WARES PROJECT PUBLICATIONS

Best Practices in Water Asset Utilization for Renewable Energy Generation

in Finland, Norway, Scotland, Northern Ireland and Ireland

Victor Pavlov, Lauri Mikkonen and Eva Pongrácz

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Introduction

This report is published within the Water Asset Renewable Energy Solutions (WARES) project. WARES is a two-year strategic project of the Northern Periphery Programme, which explores the opportunities to generate renewable energy at water utility assets. The project is led by the International Resources and Recycling Institute in Scotland, in partnership with Action Renewables in Northern Ireland, Mayo County Council and Clár-ICH in Ireland, Narvik Science Park and Northern Research Institute in Norway, and the University of Oulu in Finland. The Northern Periphery region and the location of partners is illustrated in Figure 1.

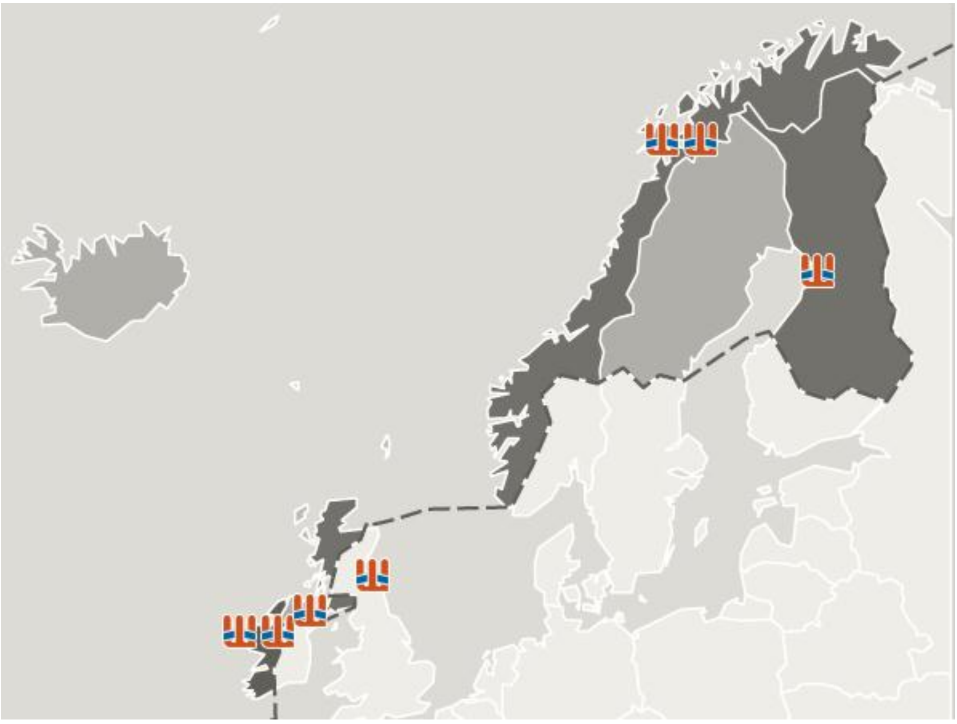

Figure 1. Map of the Northern Periphery area with the locations of WARES project partners

The aim of WARES is to provide innovative renewable energy solutions to remote areas by finding unused opportunities for renewable energy generation within the activities and property of the water sector. WARES will establish partnerships between the water industry and neighbouring communities and help sourcing the capital investment required to commercialise these opportunities, such as creating Public Private Partnerships.

This report briefly outlines different renewable energy technologies, which are currently explored in the water sector. It illustrates good practices of implementation of renewable energy solutions in the Northern Periphery Region. In addition, WARES pilot projects of utilization of water assets for renewable energy generation in Finland, Norway, Scotland, Northern Ireland and Ireland are discussed.

1 Renewable energy solutions and good practices in the water sector

Renewable energy solutions are often utilized to provide residential and other municipal buildings with energy supply. 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 the 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)

The European Commission has forced in the 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 State. The Directive obligates all Member States to produce 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 be 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. For Norway this value should be 67,5%, for Scotland – 30%, for Ireland – 16%. (BEFSCI, 2010; Ministry of Petroleum and Energy, 2012; Scottish Government, 2011) Northern Ireland has set targets for electricity and heat consumption from renewable energy sources of 40% and 10%, respectively (NSIPA, 2013). 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 pumps 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)

Currently, there are some good practices available. In this report anaerobic digestion, hydropower, wind energy, solar energy as well as aero-, hydro- and geothermal solutions (heat pumps) are considered suitable for the Northern Periphery Region: Finland, Norway, Scotland, Northern Ireland and Ireland. The principle of operation of these technologies has been explored in earlier theses (e.g. Kauriinoja 2009, Caló 2011 and Mikkonen 2013). Therefore, only brief explanations and general characteristics are given in this report. In addition, several WARES project pilot sites are discussed. Depending on water asset, hydropower, solar and wind energy solutions are utilized. Pilots are described in terms of their type, energy use, water asset availability, energy production, cost of implementation of renewable energy and payback period. Location and illustration of pilot sites are also provided.

Energy use of water and wastewater treatment 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, wastewater treatment consumes approximately 7 percent 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)

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 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 consists usually larger fraction 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 requires 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 and Norway 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, or can generate a substantial pressure loss over separation surfaces. Thus, these kinds of technologies can increase the energy consumption at the treatment phase, depending on the system used before. (Pearce, 2007)

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 also shares 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)

