradiation is greater compared to winter period, resulting to slightly lower annual solar radiation in higher latitudes. Due to these variations, the declination angle of the Earth, latitude and hour angle must be taken into account when evaluating the amount of solar irradiation. In addition, weather conditions have an influence to the direction of the radiation by scattering, reflecting and absorbing solar radiation in the atmosphere. Furthermore, the cell can be installed by having a certain slope and azimuth angle, affecting thus the final amount of reached solar radiation at a given moment. However, Figure (4) illustrates the sum of yearly irradiation on optimally inclined south oriented solar cell in Europe. As Figure (4) illustrates, the yearly sum of solar irradiation is around 1000 kWh/m$^2$, being a considerable amount of energy. Nevertheless, as discussed before, only a part of this can be converted to electricity. (Sørensen, 2011)

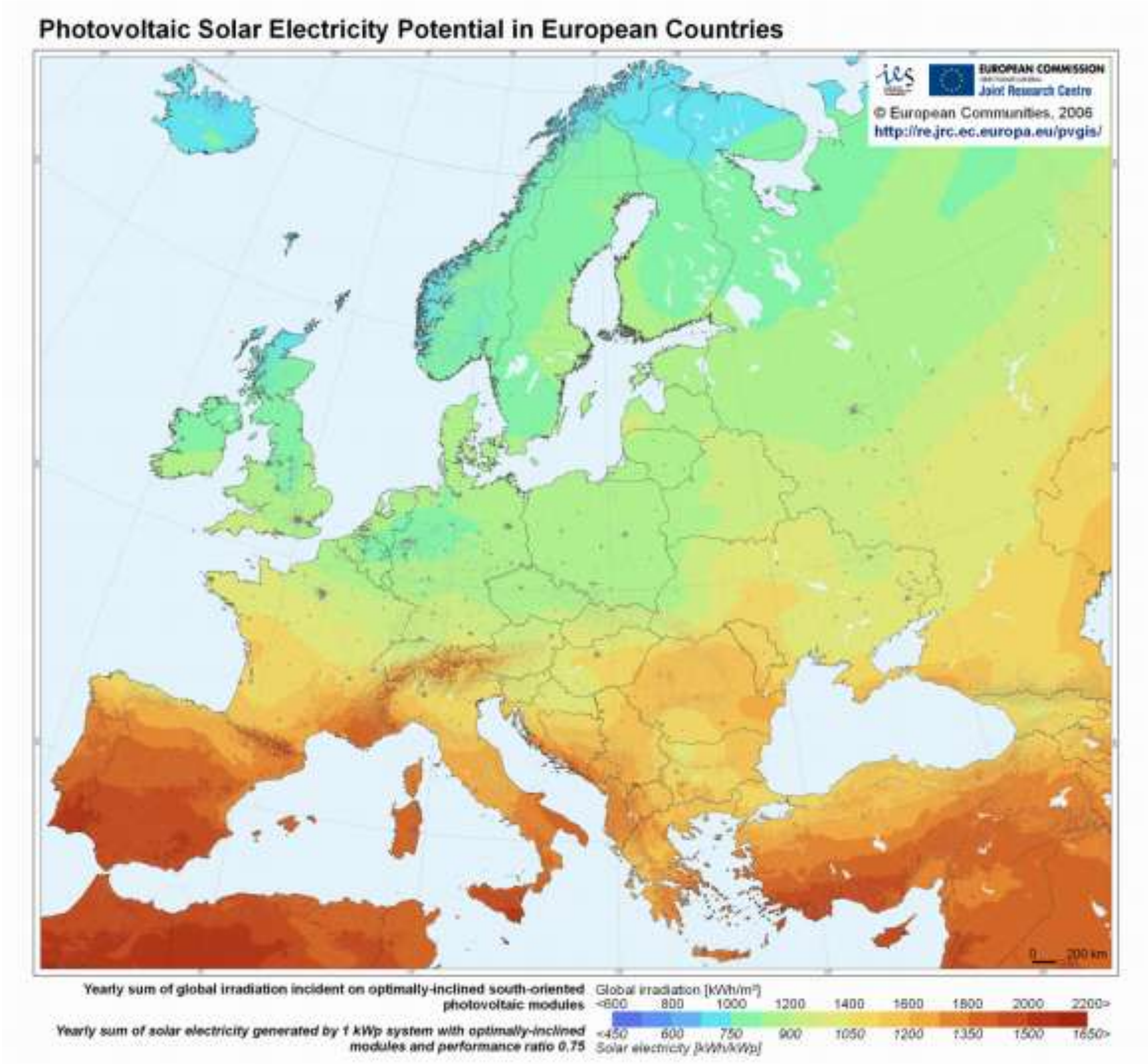


Figure 4 Yearly sum of global irradiance in Europe. (JRC a, 2006)

The most used solar cells are based on silicon (Si), an abundant material on the Earth's crust. Si-based solar cells are designed to have either monocrystalline or polycrystalline structure. The main advantage of these two designs is relatively high efficiency, but the limiting factor is usually the price of the Si-based cell, being rather high. Hence, there are several technologies existing and under development requiring less material compared to Si-based solar cells. These thin film solar cells tend to have lower efficiency, but considerably lower price. Thin film solar cells include amorphous silicon, cadmium telluride (CdTe), copper indium diselenide ($CuInSe_2$) and organic solar cells. (Bhubaneswari et al, 2010)

The efficiency of the solar cell is affected by numerous factors, such as the cell materials and the structure of the cell. Different materials are having specific physical properties, such as band gap values, photon absorption spectrum and recombination rate. Ventilation is required in the cell in order to keep the temperature at acceptable level. Indeed, the cell efficiency tends to decrease when the cell temperature increases. Thus, the structure and placement of the cell can also affect to the power conversion efficiency of the cell. In addition, the overall efficiency of the system must be considered, including inverter losses and losses in cables and storage. Shading formed by obstructions can significantly affect to the final power yield of the solar cells system. (Nelson, 2004)

The main investment cost of a solar cell system is the cell module, including the actual cell. Depending on the installation, mounting structure, inverter and other accessories must be added to the investment costs. Decreasing prices and system costs of PV modules is predicted to make solar cell technology more viable in future. The guaranteed power lifetime of conventional silicon based cell is usually 20 – 25 years or more. After this timeframe, the cell efficiency tends to decrease. The payback time depends strongly on the latitude, technology and the manner of installation, but is usually around 10 – 20 years. Produced electricity can be used by conventional electric applications, but also by water pumps. (SEAI, 2010) (Gopal et al, 2012)

## 4.4 Solar thermal

Solar thermal energy provides an option for generating energy for heating purposes. Conventionally, solar thermal collectors can be used for providing space heating or heating up hot water. Thermal energy can be used also for heating up processes. Basically, four major systems can be distinguished

- Flat plate collectors
- Evacuated tube collectors
- Concentrating collectors
- Solar air collectors

From these types of collectors, flat plate and evacuated tube collectors are most commercialized and used technologies. (Gajbert, 2008). A solar thermal collector consists of glazing, absorber material and insulating material. A glazing is installed on the top of the collector, having high transmittance values for short wave radiation and low transmittance values for long wave radiation for preventing the radiative heat loss from the collector. The glazing prevents also from heat losses from inside of the collector. The absorber material has been designed to have suitable properties for reaching high absorptance for incoming short wave radiation. In most cases, insulation material is installed at the bottom of the collector in order to prevent from conductive heat loss. (ASHRAE, 2008)

In conventional applications, heat is absorbed by the collector and being transferred then into a working fluid. Working fluid is then exchanging heat to a storage tank or to a heat transferer. In active systems, fluid is circulated by a pump, whilst passive systems operate by utilizing gravity forces and the density differences of the working fluid. The performance of the collector depends greatly on the amount of incoming radiation, collector area, tilt angle, orientation and overall efficiency of the system. (Gajbert, 2008). The produced thermal energy can be directly used for domestic hot water production, or, alternatively, stored in thermal energy storage. From the storage, thermal energy can be discharged according to demand. (Tian et al, 2012)

A typical one square meter sized solar thermal collector installed in Finland produces around 250 – 400 kWh of energy during one year (Motiva, 2013). The lifetime of a solar thermal collector is around 20 – 25 years. Initial investment costs can be rather high, but maintenance and running costs are not as high as in some other renewable energy technologies. Payback period for solar thermal systems is between 5 – 15 years. (ESTIF, 2003)

## 4.5 Wind energy

Wind energy can provide renewable electricity for water utilities. At the operation phase, wind energy is considered as emission free in terms of $CO_2$. However, noise, electro-magnetic radiation and glitter emissions are often involved. Indeed, the amounts of installed wind mills are growing rapidly in Finland. The target for 2020 set by Finnish government is to produce 6 TWh with wind power, meaning installed power capacity of 2000 MW (Ympäristöministeriö c, 2012). The installed nominal power capacity varies between 75 kW and 3,6 MW. The installation can be done either off-shore or on-shore. (Turkia et al, 2011)

A wind mill consists mainly of a foundation, tower, rotor, drive train and nacelle. In addition, a certain amount of automation and electric equipment, such as gear box and yaw system (controls the orientation of the mill) is needed, especially in larger scale wind mills. Mechanical energy is produced when wind flows through the rotor disc and part of the kinetic energy of the wind is extracted by the rotor blades. This energy is further transferred to electricity in a generator. Direct electric current must be converted into alternating current by using an inverter. Electricity can be then supplied to the grid. (Burton et al, 2001)

The performance of the wind mill depends greatly on wind velocities and the amount of the wind within a given time interval. The energy in the wind is proportional to the cube of the wind velocity. Wind mills are not producing electricity all the time due to the fact that wind speed varies annually, monthly, daily and in every second. However, the typical cut-in speed (when wind mills start to produce usable electricity) varies between 3 and 5 m/s. In addition, due to the safety issues and the design of the mill, cut-out speed shutting down the mill is around 20 – 25 m/s. The maximum power is generated by the wind mill during the rated wind speed, which in many mills lies between 10 – 25 m/s. At lower wind speeds, the wind mill power output decreases. Figure (5) below illustrates a power curve of WinWinD 1 MW (WWD-1) wind mill with the rotor diameter of 60 m. (Manwell et al, 2009) (Herbert et al, 2005)

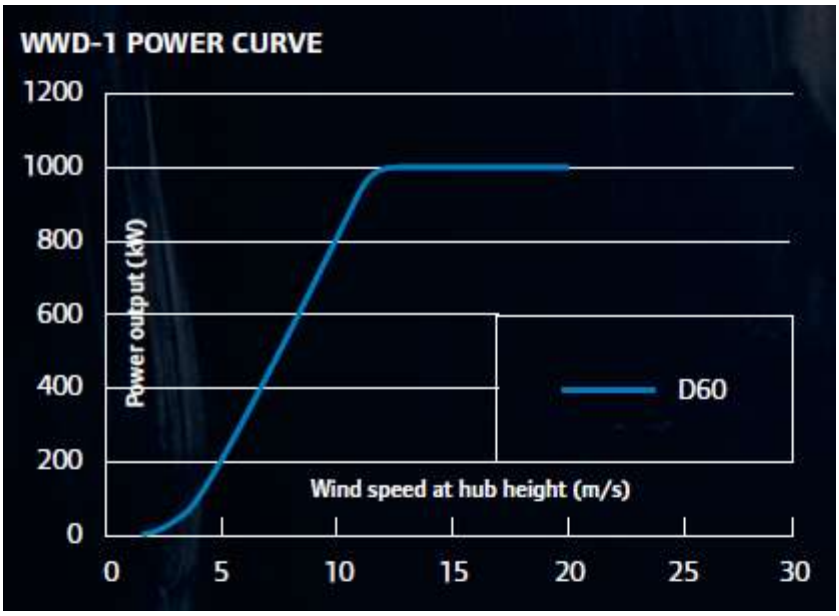


Figure 5. Power curve of WinWinD WWD-1 wind mill (WinWinD, 2013)

The usual lifetime of a windmill is around 20 years. The cost of the system depends significantly on the technology and the installation (off-shore). However, the maintenance costs are evaluated to be around 1,5 – 3 % of the initial cost of the turbine (Burton et al, 2001). The payback period depends also greatly on the wind conditions on the site. The payback period of wind mills is roughly around 10 – 15 years. (Energysolve, 2013)