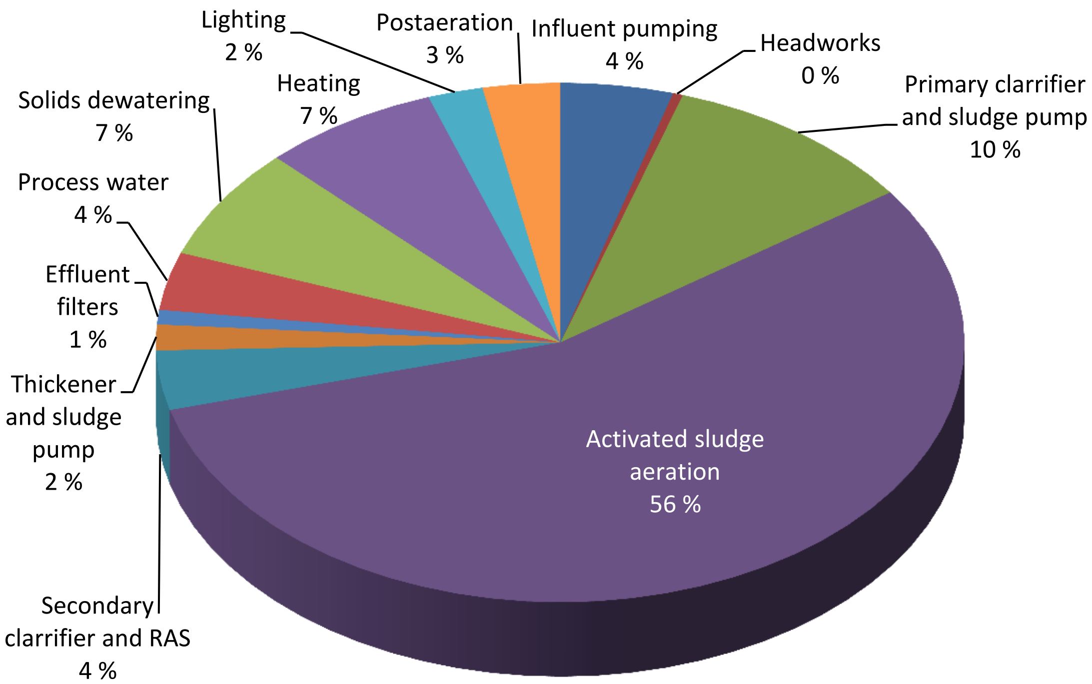

Figure 2. Energy breakdown of wastewater treatment plant with activated-sludge treatment (Based on Tchobanoglous, et al., 2004)

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 the raised pressure by the compressor. Efficient air supply of air 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 part is primary clarifiers and pumping. Also the 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)

2 Anaerobic digestion

Anaerobic digestion is a biochemical process of organic matter conversion into flammable gas, or biogas, and digestate, occurred in the condition of oxygen absence and microorganisms' presence. These two conditions are considered as a driving force of the process. The technology is normally applied by using of airtight containers, also known as digesters. The chemical composition of generated biogas is about 30–50% carbon dioxide (CO_2), 50–70% methane (CH_4) and traces gases, mostly represented by nitrogen. A lot of various wet organic feedstocks (e.g. food waste, manure, and wastewater) are utilized to get the final product. Due to minor presence of some other chemical substances and potential threat of damage of energy conversion units, biogas usually undergoes appropriate treatment (Rutz, 2012). In addition, it can be upgraded to higher quality gas with only methane composition. Apart from biogas there is formation of digestate as an output product that can be utilized on agricultural field as soil fertilizer. (IPCC, 2011) 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)

The biogas ranges of application are, for example, local heating, district heating or combined heat and power in small capacity plants in boilers, internal combustion engines and gas turbines. 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. (Rutz, 2012; Holm-Nielsen, *et al*., 2008) After special treatment and compression it can be also used as a vehicular fuel. (IPCC, 2011) Typical scale of anaerobic digesters is from small-scale installations of 0,1 MW to large-scale factories of 20 MW.

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, *at 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, *at el*., 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 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)

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)

Good practices of biogas generation

In Finland, in 2011, there were around twenty municipal and industrial anaerobic digestion facilities with biogas production from wastewater sludge. The total energy production through the biogas utilization was about 145 GWh. (Bionova, 2009; Kauriinoja, 2010; Rintala, *et al*., 2012). One of the plants that treats wastewater sludge and produces biogas is located in Vampula. The biogas production plant uses municipal sludge and organic waste as a feedstock for anaerobic digestion. As a result, 8 000 MWh of power and 9 000 MWh of heat is produced on an annual basis. (Vambio, 2014) Other biogas production plants based on wastewater treatment facilities are situated in Espoo and Turku (Biovakka, 2009; Rintala, *et al*., 2012). In Turku, biogas is utilized with production of heat and power. The amount of generated power is 4 MW. The heat is used in district heating. (Biovakka, 2009) In Jyväskylä, electricity is produced after anaerobic digestion process from biogas by using a 157 kW motor. Produced electricity is sent to compressors supplying air for aeration process. Similarly, in Tampere, produced biogas is converted into electricity and thermal energy. Produced electricity, afterwards, is used as additional energy at the wastewater treatment plant. (Latvala, 2009) By 2015, 0,2 TWh of energy can be potentially produced via utilization of sewage sludge in anaerobic digestion in Finland (Rintala, *et al*., 2012). In Kemi wastewater treatment plant, there was an estimation work done on potential energy utilization contained in wastewater. The plant consumes about 835 000 kWh of electricity and 775 000 kWh of heat on an annual basis. By implementing anaerobic digestion, one fourth of electricity needs and around half of heat demand can be covered. In connection with this, corresponding reduction of CO_2 is also possible. The potential emissions reduction constitutes one third of CO_2 emissions in 2012. (Mikkonen, *et al.*, 2013a)

In Norway, anaerobic digestion is also utilized in wastewater treatment plants. In 2010, out of 34 biogas producing facilities 24 were based on sewage sludge utilization (Rojas, 2011). For example, HIAS plant in Hamar provides wastewater treatment for the city and surrounding towns of 90 000 people. Sludge from the process serves as a feedstock for biogas production. (Cambi, 2008) In Stavanger, Oslo, Fredrikstad, Bergen, Verdal, Lillehammer and Drammen, there are biogas production plants working on sewage sludge as raw material. In all cases generated energy is used mainly to supply plants with heat and power and make it self-sustaining. In Fredrikstad, Stavanger and Oslo, there are also upgrading facilities to purify biogas and convert it to biomethane, a gas that is close to properties of natural gas. To illustrate, in Fredrikstad and Oslo, some of local buses and taxis are biomethane-fueled. Oslo Bekkelaget sewage treatment plant supplies with biofuel waste collection trucks. (Baltic Biogas Bus, 2012) There are also plans to run local bus fleet of the city of Oslo with biomethane. The Bekkelaget plant treats 40% of sewage produced in Oslo that is approximately 290 000 person equivalent. The annual amount of produced biogas is about 3 600 000 Nm^3, or 20 000 MWh in energy equivalent. (World Water, 2009)

In Scotland, there are also anaerobic digesters applied in wastewater treatment works. (Scottish Water, 2014a) In Aberdeen, there is a wastewater treatment plant operated by Scottish Water. It treats sewage from 350 000 people. Some sludge is imported from adjacent areas. There are two 4 000 m^3 anaerobic digesters which produce biogas and fertilizer. The biogas is sent to co-generation facility and converted into heat and power. The amount of produced electricity is 1 MW per year. (Cambi, 2007) Another wastewater treatment plant of Scottish Water that produces biogas is located in Edinburgh. There are six digesters of 2 500 m^3. Biogas is utilized to generate steam and 2,5 MW/year of electricity. As a by-product, fertilizer is produced. (Cambi, 2013) Some Scottish Water biogas production facilities are based on co-digestion and use not only sewage sludge but also food waste as feedstocks (Scottish Water, 2014a).

In Ireland, there are examples of utilization of anaerobic digestion technology at wastewater treatment works. A Dublin plant has three digesters to treat sewage sludge and produce 45 000 m^3 of biogas per year. As a result of biogas-to-energy conversion steam, 4 MW of electricity and biofertilizer are produced annually. (Cambi, 2009)

3 Solar photovoltaic and thermal technologies

Solar photovoltaic solution

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 energy is converted into electricity using photovoltaic (PV) cells. A group of these cells can be mounted together into a solar panel. The PV cells are made out of layers of semiconductor material such as silicon. When sunlight shines on the semiconductor a negative charge is created on one side of the surface and a positive charge on the other. This creates a voltage. The two sides of the cell are connected to a load and as the current flows from one side to the other, electricity is generated. (IPCC, 2011) Solar cells are 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) Usually, solar panels have power production values of 20 to 500 W_p (Mikkonen, 2013).

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, 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 3 below illustrates the sum of yearly irradiation on optimally inclined south oriented solar cell in Europe. As Figure 3 illustrates, the yearly sum of solar irradiation is around 1000 kWh/m^2, being a considerable amount of energy. However, only a part of this can be converted to electricity. (Sørensen, 2011) 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)

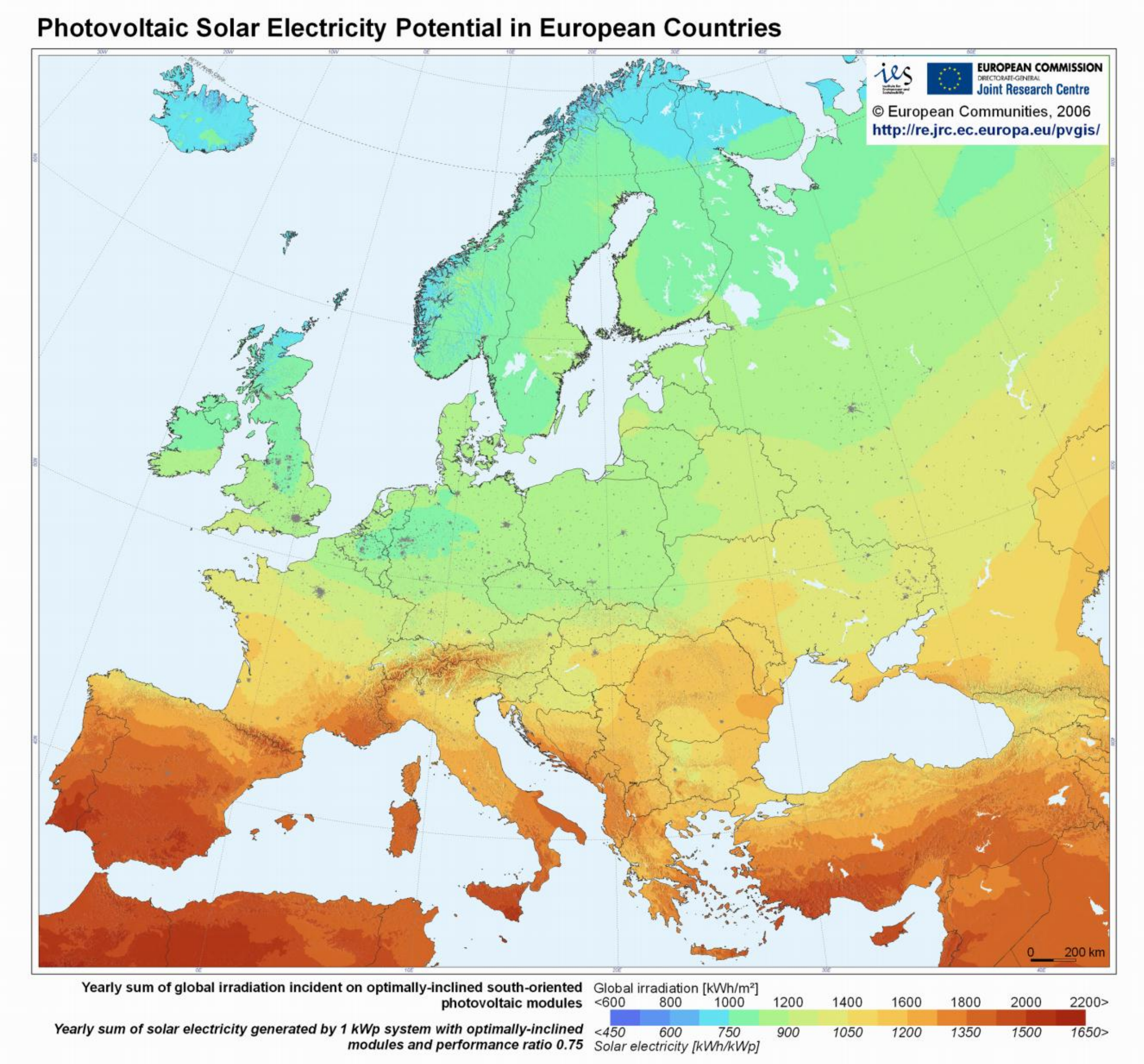

Figure 3. Yearly sum of global irradiance in Europe. (JRC a, 2006)

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 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 for conventional electric applications, but also for water pumping. (SEAI, 2010; Gopal, *et al*., 2012)

Solar thermal solution

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)

Good practices of solar energy utilization

A pilot project of solar energy utilization for groundwater pumping was considered in Tyrnävä, Finland. Tyrnävä is a small municipality close to Oulu (Figure 4). 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 495 km^2. Tyrnävän Vesihuolto is treating and supplying drinking water to the citizens of the municipality. The water utility was considering water abstraction from a new location with good water quality; however, the area is off-grid, hence exploring a solar photovoltaic solution for groundwater pumping. The location of the groundwater area, Kukkolanvaara, is illustrated in Figure 5. Solar PV was considered to be utilized during periods of sufficient solar irradiation.