## 4.6 Hydro power

Hydro power technology has been a conventional electricity conversion method for long time. In Finland, the installed amount of hydropower plants is more than 220, having power capacity of 3100 MW (Energiateollisuus, 2013). The scale of hydropower varies from hundreds of kilowatts to tens of megawatts. In the area of EU, small-scale hydropower comprises plants having nominal output less than 10 MW, whilst large-scale plants exceed the limit of 10 MW. (Pienvesivoimayhdistys ry, 2009)

The basic operation method of a hydro power plant is that water having high elevation is discharged to the lower elevation level. In many cases, separate reservoirs can be constructed for storing water. The potential energy of high elevation changes to the kinetic energy of water as water is discharged towards the turbine locating at the lower elevation level. The kinetic energy is then used to rotate the turbine in order to generate mechanical energy. The potential of power generated by a hydraulic turbine can be assessed by using equation (1)

$$P = \eta \rho g Q H \qquad (1)$$

Where $P$ = the mechanical power output of the turbine [W]

$\eta$ = the turbine efficiency [-]

$\rho$ = the density of water [kg/m$^3$]

$g$ = the gravitational accerlation constant [m/s$^2$]

$Q$ = the volume flow rate [m$^3$/s]

$H$ = the effective pressure head of water across the turbine [m]

The mechanical efficiency of a hydraulic turbine varies between 60 % and 90 % depending on the design of the turbine. The turbine efficiency tends to decrease when the turbine size decreases. Most used hydraulic turbine types can be distinguished into Pelton, Turgo and Cross flow turbines. (Paish, 2002)

In addition to a turbine, hydropower plants may require the construction of reservoirs, dams, transformers etc. Advantages of hydro power include very robust operation of the system, long life time, high efficiency and little maintenance. Furthermore, hydropower has been considered rather emission free energy production technology. Still, especially in larger scale, hydropower may have some negative impacts on aquatic biology and environment. (Pienvesivoimayhdistys ry, 2009)

Hydropower plants have relatively long lifetime, often at least 50 years. Since the plant is often generating electricity continuously with relatively high efficiency, payback period can be approximately between 10 and 20 years despite of high investment cost. Hydropower plants tend to have also rather low maintenance and operation costs. (Paish, 2002)

## 4.7 Heat recovery from wastewater

Wastewater coming from domestic, industrial and other sources contains always a certain amount of heat, which could be recovered. (Frijns et al, 2011) According to Intelligent Energy 2007, this energy potential is often unused due to the lack of information, meaning that heat is being rejected to the environment. Thus, heat recovery from wastewater could provide a considerable option for generating renewable energy on the site of a water utility. (Intelligent Energy, 2007)

The potential annual amount of thermal energy in wastewater can be evaluated by equation (2)

$$Q_{TH} = mc_p\rho\Delta T \qquad (2)$$

Where $Q_{TH}$ = acquired amount of thermal energy [MJ/year]

$m$ = the produced amount of wastewater [l/year]

$c_p$ = the specific heat capacity of wastewater [kJ/kg°C]

$\rho$ = the density of wastewater [kg/l]

$\Delta T$ = the temperature difference [°C]

The equation (2) gives a simple tool to evaluate the potential in theory. Still, the equation does not take into account that the amount of produced wastewater varies hourly, daily, monthly and annually. The term $\Delta T$, which is the temperature difference between incoming and outgoing wastewater flows, can also vary significantly. However, main factors affecting to the thermal energy potential in a given situation are the temperature difference and the amount of produced wastewater, considering that the specific heat capacity and the density of wastewater are near to constant values. (Tekes, 2013)

As mentioned before, the temperature of wastewater can vary at a given time interval. Wastewater temperature can also decrease between producing and treatment positions. Principally, the heat is lost in the piping system. According to Sallanko 2006, the temperature decrease of wastewater in a sewage pipe in Finland was 0,16 – 0,27 °C in the beginning of the pipe and 0,02 – 0,10 °C in the final part of the pipe. The research made by Sallanko concluded that the temperature of wastewater decrease 0,12 – 0,17 °C/h. According to Tekes, 2013, the temperature of wastewater at the beginning of the sewage pipe is 20 – 30 °C and can be anywhere between 5 up to 23 degrees at the wastewater treatment plant. (Sallanko, 2006) (Tekes, 2013)

Heat can be recovered at several different points at the wastewater system. First of all, heat recovery system can be situated immediately after wastewater is being produced. On the other hand, a heat recovery system can be installed in a sewer or at the wastewater treatment plant, as illustrated in Figure (6).

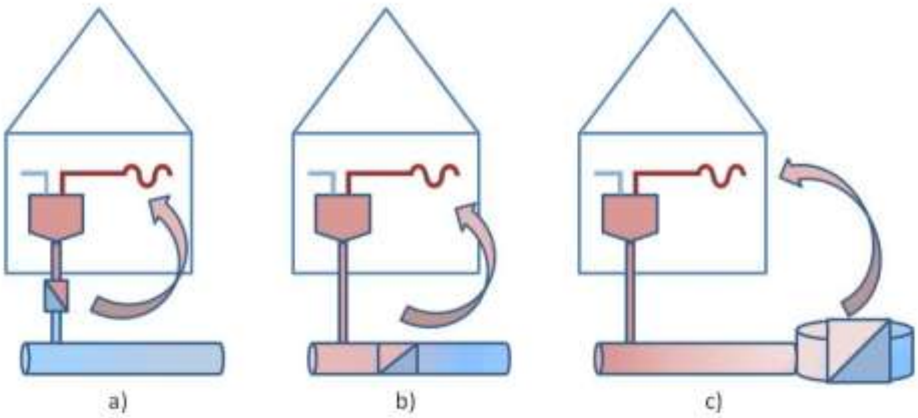


Figure 6. Options for placing a heat recovery system from wastewater. a) inside a building, b) in a sewage pipe and c) at the wastewater treatment plant (based on EAWAG, 2013)

Heat can be recovered from wastewater by using either a heat recovery system or a heat pump. Principally, the heat recovery system is a heat exchanger allowing wastewater to flow through the system and transferring heat from warmer wastewater to colder fluid flowing in the heat exchanger. This kind of system is conventionally installed in a building or in a sewer system. For wastewater heat recovery from a wastewater treatment plant, heat pumps tend to be more efficient, even though the investment costs of heat pump systems are considerably higher compared to heat recovery systems. In heat pump systems, heat is recovered by a heat exchanger from wastewater (evaporator) and brought to a compressor raising the pressure and temperature of working fluid. Heat is being transferred out in a condenser. The heat rejection includes usually a phase change from gas to liquid. The circle is closed by an expansion valve decreasing the pressure and temperature of the working fluid. In most of the cases, heat energy output is considerably higher compared to the electricity consumption of the compressor. On the other words it means that the coefficient of performance (COP) is having higher values. Furthermore, heat pump systems can operate other way around, producing cooling energy. (Meggers et al, 2010)

The temperature decrease of wastewater due to the heat recovery can affect to water treatment processes, especially if heat is being recovered before these processes. According to Wanner et al, 2005, even 1 °C decrease in temperature can decrease the operation efficiency of nitrification by 10 %. The decreased amount of wastewater entering the wastewater treatment process can also affect negatively to other biological or bio-chemical processes. (Wanner et al, 2005) (Tekes, 2013)

It is possible to utilize recovered heat from wastewater in order to warm up building interiors or hot usage water, or in processes, such as anaerobic digestion and sludge drying. Heat can be also exchanged into a district heating system. As mentioned earlier, the heat pump system can produce also cooling energy, especially during warmer seasons, increasing thus the overall annual efficiency of the system. (Tekes, 2013)

Small-scale heat recovery plants installed in Finland are having the scale from around 100 kW to 1 MW. Bigger scale plants are operating from 20 to up to 90 MW. The amount of produced cooling energy is usually slightly lower compared to the amount of heating energy. Because of the organic content of wastewater, both heat energy system and heat pump technology require maintenance and protection from the fouling of the heat exchanger surfaces. (Tekes, 2013)

The payback period of the installed system varies significantly depending on the installed technology, scale and operating conditions, to mention some. Nevertheless, some installations in Finland are aimed to have payback period of 2 – 3 years. (Tekes, 2013)

## 4.8 Emerging technologies

### *4.8.1 Fuel cells*

The one of the most promising electrochemical energy conversion technology at the moment is fuel cell technology, being able to convert mainly electricity, but also heat from chemical energy from reactants fed to the cell. In a typical fuel cell, hydrogen ($H_2$) is fed into a negative electrode having a catalyst. A catalytically aided reaction takes place by breaking a hydrogen molecule into electrons ($e^-$) and hydrogen ions ($H^+$). Hydrogen ions are being transferred through an electrolyte and electrons via an external circuit into a positive electrode, where oxygen ($O_2$) is supplied, resulting the production of water ($H_2O$). Even though some fuel cells are already commercially available, fuel cells are actively under research, including cell types such as phosphoric acid cells, solid electrolyte cells, alkaline cells, proton exchange membrane cells and molten carbonate fuel cells. Fuel cells can be integrated in buildings, processes and vehicles. (Sørensen, 2011) (Mekhilef et al, 2011)

### *4.8.2 Concentrating/hybrid solar cells and floating structures*

Concentrating solar cells have gained attention by being able to result high efficiency and high electricity conversion rates. This technology could be integrated into a water utility as well. Researchers believe that the market of concentrating solar power system can double from 2012 to 2020. The cost-effectiveness of the system is predicted to be reduced considerably by 2020 as well. (Pike Research, 2012)

The efficiencies of solar cells tend to be rather low. Most of captured energy from the incoming irradiation is heat. There are a few prototypes for panels producing both electricity and heat, called as photovoltaic/thermal hybrid solar technology. Also other hybrid technologies might emerge, such as wind mills with integrated photovoltaic system; solar cells integrated with heat pump and solar thermal/heat pump hybrids. (Chow, 2009)

New technologies could also enable more cost-efficient installation and conversion of off-shore energy. Researchers have developed floating structures for off-shore wind mills in order to place wind mills at the windy sites whilst minimizing the material requirements, environmental impact and costs. Similar structures have been developed for solar cells as well. (Lunn, 2012)

### *4.8.3 Osmotic power*

The potential of several different ocean and hydroelectric energy conversion technologies have been assessed recently by researchers. One of the possible emerging technologies could be osmotic power. In osmotic power, the water flows through a semi-permeable membrane from low salinity level into high salinity level. By utilizing these concentration differences and membrane technology, high pressure can be created at the high salinity concentration side of the process. This pressure can be utilized in order to drive a conventional turbine producing electricity. Current research predicts that the technology can take a huge step in next two years. (Mourant, 2012)

### *4.8.4 Small-scale hydropower*

Small-scale hydro power in this work is divided into two categories: Micro-hydro power having the scale between 5 and 100 kW and pico-hydro power having the scale less than 5 kW. Such systems do not necessarily require any kind of reservoir, as larger scale hydro power plants often do. Small-scale hydro power plants can also operate at lower discharge rates. In this way, impacts on the aquatic environment can be minimized. At the same time, small-scale hydro turbines can be installed in various resorts having also lower effective pressure head over the turbine. (Williamson et al, 2011)

### *4.8.5 Organic solar cells*

One of the main disadvantages of solar photovoltaic solar cells besides low efficiency is the high cost of the system. Lots of material is needed in silicon based cells and the manufacturing process can be very slow and expensive (Nelson, 2004). Thus, researchers have developed so called thin film solar cells requiring much less material and less expensive and faster manufacturing process compared to traditional solar cells. In this way, solar cells can be more economically feasible, while having also improved environmental status. Within thin film technologies, organic solar cells can provide a considerable solution in the future. (Cai et al, 2009)

Organic solar cells are mainly constructed from polymers. At the moment, the best organic solar cells have power conversion efficiency of 6 % in the laboratory conditions. Still, researchers believe that the cell efficiency will be improved, exceeding more than 10 %. Organic solar cells, besides low cost, have also advantages by being flexible and transparent. Thus, these cells can be integrated on more complex surfaces and transparent systems, such as windows. (Cai et al, 2009)

## 4.9 Summary of renewable energy technologies

There are several renewable energy technologies available and the feasibility of each technology must be evaluated separately according to the surrounding conditions and the need of energy at the load side. Table (4) summarizes general scales and payback periods of renewable energy technologies in Finland. Values are general, and payback periods may vary strongly depending on ambient conditions and the system architecture.