Figure 4 *Location of Tyrnävä in Finland*

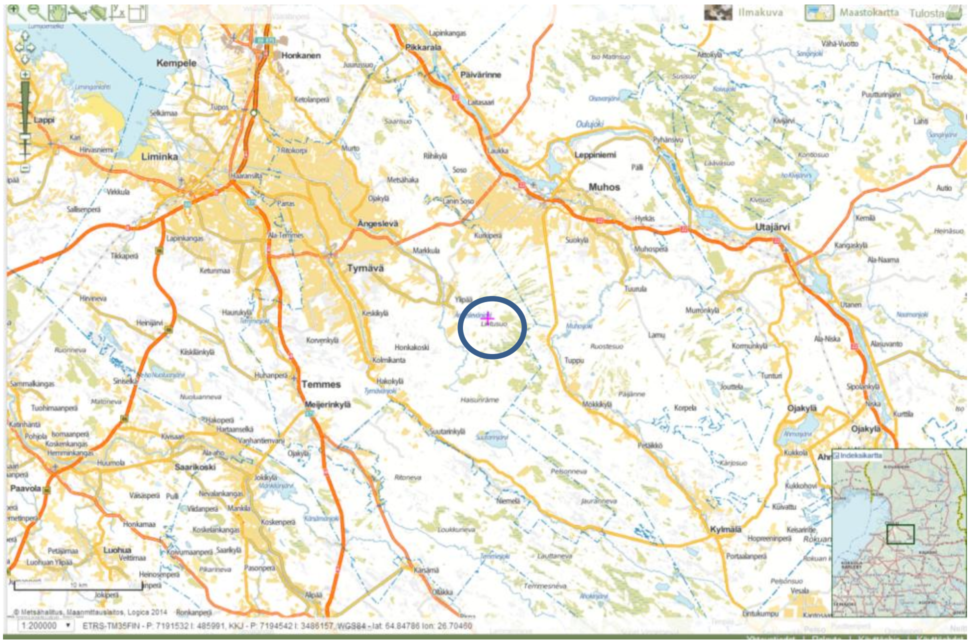

Figure 5. Location of Tyrnävä groundwater area

Pumped water would go straight to the existing treatment plant, and further to end-users. The results for energy production and pumped amount of groundwater are illustrated in Figures 6 and 7. In an ideal situation, ~50 000 m^3 of groundwater could be pumped annually. Table 1 illustrates the economics of solar PV.

The calculations made various assumptions, however, the system seems very profitable.