Table 4 Typical scales and payback periods of renewable energy technologies

| Energy conversion method | Scale | Payback period [years] |
|---|---|---|
| Wind power | 0,1 - 3,6 MW | 10 - 20 |
| Solar thermal | 250 - 400 kWh/m2/year | 5 - 15 |
| Solar photovoltaic | 20 - 500 Wp | 10 - 20 |
| Hydro power | 0,1 - > 100 MW | 10 - 15 |
| Anaerobic digestion | 0,1 - > 20 MW | 10 - 25 |
| Heat recovery from wastewater | 0,1 - 90 MW | 2 - 10 |

The scale of solar photovoltaic cell is expressed as watt peak ($W_p$) (see chapter 4.3) rated under standard testing conditions. The amount of energy production in solar photovoltaic technology depends greatly on the installed area of the cells and the amount installed cells. The power production of solar thermal collectors and PV cells can be increased significantly by having a control system, in which the cell/collector follows the direction of the Sun. In this way, the cell/collector can be oriented ideally towards the sun dynamically. (Nelson, 2004)

## 4.10 Barriers of renewable energy

Energy conversion from renewable energy sources may be uneven. For instance, solar photovoltaic system may not be able to provide enough electricity during a cloudy day, night time or winter season. Similar uncertainty can be found with solar thermal systems, wind mills and hydropower. In case of anaerobic digestion, the amount of feedstock can also vary seasonally. In addition, heat recovery from wastewater may have seasonal variety in the temperature of wastewater at the wastewater treatment plant. (Twidell et al, 2006)

Another problem can occur during a situation, when energy consumption is low at the end-use phase, but energy production is excessive. The situation can be also vice versa, as it can be for example during winter period with solar energy. Peak consumption hours occur during certain periods during the day. Thus, these energy peaks should be able to be satisfied, or preferably, removed or at least lowered. Examples of the key solutions for balancing the uneven production and consumption of energy are energy hybrid systems, energy storage and smart grids. (Twidell et al, 2006)

Hybrid systems can include integrated technologies, for instance simultaneous wind power and solar photovoltaic power generation. In this way, energy can be produced more reliably. For instance, even though it is not windy, sufficient amount of solar radiation may be available. The aim is to secure the energy conversion making it more reliable. (Sørensen, 2011)

Energy storage plays an important role in securing the supply of energy and promoting renewable energy sources. Produced excess energy can be stored in storage when not needed, and utilized when energy demand is growing. Energy storage can enable also the moving of energy in some other form, such fuel. Energy storages can be distinguished to electrical, thermal, mechanical, chemical and biological storage. (Twidell et al, 2006)

Thermal energy can be stored into a thermal storage. Materials with suitable thermodynamic properties are utilized to capture the produced heat. For example, water is often used due to its high specific heat capacity. For instance, solar thermal collectors often use water tanks as thermal storage. Phase change materials, salt hydrate etc. can be also used in order store not only sensible heat, but also latent heat. (Sørensen, 2011)

Batteries are conventional devices for storing electricity. The lead acid battery is the most conventional type of battery. Also other materials and compounds can be used. Batteries can be utilized to store generated power from wind mills, photovoltaic, anaerobic digestion and hydropower. It is also possible to store electricity or heat into chemical compounds. As chemical reactions are endo- or exothermic, stored energy can be further utilized by burning fuel, for instance. One example of this kind of storage is hydrogen storage, in which electricity can be stored into hydrogen bounds by using electrolysis. When energy demand increases on the load side, energy carried by hydrogen can be used in a fuel cell producing electricity and heat. (Twidell et al, 2006)

Mechanical storage can store mechanical energy, such as rotation energy or pumped energy. Typical mechanical energy storage can be found in the relation of hydropower plants, where energy of water in a reservoir is stored as potential energy due to the elevation. Mechanical energy can be also stored into flywheels and compressed air storage. Energy from mechanical storage can be further converted into electricity or heat, depending on the type of the storage. (Twidell et al, 2006)

Nowadays, energy supply is mainly organized by larger centralized energy suppliers. Energy is transmitted from the centralized plant to the end-user, consumer. In this kind of one-way communication system, the user does not have much freedom to affect to energy supply. In addition, the current electrical network does not necessarily support renewable energy systems in a level it should support. Thus, conventional electric network has started to undergo several development actions in order to achieve a network, in which two way communication and liberalization of energy markets are possible. This kind of network utilizing information technologies and high degree of automation is also called as smart grid. (European Commission, 2006)

Smart grid enables energy distribution, storage and supply as well as communication between centralized and decentralized energy systems and consumers. The network communicates in real-time within these systems. In this kind of model, the consumer is not only consuming energy, but can also produce it and sell it back to the grid. By combining possibilities of energy storage, decentralized supply and two-way communication, small-scale renewable energy conversion technologies can be supported better. Smart grid can significantly improve the reliability of the grid, while being also very cost-effective. (European Commission, 2006)

Barriers for renewable energy technologies can be also non-technical. For instance, financial and economic support may not be always included. Renewable energy sources often tend to have high investment costs, which may affect to the decision of installation. In addition, the lack of awareness of renewable technology and behavioral barriers can take place. It is also possible, that national policy is not supporting some certain renewable energy technology. (Sudhakar et al, 2003)

# 5 SUSTAINABILITY OF RENEWABLE ENERGY INVESTMENTS

Energy is studied to be one of the main responsible for global change and environmental problems. As it is used everywhere extensively, it has a significant impact on economy and society. Thus, especial attention must be paid on sustainability assessment of any renewable energy source. Sustainability of energy technologies is assessed separately for environment, economy and society.

In energy, one of the key challenges met by sustainable development is developing alternative energy systems for society. This means less polluting, renewable energy technologies, preferable as a source of primary energy. At the same time, the growing economy should become less energy intensive. In this battle, energy efficiency and recycling become very fundamental. Future solutions should be also safe, providing social and economic benefit. (Baker, 2006)

## 5.1 Sustainable development

European Commission defines sustainable development (SD) as "development standing for meeting the needs of present generations without jeopardizing the ability of futures generations to meet their own needs". An action, which has been undertaken, has been seen from local, regional and global point of view in SD by integrating social, environmental and economic dimensions. Nowadays sustainable development has not been seen only as a guideline in policy, but also as a principle for every people. The Figure (7) below illustrates the dimensions of SD. (Eurostat 2009)

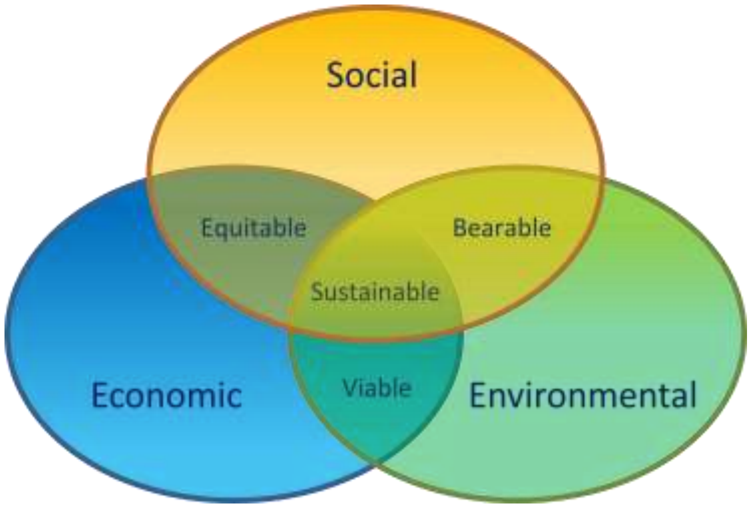


Figure 7 Dimensions of SD (based on Baker, 2006)

Main dimensions seen in figure 7 can be divided into social, economic and ecological sustainability (the environmental part of SD). SD targets to improvements in social equity and cohesion, the protection of environment and the enhancement of economic prosperity. Progress of any action should be viable, equitable and bearable both in short and long-term time interval. All these dimensions evaluated together form a concept of sustainability assessment. These dimensions are introduced more detailed in following sub-chapters as well as the a few common tools for evaluating these dimensions. (Eurostat 2009)

## 5.2 Ecological sustainability

Ecological sustainable development is defined as "using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in future, can be increased". The definition broadly means that future generations are given the same opportunities we have by preserving the environment. The environmental impacts from actions should be minimized and biodiversity conserved. Ecological sustainability also drives the environment in a direction where social institutions and processes can be maintained. (Baker, 2006)

Energy projects in Finland often have to undergo environmental impact assessment (EIA) in order to preserve environment and society from harmful impacts arising from a certain technology. EIA consists of wide-ranging evaluation of impacts to the atmosphere, hydrosphere, lithosphere and biosphere. However, small-scale investments, such as small rooftop PV panel, do not necessarily require EIA. (Ympäristö.fi, 2013)

There are numerous commonly used indicators for ecologically sustainable development. One of them is carbon footprint measuring the total $CO_2$ and other greenhouse gas emissions associated with a certain product during its whole lifetime. Carbon footprint includes transportation, energy production, fuels and other processes associated with a product. Finally, carbon footprint can be indicated as global warming potential (GWP) reflecting the relative effects of a greenhouse gas in terms of climate change over a certain period. When evaluating the overall impact of a product, life cycle assessment (LCA) is commonly used tool by being able to take into account the total environmental burden and use of resources, such as the extraction of raw-materials and manufacturing of goods. (JRC b, 2007)

In water sector, according to Lemos, et al., 2013, the treatment and acquisition of water and wastewater causes largest environmental impact when considering urban water systems. Often, the reason is the discharge of nutrients from treatment processess to natural water systems and relatively large consumption of electricity. (Lemos, et al., 2013) In addition, especial attention should be paid on groundwater sources as pollution and excessive acquisition of these resources can seriously damage environemnt. (Collin et al, 2000)

## 5.3 Economic sustainability

Sustainable economic development aims to adapt the growing economy with the carrying capacity of the environment, without damaging the social dimension of the sustainability principle. The target of sustainable economic development is thus to find a balance between other dimensions of sustainable development in long-term time interval by avoiding getting into debt by using natural resources moderately. At the same time, the well-being of citizens should be improved. (Leppälä et al, 2011)

Economically sustainable development targets to promote improved collaboration between business partners by taking regional and local level into account as well as private sector. At the same time, employment should be created, also in small and medium size enterprises. For enabling this, financing support models should be appropriate in order to support these enterprises to prosper and create jobs. Here, evaluating and assessing the consequences of economically sustainable development can be challenging and the information should be able to be shared with all sides involved. For enabling this, there are several indicators developed for measuring sustainable economic development. (Institute for Sustainable Communities, 2011)

Whilst assessing economic sustainability, it is recognized that Gross Domestic Product (GDP) may not be appropriate indicator. Instead of concentrating on measuring production, indicators should be able to evaluate income and consumption and how these are distributed between citizens. Genuine Progress Indicator (GPI) aims to assess these factors. GPI evaluates economic growth within the framework of sustainable development by taking into account the consumption of natural resources, the condition of the environment, individual consumption of citizens and how income is being distributed between citizens. Thus, it has been seen as a worthy tool for economic sustainability assessment, even though the indicator does not concern e.g. the happiness of citizens. (Leppälä et al, 2011)

There are also numerous individual indicators, which together can be used for evaluating sustainable economic development. These indicators include employment and unemployment rates, salaries between genders, differences in salaries between citizens, the percentage of households getting into debt, the number of enterprises concentrating on environmental business and unemployment rate of young people. (Leppälä et al, 2011)

## 5.4 Social sustainability

Social sustainability promotes sustainable society, in which it is possible to maintain necessary needs of life at the personal, organizational, institutional and societal level. There might be also some overlapping with economic sustainability. Main targets of social sustainability are to contribute social relationships and cohesion, promoting justice, equality and identity. Promoting social sustainability has been seen very beneficial and these principles are integrated also in policies. As social sustainability, targets improving social cohesion, confidence and health, there is often a straight correlation between social sustainability and economy. (Alila et al, 2011)

As an important part of SD, social impact assessment (SIA) is often conducted in touch with a renewable energy project. According to Vanclay 2003, SIA "includes the process of analyzing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions. Its primary purpose is to bring about a more sustainable and equitable biophysical and human environment". So SIA generally aims to analyze, monitor and manage social consequences origin from development. (Vanclay, 2003)

Social phenomena are very complex and multi-dimensional. There are several indicators concerning social sustainability, but it can be challenging to find a suitable indicator for each situation. However, conventional SIA indicators include e.g. the assessment the rate of crime, homelessness and the percentage of educated people. In renewable energy projects, however, the evaluation of the impact on natural and cultural heritage is often taken into account as well as aesthetic issues and the feelings (opinions) of citizens. These impacts are always evaluated separately for each project, since every site may have its own recreational, historic and archaeological value. In addition, general well-being and safety are also evaluated. Uncomfortable issues can origin from e.g. noise and pollution. Enquiry for citizens is always included for making a SIA. (Alila et al, 2011)

Employment situation may affect significantly to the decision-making of renewable energy technology. From socio-economic perspective technologies having similar social impact, may still have different employment impact. Often technologies having higher impact on increasing the employment is chosen. This is especially true if a certain area is having high unemployment situation. (Sørensen, 2011)

Gross domestic product (GDP) index is commonly used in order to express societal development. Still, GDP rate does not describe how economic welfare is divided in the society. It can be also difficult to evaluate the relationships between economic growth and social sustainability. Thus, many different indicators are needed in extensive SIA. However, evaluating social impact of installing e.g. a certain small-scale energy system in buildings can be difficult. In Finland SIA is often conducted in touch with larger scale actions. (Alila et al, 2011)

Social impact assessment may be of great interest to conduct in the water sector. Especially, if a water source is very limited, the excessive water abstraction can lead into a conflict in a worst case scenario. (Pokharel, 2005) In addition, as discussed earlier, water acquisition and treatment can contaminate water. Emitted contaminants can accumulate to consumers for instance when drinking water, which can lead to health impacts. Studies show that improvements in drinking water quality can significantly contribute to human health. (Zhang, 2012)

# EXPERIMENTAL PART

# 6 THE WARES PROJECT

This study was done as a part of the "Water Asset Renewable Energy Solutions" (WARES) Northern Periphery (NPP) project financed by European Union.