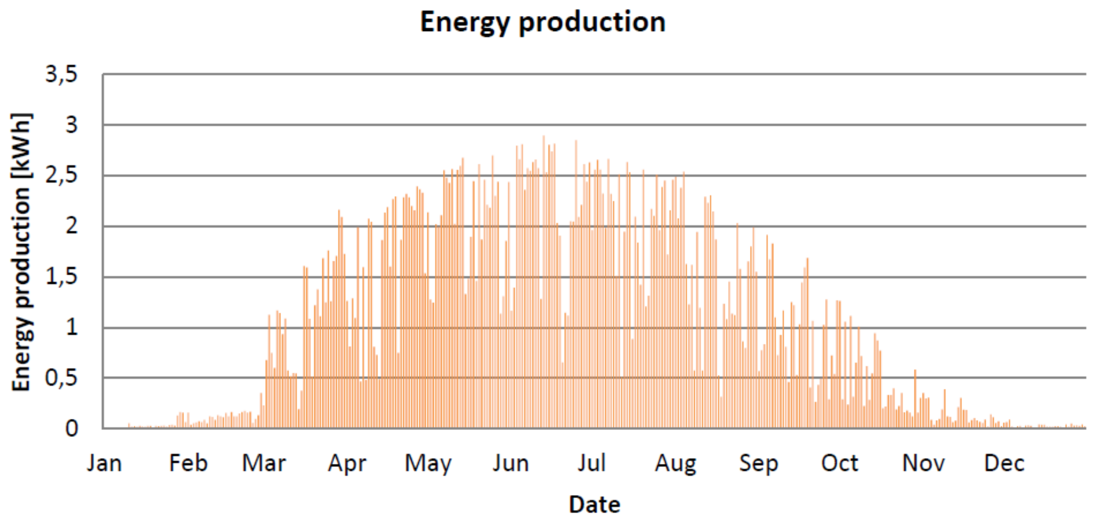

Figure 6. Energy production of PV in Tyrnävä

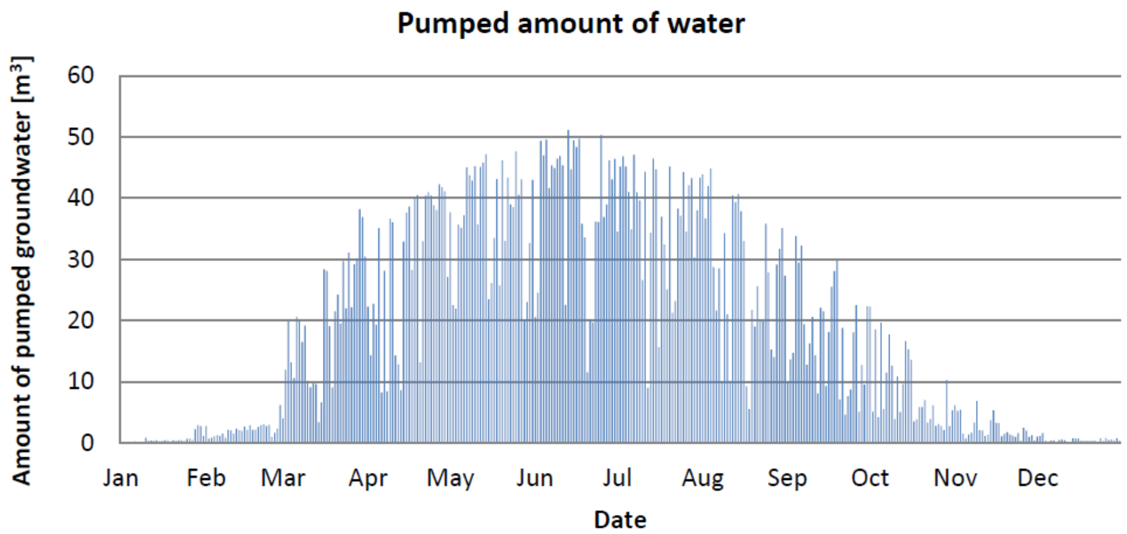

Figure 7. Pumped amount of groundwater in Tyrnävä

Table 1. Economic calculation of PV in Tyrnävä

	VALUE	UNIT
MODULE PRICE:	*11 200*	*€*
PUMP PRICE:	*4 000*	*€*
CAPITAL COST OF THE SYSTEM:	*15 200*	*€*
WATER PRICE:	*0,2*	*€/m*^{3}
WATER QUANTITY:	*49 289*	*m*^{3}
OPERATION AND MAINTENANCE COSTS:	*9 858*	*€/a*
PROFIT FROM PUMPED WATER:	*3 040*	*€*
PAYBACK PERIOD:	*2,2*	*years*
PAYBACK PERIOD WITH INVESTMENT SUPPORT 30%:	*1,7*	*years*

Regarding system components, it consists of a cell module, a mounting system, cabling, charge controller and pump (Figure 8). 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.

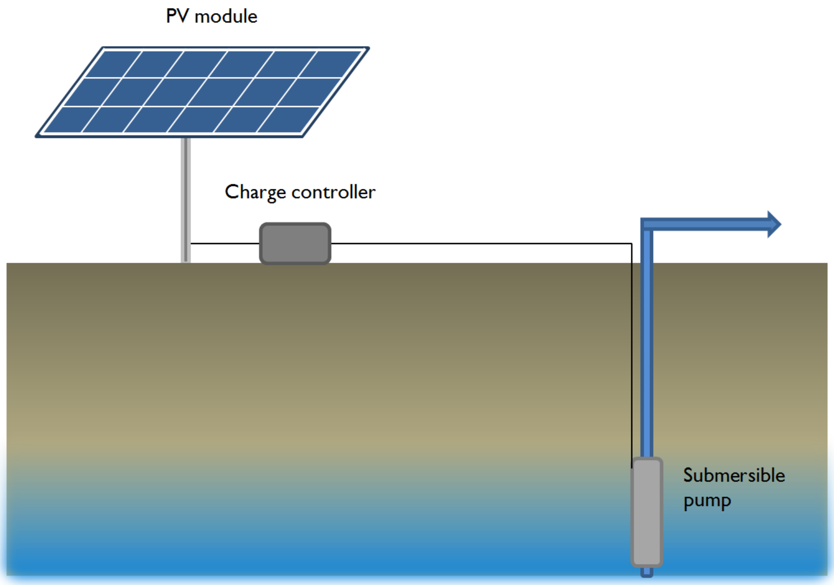

Figure 8. PV module system components in water pumping

A battery system was not included, water is pumped only when sufficient irradiation is available and added further to the existing water system and pumped groundwater can flow to the storage by gravity. 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.

To sum up, in Tyrnävän Vesihuolto Oy, the potential of a solar pump was evaluated and found economically feasible. As the potential water pumping area in Kukkolanvaara is off-grid, solar PV could be used to avoid the construction of power lines. Groundwater would be pumped only when solar irradiation is sufficient and fed to the existing storage by gravity flow. This relatively cheap water pumping system could increase security of water supply and decrease water charges.

Solar panel installations are set on Scottish Water assets to generate power (Scottish Water, 2014a). There are six solar panels are installed as an *in situ* water asset utilization. Each solar panel produces annually 0,2 GWh of electricity. This supplies water treatment works with up to one fourth of their electricity demand. There are solar panels embedded on the roof of buildings as it is at Carron Valley (North Lanarkshire), Balmore (Glasgow), Blairlinnans (West Dunbartonshire); as well as installed on the ground of the Scottish Water land assets as it is at Mannofield (Aberdeen), Spey Valley (Aviemore) and Forehill (Peterhead). (Scottish Water, 2014b)

WARES solar pilot projects

Figure 9 illustrates a WARES pilot in Loughmacrory in Northern Ireland. There are numerous renewable energy projects in Ireland within the water sector. Within WARES, two of the projects are related to Group Water Schemes (GWS). One of them, in Killaturley, is shown in Figure 10. The second one, in Kilmeena, is described in Figure 11. Another Irish solar WARES project – the Achill Island Central project - is shown in Figure 12.

WARES pilot site: Loughmacrory, Northern Ireland

In Loughmacrory, there are plans to implement solar energy solution on the land belonging to Northern Ireland Water. The renewable energy implementation is projected in a club building. The roof area of 560 m^2 of the building is planned to be used for solar panel installation.

The potential estimated for solar energy is 80 kW. The possible annual energy savings can be up to 2 750 euro. The capital cost of the solar panels is projected to be about 86 000 euro. The payback period is up to 20 years.

Solar PV

Type: *water utility*

Energy use: *37 800 kWh*

Water asset: *infrastructure*

Energy production: *37 500 kWh*

Cost of RES: *86 000 €*

Payback: *20 years*

Figure 9. Solar WARES pilot in Loughmacrory, Northern Ireland (ARNI, 2014; D-maps.com, 2014c)

WARES pilot site: Killaturley, Ireland

This WARES pilot project considers implementation of solar energy. The Group Water Scheme supplies 400 domestic users. After implementation of the project, it will be possible to gain energy savings. The capital cost of the 25 kW solar panel installation is about 52 000 euro. The payback period is 17 years.