## 6.1 Project objectives and partnership

The aim of the project was to map out and select water utilities in Northern Periphery Area in order to assess hidden and unexploited renewable energy potential in selected utilities. Ultimately, WARES-project could lead to a renewable energy investment. The possibility of generating Public-Private-Partnerships is also considered in this project as well as social and community engagement, political engagement and environmental benefits. In this work, water utilities in Northern Finland are mapped out and renewable energy potential is assessed in selected utilities. (WARES, 2013)

The project partners included International Resources and Recycling institute (IRRI) in Scotland (project leader), Mayo County Council in Ireland, Clar ICH in Ireland, University of Oulu in Finland, Action Renewables in Northern Ireland, Narvik Science park in Norway and Norut Research Institute in Norway. Each partner provides information and potential pilot sites from their region. The project is done with close collaboration with project partners. (WARES, 2013)

## 6.2 Project content

Project content was divided into five different work packages (WP). In WP1, project management, communication and coordination took place. The purpose was to spread adequate information to project partners concerning work packages, publications and project management. The aim of WP2 was to map out skills and resource requirements that each project partner can provide to the project. In WP2, each project partner studied the financial model and funding sources of water utilities in a certain area including how water services are organized by utilities.

In WP3, water utilities were mapped out in order to find suitable pilot cases to the project. Water utilities willing to join the project and having considerable renewable energy potential on their site were chosen as possible pilot cases. Tasks in WP3 included the assessment of renewable energy potential in chosen water utilities, besides pilot selection, utility review, site analysis and community presentation. Community presentation included stakeholder identification and engagement.

In the fourth WP the aim was to assist the implementation WARES service in cases of selected pilot assets. The governance of PPP, $CO_2$ reduction potential and the identification of funding sources were included. Furthermore, sources for technologies and the monitoring and evaluation of economic performance of the assessed renewable energy technologies were undertaken. Ultimately, the goal of WP4 is pilot implementation.

In WP 5, social and political benefits are identified in each area. Tasks include the review of social and community benefits in the case of installed technology, investment plans for community benefits, plan of engagement of policy-makers in the area and policy recommendations and development. In addition, long-term options for WARES-service and long-term WARES business plan are reviewed. The goal of this work is to contribute to WP2, WP3 and WP4.

## 6.3 Pilot selection in Finland

The aim of pilot selection was to find out two suitable utilities interested in assessing renewable energy potential on their site. In this work, the interest was to assess the potential at different utilities in terms of organizational level and utility size. Thus, the target was to find one bigger sized and one smaller sized utility in order to be able to compare differences in energy usage between these utilities. In addition, the target was to find a different renewable energy technology suitable for each utility. In this way, it was possible to assess the energy production potential and economic feasibility of two different renewable technologies.

Pilot utilities were contacted mainly by e-mail by asking the interest of the utility of taking part of this project. In the case of Tyrnävän Vesihuolto Oy, contacts were used in order to be in touch with the utility. Two of the fastest answered utilities were chosen as pilot cases. As mentioned before, the interest was also to assess the potential in different utilities, so the decision-making of the pilot selection was done by taken this into consideration as well. Contacted utilities can be found from Appendix 1. As a result, Kemin Vesi Oy and Tyrnävän Vesihuolto Oy were chosen as pilot cases to the renewable energy potential assessment. The locations of these two municipalities are shown in Figure (8).

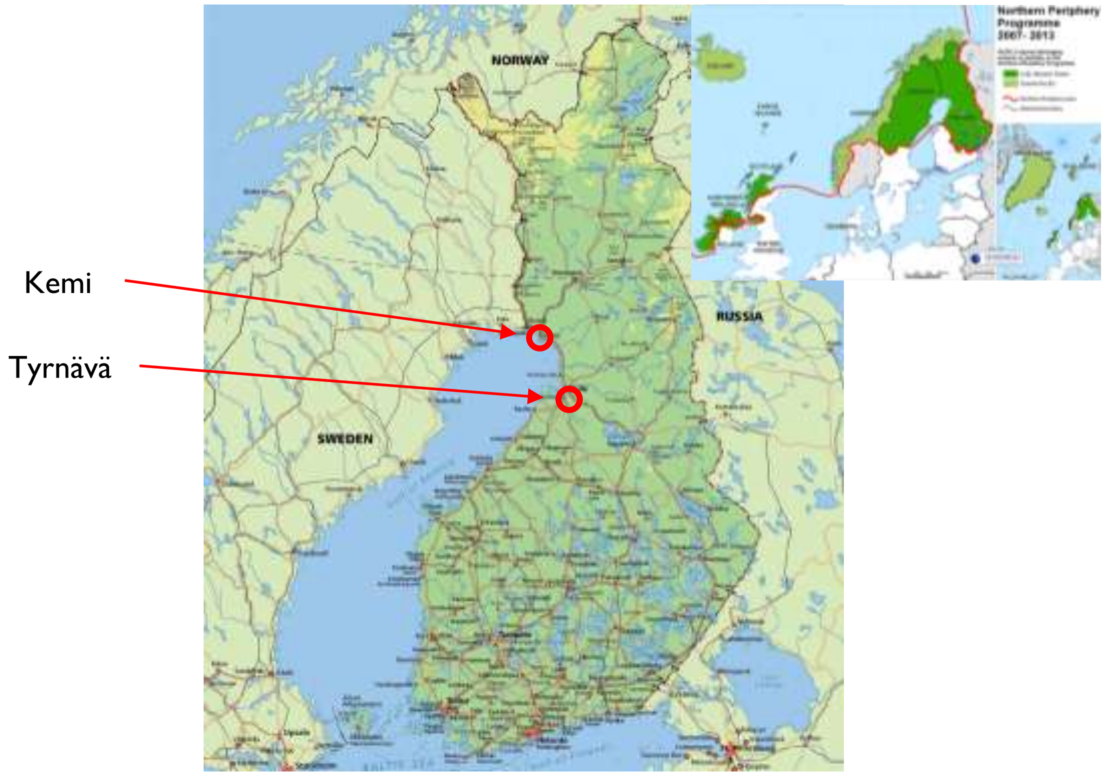


Figure 8 Region of NPP area and locations of Kemi and Tyrnävä (Miilumäki, 2013)

After confirmation from the utility of being a part of the project, the head of the utility was interviewed. The interview mainly included a discussion about the suitable renewable energy technologies and the possibility to use hidden potential. The main focus was on assessing a suitable technology, which could provide energy for the utility's own use, by enhancing the energy security at the same time. Also possible social impacts of the system were overviewed briefly.

### *6.3.1 Suggesting technologies*

As discussing with water utilities about suitable renewable energy technologies, technologies from earlier chapters were presented. These technologies were seen to have the highest potential in the Northern areas. In addition, a criterion for choosing these technologies was the market availability. Some bio-energy technologies, such as gasification, pyrolysis and alcohol fermentation, were left out since it was seen that raw-materials in these cases should be imported outside the utility. Furthermore, technologies such as tidal power and other ocean energy were left out as the potential in Northern Finland is not very significant. The target was to utilize the energy potential from utility's own raw-material flows or the local energy potential on site.

### *6.3.2 Kemin Vesi Oy*

Kemi is a municipality located at the coast near the Swedish border. The area of the municipality is 747 $km^2$. Kemi offers to its citizens a great variety of services from health care and education to sports and culture. In 2013, the population of Kemi was 22 257. (Kemi.fi, 2013)

Kemin Vesi Oy organizes water services in the municipality of Kemi. Organized services include acquiring and supply of drinking water, wastewater collection, distribution and treatment and rainwater management. Drinking water is mainly acquired from another water company, Meri-Lapin Vesi Oy, owned by municipalities of Kemi, Tornio, Keminmaa and Tervola. Drinking water is taken mainly from groundwater sources. In Peurasaari wastewater treatment plant, wastewater sludge is dried on site and transported to Jätekeskus Jäkälä for composting. (Kemin Vesi Oy, 2013)

As a result of discussion with Kemin Vesi Oy, anaerobic digestion was decided to be assessed. Since the potential use of heat recovery from wastewater was evaluated earlier by Pöyry Environment consulting, an anaerobic digestion process was seen to be the most relevant renewable energy technology in order to generate energy for the utility's needs. According to Kemin Vesi Oy, installation of anaerobic digestion could provide both heating and electrical energy for the utility. This could result to the decreased pressure on increasing the amount of water charges for consumers.

At the moment, wastewater sludge From Kemin Vesi Oy wastewater treatment plant is composted at Jätekeskus Jäkälä landfill area. Kemin Vesi Oy is satisfied with the solution as long as the agreement with Jätekeskus Jäkälä is valid and the sludge can be composted legally. Still, Kemin Vesi Oy is willing to assess the potential of using wastewater sludge for anaerobic digestion, since the process may become a central investment in future. Anaerobic digestion was seen to have the highest possibility of feasible energy production.

### *6.3.3 Tyrnävän Vesihuolto Oy*

Tyrnävä is a small municipality next to the municipality of Oulu. In 2013, the amount of inhabitants in the municipality was around 6 600, and this amount is predicted to increase in future. The area of the municipality is 494,89 $km^2$. (Tyrnävä.fi, 2013)

Tyrnävän Vesihuolto is treating and supplying drinking water to the citizens of the municipality. Water is acquired from groundwater sources and treated in Kukkolanvaara area. In this area, there are small unused underground resources, which Tyrnävän Vesihuolto Oy has been planning to utilize in future. As this unused groundwater area is off-grid, and water resources are relatively small, the utility would be interested in using renewable energy sources to exploit this water resource. (Sarsila, 2013)

Two main renewable energy technologies the utility was interested in included solar photovoltaic and wind energy. Whilst discussing with the utility, the possibility of having a hybrid systems of these two technologies was considered. However, as the area is in the middle of forest and the power requirement for small-scale water pumping was discussed to be low, wind power was left out. As the result of the discussion with the utility, solar photovoltaic module was considered to be an interesting choice in order to utilize small groundwater resources during periods of sufficient solar irradiation. Pumped water would go straight to the existing treatment plant, and thus to the end-users, consumers. (Sarsila, 2013)

# 7 CASE KEMIN VESI OY

The planning of anaerobic digestion plant is done by using data from 2012 given by Kemin Vesi Oy. According to Kemin Vesi Oy, the amount of annually produced sludge at Peurasaari wastewater treatment plant in 2012 was 2796 tonnes. The dry matter content of the dried sludge was measured to be 26 % and the organic matter content (volatile solids, VS) was estimated to be 19,5 %.

Kemin Vesi Oy decided the location for the anaerobic digestion plant to be at the Peurasaari wastewater treatment plant property. The area is large enough for installing the system. In addition, as the biogas plant is fed only with wastewater sludge, the transportation distances are thus minimized.

## 7.1 Estimation of methane yield, reactor size and energy production

The amount of produced methane depends greatly on the amount of produced sludge. Since microorganisms produce methane from organic matter, this parameter has to be taken into account. The amount of organic matter can be assessed by multiplying the annual amount of sludge with organic matter content of the dried sludge. The amount of produced methane during one year was assessed by using equation (3)

$$Methane\ production = sludge\ production * VS - \% * production\ potential \quad (3)$$

Where Methane production is the amount of produced methane in one year [$m^3_{CH4}/a$]

Sludge production is the amount of sludge produced in one year [tonnes/a]

VS - % is the organic solid matter content [%]

Production potential is the potential amount of produced methane from one tonne of organic dry matter [$m^3_{CH4}/tVS$]

The production potential for methane when wastewater sludge is used as raw-material is 150 $m^3_{CH4}/tVS$ (Latvala, 2009). When assessing the amount of energy potential, the produced amount of methane must be multiplied with the specific energy content of methane. Used value for specific energy content for methane in this work is 10 kWh/ $m^3_{CH4}$. (Rutz, 2012)

The size of the reactor depends on the amount of produced sludge and the retention time of the sludge in the reactor. In this work, the conventional retention time of 21 days for mesophilic reactor is used in order to estimate the reactor size (Latvala, 2009). The volume of the reactor, according to Seadi, et al., 2008, is calculated by using equation (4).

$$V_R = \frac{Sludge\ production}{365/_{RT}} * f \tag{4}$$

Where $V_R$ is the volume of the reactor [$m^3$]

Sludge production is the produced amount of sludge in one year [$m^3$/a]

RT is the retention time of the sludge in the reactor [d]

f is the coefficient for over sizing the reactor [-]

There must be some excess room for the gas and the possible foaming phenomena. In addition, the amount of raw-material can increase in the future. Thus, the coefficient *f* must be taken into account in order to oversize the reactor. (Rutz, 2012)

When estimating the energy output of the system, it is assumed that combined heat and power (CHP) unit with a gas motor is used in order to produce both electricity and thermal energy for the utility's need. It is assumed that the electrical power conversion efficiency ($\eta_{el}$) is 25 % and thermal energy conversion coefficient ($\eta_{TH}$) 45 %. As anaerobic digester requires heat in order to operate, it is assumed that 5 % of the produced thermal energy is used for heating up the process. In addition, the electrical and thermal capacities are evaluated for the CHP unit. (Latvala, 2009)

$CO_2$ emissions are being evaluated in later chapter. This is done by setting up a zero emission factor for biogas as it is renewable energy source. $CO_2$ emissions are thus evaluated by assessing current emissions an energy production from biogas. The principle is that a proportion of energy purchased outside the utility could be replaced with $CO_2$ free biogas. Different emission factors are used for both electricity and thermal energy.

## 7.2 Economic assessment

In this work, a simple payback period model is used to define the limit for the investment costs of the biogas plant. The payback period model takes into account the prices and amounts of both electricity and thermal energy. Thermal energy in this case concerns district heat. In order to give more realistic estimation of investment costs, operation and maintenance costs are included by assuming their share to be 20 €/MWh (IBBK & energieZENTRUM, 2007). The investment costs of the plant are calculated for following situations:

- Plant has no financial support
- Investment support of 30 %
- Feed-in tariff of 45 €/MWh
- Thermal energy support of 50 €/MWh
- Both feed-in tariff and thermal energy support

In order to define investment costs, the payback period is assumed to be 12 years and 15 years, as the average lifetime of energy conversion equipment and the plant varies around 20 years (MicrE, 2013). Usually, after 20 year period the plant requires more maintenance. Feed-in tariff is also valid for 12 years. This means that the model will give answer for the maximum investment costs during each situation, if 12 or 15 years payback time is the target. The investment costs of the plant are calculated by using equation (5). (Manwell et al, 2009)

$$C_c = PP \ * \ (P_{el}E_{el}P_{TH}E_{TH}) - E_{tot}C_{O\&M} \qquad (5)$$

Where $C_C$ is the capital cost of the plant [€]

PP is payback period [a]

$P_{el}$ is price of electricity [€/MWh]

$E_{el}$ is production of electricity [MWh]

$P_{TH}$ is price of thermal energy [€/MWh]

$E_{TH}$ is production of thermal energy [MWh]

$E_{tot}$ is total production of energy [MWh]

$C_{O\&M}$ is operation and maintenance costs [€/MWh]

The calculation assumes also that produced electricity and thermal energy is either used at the plant or sold to the electric grid or district heating system. Thus, the wastewater treatment plant can either save in its energy bills or make profit from produced energy by selling it preferably during daytime, when electricity price is higher.

According to Kemin Vesi Oy, current electricity prices (in 2013) are 5,45 snt/kWh and 3,611 snt/kWh for electricity transfer. The combined total price of the electricity expressed as Euros per year is thus 90,61 €/MWh. As the wastewater treatment plant is connected into a district heating system, the cost of district heating is evaluated to be 65,35 €/MWh (Kemin Energia Oy, 2013). The price for the feed-in tariff is fixed to be 45 €/MWh and 50 €/MWh for thermal energy support, if the energy is going to utilization (based on Energiamarkkinavirasto, 2013). The amount of produced energy is estimated by using methods described in the chapter 9.1.1.

## 7.3 Results

Table (5) illustrates results for methane and potential energy production by using given values from Kemin Vesi Oy.

Table 5 Estimation of methane and potential energy production of methane in Kemin Vesi Oy

| Parameter | Value | Unit |
|---|---|---|
| Sludge production | 2796 | t/a |
| Dry matter content (TS) | 26 | % |
| Organic matter content (VS) | 19,5 | % |
| Production potential of methane | 150 | $m^3_{CH4}$/tVS |
| **Methane production** | **81783** | **$m^3_{CH4}$/a** |
| Energy content of $CH_4$ | 10 | kWh/$m^3_{CH4}$ |
| **Potential energy production** | **817830** | **kWh/a** |
| Sludge production by volume | 2330 | $m^3$/a |
| Hydraulic retention time (HRT) | 21 | d |
| Overdesign of the reactor size | 20 | % |
| Reactor size (VR) | 161 | $m^3$ |

The organic matter content of the sludge is high due to the fact that the sludge is pre-dried before anaerobic digestion process. The potential energy production value is the maximum theoretical rate for energy production from methane.

The amount of produced methane can vary annually as the amount of produced sludge varies. In future, the biogas potential can increase if new properties are connecting to the wastewater network. However, the amount of produced methane could be increased by mixing other raw-materials into the reactor, such as residuals from agriculture, since these materials often have higher methane production potential values.

Since irreversibilities take place during the energy conversion process, the efficiencies of the CHP unit for both thermal energy and electricity are included. Table (6) illustrates electricity and thermal energy after biogas conversion. Thermal energy output includes also the proportion of 5 % on thermal energy, which is used in the reactor.

Table 6 Capacities and electricity and thermal energy output after energy conversion of biogas in a CHP unit

| Parameter | Value | Unit |
|---|---|---|
| Potential energy production | 817830 | kWh/a |
| Electrical efficiency ($\eta_{el}$) | 25 | % |
| Thermal efficiency ($\eta_{TH}$) | 45 | % |
| **Electricity ouptut** | **204458** | **kWh** |
| **Thermal energy output** | **349622** | **kWh** |
| Electrical capacity of the motor | 23 | $kW_{el}$ |
| Thermal capacity of the motor | 40 | $kW_{TH}$ |
| Current electricity consumption | 833288 | kWh |
| Current thermal energy consumption | 775000 | kWh |

Based on the calculations presented in the table above, thermal energy converted from biogas could potentially satisfy roughly 45 % of the annual needs of heating at the wastewater treatment plant. In addition, roughly 25 % of the purchased electricity could be replaced by the electricity produced by the plant. The capacities estimated for the motor size result to the fact that stirling motor or micro turbine would be recommended for this scale energy conversion. Fuel cell being able to use methane as fuel could be also possible to apply for this scale.

As the energy produced by the plant could result directly to savings in terms of annual purchased energy, the plant could give economic benefit. In addition, if the produced energy is supplied to the grid or district heating network, feed-in tariffs could increase the economic profitability of the biogas facility. Table (7) illustrates the profit (or saving), which could be achieved by selling the produced energy or utilizing it on-site. In terms of economic profit, it would be wiser to sell produced energy, if feed-in tariff or support for thermal energy would be admitted for the plant. Here, it must be noted that feed-in tariff is valid only for biogas plants exceeding the capacity of 100 kW.

Table 7 Profit made from energy utilization/selling of biogas

| Parameter | Value | Unit |
|---|---|---|
| Current electricity bill | 76000 | €/a |
| Current district heating bill | 43000 | €/a |
| Total energy bill | 119000 | €/a |
| Price of electricity | 90,61 | €/MWh |
| Price of district heating | 65,35 | €/MWh |
| Electricity from biogas | 204 | MWh |
| Thermal energy from biogas | 350 | MWh |
| **Profit from energy without support** | **41374** | **€/a** |
| Feed-in tariff | 45 | €/MWh |
| Heating support | 50 | €/MWh |
| Feed-in tariff + heating support | 95 | €/MWh |
| **Profit from energy with feed-in tariff** | **50574** | **€/a** |
| **Profit from energy with heating support** | **58855** | **€/a** |
| **Profit from energy with feed-in tariff and heating support** | **68055** | **€/a** |

In terms of energy costs, the biogas plant could potentially reduce the energy costs of the wastewater treatment plant significantly, between 35 and 57 % considering the data and conditions during 2012 from Peurasaari wastewater treatment plant. Feed-in tariff and heating support would substantially increase the profit made from energy selling, if such an agreement is done. In future, if energy price is increasing, the plant could be even more economically viable by being able to produce energy for utility's needs.

The data from table above is used for energy profit when undertaking the assessment of investment costs of the plant. The limit for investment costs have been done in the case of support, with investment support of 30 %, feed-in tariff, heating support and with both heating support and feed-in tariff separately. Table (8) summarizes the limits for investment costs of the biogas plant if payback period is targeted to be 12 years.

Table 8 Limit for investment costs of the biogas plant

| Parameter | Value | Value | Unit |
|---|---|---|---|
| Payback period | 12 | 15 | a |
| O&M costs | 20 | 20 | €/MWh |
| **Investment costs without support** | **363505** | **454382** | **€/a** |
| **Investment costs with 30 % investment support** | **472557** | **590696** | **€/a** |
| **Investment costs with feed-in tariff** | **473912** | **564789** | **€/a** |
| **Investment costs with heating support** | **573279** | **716598** | **€/a** |
| **Investment costs with feed-in tariff and heating support** | **683686** | **827006** | **€/a** |

If investment support, feed-in tariff or heating support is applied to the biogas plant, Kemin Vesi Oy has, say, more choice to choose a proper process for sludge digestion. Without any kind of support, the maximum investment costs for the process would be 363505 €, which would not be enough to install such a system. However, chapter 8.3.2 will show that the biogas plant can have other considerable benefits.

According to the table above, investment costs exceeding the limit value would directly mean the raising of the payback period. For instance, if payback period of 15 years is acceptable, the water utility can have more capital in order to find out a suitable process for sludge digestion. However, in the case of feed-in tariff, which is valid for 12 years, the payback period would increase faster, since less profit is done by selling produced electricity.

Even though the main income for the investment cost assessment is energy, there could be also some other incomes in case of other raw-materials were used in the process. In Finland, a separate charge from materials entering outside the utility can be taken. This could bring extra income for the utility. However, as a financial point of view, the utility is the main responsible for financing the plant.

### *7.3.1 Suitable process for anaerobic digestion*

Anaerobic digestion of sludge from wastewater treatment plant has essential process components. The main components of the plant include a reactor, biogas storage, CHP-unit, post treatment unit for the digestate and storage for the digestate. If the reactor is not continuously fed, the sludge from the wastewater treatment process may also need storage. Figure (9) illustrates the basic components required by the anaerobic digestion plant.