Solar PV

Type: *water supply plant*

Energy use: -

Water asset: *infrastructure*

Energy production: -

Cost of RES: *52 000 €*

Payback: *17 years*

Figure 10. WARES pilot in Killaturley, Ireland (D-maps.com, 2014a; NPP, 2014a)

WARES pilot site: Kilmeena, Ireland

In Kilmeena, water supply plant serves 405 households. There are also plans to utilize water assets and install solar photovoltaic panels totaling 8 kW capacity. The estimated capital cost is around 17 000 euro. The time to recover return on investments is 13 years.

Solar PV

Type: *water supply plant*

Energy use: -

Water asset: *infrastructure*

Energy production: -

Cost of RES: 17 *000* €

Payback: *13 years*

Figure 11. WARES pilot in Kilmeena, Ireland (D-maps.com, 2014a; NPP, 2014a)

WARES pilot site: Achill Island Central, Ireland

In Ireland, in the Achill Island Central project the implementation of solar panels (10 kW) is considered to power a wastewater treatment plant serving 4 000 people. The capital cost for the solar energy solution is 17 000 euro. The projected production of energy is 9 MWh. The payback period is about 12 years.

Solar PV

Type: *wastewater treatment plant*

Energy use: *160 000 kWh*

Water asset: *infrastructure*

Energy production: *9 000 kWh*

Cost of RES: 17 *000* €

Payback: *12 years*

Figure 12. Solar WARES pilot in Achill Island Central, Ireland (D-maps.com, 2014a; MayoCoCo, 2014)

4 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 13 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)

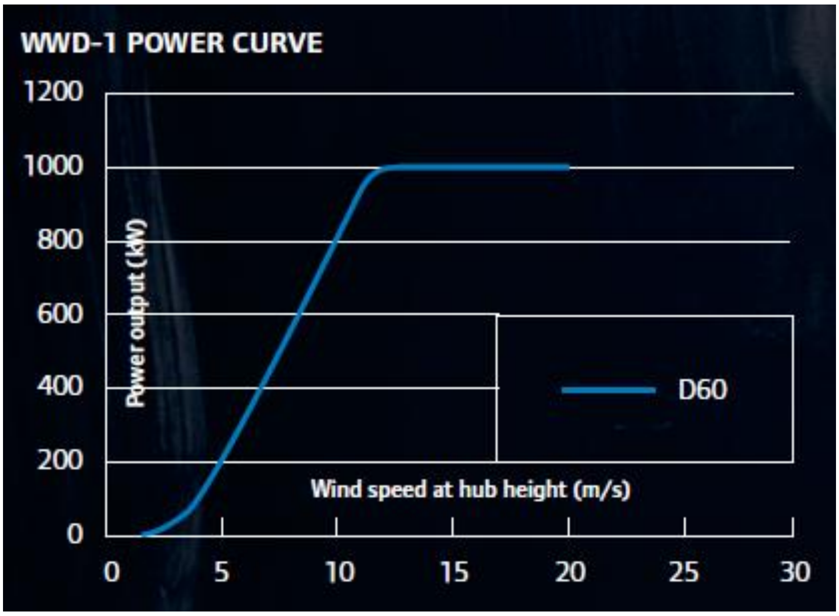

Figure 13. Power curve of WinWinD WWD-1 wind mill (WinWinD, 2013)

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)

Good practices of wind energy utilization

Part of land resources of Scottish Water are used to produce wind energy. There are about sixty large-scale and ten small-scale wind turbines built. (Scottish Water, 2014a) Wind energy is utilized at Touch in Stirling water treatment works. The annual electricity production is about 300 MWh. (McConnell, 2011) Near Stornoway on the Isle of Lewis, there is also a wind turbine at wastewater treatment works (CIWEM, 2013). Six wind turbines are installed at water treatment works at Broadford on the Isle of Skye and on Rassay. The turbines produce power enough to supply up to 50% of the works demand. (Evance Wind, 2013)

WARES wind pilot projects

In Northern Ireland, wind energy as a part of WARES is explored in Loughmacrory pilot site, illustrated in Figure 14. In Ireland, implementation of wind energy within the WARES project is on the way. Figure 15 gives information about the pilot site in Achill.

WARES pilot site: Loughmacrory, Northern Ireland

In Loughmacrory, apart from solar panels implementation, there are also plans to utilize wind energy on the land belonging to Northern Ireland Water. The potential estimated for wind energy is 225 kW. The possible annual energy savings can be up to 7 350 euro. The capital cost of the wind turbine installation is approximately 615 000 euro. The payback period is 20 years.

Wind energy

Type: *water utility*

Energy use: *37 800 kWh*

Water asset: *land*

Energy production: *370 000 kWh*

Cost of RES: *615 000 €*

Payback: *20 years*

Figure 14. Wind WARES pilot in Loughmacrory, Northern Ireland (ARNI, 2014; D-maps.com, 2014c)

WARES pilot site: Achill Island Central, Ireland

In the Achill Island Central project, a wind turbine of 20 kW is going to be installed to power a wastewater treatment plant serving 4 000 people. The capital cost of the wind turbine investment is 100 000 euro. The projected production of energy is 76 MWh. The payback period is 8 years.