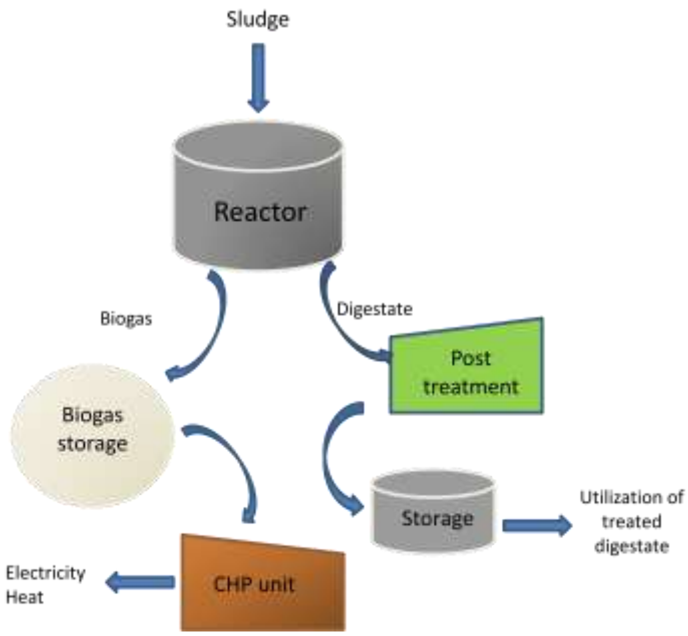


Figure 9 Basic process components required in anaerobic digestion of wastewater sludge

Since the dry matter content of the sludge is high (around 26 %), it is recommended to use dry process as a reactor (Latvala, 2009). In case of the pre-drying of the wastewater sludge at Peurasaari wastewater treatment plant would be removed, then a wet process would be more suitable as reactor design. In addition, reactor can be also mesophilic or thermophilic. Thermophilic reactor can result higher biogas yield and shorter retention time of the sludge in the reactor, but requires more energy in order to maintain higher process temperature.

The reactor can be also continuous or batch type of reactor. In continuous design, sludge is constantly fed into the reactor, whilst in batch type design, in proportion, the fed is separated into batches. Although the gas production from continuous reactor can be more predictable, stirring is required and investment costs can be higher compared to a batch reactor. (Rutz, 2012)

Storage for biogas is also required, since the gas production can fluctuate significantly. Biogas storage can be either external unit or integrated on the top of the reactor. Reactor integrated storage can have lower investment costs. There are also low cost biogas storages on the market using a plastic bag technology.

Finally, CHP-unit is fed with biogas from the storage. At this stage, biogas may require purification from impurities, such as $CO_2$ and $H_2S$. The requirements for purification are always depended on the type and properties of the CHP unit, and on the other hand, the properties of the produced gas.

Besides the production of biogas, anaerobic digestion produces also digestate. In order to utilize digestate, a post-treatment is required. Post-treatment can be done either by composting, incinerating the digestate or by using thermal dryer. The aim of the post-treatment is to stabilize the waste so that it does not cause environmental damage under utilization. During the treatment, pathogenic bacteria are also destroyed. As wastewater sludge is used as raw-material for the reactor, it is also possible to satisfy the criteria for digestate utilization by using a thermophilic reactor and appropriate retention time. Table (9) illustrates the possibilities for sludge post-treatment in the area of Kemi.

Table 9 Possible post-treatment technologies for sludge with advantages and disadvantages

| Post-treatment technology | Effect on smell reduction | Trasnportation costs | Hygienization of digestate | Effect on investment costs | Other benefits | Other disadvantages |
|---|---|---|---|---|---|---|
| Composting at Jätekeskus Jäkälä | + | − | + | ○ | Destroys pathogenic bacteria | Requires energy |
| Composting on site | − | ○ | + | + | Destroys pathogenic bacteria | Requires energy |
| Thermal drying | + | ○ | + | + | Destroys pathogenic bacteria | Requires energy |
| Incineration | + | ○ | ○ | + | Generates energy | Generates waste |
| Thermophilic process | ○ | ○ | + | + | Higher biogas yield, destroys pathogenic bacteria, post-treatment may not be necessary | Requires more energy for heating up the reactor |

+ positive
− negative
○ neutral

Currently, the dried sludge could be post-treated at Jätekeskus Jäkälä. However, transportation of sludge is required, which may cause emissions and noise, besides adding extra cost. For these reasons, on-site treatment would be recommended, even though investment costs would increase. On-site treatment would minimize transportation costs. However, there is a risk of smell in the case of on-site composting.

After post-treatment, storage for digestate may be required since it can be challenging to remove sludge continuously. Markets available for digestate can be also seasonal, and it is recommended that it should be possible to store the digestate for a few months. Other equipment required for biogas production includes a control unit, pumps and pipes. The utilization of electricity and thermal energy would need also extra installations.

### *7.3.2 Benefits of anaerobic digestion in Kemin Vesi Oy*

The utilization of biogas can have a benefit to produce energy in forms of electricity and heat for the utility's needs. Produced biogas could be also used as vehicle fuel, but in this case, the gas production should be greater. After the process has paid back its investment costs, the plant would be able to cut down the energy charge. In this way, the utility could make better profit. By reducing energy costs, it could be also possible that Kemin Vesi Oy would have reduced pressure on increasing the amount of water charge. If the drying process would be removed, energy savings and avoidance of maintenance costs could be also reached since energy would not be required for drying.

Anaerobic digestion of wastewater sludge has a benefit of being able to reduce the volume of the waste, whilst stabilizing it. In addition, it is possible to reduce odor emissions from the site. As sludge is currently being transported to Jätekeskus Jäkälä, transportation costs and emissions could be avoided by treating the sludge on site. In addition, further transportation costs of digestate compared to wastewater sludge could be lower since the size of the waste is reduced during the anaerobic digestion process.

Utilization of energy from biogas could reduce $CO_2$ emissions in case of Kemin Vesi Oy. As biogas is considered as renewable energy source, the emission factor for $CO_2$ emissions is zero. Currently, the production of district heat and electricity in Kemi is emitting $CO_2$ emissions. Table (10) illustrates these emissions and $CO_2$ savings, which could be reached if produced electricity and thermal energy from biogas replaced current fossil fuel based energy.

Table 10 $CO_2$ savings if produced biogas replaced equal proportion of fossil and wood fuels used in Kemin Energia Oy (factors based on Motiva b, 2012).

| Parameter | Value | Unit |
|---|---|---|
| Consumption of electricity | 833 | MWh/a |
| Consumption of heating | 775 | MWh/a |
| Production of electricity | 204 | MWh/a |
| Production of heating | 350 | MWh/a |
| $CO_2$ emissions factor for electricity | 210 | $kgCO_2$/MWh |
| $CO_2$ emissions factor for heating | 161 | $kgCO_2$/MWh |
| **Current $CO_2$ emissions** | **300** | **tCO2/a** |
| **$CO_2$ savings** | **99** | **tCO2/a** |

As seen from Table (10), $CO_2$ emissions could be potentially reduced significantly, around one third of current emissions. This action could also contribute to the climate strategy of the municipality of Kemi. Furthermore, the amount of other emissions could be also reduced, such as particle emissions.

Digestate from the reactor using wastewater sludge as raw-material can be utilized as a compost material in agriculture for landscaping. Especially for landscaping, the digestate offers suitable material properties being rich in different nutrients. Thus, digestate can replace other materials, such as chemicals, in landscaping. There are also markets available for the digestate, which can bring extra income to the utility if selling it.

Anaerobic digestion can bring also social benefits by reducing odor emissions, bringing new knowledge and create employment. Using of anaerobic digestion could also improve the image of Kemin Vesi Oy by being more environmental friendly company. All these impacts together can be evaluated through a sustainability assessment. Table (11) summarizes the positive impacts of anaerobic digestion in case of Kemin Vesi Oy.

Table 11 Environmental, economic and social impacts of anaerobic digestion.

| Environmental impact | Economic impact | Social impact |
|---|---|---|
| • Reduces CO2 and other emissions<br>• Hygienization of digestate | • Profit from produced energy<br>• Avoidance of transportation of wastewater sludge | • Reduces the amount of odors<br>• Improves the image of the utility<br>• Employment, knowledge |

Environmental and economic impact assessment is based on the prior calculations and literature. Social impact assessment is done by putting an enquiry to the council of the municipality of Kemi. In the enquiry, members of the council mentioned that the anaerobic digestion could bring employment to the municipality. The project could also have a positive effect on the value of the built environment, whilst improving the image of the utility. The council experiences the possibility of having anaerobic digester as an innovative solution, which could bring also innovation excursions to the area. Digestion of wastewater sludge could also reduce the amount of odors. (Miilumäki, 2013)

Anaerobic digestion technology may have some other positive impacts, which should be also taken into account. These impacts may include for example the security of the energy supply. Technologies can be also compared by assessing the robustness of the system as well as the possibility of decentralization of systems (Sørensen, 2011). In case of Kemin Vesi oy, anaerobic digestion could improve the grid dependency of the utility.

### *7.3.3 Troubleshoot and safety*

The properties of raw-material to the digester have a significant effect on biogas production. In this case, sludge is only fed to the reactor and it is important to observe sludge properties such as TS content and VS content. Still, these contents remain rather stable over a year. From this point of view, raw-material is not very often causing problems in this kind of digestion process. Still, a proper amount of feedstock must be introduced to the reactor between proper time intervals.

For appropriate methane yield, the retention time must be sufficient in the reactor. In addition, process temperature plays an important role. It is important to check these parameters, if the methane yield is low. For instance, heating surfaces must be free from obstacles and the insulation of the reactor must be proper. As the process is anaerobic, significant amounts of oxygen in the reactor can immediately affect to the methane yield.

Other significant parameter for microorganisms in the anaerobic digestion process is pH-value. Usually, an optimum pH-value for methanogenic bacteria is around 7,0 – 8,0. In addition, monitoring the amount of volatile fatty acids can indicate whether the process is instable or not. (Rutz, 2012)

Anaerobic digestion process produces hazardous compounds, such as $CH_4$, $H_2$ and $H_2S$. These compounds are explosive and can set up fire. Thus, continuous monitoring of concentration of these gases must be measured, and mixtures must be handled with care. Methane and $H_2S$ can be also very toxic gases if inhaled, being able to cause asphyxiation.

Hot surfaces can cause thermal shocks and risk of fire. CHP unit often involves hot surfaces, which must be avoided by users and maintenance personnel. These surfaces can be also found from the digester reactor heating unit. Safety risks can also origin from stirring or CHP unit involving mechanically rotating parts. In addition, electrical shocks from electric equipment are possible.

Anaerobic digestion process, especially if processing wastewater sludge, can have a high risk of contamination if leakage occurs. In addition, digestate can include contaminants if not treated properly (e.g. retention time and temperature are not sufficient). In these cases, pathogenic bacteria can act as a contaminant spreading diseases to the surrounding environment.

# 8 CASE TYRNÄVÄN VESIHUOLTO OY

Electricity produced by solar photovoltaic module is assessed in water pumping in case of Tyrnävän Vesihuolto Oy. Pumped water would be additional source to the utility. The preliminary energy assessment is done by assessing the energy consumption of a submersible pump. According to the energy consumption of the pump, a solar module is dimensioned to produce the same amount of energy than pumping requires.

Calculations are performed according to data given by Tyrnävän Vesihuolto Oy. Groundwater pumping depth in the area is around 6-8 meters and the desired pumping amount of water is about 50 000 $m^3$ per year by using 4-5 different intakes. In this work, pumping depth of 8 meters is used. As solar module is not able to produce substantial amounts of energy during insufficient irradiation periods, the system is dimensioned to produce the amount of energy required to pump desired amount of water annually. (Sarsila, 2013)

## 8.1 Power requirement for water pump

Power required for any water pump at certain fixed values can be roughly assessed by using equation (6). (Karttunen, et al., 2003)

$$P_p = \frac{\rho g Q H}{\eta_p} \tag{6}$$

Where $P_p$ = power requirement of the pump [W]

$\rho$ = density of water [1000 kg/$m^3$]

g = gravitational constant [9,81 m/$s^2$]

Q = discharge [$m^3$/s]

H = water head [m]

$\eta_p$= pump efficiency [-]

The amount of water head, H, depends on static water head the pump have to overcome when rising the water from the source to a reservoir. Often, H is referred as dynamic water head including also pressure losses in the pipe due to friction. However, in this work, as there is no constructed pipe system in desired water intake area, H takes into account only the static water head. In more detailed assessment, dynamic water head could be calculated by using Bernoulli's equation. In reality, the motor efficiency of the pump affects the total power requirement of the pump. Equation (7) defines the total power requirement of the pump, when motor efficiency is taken into account. (Karttunen, et al., 2003)

$$P_{tot} = \frac{P_p}{\eta_m} \tag{7}$$

Where $P_{tot}$ = total power requirement of the pump [W]

$\eta_m$ = motor efficiency [-]

Equations 6 can be substituted into equation (7), resulting to equation (8).

$$P_{tot} = \frac{\rho g Q H}{\eta_p \eta_m} \tag{8}$$

As power produced by solar photovoltaic system is often irregular, the pump cannot operate full year, or full day. However, if the desired amount of pumped water is known, the required amount of energy can be estimated by using equation (9). (Karttunen et al, 2003)

$$W = \frac{QH}{367\eta} \tag{9}$$

Where W = required amount of energy [kWh]

$\eta$ = pump and motor efficiency [-]

In this work, it is assumed that a submersible pump running with constant values is used in water pumping. As the pump will be rather small scale, the pump efficiency is set to 55 % and motor efficiency to 70 %, respectively. (CAE, 2013)

## 8.2 Power produced by PV system

In this work, the size and energy output of the PV system is assessed by following instructions set by the Finnish Ministry of Environment concerning building energy consumption. Säteri et al, 2012 gives guidelines for assessing the potential energy production of building integrated PV system. Calculation models do not take cable, inverter and battery losses into account. However, cable losses are included in this work to the energy potential assessment. (Säteri et al, 2012)

The power produced by PV cells is assessed by using equation (10).

$$W_{PV} = \frac{G_{sol} * P_{max} * F_{use}}{I_{ref}} \tag{10}$$

Where $W_{PV}$ = energy produced by the cell [kWh/a]

$G_{sol}$ = irradiation received by the cell [kWh/m$^2$]

$P_{max}$ = maximum power output during reference conditions [kW]

$F_{use}$ = coefficient of usage [-]

$I_{ref}$ = Reference irradiation [1 kW/m$^2$]

The coefficient of usage depends on whether the cell module is ventilated or not. Coefficients can be found from Appendix 2. In this work, it is assumed that the cell module will be slightly ventilated, as no assisting mechanical ventilation system is integrated with the PV system. Furthermore, as the equation does not take other losses (cable and inverter losses), this will be taken into account in calculations by setting up 8 % of power losses (5 % power loss in charge controller and 3 % losses in cables). (Twidell et al, 2006)

The irradiation received by the cell depends on the installation angles, namely azimuth and inclination angles, and these factors are taken into account by using equation (11).

$$G_{sol} = G_{hor} * F_{pos} \tag{11}$$

Where $G_{hor}$ = annual irradiation received by horizontal plane [kWh/m$^2$]

$F_{pos}$ = correction coefficient [-]

The correction coefficient takes into account the cardinal point and the inclination angle of the cell. In this case, it is assumed that the position of the cell is fixed. Thus, the correction coefficient can be calculated by using equation (12).

$$F_{pos} = F_1 F_2 \tag{12}$$

Where $F_1$ = cardinal point factor [-]

$F_2$ = Inclination factor [-]

The factors are defined by Säteri et al, 2012 and can be found from Appendix B. In this work, it is assumed that the cell is facing towards the South with an inclination angle between 30° and 70°.

From the equation (10), the parameter $P_{max}$ can be obtained in order to assess the scale of the cell required for delievering a certain amount of power. This can be done by matching the annual energy requirement of the pump (equation (9)) with the energy production of the cell during one year ($W_{PV}$). Parameter $G_{sol}$ is obtained from meteorological data measured in 2011, being 766 kWh/m$^2$ annually at latitudes of Tyrnävä. (Louis, 2013) The data includes also hourly irradiation levels. The area required for certain power output depends on the cell efficiency. The area of the cell can be calculated by using equation (13).

$$A_{cell} = \frac{P_{max}}{K_{max}} \tag{13}$$

Where $A_{cell}$ = area of the cell [m$^2$]

$K_{max}$ = peak power coefficient [kW/m$^2$]

The peak power coefficeint depends on the type of the cell. According to Säteri et al, 2012, $K_{max}$ for conventional silicon based solar cells varies between 0,10 – 0,18. In this work, value for $K_{max}$ is assumed to be 0,14, corresponding to 14 % efficient cell.

## 8.3 Economic assessment of PV system

The cost of the PV system is assessed by using the result $P_{max}$ obtained from PV power calculations. According to the rated power of the cell, the capital cost for the cell module and pumping system can be approximated. Payback period for the system can be assessed essentially by using the equation 5 presented previously by setting water price instead of energy price. Payback period can be thus assessed by using equation (14).

$$PP = \frac{C_c}{P_{water} * q_{water} - C_{O\&M} * W_{PV}} \tag{14}$$

Where $C_c$ = capital cost of the system [€]

$P_{water}$ = Water price [€/m$^3$]

$q_{water}$ = Quantity of pumped water [m$^3$/a]

$C_{O\&M}$ = Operation and maintenance costs of the system [€/kWh]

$W_{PV}$ = energy produced by the cell [kWh/a]

Operation and maintenance cost to the cell module and pumping system is assumed to be around 20 % of investment costs and water price is assumed to be 0,2 €/$m^3$. Water price includes water charge in the municipality of Tyrnävä and excludes organizational expenses and water treatment and supply costs. The capital cost of the system is assessed by utilizing the prices of solar cells provided by Finnwind Oy. (Finnwind 2013)

## 8.4 Results

Energy production of the module is calculated by using solar data from year 2011. (Louis, 2013) Based on give data, and hourly energy production is calculated for 4,4 kW size solar module facing South with an inclination angle of 45°. Results can be seen from Figure (10).

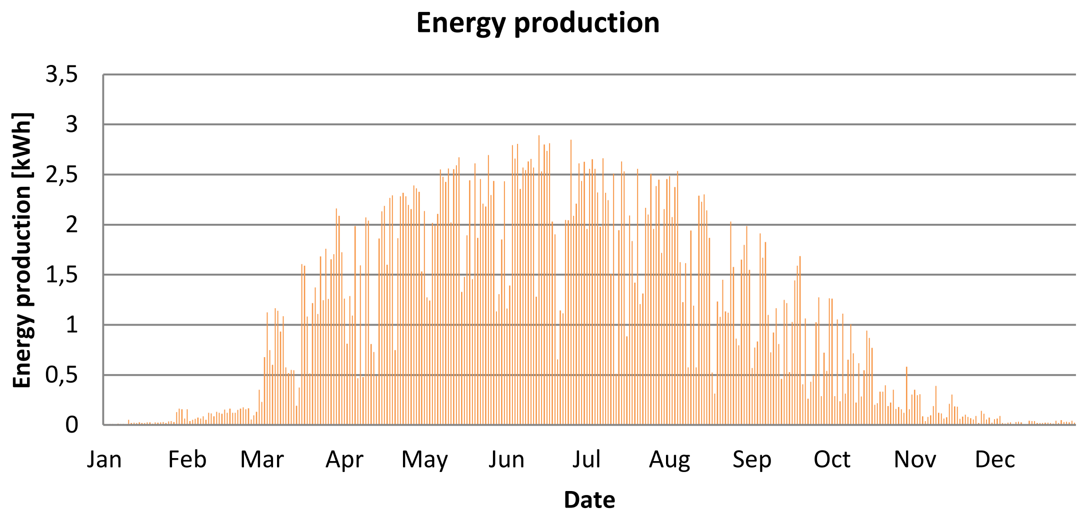


Figure 10 Energy production of the solar module according to weather data in 2011.

As Figure (10) indicates, energy production of the module varies significantly seasonally. Energy production is very low during winter period due to insufficient irradiation levels and greater during summer. In summer, energy production of the module can decrease during overcast periods. The amount of pumped water by the submersible pump is defined by module energy production. Figure (11) illustrates the pumped amount of groundwater in Tyrnävä according to energy production in Figure (10). Energy requirement for the pump is calculated for fixed pumping depth of 8 meters.

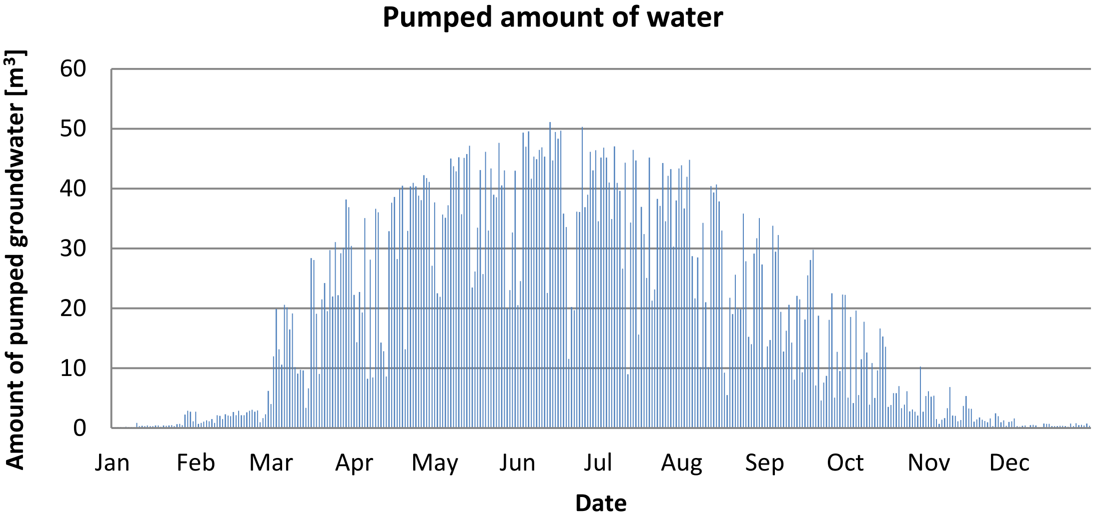


Figure 11 Pumped amount of groundwater according to energy production of the solar module

According to figure (11), groundwater can be pumped significantly during summer compared to winter period, when sufficient solar irradiation is not available. In addition, overcast periods decrease the amount of pumped water. During high irradiation periods, more than 50 $m^3$ of groundwater can be pumped daily. Even in spring, 30 – 43 $m^3/d$ could be pumped. Thus, considerable amount of water can be pumped from March to October.

As the total amount of pumped groundwater was desired to be 50 000 $m^3$ annually, 4,4 kW solar module was used in order to produce the required amount of energy. The cell area required for efficiency of 14 % is about 31,4 $m^2$. Parameter values for the solar module and pump can be seen from table (12). Table (12) also illustrates the total pumped amount of groundwater annually.

Table 12 PV module and pump parameters for pumping the desired amount of groundwater

| Parameter | Value | Unit |
|---|---|---|
| $G_{hor}$ | 766 | $kWh/m^2$ |
| $F_1$ | 1 | - |
| $F_2$ | 1,2 | - |
| $F_{pos}$ | 1,2 | - |
| $G_{sol}$ | 919,2 | $kWh/m^2$ |
| $F_{use}$ | 0,75 | - |
| $I_{ref}$ | 1 | $kW/m^2$ |
| $P_{max}$ | 4,4 | kW |
| $W_{PV}$ | 2791 | kWh/a |
| $A_{cell}$ | 31,4 | $m^2$ |
| $\eta_{pump}$ | 0,55 | - |
| $\eta_{motor}$ | 0,7 | - |
| H | 8 | m |
| **Amount of water** | **49289** | **$m^3$** |

The size of the module is calculated to be 4,4 kW. Care must be taken with the module size, as the calculation does not take into account the dust and snow on neither the module surface nor the effect of surrounding forest reducing energy production, the system can be oversized. However, prices and the size of the solar module is assessed to be 11 200 € for 4,4 kW module readily to be installed. The price includes the installation and cabling of the module. (Fortum, 2013) As the pumping is desired to organize from 4-5 different intakes, at least 4 pumps are being invested. The price of a borehole pump including cabling is estimated to be 1000 € (based on L-tuotanto Oy, 2013) Table (13) illustrates payback period of the system with described investment costs and other parameters.

Table 13 Payback period of solar PV pumping system

| Parameter | Value | Unit |
|---|---|---|
| Module price | 11200 | € |
| Pump price | 4000 | € |
| Capital cost of the system | 15200 | € |
| Water price | 0,2 | €/$m^3$ |
| Water quantity | 49289 | $m^3$ |
| Profit from pumped water | 9858 | €/a |
| Operation and maintenance costs | 3040 | € |
| **Payback period** | **2,2** | **years** |
| **Payback period with investment support of 30 %** | **1,7** | **years** |

As we can see from Table (13), payback period for the system, according to simple payback period calculation, is very short. This is due to the fact that after the investment, PV module is producing electricity, which means that no electricity must be purchased outside. Moreover, the price of the water per cubic meter is high, as water is sold to consumers. Thus, according to this calculation, the PV water pumping system is economically viable. If 30 % investment cost aid is obtained to the solar module, payback period can be even shorter. However, there are several uncertainties in the calculation, such as inflation. Furthermore, water prices and operation & maintenance costs are assumed values, which may be different in reality. Capital cost of the overall system may be also higher due to the fact that other systems, such as pipes may be installed in the area.