Wind energy

Type: *wastewater treatment plant*

Energy use: *160 000 kWh*

Water asset: *land*

Energy production: *76 000 kWh*

Cost of RES: *100 000 €*

Payback: *8 years*

Figure 15. Wind WARES pilot in Achill Island Central, Ireland (D-maps.com, 2014a; MayoCoCo, 2014)

5 Hydropower

Hydropower 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)

$$P = \eta \cdot \rho \cdot g \cdot Q \cdot H \tag{1}$$

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

η = the turbine efficiency [-]

ρ = the density of water [kg/m^3]

g = the gravitational acceleration 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 can be classified in large scale and small scale installations. Large-scale installations have capacity of more than 100 kW, small scale – 0-100 kW. The small scale plants consist of micro-hydro power units of the capacity between 5 and 100 kW, and pico-hydro power units 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) Large scale 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)

Good practices of hydropower utilization

In Norway, there is a strong hydropower expertise. Norway is the largest European producer of hydropower with more than 100 years of experience in all aspects of hydropower implementation: from planning and engineering to equipment installation and management. The Norwegian potential in hydropower is widely utilized; at the present time, Norway is more oriented towards the respective projects abroad: Central and Southeast Europe, Asia and South America. (NMPE, 2013) Moreover, there is current discussion about Norway being a "green battery" for the EU. There is a great pumped-storage hydropower potential in Norwegian water reservoirs. For Europe, access to this kind of energy storage would be a good solution to tackle variations in renewable energy production, for instance, from wind and/or solar energy. (Gullberg, 2013) Another ongoing discussion is transition from traditionally large scale of hydropower to small-scale installations and whether small-scale hydropower plants are environmentally better than large-scale plants. (Kjærland, 2007; Bakken, *et al*., 2014). Concerning, implementation of hydropower in the water sector, one of examples is a 1,5 MW hydropower plant working combined with water supply facility in Taraldsvik, Narvik (SHP News, 2003).

In Scotland, 25 GWh of hydropower potential is projected to be utilized by 2015 via hydro-turbine schemes. The Scottish hydropower schemes are mostly small scale (HI energy, 2010; McKenzie, 2007). At present, there are ten of them in operation in Scottish Water. (Scottish Water, 2014a) Hydropower is utilized at water and wastewater treatment works at Turret in Perthshire, Lintrathen and Tannadice Angus and Castle Moffat East Lothian. Moreover, the works function in a self-sufficient manner due to the water asset utilization. (McArdle, 2013) In the water works of Castle Moffat, there is in-pipe micro-hydro turbine installed to produce power (Global Water Research Coalition, 2010). At Glencorse in Edinburgh, water treatment plant has a gravity-fed facility with hydro turbine. It generates power and satisfies two thirds of the plant power demand. (O'Fee, 2014) As a whole, it is likely that the role of hydropower in Scotland will increase in the years to come. The reason for this is the developing Hydro Nation initiative (Scottish Government, 2012).

WARES hydropower pilot projects

A Norwegian WARES pilot project is on the development stage. It deals with renewable energy implementation in the water industry – Sagelva project. The description is provided in Figure 16.

Within WARES, in Scotland, there are two community pilot projects in Evanton and Roybridge, Inverness-shire. The pilot sites are in the planning stage before implementation. The technological renewable energy solution to be utilized is hydropower. (IRRI, 2014)

In Ireland, in the Archill Island Regional project with a water supply company, hydropower is used as a renewable energy solution. One of the most unique Irish WARES pilot projects is connected with the implementation of in-pipe hydropower technology shown in Figure 17.

WARES pilot site: Sagelva, Norway

The Norwegian pilot project focuses on a water supply company that delivers water to domestic users in the municipality of Hemnes in the county Nordland. There are plans to implement a micro-scale hydropower plant on the water assets. The project is done within the PPP mechanism. The public entity are the water asset owner (and land owners) and the private sector partner is Fjellkraft AS. The private company is an expert in small-scale hydropower technology. Within the project a new project company is supposed to be established to implement the project.

The capacity of the planned micro-scale hydropower plant is 1,5 MW. The capital cost of the project is estimated to be about 2,2 million euro. The source of funding originates from the quota obligation support program and private company investments.

Hydro power

Type: *waste supply plant*

Energy use: -

Water asset: *water*

Energy production: *4 000 000 kWh*

Cost of RES: *2 200 000 €*

Payback: -

Figure 16. WARES hydropower pilot in Norway (D-maps.com, 2014b; NPP, 2014b)

WARES pilot site: Lough Mask, Ireland

It is planned to be done under the Lough Mask Regional project. The return of the 70 000 euro investment is calculated to be in 5 years. The capacity of the installation is 14 kW. It converts energy of running water inside the pipe (with up to 1,4 m/s flow rate) into electricity. The expected energy production is 120 MWh. The source of funding for all the Mayo projects is based on the PPP model. Irish Water, in particular, also provides some financial support of the projects.

Hydro power

Type: *waste supply plant*

Energy use: -

Water asset: *infrastructure*

Energy production: *120 000 kWh*

Cost of RES: *70 000 €*

Payback: *5 years*

Figure 17. WARES hydropower pilot in Ireland (D-maps.com, 2014a; MayoCoCo, 2014)

6 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)

$$Q = m \cdot c_p \cdot \rho \cdot \Delta T \quad (2)$$

Where Q = 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]
ρ = the density of wastewater [kg/l]
ΔT = the temperature difference [°C]

The Equation 1 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 ΔT, 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 18.

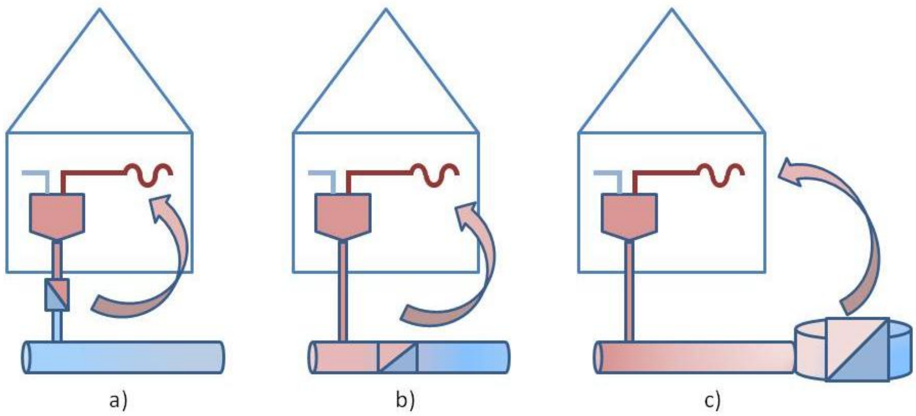

Figure 18. Options for placing a heat recovery system from wastewater:

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)

Good practices of heat recovery utilization

Thermal energy is utilized via heat recovery from wastewater to heat up building spaces at wastewater treatment plants in Finland. In Lapua, a 120 kW heat pump recovers energy from wastewater for heating utilization. The investment of 45 000 euros has a payback period of 2-3 years (Mikkonen, *et al.*, 2013b). Similarly, a heat pump system is used for space heating at a wastewater treatment plant in Vaasa and Helsinki. (Heinonen, 2013; Tekes, 2013) In Savonlinna, at wastewater treatment plant that utilizes accelerating composting unit to produce compost has also heat recovery embedded in the technological scheme (Green Net Finland, 2008).