### *8.4.1 System components*

The system comprises essentially of the cell module, mounting system, cabling, charge controller and pump. The cell is producing electricity from the incoming irradiation, whilst the mounting system fixes the inclination angle and cardinal point of the cell module. Charge controller protects the system from electric malfunctions. The system components are illustrated in Figure (12).

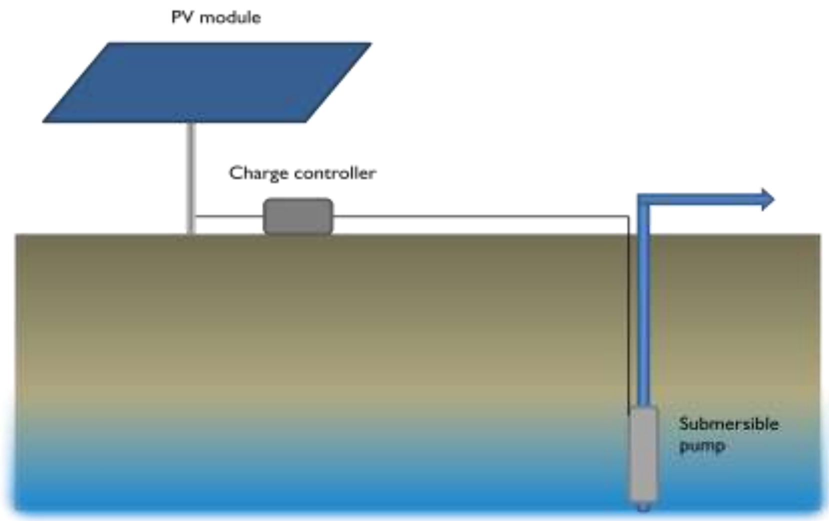


Figure 12 PV module system components in water pumping.

In this case, a battery system was not included. Water is pumped only when sufficient irradiation is available and added further to the existing water system. Moreover, there is also existing water storage nearby Kukkolanvaara. Pumped groundwater can actually flow to the storage by gravity. Thus, pumped water could be stored there. However, this kind of procedure might require a control system regulating the amount of groundwater coming from solar PV module and the amount of water coming from the existing system.

A variable speed motor submersible borehole pump running with direct current (DC) would most likely to be beneficial. During lower irradiation periods, the pump motor could reduce the motor speed according to the power available. Thus, smaller amounts of water could be pumped with lower power.

### *8.4.2 Benefits of PV system*

As the desired water pumping area in Kukkolanvaara is off-grid, any electricity line from existing electricity source may not be necessary to construct, if solar PV is used. Groundwater, which could be pumped when solar irradiation is sufficient, could be extra water for Tyrnävän Vesihuolto Oy. Water could be sold to consumers. At the same time, security of water supply could be improved. In addition, the PV module has an advantage to be able to produce energy to the pump during daytime, when water consumption is also higher compared to nighttime. Relatively cheap water pumping could decrease the pressure on increasing water charge in the municipality of Tyrnävä.

As an environmentally friendly technology, solar PV in Tyrnävä would not generate any $CO_2$ emissions, whilst utilized in water pumping. In addition, other air pollutants, such as particles, are not emitted. The system could improve the image of the utility, as water is pumped up by using renewable energy source. The utility could become a forerunner in using solar PV in water pumping in Northern areas. At the same time, Tyrnävän Vesihuolto Oy could become an interesting destination for visitors as well.

### *8.4.3 Troubleshoot and maintenance of PV system*

According to Fraas et al, 2010, the reliability of solar cell systems, taking into account cells, inverters, controllers, cabling and other components, is high. Still, electrical malfunctions associated mainly with inverters, controllers and PV modules may occur. If the PV module includes a tracking system, mechanical malfunctions may be also possible. In addition, a charge controller is an essential part of the system by protecting other electric equipment, such as the battery, from overload or total discharging. (Fraas et al, 2010)

The power output of the PV cell must be maximized by facing the cell towards the South. The angle of the cell commonly in Northern latitudes varies between 30 and 90°, depending on in which season power output is intended to be maximized. Thus, the inclination angle of the cell should be optimized and considered with care. The installation should be also free from any shading; Shading can substantially decrease the performance of the cell. Shading can origin for instance from surrounding forest or buildings. In addition, the charge controller must be placed properly by protecting these systems from over-heating, too cold temperature and moisture. (NAPS, 2009)

The temperature of the cell may affect the cell efficiency. As the cell temperature increases, the efficiency tends to decrease and vice versa. (Nelson, 2004) Thus, proper ventilation of the cell is essential. Avoiding the placing of cells near black surfaces is preferable. Furthermore, the cleaning of the cover glass of the cell is also necessary maintenance routine, since dust, for instance, can decrease the transmittance of the cover glass and hence affect the cell efficiency and overall power output. (Elminir et al, 2006) During winter period, snow accumulating on the cell glazing must be removed as the efficiency of the cell may decrease significantly due to snow blocking away irradiation. (Marion et al, 2013) In addition, water pipes and pump must be protected from freezing.

During lower irradiation periods, the pump may not be able to supply substantial amount of water. This is also due to the fact that the pump can require more energy when it starts to operate. It could be also possible that more than one pump are installed in different intakes. Thus, it may not be possible to operate pumps simultaneously during lower irradiation periods. In addition, the groundwater resource may move to drier or deeper direction during certain periods, when less precipitation is available to fill the water source.

# 9 SUMMARY AND CONCLUSIONS

This work was done as a part of WARES-project (Water Asset Renewable Energy Solutions) funded by European Union. In the theory part of this thesis, the aim was to study the organization of water services in Finland, including also legislative perspectives. Financial model for water services and the role of Public Private Partnerships (PPP) was carried out as well. It was found out that Finnish water utilities are offering the supply and distribution of domestic drinking water, management of wastewater and sludge, storm water management, management of industrial and commercial water and wastewater and management of drainage water from building foundations. Water utilities are publically owned, co-operatives, shareholder companies or partnerships. The operation of utilities is greatly regulated by EU Directives and Finnish legislation, and many operations utilities offer are outsourced to the private sector. The operation of the utility is mainly funded by water charges consisting of usage, fixed, service and joining charge, depending on the structure and organizational level of the utility.

In the energy part of the theoretical section, the study included the energy consumption of water utilities and commercialized renewable energy technologies suitable for energy generation in Northern conditions. The study underlined that water pumping and advanced wastewater treatment processes can greatly contribute to the overall energy consumption of the utility. Brief insight for sustainability impact assessment was also performed. Studied renewable energy technologies included solar photovoltaic, solar thermal collectors, wind power, anaerobic digestion, hydro power and heat recovery from wastewater.

In the experimental part of the work, the aim was to map out water utilities located in Northern Finland in order to find out whether these utilities are utilizing renewable energy or not. The target was to find utilities interested in renewable energy conversion. As a result, two water utilities, Kemin Vesi Oy and Tyrnävän Vesihuolto Oy, were chosen to the project and suitable renewable energy technology for each case was discussed with utilities. As a result, energy potential and economic calculations for each case were performed in order to assess the viability of these technologies.

The potential of anaerobic digestion in case of Kemin Vesi Oy was assessed. Energy analysis included the potential production amount of methane by using dried sludge as feed. According to given data by Kemin Vesi Oy, the sludge production from wastewater treatment plant in 2012 was 2769 tonnes/year, with VS-content of 19,5 % (organic matter content). The amount of produced energy was calculated to be 204 458 kWh of electricity and 349 622 kWh of thermal energy, when assuming the conversion efficiencies of 25 % for electricity and 45 % for thermal energy conversion, respectively. Energy conversion from produced biogas could potentially satisfy roughly 45 % of heating needs and roughly 25 % of electricity needs at the wastewater treatment plant. Whilst performing economic calculations, it was noticed that installation costs of the system can be rather high with, if desired payback period is 12 or 15 years, thus setting a barrier for the installation of the system.

Despite of energy production, anaerobic digestion of wastewater sludge in Kemin Vesi Oy could provide other advantages by being able to reduce $CO_2$ emissions approximately 33 %, controlling the amount of odors and reducing the specific volume of sludge. As sludge is currently being transported to waste handling center Jäkälä, transportation costs could be avoided by treating wastewater sludge on the utility's site. Anaerobic digestion process was also found to be acceptable according to the city council of the municipality of Kemi.

The potential of solar photovoltaic energy in pumping of additional drinking water in Tyrnävän Vesihuolto Oy was studied. According to energy analysis based on solar data in 2011, 2791 kWh of energy could be provided annually by having 4,4 kW size PV module. PV module size would be 31,4 $m^2$ with 14 % efficiency. Produced energy would be directly used by a submersible borehole pump pumping groundwater from the depth of 8 meters. Pumped water would be further stored in an existing water tank. As a result, approximately 50 000 $m^3$ of water could be pumped with four pumps. Most of water would be pumped during summertime, when greater amount of irradiation is available. In wintertime, the amount of pumped water is small due to the fact of insufficient irradiation received by the PV module surface.

Water pumping with solar energy in Tyrnävä could be economically very feasible, as payback period was calculated to be 2,2 years without any investment support and 1,7 years with solar module investment support of 30 %, respectively. However, many uncertainties, such as inflation and changing water value take place. Energy production of PV module can be also significantly disturbed by surrounding forest, causing large error to the calculation of energy production. There are also numerous assumed values for parameters such as operation & maintenance costs. Capital cost of the overall system may be also higher due to the fact that other systems, such as pipes may be installed in the area.

The conclusion of this study is that there is a water-energy – nexus existing in water utilities. The study in case of Kemin Vesi Oy shows that energy can be produced by digesting wastewater sludge into methane. At the same time, anaerobic digestion can be also considered as a water-waste-energy – nexus process as wastewater sludge is treated in a proper way. In addition, in case of Tyrnävän Vesihuolto Oy, solar PV panels in water pumping could be used in additional water pumping in off-grid area. Thus, case-specific hidden energy potential can be utilized to provide energy to water utilities in Northern Periphery Area.

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## Appendix I Contacted water utilities

| Utilities being contacted | Answered | Interested in project | Pilot case |
|---|---|---|---|
| Kemin Vesi Oy | **Yes** | **Yes** | **Yes** |
| Meri-Lapin Vesi Oyj | Yes | Yes | No |
| Tyrnävän Vesihuolto Oy | **Yes** | **Yes** | **Yes** |
| Keminmaan Vesi Oy | No | - | |
| Ranuan Vesihuolto Oy | No | - | |
| Rauman Vesihuolto | Yes | No | |
| Napapiirin Vesi | No | - | |
| Haapajärven Vesi Oy | No | - | |
| Iin Vesiliikelaitos | Yes | No | |
| Kempeleen Vesihuolto Oy | No | - | |
| Limingan Vesihuolto Oy | No | - | |
| Muhoksen Vesihuolto Oy | No | - | |
| Nivalan Vesihuolto Oy | No | - | |
| Oulun Vesi | Yes | No | |
| Pyhäjokisuun Vesi Oy | No | - | |
| Vihannin Vesi Oy | No | - | |
| Vetelin Vesihuolto | No | - | |
| Kajaanin Vesi | No | - | |
| Sotkamon Vesihuolto | No | - | |
| Vaalan Vesihuolto | No | - | |
| Joensuun Vesi | No | - | |
| Kuopion Vesi | No | - | |
| Jyväskylän Seudun Puhdistamo Oy | Yes | No | |

# Appendix 2 Calculation data for solar cells

| Cardinal point factor | $F_1$ |
|---|---|
| South/South-East/South-West | 1 |
| West/East | 0,8 |
| North/Nort-East/North-West | 0,6 |

| Inclination angle | $F_2$ |
|---|---|
| < 30° | 1 |
| 30° - 70° | 1,2 |
| > 70° | 1 |

| Type of installation | $F_{use}$ |
|---|---|
| Ventilation free module | 0,7 |
| Slightly ventilated module | 0,75 |
| Strongly ventilated or mechanically ventilated module | 0,8 |