In Sweden, there is the largest heat recovery from wastewater in the world. It utilizes energy contained in wastewater that has temperature within range of 7-22 ^{0}C. By producing more than 1 200 GWh of thermal energy on an annual basis, the wastewater treatment plant provides heat to around 95 000 households. (Mikkonen, *et al.*, 2013b)

In Norway, Oslo offices and residential buildings are supplied by half from energy coming from a wastewater treatment plant. Contained heat is recovered by heat pumps. As a result, CO_2 emissions are reduced by 6 000 tons per year along with increase of efficiency of biological wastewater treatment. (Mikkonen, *et al.*, 2013b)

7 Challenges of renewable energy generation

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)

8 Summary

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 2 summarizes general scales and payback periods of renewable energy technologies. Values are general, and payback periods may vary strongly depending on ambient conditions and the system architecture.

Table 2. Typical scales and payback periods of renewable energy technologies

	SCALE	PAYBACK PERIOD, YEARS
WIND POWER:	*0,1 – 3,6 MW*	*10 – 20*
SOLAR THERMAL:	*250 – 400 kWh/m^2/year*	*5 – 15*
SOLAR PHOTOVOLTAIC:	*20 – 50 W_p*	*10 – 20*
HYDROPOWER:	*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) 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)

Concerning implementation of the considered technologies, the Northern Periphery Region is gradually including more renewable energy sources in energy supply for the water industry. Hydropower, solar and wind energy are applied in Norway, Scotland, Northern Ireland and Ireland. Anaerobic digestion is common for Finnish, Norwegian, Scottish and Irish water service sector. Heat recovery is employed in Finland.

As a whole, water assets are the most utilized for renewable energy generation in Scotland and Ireland. These countries have the highest number of water-energy projects. Northern Ireland and Norway can be second place in this sense. In Finland, heat pumps and anaerobic digestion are used. But the scale of implementation of hydropower, solar and wind energy is negligible and there is still unutilized potential.

In Ireland, there is a list of pilot projects in terms of renewable energy implementation. The prioritized renewable energy technologies are wind energy, solar PV energy and hydropower. (MayoCoCo, 2014)

As regards the Scottish water industry, there are also numerous water-energy projects utilizing such renewable energy solutions as anaerobic digestion, solar, wind energy and hydropower. One of the key reasons of broad renewable energy development in Scotland is that Scottish Water is one of the largest energy consumers in the country and aims to become an energy self-sufficient entity. In this context, the water assets such as land, water and community resources are in the focus of attention. There are quite many renewable energy initiatives applied and now Scottish Water produces about 7% of their total energy consumption. (Scottish Water, 2014a) The objectives are to export energy to the national grid, support the Renewable Energy Directive targets in the country and produce up to 5% via the Scottish Water asset utilization (McArdle, 2013; O'Fee, 2014). In total, Scottish Water has approximately 285 km^2 of land area. High land areas possess hydropower energy potential. Land areas can be also used for wind energy production. Scottish Water reservoirs can be converted into dams to generate hydropower. High-pressure water pipelines of the water infrastructure can be supplied with small in-pipe turbines to produce micro-hydropower. (O'Fee, 2014) Some of the renewable energy potential in the water sector is already utilized now. However, there are still unused opportunities for water asset utilization.

Concerning WARES projects and corresponding implementation of renewable energy solutions, their summary is presented in Table 3.

Table 3. WARES pilot projects of water asset utilization for renewable energy generation

	SOLAR PV	WIND ENERGY	HYDROPOWER
COUNTRY:	*Northern Ireland*	*Northern Ireland*	*Norway*
TYPE:	*water utility*	*water utility*	*water supply plant*
ENERGY USE:	*37 800 kWh*	*37 800 kWh*	-
WATER ASSET:	*infrastructure*	*land*	*water*
ENERGY PRODUCTION:	*37 500 kWh*	*370 000 kWh*	*4 000 000 kWh*
COST OF RES:	*86 000 €*	*615 000 €*	*2 200 000 €*
PAYBACK:	*20 years*	*20 years*	-
COUNTRY:	*Ireland*	*Ireland*	*Ireland*
TYPE:	*wastewater treatment plant*	*wastewater treatment plant*	*water supply plant*
ENERGY USE:	*160 000 kWh*	*160 000 kWh*	-
WATER ASSET:	*infrastructure*	*land*	*infrastructure*
ENERGY PRODUCTION:	*9 000 kWh*	*76 000 kWh*	*120 000 kWh*
COST OF RES:	*17 000 €*	*100 000 €*	*70 000 €*
PAYBACK:	*12 years*	*8 years*	*5 years*
COUNTRY:	*Ireland*	-	-
TYPE:	*water supply plant*	-	-
ENERGY USE:	-	-	-
WATER ASSET:	*infrastructure*	-	-
ENERGY PRODUCTION:	-	-	-
COST OF RES:	*52 000 €*	-	-
PAYBACK:	*17 years*	-	-
COUNTRY:	*Ireland*	-	-
TYPE:	*water supply plant*	-	-
ENERGY USE:	-	-	-
WATER ASSET:	*infrastructure*	-	-
ENERGY PRODUCTION:	-	-	-
COST OF RES:	*17 000 €*	-	-
PAYBACK:	*13 years*	-	-

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WARES

water asset renewable energy solutions

WARES (Water Asset Renewable Energy Solutions) is a 2-year Northern Periphery Programme strategic project which explores the opportunities to generate renewable energy at water utility assets. The focus is on sites with previously unused, hidden potential. The outcomes of the project will be used to propose a scheme of policy refinements for each region. The project is implemented during 2012-2014.

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